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Replacement of cornmeal with spineless cactus meal in dairy calf diets: a productive and economic evaluation

Substituição do fubá de milho por farelo de palma forrageira em dietas de bezerras leiteiras: avaliação produtiva e econômica

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Highlights

Replacing cornmeal with spineless cactus meal did not affect weight gain.
The digestibility of the concentrate supplements decreased as cornmeal was replaced.
The inclusion of spineless cactus meal reduced the unit cost of the total diets.

Abstract

The objective of this study was to evaluate the productive performance and economic viability of replacing cornmeal (CM) with spineless cactus meal (SCM) in the diet of female dairy calves. The experiment followed a completely randomized design with four treatments and six replicates. Twenty-four weaned 5/8 Girolando calves, with an initial body weight of 98.5 ± 16.88 kg and an average age of 131 days, were used. The experimental treatments included SCM at 0%, 12%, 22%, and 32% of the diet. Dry matter intake (DMI), average daily weight gain (ADG), and feed costs were evaluated. The *in vitro* dry matter digestibility (IVDMD) of the concentrate supplements was also determined. IVDMD decreased linearly from 89.39% to 81.96% as the inclusion of SCM increased from 0% to 32%. Replacing CM with SCM had no significant effect on final weight, ADG, or DMI, which averaged 162.04 kg, 0.802 kg day^{-1}, and 3.42 kg day^{-1}, respectively. The cost per kilogram of weight gain was $1.14, $1.09, $1.04, and $1.27 for the 0%, 12%, 22%, and 32% SCM groups, respectively. Including SCM in place of CM at up to 32% of

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the diet does not affect weight gain, and the 22% inclusion level is the most economically advantageous.
Key words: Dairy cattle. By-product. Feed cost. Heifer performance. *Nopalea cochenillifera* Salm-Dyck.

Resumo

O objetivo com o estudo foi avaliar o desempenho produtivo e a viabilidade econômica da substituição do fubá de milho (FM) pelo farelo de palma (FP) em dietas para bezerras leiteiras. O experimento foi conduzido em delineamento experimental inteiramente casualizado com quatro tratamentos e seis repetições. Foram utilizadas 24 bezerras desmamadas 5/8 Girolando com peso corporal médio de 98,5 ± 16,88 kg e idade média de 131 dias. Os tratamentos experimentais consistiram na inclusão do FP em 0, 12, 22 e 32% da dieta total. Foram avaliados a ingestão de matéria seca (IMS) das dietas experimentais, ganho de peso médio diário (GMD) dos animais e o custo alimentar. A digestibilidade *in vitro* da matéria seca (DIVMS) dos suplementos concentrados também foi determinada. A DIVMS reduziu linearmente de 89,39 para 81,96% entre 0 e 32% de inclusão do FP. Não houve efeito da substituição do FM pelo FP sobre o peso final, GMD e IMS, que apresentaram médias de 162,04 kg; 0,802 kg dia^{-1} e 3,42 kg dia^{-1}, respectivamente. O custo do ganho de peso foi de $1,14, $1,09, $ 1,04, e $ 1,27 para os grupos 0, 12, 22 e 32% FP, respectivamente. A substituição do FM por FP em até 32% da dieta não altera o ganho de peso dos animais e a inclusão de 22% de FP é a mais vantajosa economicamente.
Palavras-chave: Bovinos de leite. Coproduto. Custo alimentar. Desempenho da recria. *Nopalea cochenillifera* Salm Dyck.

Introduction

Dairy cattle nutrition in semi-arid regions faces significant challenges, as pasture productivity is typically low and highly seasonal (Rocha et al., 2021). Consequently, corn- and soybean-based concentrates are commonly used as supplements. However, these commodities are expensive, and their cultivation in semi-arid areas is difficult, contributing to the rising prices of these inputs (Alves et al., 2023). The high cost of corn has prompted the search for alternative ingredients, particularly by-products rich in digestible fibers, which are being evaluated as potential energy sources to replace starch-based grains in concentrate formulations (Alves et al., 2023; Frota et al., 2015).

In this context, spineless cactus, a species well adapted to arid and semi-arid climates, offers potential for both forage and meal production, making it a viable option for ruminant feeding. This is due to its crassulacean acid metabolism, which allows for greater water-use efficiency compared to C3 and C4 plants (R. M. dos S. Pessoa et al., 2022; Frota et al., 2015).

Furthermore, spineless cactus contains high levels of total carbohydrates, ranging from 73.8% to 85.2%, and non-fibrous carbohydrates (NFC), from 42.3% to 65.0% of the dry matter (DM). Additionally, studies have reported DM digestibility values between 67.3% and 78.8%, NFC digestibility between 91.7% and 96.4%, and neutral detergent fiber (NDF) digestibility between

59.7% and 62.2% (Siqueira et al., 2017; Silva et al., 2017; Cardoso et al., 2019; Monteiro et al., 2019).

In response to rising feed ingredient costs, many producers are now prioritizing the nutrition of lactating cows, often at the expense of other categories, particularly in regions with severe seasonal rainfall. As a result, heifers, being in a developmental stage and not yet producing milk, are frequently subject to dietary restrictions as a cost-saving measure (Cordeiro et al., 2023). Although this practice is common, inadequate nutrition during the rearing phase can delay growth and development, resulting in a later age at first calving and negatively impacting the economic return of dairy production. Therefore, introducing corn substitutes that are either more cost-effective or have greater agronomic viability in dryland systems could enhance the nutrition of heifers (Marques et al., 2017).

The potential of spineless cactus to promote high weight gain (0.80 kg day^{-1}) in weaned dairy calves was demonstrated by Barros et al. (2018). However, in that study, spineless cactus was used as a roughage source; its evaluation as a concentrate ingredient, replacing CM in diets, still requires further investigation.

In this context, SCM retains its nutritional value and can be stored during periods of scarcity or when commonly used inputs become more expensive, making it a promising alternative to CM. However, it is essential to determine the optimal level of substitution that maximizes both zootechnical and economic performance in diets formulated for high weight gain in dairy calves.

Therefore, the aim of this study was to assess the productive performance and economic viability of replacing CM with SCM in the diets of dairy calves.

Material and Methods

The study was conducted from August 22 to November 8, 2023, at the experimental farm of the Federal University of Minas Gerais (UFMG) in Montes Claros, MG (16.686316° S, 43.843763° W). The climate of the region is classified as Tropical Savannah (Aw) according to the Köppen classification. All animal handling procedures were approved by the Animal Use Ethics Committee (CEUA) of UFMG (case number 123/2017).

A completely randomized experimental design with four treatments and six replicates was adopted. Twenty-four weaned 5/8 Holstein × 3/8 Gyr female calves were used, with an average initial body weight (BW) of 98.5 ± 16.88 kg and an average age of 131 days.

The experimental diets included SCM replacing CM at 0% (T0), 12% (T12), 22% (T22), and 32% (T32) of the total diet (Table 1). The T32 diet represented a complete (100%) replacement of CM with SCM.

Table 1
Proximate composition of experimental diets for dairy calves with increasing content of spineless cactus meal replacing cornmeal180 g kg^{-1}, calcium (max) 220 g kg^{-1}, phosphorus (min) 80 g kg^{-1}, sodium (min) 100 g kg^{-1}, magnesium (min) 10 g kg^{-1}, sulfur (min) 12 g kg^{-1}, copper (min) 1145 mg kg^{-1}, iodine (min) 57 mg kg^{-1}, manganese (min) 1145 mg kg^{-1}, selenium

Ingredient (%)	[1]Experimental diet (% in the DM)			
	T0	T12	T22	T32
Spineless cactus meal	0.00	11.83	22.19	31.80
Cornmeal	36.70	23.10	11.08	0.00
Soybean meal	11.77	13.55	15.21	16.67
Mineral mix[2]	1.53	1.53	1.53	1.53
Corn silage	50.00	50.00	50.00	50.00

[1]Experimental diets: inclusion of spineless cactus meal at 0, 12, 22 and 32% of dry matter. [2]Mineral mix: calcium (min) (min) 22 mg kg^{-1}, cobalt (min) 50 mg kg^{-1}, zinc (min) 3437 mg kg^{-1} and maximum fluorine of 800 mg.

All diets were formulated to achieve an average daily weight gain (ADG) of 0.60 kg day^{-1}, following the guidelines of the National Research Council [NRC] (2001), and consisted of SCM, CM, soybean meal (SM), a commercial mineral mix, and corn silage (CS) as the roughage source. The roughage:concentrate ratio was 50:50 on a DM basis (Table 1). SCM and CS were produced in the experimental field at UFMG, while CM, SM, and the mineral mix were acquired from external suppliers. Table 2 provides the chemical composition of the experimental diets and ingredients.

The spineless cactus used in the study was cultivated on the experimental farm of UFMG. The grove used for harvesting consisted of the IPA Sertânia cultivar (*Nopalea cochenillifera* Salm-Dyck), covering approximately 2 ha. The plants were arranged in single rows, with a spacing of 0.25 m between cladodes and 2.7 m between rows. Fertilization at planting consisted of 300 g of NPK (10-10-10) per linear meter, equivalent to 111 kg of nitrogen, phosphorus, and potassium per hectare.

Cladodes for meal production were harvested manually after 24 months of growth. They were processed using a Trapp® JK-500 spineless cactus shredder, then spread on a concrete floor and left to dry in the sun, with the material turned daily. After nine days of drying, the chopped and dehydrated spineless cactus was ground in a Nogueira® disintegrator using a 3 mm mesh sieve to obtain the SCM.

Table 2
Chemical composition of ingredients and experimental diets for dairy calves with increasing levels of spineless cactus meal replacing cornmeal

Ingredient	DM	MM	CP	NDF	ADF	EE	NFC	TDN
	g kg^{-1} DM							
Spineless cactus meal	874.5	186.0	50.3	290.1	191.1	8.7	464.9	590.0
Cornmeal	869.8	13.5	117.7	266.0	73.2	26.7	576.1	698.5
Soybean meal	866.7	66.9	554.4	101.8	62.0	5.3	235.5	602.3
Corn silage	267,0	77.7	68.5	520.8	275.6	36.7	296.3	567.2
T0 *	566.9	65.6	125.6	378.3	168.4	28.8	401.8	620,6
T12 *	567.5	80.6	121.3	366.9	172.4	25.2	406.1	614.1
T22 *	567.2	103.5	116.3	364.7	183.5	21.2	394.5	599.3
T32 *	569.3	121.3	116.3	369.5	197.4	19.6	373.5	585.9

DM: dry matter (g 1000 g^{-1} as fed). MM: mineral matter. CP: crude protein. NDF: neutral detergent fiber. ADF: acid detergent fiber. EE: ether extract; NFC: non-fibrous carbohydrates. TDN: total digestible nutrients. *Experimental diets with inclusion of spineless cactus meal at 0, 12, 22, and 32% of the dry matter.

The experimental period lasted 79 days, following a 15-day adaptation phase during which the dairy calves adjusted to the area and experimental conditions. The animals were housed individually in 15 m² wire-fenced pens. Each pen had a dirt floor and a roofed area of approximately 10 m² covered with cement tiles. The pens were located in the cattle breeding sector of the experimental farm and equipped with feeders and plastic water containers, which were cleaned twice daily. Water was provided *ad libitum.*

On the first day of the adaptation period, the calves were dewormed with levamisole phosphate (1 mL 40 kg^{-1}, subcutaneous injection) and vaccinated against clostridial infections with Clostrisan 11 (VIRBAC®) at a dose of 5 mL (intramuscular injection), followed by a booster 30 days later. After seven days, parasitic infections were treated with diminazene diaceturate (7 g; 0.5 mL 10 kg^{-1}, intramuscular injection) and oxytetracycline (1 mL 10 kg^{-1}, intramuscular injection), with additional doses administered as needed. Thirty days after the start of the adaptation period, the calves received albendazole (10%) orally at 1 mL 10 kg^{-1} and doramectin (1%) at 1 mL 50 kg^{-1} (subcutaneous injection).

The experimental diets were offered as a complete mixture at 06h00 and 15h00. The amount of feed provided was adjusted daily to maintain leftovers at approximately 10%. Before the morning feeding, the leftovers from each experimental unit were collected, weighed, identified, and sampled (200 g), placed in plastic bags, and stored frozen at -10 °C. Every 15 days, the samples were thawed at room temperature and pooled into composites.

The ingredients and composite samples of diet leftovers were weighed and dried in a forced-air circulation oven at 55 °C for 72 h (method INCT-CA-G-001/1). The samples were then processed in a Wiley knife mill with a 1 mm sieve and analyzed for dry matter (DM; dried overnight at 105 °C, method INCT-CA-G-003/1), mineral matter (MM; complete combustion in a muffle furnace at 600 °C for 4 h, method INCT-CA-M-001/1), crude protein (CP; Kjeldahl procedure, method INCT-CA-N-001/1), ether extract (EE; Goldfish procedure, method INCT-CA-G-004/1), neutral detergent fiber (NDF; method INCT-CA-F-001/1), and acid detergent fiber (ADF; method INCT-CA-F-003/1), according to Detmann et al. (2012). Non-fibrous carbohydrate (NFC) content was estimated using the equation NFC = 100 – (CP + NDF + EE + MM) (Sniffen et al., 1992), and total digestible nutrients (TDN) were calculated using the equation TDN = 40.2526 + 0.1969 CP + 0.4028 NFC + 1.903 EE – 0.1379 ADF (Kearl, 1982).

Dry matter intake was calculated using the formula:

DMI = [(Roughage (kg) × % DM of roughage) + (Concentrate (kg) × % DM of concentrate)] – (Leftover (kg) × % DM of leftover).

This value was expressed as a percentage of average body weight (DMI, %BW) and in metabolic weight (DMI, $BW^{0.75}$). The intake of CP, NDF, NFC, and TDN was estimated based on DMI. The DM content of the consumed diet (DM, %) was calculated as the ratio between DMI and fresh matter intake, multiplied by 100.

The calves were weighed using mechanical cage scales on days 0, 21, 42, 63, and 79 of the experimental period. Total weight gain (WG) was calculated as the difference between final BW (day 79) and initial BW (day 0), with the animals having received only water for 12 h prior to weighing. The ADG was determined by dividing total WG by the duration of the experimental period (79 days). The feed conversion ratio (FCR) was calculated as the ratio of DMI (kg day-1) to ADG (kg day^{-1}). Average BW was obtained by averaging the initial and final BW.

Samples of the four concentrate supplements, as well as the diet ingredients SCM, CM, SM, and CS, were evaluated for IVDMD using the two-stage technique described by Tilley and Terry (1963). Rumen fluid was collected from five male Nellore cattle with an average age of 20 months old, at a commercial slaughterhouse. Immediately after slaughter, the rumen fluid from all five animals was homogenized, stored in a thermos, and transported to the Chemical Analysis Laboratory of ICA/UFMG. Its characteristics pH, color, odor, consistency, and methylene blue reduction time (PRAM) were evaluated according to the protocol of Dirksen (2008). In the PRAM test, a reduction time of up to 3 min indicated active microbial presence. The fluid was yellowish-brown, had an aromatic odor, and showed slightly viscous consistency. The pH was measured using an INSTRUTHERM® benchtop digital pH meter (PH2600), and the fluid was stabilized with CO2 until it reached a pH of 6.82, at which point it was inoculated with the samples for IVDMD analysis.

Diet ingredient samples were ground to 1 mm and sealed in pre-weighed F-57 Ankom® filter bags (5.5 cm × 5.5 cm). The bags were placed in a Tecnal® in vitro incubator (TE-150) for fermentation in a buffer solution containing rumen fluid for 48 h, followed by 24 h of digestion in a pepsin-acid solution to simulate abomasal digestion. After incubation, the bags were removed, washed with distilled water, and dried in a forced-air oven at 55 to 60 °C for 12 h. They were then dried at 105 °C for 2 h to determine the DM content. The IVDMD was calculated as the difference between the incubated and residual sample masses. Four replicates were used per treatment.

The unit cost of the experimental diets ($) was calculated based on the acquisition prices in June 2023 (1 Dollar = R$ 4.85) for SM, CM, and the vitamin-mineral supplement, which were $0.60, $0.27, and $0.90, respectively. The cost of SCM was determined based on production costs (including soil preparation, seedling and fertilizer purchase, and labor for planting and fertilization) and processing costs (including transportation of green and dry spineless cactus, bag purchase, labor for crushing, grinding, and bagging, and electricity) in the collection area, extrapolated on a per-hectare basis. The total production cost was divided by the yield per hectare, resulting in a unit cost of $0.15. The cost of CS was based on the commercial price quoted in Montes Claros, MG, in June 2023, with a unit value of $0.04.

The unit cost of each ingredient ($) was determined by dividing its unit cost on an as-fed basis by its DM content. The unit cost of the concentrate supplements ($) was calculated by multiplying the cost of each ingredient by its respective proportion in the supplement. The unit cost of the total diet ($) was obtained by summing the cost of the supplement and the cost of CS, calculated as the percentage of silage inclusion multiplied by the unit cost of CS. The daily feed cost ($) was determined by multiplying the total diet cost by the DMI. Finally, the cost of ADG ($) was calculated as the ratio of feed cost to ADG for each treatment.

The statistical model used in data analysis was:

$$y_{ij} = \mu + T_i + \beta_1 (X_{ij} - \underline{X}) + \beta_2 (X_{ij} - \underline{X})^2 + e_{ij},$$

where y_{ij} is the observation of the response variable measured in treatment i and replicate j; μ is the overall mean of the response variable; T_i is the effect of treatment i; β_1 is the linear effect of the covariate 'initial weight'; X_{ij} is the value of the covariate in the experimental unit of treatment i and replicate j; X is the mean of the covariate 'initial weight'; β_2 is the quadratic effect of the covariate 'initial weight'; and e_{ij} is the experimental error associated with treatment i and replicate j.

Economic data were analyzed using descriptive statistics. Intake and production performance data were evaluated through analysis of variance (ANOVA) and regression analysis for performance traits, with a 5% significance level. The REG procedure was used for regression analysis, including calculation of the residual coefficient of variation (CV) and model determination coefficient (R²). The GLM procedure was applied to test the initial BW as a covariate and to assess model lack of fit (SAS 2014).

Results and Discussion

The replacement of CM with SCM resulted in a linear reduction ($p<0.05$) in the IVDMD of the concentrate supplements ($\hat{y} = 0.23x + 90.07$, $r^2 = 0.92$), with mean values of 89.4%, 88.0%, 86.0%, and 82.0% for the T0, T12, T22, and T32 diets, respectively. This outcome can be attributed to the higher IVDMD of CM (90.51%) compared to that of SCM (73.30%).

Despite this effect, all concentrate supplements displayed IVDMD values above 80%, with a maximum variation of 7.28% between the T0 and T32 diets. It is important to note that CM is derived from grain processing and is primarily composed of starch (73.64% of DM), whereas SCM originates from the vegetative parts of the plant. Although starch and pectin levels were not determined in this study, both are components of NFC, the most digestible carbohydrate fraction in feeds. Spineless cactus contains 18 to 21% pectin in its DM (D. V. Pessoa et al., 2020).

IVDMD values above 80% have been reported for several spineless cactus cultivars, including IPA 20 (*Opuntia ficus-indica* Mill), IPA Sertânia (*Nopalea cochenillifera* Salm Dyck), Gigante (*Opuntia ficus-indica* Mill), and *Ereta Espinhosa* Pera (*Opuntia stricta* Haw). Additionally, 65.74% of the carbohydrates in spineless cactus are classified as rapidly or intermediately degradable, with only 11.57% considered rumen undegradable (D. V. Pessoa et al., 2020). Spineless cactus also contains 12.9% starch, a relatively high content for forages (Batista et al., 2003).

SB also showed high IVDMD (87.0%), with an intermediate value between CM and SCM. CS exhibited an IVDMD of 65.67%, which is considered good for a forage, as reported values in the literature range from 34.70% to 76.20% (Santos et al., 2020). Based on the IVDMD results, the dietary ingredients can be considered highly digestible. Several factors influence the digestibility of grains and CS, including endosperm vitreousness, prolamin content, starch granule exposure to microorganisms, nitrogen fraction, fiber quality, ear proportion, plant height, and maturity (Lima et al., 2022; Varela et al., 2023). Likewise, SCM digestibility is affected by its pectin, NDF, and ADF content, as well as crop management practices, harvest stage, and cultivar (Batista et al., 2003; D. V. Pessoa et al., 2020).

The replacement of CM with SCM did not significantly affect ($p>0.05$) DMI, ADG, total WG, final BW, or average BW, with mean values of 3.42 kg day^{-1}, 0.802 kg day^{-1}, 63.54 kg, 162.04 kg, and 130.30 kg, respectively (Table 3).

Table 3
Performance of dairy calves fed increasing levels of spineless cactus meal as a substitute for cornmeal in the experimental diet

Variable	[1]Experimental diet (%DM)				[2]Regression	[3]CV (%)
	T0	T12	T22	T32		
DMI, kg day^{-1}	3.30	3.32	3.47	3.58	ŷ = 3.42	9.45
DMI, %BW	2.51	2.53	2.60	2.81	ŷ = 0.01x +2.49 r² = 0.27	8.76
DMI, g BW$^{0.75}$	8.49	8.54	8.80	9.40	ŷ = 0.03x +8.45 r² = 0.19	10.17
ADG, kg	0.81	0.82	0.87	0.71	ŷ = 0.802	16.49
TWG, kg	64.00	65.17	69.00	56.00	ŷ = 63.54	16.49
FBW, kg	163.67	162.83	166.50	155.17	ŷ = 162.04	6.19
ABW, kg	131.67	130.25	132.00	127.17	ŷ = 130.30	4.14
FCR	4.18	4.11	3.97	5.02	ŷ = 0.002x2 -0.05x + 4.26 r² = 0.47	14.03
DM, %	42.87	43.42	46.81	51.05	ŷ = 0.24x + 51.34 r² = 0.80	4.29
CPI, kg	0.44	0.45	0.44	0.54	ŷ = 0.003x – 0.012 r² = 0.71	13.25
NDFI, kg	1.62	1.61	1.69	1.62	ŷ = 1.63	14.69
NFCI, kg	1.46	1.43	1.47	1.48	ŷ = 1.46	12.04
TDNI, kg	2.43	2.42	2.49	2.51	ŷ = 2.46	9.02

[1]Experimental diets: inclusion of spineless cactus meal at 0, 12, 22, and 32% of dry matter. [2]Regresson: significant at 5% probability. [3]CV: coefficient of variation. DMI: dry matter intake. DMI, %BW: dry matter intake relative to body weight. DMI, BW$^{0.75}$: dry matter intake relative to metabolic body weight. ADG: average daily gain. TWG: total weight gain. FBW: final body weight. ABW: average body weight. FCR: feed conversion ratio. DM: dry matter content of the diet consumed. CPI: crude protein intake. NDFI: neutral detergent fiber intake. NFCI: non-fibrous carbohydrate intake. TDNI: total digestible nutrient intake.

These results demonstrate that SCM served as a viable alternative energy source to CM, effectively meeting the nutritional requirements of dairy heifers for high ADG. The observed ADG of 0.80 kg day^{-1} surpassed the expected target of 0.60 kg day^{-1}, which is aimed at achieving first calving around 24 months of age.

Similar performance was reported by Barros et al. (2018) in Girolando heifers, with ADG values ranging from 0.76 to 0.83 kg day^{-1} when replacing Tifton 85 hay with fresh spineless cactus (0-100% of the diet). Likewise, Holstein × Zebu heifers exhibited ADG values of 0.72 kg day^{-1} and 0.84 kg day^{-1} with the inclusion of elephant grass silage

'BRS Capiaçu' with spineless cactus (60:40) and sorghum silage with spineless cactus (60:40) at a 75:25 roughage:concentrate ratio (Cordeiro et al., 2023). The high ADG observed in these studies was attributed to increased NFC intake, which consequently enhanced rumen microbial production and improved CP digestibility. This evidence supports the strategic use of spineless cactus as a CM replacement without negatively affecting ADG in dairy calves.

The response of FCR to increasing levels of SCM inclusion in the diets was quadratic ($p<0.05$), reaching a minimum value of 3.95 with 12.5% SCM inclusion (Table 3). This response indicates that animals in the T32 group exhibited the poorest feed conversion efficiency in terms of ADG.

The observed effect on FCR can be attributed to the linear increase ($p<0.05$) in DMI (%BW) and DMI ($BW^{0.75}$) with increasing levels of SCM in the diet (Table 3). Higher FCR, DMI (%BW), and DMI ($BW^{0.75}$) values, without a corresponding increase in ADG, may indicate reduced performance efficiency or increased feed costs.

Although a linear effect was observed on the IVDMD of the concentrate supplements (which accounted for 50% of the dietary DM), it was not sufficient to alter DMI (kg day^{-1}) among animals, which helps explain the similar ADG across treatments. Furthermore, replacing CM with SCM did not significantly affect ($p>0.05$) the intake of NDF, NFC, or TDN, with average values of 1.63, 1.46, and 2.46 kg day^{-1}, respectively (Table 3).

The replacement of CM with SCM had a significant linear effect ($p<0.05$) on DM content (%). For every 1% increase in SCM inclusion, DM content increased by 0.24%. This result reflects diet selection behavior, as the animals consumed more concentrate supplement (which had a higher DM content than CS; Table 2), as SCM inclusion increased. Thus, despite similar DMI across groups, the higher proportion of concentrate in the ingested diet may have compensated for the lower IVDMD of SCM relative to CM, contributing to the similar ADG among animals. Indeed, differences in diet selection were visibly evident during the experimental period, as shown by the characteristics of feed leftovers in the trough (Figure 1) between groups T0 and T32.

Greater selection of diets containing SCM may be associated with the high pectin content and its effects on ruminal pH (Abreu et al., 2022). Pectin, part of the NFC fraction in SCM, promotes higher acetate production during fermentation compared to starch, the main NFC in CM. In contrast, starch tends to generate more propionate or lactate, both of which have greater potential to lower ruminal pH (D. V. Pessoa et al., 2020; Abreu et al., 2022).

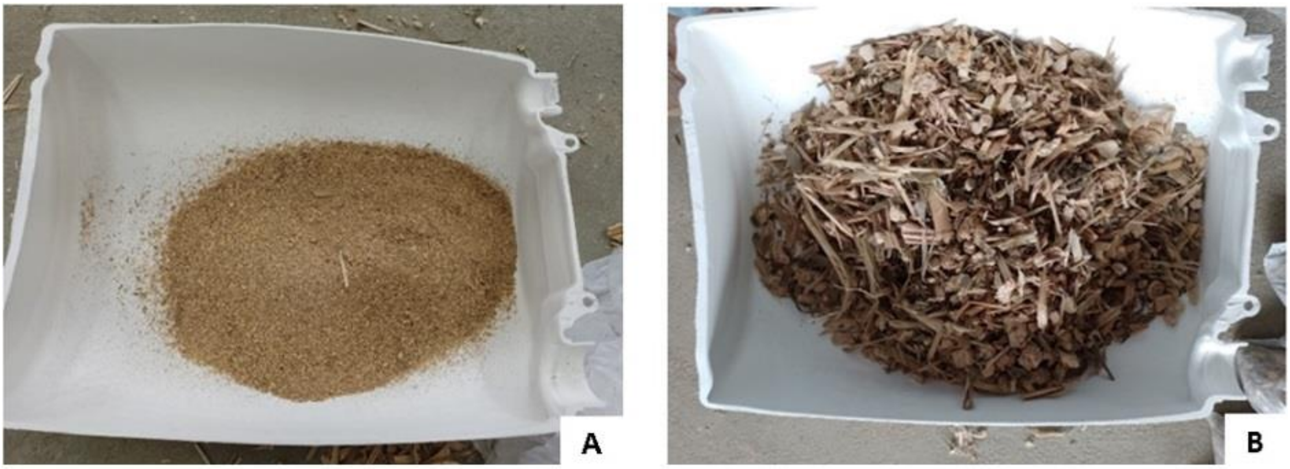

Figure 1. Characteristics of feed leftovers from the treatment with no inclusion (0%) (A) and with 32% inclusion (B) of spineless cactus meal in the experimental diet.

The substitution of CM with SCM resulted in a linear increase ($p<0.05$) in CP intake, with an increase of 0.036 kg for each 1% increment of SCM in the diet. This effect is likely due to greater selection of the concentrate over CS, as the former had a higher CP content (Table 2).

The unit cost of concentrate supplements on a DM basis decreased with the replacement of CM with SCM (Table 4), due to the higher price of CM compared to that of SCM ($0.31 vs. $0.17). Consequently, the largest difference in unit costs was observed between the T0 and T32 supplements, totaling $0.05. Since CS inclusion was consistent across all diets (50% of DM), the total diet cost ($ kg^{-1}) reflected this trend, with a $0.03 difference between T0 and T32.

Table 4
Economic performance of dairy calves fed increasing levels of spineless cactus meal as a substitute for cornmeal in experimental diets

Parameter	[1]Experimental diet (% DM)			
	T0	T12	T22	T32
Cost of supplement ($ kg^{-1})	0.42	0.40	0.38	0.37
Cost of total diet ($ kg^{-1})	0.28	0.27	0.26	0.25
Feed cost ($ day^{-1})	0.92	0.89	0.90	0.90
Cost of weight gain ($ kg^{-1})	1.14	1.09	1.04	1.27

[1]Experimental diets = inclusion of spineless cactus meal at 0, 12, 22 and 32% of dry matter. Cost of the supplement: unit cost of the dry matter of each ingredient ($) × percentage of inclusion of each concentrate ingredient (kg). Total diet cost: cost of the supplement + (percentage inclusion of silage × unit cost of the dry matter of silage). Daily feed cost: total diet cost ($) × dry matter intake (kg). Cost of weight gain: Total feed cost / average daily weight gain (kg).

In contrast, the daily feed cost varied differently from the supplement and total diet costs. While the T0 group had the highest feed cost, the T12 group had the lowest, with a difference of \$0.13 between them. All groups receiving SCM in their supplements (T12, T22, and T32) exhibited lower feed costs than the group fed only CM (T0), indicating that SCM helped reduce overall diet costs.

The T32 group showed the highest unit cost of weight gain, while the lowest was observed in the T22 group, with a difference of \$0.23 between them. The elevated cost per unit of weight gain in the T32 group is attributed to its poorer performance in terms of FCR, DMI (%BW), and DMI ($BW^{0.75}$).

It is important to emphasize the relevance of correlating supplement or total diet cost with performance traits. Although the T32 diet exhibited a lower cost, when associated with ADG, it resulted in the highest cost per unit of weight gain. However, in scenarios where the ADG target is low to moderate (up to 0.50 kg day^{-1}) or where the price difference between CM and SCM is greater than that observed in this study, the T32 diet may offer more favorable feed and weight gain costs compared to CM-based supplements. This is particularly relevant because the cultivation and use of spineless cactus are concentrated in regions with low and seasonal average annual precipitation, where corn cultivation is more agronomically challenging and acquisition costs may be even higher than those reported in the present study.

A study involving Holstein × Zebu steers on pasture, receiving supplements at 0.6% of their BW with 0 to 90% SCM replacing CM, found that a 45% replacement level provided the best economic return (Abreu et al., 2022). However, in that study, the unit costs of SCM and CM were \$0.08 and \$0.12, respectively, which are lower than the values reported here. Therefore, the optimal CM substitution level with SCM depends not only on performance outcomes, but also on input acquisition costs, animal category, and supplementation level. Overall, SCM showed potential as an energy source in the diet of dairy calves for achieving optimal performance, with the T22 supplement emerging as the most economically advantageous option for an ADG of 0.80 kg day^{-1}.

Conclusion

The inclusion of spineless cactus meal up to 32% of the total diet increases dry matter intake relative to body and metabolic weight, without affecting weight gain in dairy calves.

Replacing cornmeal with up to 22% spineless cactus meal in the diet results in the lowest cost per unit of weight gain, making it the most economically advantageous option.

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References

Abreu, G., Fº., Silva, R. R., Silva, F. F., Silva, A. P. G., Paixão, T. P., Souza, S. O., Lisboa, M. M., Barroso, D. S., Silva, J. W. D., Alba, H. D. R., & Carvalho, G. G. P. de. (2022). Effects of replacing ground corn with *Nopalea cochenillifera* meal on the intake, performance, and economic viability of grazing steers. *Tropical Animal Health and Production, 54*(1), 35-44. doi: 10.1007/s11250-021-03029-y

Alves, K. de A., Lima, J. A. M., Costa, M. R. G. F., Silva, T. C., Brito, C. de L., Gomes, M. L. R., Pereira, J. M., Fº., Oliveira, J. P. F., Nascimento, R. R., & Bezerra, L. R. (2023). Effect of replacing corn with cactus pear on the performance and carcass traits and meat quality of feedlot finished lambs. *Ciência Animal Brasileira, 24*(1), e–75322E. doi: 10.1590/1809-6891v24e-75322E

Barros, L. J. A., Ferreira, M. A., Oliveira, J. C. V., Santos, D. C., Chagas, J. C. C., Alves, A. M. S. V., Silva, A. E. M., & Freitas, W. R. (2018). Replacement of Tifton hay by spineless cactus in Girolando post-weaned heifers´ diets. *Tropical Animal Health and Production, 50*(1), 149-154. doi: 10.1007/s11250-017-1415-4

Batista, A. M., Mustafa, A., Mcallister, T., Wang, Y., Soita, H., & Mckinnon, J. (2003). Effects of variety on chemical composition, in situ nutrient disappearance and in vitro gas production of spineless cacti. *Journal of the Science of Food and Agriculture, 83*(5), 440-445. doi: 10.1002/jsfa.1393

Cardoso, D. B., Carvalho, F. F. R., Medeiros, G. R., Guim, A., Cabral, A. M. D., Véras, R. M. L., Santos, K. C., Dantas, L. C. N., & Nascimento, A. G. de O. (2019). Levels of inclusion of spineless cactus (*Nopalea cochenillifera* Salm Dyck) in the diet of lambs. *Animal Feed Science and Technology, 247*(1), 23-31. doi: 10.1016/j.anifeedsci.2018.10.016

Cordeiro, M. W. S., Rocha, V. R., Jr., Monção, F. P., Palma, M. N. N., Rigueira, J. P. S., Carvalho, C. C. S, Costa, M. D. da, D'Angelo, M. F. S. V., Costa, N. M., & Oliveira, L. I. S. de. (2023). Tropical grass silages with spineless cactus in diets of Holstein × Zebu heifers in the semiarid region of Brazil. *Tropical Animal Health and Production, 55*(2), 89-104. doi: 10.1007/s11250-023-03506-6

Detmann, E., Souza, M. A., Valadares, S. C., Fº., Queiroz, A. C., Berchielle, T. T., Saliba, E. O. S., Cabral, L. S., Pina, D. S., Ladeira, M. M., & Azevedo, J. A. G. (2012). (Eds.). *Métodos para análise de alimentos. INCT.* Ciência animal. Suprema.

Dirksen, G. (2008). Sistema digestivo. In G. Dirksen, H. Gründer, & M. Stöber (Eds.), *Exame clínico dos bovinos* (pp. 166-228). Guanabara Koogan.

Frota, M. N. L., Carneiro, M. S. de S., Carvalho, G. M. C., & Araujo, R. B. de., Neto. (2015). *Palma forrageira na alimentação animal.* (Documentos, 233). EMBRAPA Meio-Norte. http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1037123

Kearl, L. C. (1982). *Nutrient requirements of ruminants in developing countries.* Utah State University. doi: 10.26076/6328-a024

Lima, L. M., Bastos, M. M., Ávila, C. L. S., Ferreira, D. D., Casagrande, D. R., & Bernardes, T. F. (2022). Factors determining yield and nutritive value of maize for silage under tropical conditions. *Gross and Forage Science, 77*(3), 201-215. doi: 10.1111/gfs.12575

Marques, O. F. C., Gomes, L. S. de P., Mourthé, M. H. F., Braz, T. G. dos S., & Pires, O. de S., Neto. (2017). Palma forrageira: cultivo e utilização na alimentação de bovinos. *Caderno de Ciências Agrárias, 9*(1), 75-93. https://periodicos.ufmg.br/index.php/ccaufmg/article/view/2940

Monteiro, C. C. F., Ferreira, M. A., Véras, A. S. C., Guido, S. I., Almeida, M. P., Silva, R. C., & Inácio, J. G. (2019). A new cactus variety for dairy cows in areas infested with *Dactylopius opuntiae. Animal Production Science, 59*(3), 479-485. doi: 10.1071/AN17256

National Research Council (2001). *Nutrient requirements of dairy cattle* (7nd ed.). The National Academies Press.

Pessoa, D. V., Andrade, A. P., Magalhães, A. L. R., Teodoro, A. L., Santos, D. C. dos, Araújo, G. G. L. A., Medeiros, A. N. de, Nascimento, B. D. do, Valença, R. L., & Cardoso, D. B. (2020). Forage nutritional differences within the genus Opuntia. *Journal of Arid Environments, 181*(1), 104243. doi: 10.1016/j.jaridenv.2020.104243

Pessoa, R. M. dos S., Pessoa, A. M. dos S., Costa, D. C. da C. C., Azevêdo, P. C. da S., Gois, G. C., Campos, F., Vicente, S. L. A., Ferreira, J. M. de S., Araújo, C. de A., & Lima, D. O. (2022). Palma forrageira: adubação orgânica e mineral. *Research Society and Development, 11*(13), e12111334257. doi: 10.33448/rsd-v11i13.34257

Rocha, R. R., Fº., Santos, D. C., Véras, A. S. C., Siqueira, M. C. B., Monteiro, C. C. F., Mora-Luna, R. E., Farias, L. R., Santos, V. L. F., Chagas, J. C., & Ferreira, M. A. (2021). Miúda (*Nopalea cochenillifera* (L.) Salm-Dyck) the best forage cactus genotype for feeding lactating dairy cows in semiarid regions. *Animals, 11*(6), 1774. doi: 10.3390/ani11061774

Santos, A. de O., Dias, G. S., Jr., Pereira, M. N., Schwan, R. F., & Ávila, C. L. S. (2020). A survey of whole-plant corn silages from Minas Gerais dairy farms. *Scientia Agricola, 77*(2), e20180080. doi: 10.1590/1678-992X-2018-0080

Silva, E. T. S., Melo, A. A. S., Ferreira, M. de A., Oliveira, J. C. V., Santos, D. C., Silva, R. C., & Inácio, J. G. (2017). Acceptability by Girolando heifers and nutritional value of erect prickly pear stored for different periods. *Pesquisa Agropecuária Brasileira, 52*(9), 761-767. doi: 10.1590/S0100-204X2017000900008

Siqueira, M. C. B., Ferreira, M. de A., Monnerat, J. P. I. dos S., Silva, J. de L., Costa, C. T. F., Conceição, M. G. da, Andrade, R. de P. X. de, Barros, L. J. A., & Melo, T. T. de B. (2017). Optimizing the use of spineless cactus in the diets of cattle: total and partial digestibility, fiber dynamics and ruminal parameters. *Animal Feed Science and Technology, 226*(1), 56-64. doi: 10.1016/j.anifeedsci.2016.12.006

Sniffen, C. J., O'Connor, J. D., Van Soest, P. J., Fox, D. G., & Russell, J. B. (1992). A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. *Journal of Animal Science, 70*(11), 3562-3577. doi: 10.2527/1992.70113562x

SAS - Institute Inc. (2014). In SAS® OnDemand for Academics: User's Guide. Cary, NC.

Tilley, J. M. A., & Terry, R. A. (1963). A two-stage technique for the in vitro digestion of forage crop. *Journal of the British Grassland Society, 18*(2), 104-111. doi: 10.1111/j.1365-2494.1963.tb00335.x

Varela, J., Ferraretto, L. F., Kaeppler, S. M., & León, N. de. (2023). Effects of endosperm type and storage length of whole-plant corn silage on nitrogen fraction, fermentation products, zein profile, and starch digestibility. *Journal of Dairy Science, 106*(12), 8710-8722. doi: 10.3168/jds.2023-23382