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ORIGINAL ARTICLE

Nutrient intake and digestibility in sheeps fed diets with corn germ and Miúda forage cactus (Nopalea cochenillifera)

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Consumo e digestibilidade de nutrientes em ovinos alimentados com dietas com gérmen de milho e palma forrageira Miúda (Nopalea Cochenillifera)

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KEYWORDS

association, intake, digestibility, lipidic source, forage cactus.

ABSTRACT. The objective was to evaluate the effect of using corn germ and the forage cactus cv. Miúda in the diet of sheep on nutrient intake and digestibility. Four male sheep with an average initial weight of 35 kg, were used, and distributed in a Latin square experimental design. The treatments consisted of four experimental diets: without Miúda cactus (MFC) and germ (CONT); without MFC + germ (GIMEX); with MFC and without germ (MFC); with MFC and germ (MFC+GIMEX). However, a significant effect (P<0.05) of the treatments (T) was observed for the variables of dry matter intake (DMI) (955 x 1304.9 g day-1), mineral matter intake (MMI) (58.7 x 122.1 g day-1), crude protein intake (CPI) (119.9 x 162.9 g day-1) and ether extract intake (EEI) (36.7 x 77.8 g day-1). The diet (GIMEX+MFC) promoted higher DMI and other constituents, while the diet (GIMEX) resulted in lower DMI, MMI and CPI, but favored higher EE intake compared to the diet (GIMEX+MFC). The nutrient digestibility coefficients were not influenced by the association of MFC with corn germ (P>0.05); however, significant effects were observed for the coefficients of digestibility of organic matter (OM) (664.5 x 742.7 g kg-1 DM) and NFC (657.1 x 838.8 g kg-1

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DM). The present study determined that combining corn germ with forage palm is a viable option for sheep production in northeastern Brazil in terms of diet quality and utilization.

PALABRAS CLAVE

asociación, consumo, digestibilidad, fuente lipídica, palma forrajera.

RESUMEN. El objetivo del estudio fue evaluar el efecto del uso de germen de maíz y del cactus forrajero cv. Miúda en la dieta de ovinos sobre el consumo y la digestibilidad de nutrientes. Se utilizaron cuatro ovinos machos con un peso inicial promedio de 35 kg, distribuidos en un diseño experimental en cuadrado latino. Los tratamientos consistieron en cuatro dietas experimentales: sin cactus Miúda (MFC) y sin germen (CONT); sin MFC + germen (GIMEX); con MFC y sin germen (MFC); y con MFC + germen (MFC+GIMEX). Se observó un efecto significativo ($P<0.05$) de los tratamientos sobre las variables consumo de materia seca (DMI) (955 × 1304.9 g día^{-1}), consumo de materia mineral (MMI) (58.7 × 122.1 g día^{-1}), consumo de proteína cruda (CPI) (119.9 × 162.9 g día^{-1}) y consumo de extracto etéreo (EEI) (36.7 × 77.8 g día^{-1}). La dieta MFC+GIMEX promovió un mayor DMI y mayores consumos de los demás constituyentes, mientras que la dieta GIMEX resultó en menores valores de DMI, MMI y CPI, pero favoreció un mayor consumo de EE en comparación con la dieta MFC+GIMEX. Los coeficientes de digestibilidad de los nutrientes no fueron afectados por la asociación de MFC con germen de maíz ($P>0.05$); sin embargo, se observaron efectos significativos para los coeficientes de digestibilidad de la materia orgánica (OM) (664.5 × 742.7 g kg^{-1} MS) y de los carbohidratos no fibrosos (NFC) (657.1 × 838.8 g kg^{-1} MS). El presente estudio determinó que la combinación de germen de maíz con palma forrajera constituye una alternativa viable para la producción ovina en el nordeste de Brasil, en términos de calidad y aprovechamiento de la dieta.

PALAVRAS-CHAVE

associação, consumo, digestibilidade, fonte lipídica, palma forrageira.

RESUMO. O objetivo deste estudo foi avaliar o efeito do uso de gérmen de milho e do cactus forrageiro cv. Miúda na dieta de ovinos sobre o consumo e a digestibilidade de nutrientes. Foram utilizados quatro ovinos machos, com peso inicial médio de 35 kg, distribuídos em um delineamento experimental em quadrado latino. Os tratamentos consistiram em quatro dietas experimentais: sem cactus Miúda (MFC) e sem gérmen (CONT); sem MFC + gérmen (GIMEX); com MFC e sem gérmen (MFC); e com MFC + gérmen (MFC+GIMEX). Observou-se efeito significativo ($P<0.05$) dos tratamentos sobre as variáveis consumo de matéria seca (DMI) (955 × 1304.9 g dia^{-1}), consumo de matéria mineral (MMI) (58.7 × 122.1 g dia^{-1}), consumo de proteína bruta (CPI) (119.9 × 162.9 g dia^{-1}) e consumo de extrato etéreo (EEI) (36.7 × 77.8 g dia^{-1}). A dieta MFC+GIMEX promoveu maior DMI e maiores consumos dos demais constituintes, enquanto a dieta GIMEX resultou em menores valores de DMI, MMI e CPI, mas favoreceu maior consumo de EE em comparação com a dieta MFC+GIMEX. Os coeficientes de digestibilidade dos nutrientes não foram influenciados pela associação entre MFC e gérmen de milho ($P>0.05$); entretanto, foram observados efeitos significativos para os coeficientes de digestibilidade da matéria orgânica (OM) (664.5 × 742.7 g kg^{-1} MS) e dos carboidratos não fibrosos (NFC) (657.1 × 838.8 g kg^{-1} MS). O presente estudo demonstrou que a combinação de gérmen de milho com palma forrageira é uma alternativa viável para a produção de ovinos no nordeste do Brasil, em termos de qualidade e aproveitamento da dieta.

1. INTRODUCCIÓN

The Northeast region of Brazil is characterized by a semi-arid climate and water scarcity for most of the year, as the volume of water in the region's rivers is insufficient, since most of it is intermittent, with irregular rainfall distribution due to the greater concentration of precipitation at certain times of the year, for example, in certain regions, from November to March (Rebouças, 1997; Novais et al., 2022). Given these characteristics, the local vegetation is characterized by its strategies for storing and saving water, featuring woody trunks; roots with the power to retain water and store nutrients for long periods of drought, in the shape of potatoes; and because they lose their leaves at the beginning of the dry season, a process known as senescence in which the plants remain dormant; in addition to protection against predators, such as thorns which, in certain plants, are adaptations of the leaf to capture and retain water; these modifications characterize the vegetation of the Caatinga, especially the cactaceae (Almeida et al., 2014; Fernandes et al., 2022; Accioly et al., 2024).

Given the greater viability of producing cactaceous plants due to their adaptation to soil and climate conditions, spineless cactus is a forage species that deserves to be highlighted from a strategic perspective, due to its inherent characteristics such as its photosynthetic metabolism (CAM - crassulacean acid metabolism), characterized by the opening of stomata at night, capturing CO2 and minimizing water losses (Santos Neto et al., 2022; Nascimento et al., 2024). That said, spineless cactus is of great importance, mainly due to the aforementioned characteristics, as well as its resistance to poorly fertile soils, its high production of forage mass per unit area, especially in dense planting systems, and its great contribution from an energy point of view, congruent with its high content of NFC (non-fibrous carbohydrates) (Dubeux Júnior et al., 2021). All of the above-mentioned features highlight the importance of this roughage for the semi-arid region and for feeding ruminant animals, with the potential to mitigate the edaphoclimatic challenges inherent to the Northeast.

Taking into account the challenges posed by the Brazilian semi-arid region, formulating balanced diets linked to the profitability of livestock enterprises becomes a challenge, given that animal production is closely related to the quality and adequacy of their feed. Therefore, the search for innovative and unconventional feeding strategies is essential, testing and evaluating ingredients with the potential to be used in animal feed, optimizing performance without causing health, production and, consequently, economic damage (Da Silva, 2021a). In addition to the use of species and breeds adapted to local conditions, the combination of by-products of commodity such as GIMEX (whole extra-fat corn germ), which acts as a valuable source of energy and maintains the quality of the animal's diet, is of paramount importance in achieving the goals and objectives of profitable and sustainable livestock farming (Souza et al., 2024).

In this way, it is possible to see the importance of ingredients such as spineless cactus and GIMEX as food alternatives to more expensive ingredients, because in addition to meeting the nutritional needs of animals in situations where there may be less availability of resources for investment, they are more accessible in the semi-arid region, since cacti is easier to grow in this region (Dubeux Júnior et al., 2021; Souza et al., 2024). Nevertheless, the nutritional composition of these ingredients has characteristics that can cause a reduction in animal performance due to the use of the ingredients; mainly due to disturbances that can occur when, for example, forage cactus is supplied without a source of fiber in ruminant feed (Rocha Filho et al., 2021); however, it is known that these factors can be minimized when the cacti is supplied with a fibrous source such as hay and when these and GIMEX are used in consortium in the form of TMR (total mixture ratio), promoting greater use of nutrients at rumen level, guaranteeing the animal's health integrity and optimizing its performance in milk or meat production (Silva et al., 2022).

Given this reality, it was hypothesized that the use of forage cactus cv. Miúda (*Nopalea cochenillifera* - Salm Dyck) and GIMEX in the diet of beef sheep enhances the consumption and digestibility of nutrients, favoring their performance and obtaining animals for slaughter in a shorter period of time, due to the increase in the animals' weight gain.

This study aimed to evaluate the effects of including corn germ and the forage cactus Miúda (Nopalea cochenillifera) in sheep diets on nutrient intake and apparent digestibility.

2. METHODS

The experimental and handling procedures with the animals were carried out in accordance with the recommendations and general rules of the National Council for the Control of Animal Experimentation (CONCEA), which followed the guidelines established by the Ethics Committee on the Use of Animals for Research (CEUA), under license number 1556250684, in accordance with the Laws governing the use of animals for experiments.

The experiment was conducted in the research and development sector of Cabanha Severino - Criação de Caprinos e Ovinos, located in the district of Serra do Vento, Belo Jardim - PE, Brazil, at geographical coordinates 8º13'55'' South and 36º20'56'' West at 643 m altitude. According to Alvares et al. (2013), the climate is characterized as BSh or hot tropical semi-arid, or tropical dry, with an average annual minimum temperature of 18ºC and a maximum of 35ºC. According to data from Climatempo (2025), monthly rainfall is 32.4 mm, with 72% of rainfall occurring in the summer and fall seasons and 28% in the spring and winter.

Animals, management and experimental diets

For the experiment, four castrated male sheep, fistulated and cannulated in the rumen, with an initial body weight of 38±3.9 kg, were used. Before the start of the experiment, the animals were weighed on a commercial scale with a capacity of 500 kg, identified with earrings and a tattoo on the ear pinna, treated against broad-spectrum endo- and ectoparasites, vaccinated against clostridiosis and kept in a total confinement system in individual stalls measuring 2.0 m x 1.5 m (3 m^2/animal), with a slatted floor 30 cm above the ground, so that they were free from direct contact with feces and urine, and equipped with feeders and drinkers, where the animals had *ad libitum* access to clean, fresh water.

A Latin square experimental design was used, with 4 animals and 4 treatments, according to the methodology described and indicated by Keedwell and Dénes (2015), Sampaio (2015) and Montgomery (2020). The experimental period lasted 84 days, with four experimental periods lasting 21 days, 14 days for adaptation to the diets and management and 7 days for data and sample collection.

Table 1 shows the bromatological composition of the ingredients used to formulate the diets; Table 2 shows the proportion of ingredients and the chemical composition of the experimental diets. The experimental diets were formulated based on the recommendations of Da Silva (2021ab) and BR Caprinos e Ovinos (2024), to meet the nutritional needs of sheep at maintenance based on body weight (BW). The diets were made up of roughage based on forage cactus cv. Miúda or sweet (*Nopalea cochenillifera* - Salm Dyck) and a fiber source consisting of Tifton-85 hay (*Cynodon dactylon* L.), and concentrate made up of ground corn, soybean meal, common salt, commercial mineral mixture (mineral salt, SUPRA®), and whole extra-fat corn germ, with a 60:40 volume:concentrate ratio, as recommended by Da Silva (2021ab).

Table 1

Bromatological composition of ingredients

Ingredients	Chemical composition (g kg^{-1} DM)							
	DM[1]	MM[2]	CP[3]	EE[4]	NDF[5]	NDFap[6]	CHOT[7]	NFC[8]
Tifton-85, hay	890.5	49.9	83.8	17.5	734.4	698.2	853.2	147.3
Miúda, forage cactus (MFC)	92.0	126.6	46.0	14.8	275.9	247.6	812.6	565.0
GIMEX*	963.9	13.6	111.5	527.9	258.5	220.8	347.0	126.2
Maize	894.9	19.1	94.2	52.8	199.7	174.6	834.0	651.0
Soybean, bran	895.2	67.5	473.8	36.4	350.1	190.1	424.1	234.0
Mineral, salt	1000	1000	-	-	-	-	-	-

Note. *Extra fat whole corn germ. [1]Dry matter (g kg natural matter). [2]Mineral matter. [3]Crude protein. [4]Ethereal extract. [5]Neutral detergent fiber. [6]Neutral detergent fiber corrected for ash and protein. [7]Total carbohydrates, estimated according to Sniffen *et al*. (1992), where: CHOT = 100 – (%CP + %EE + %MM). [8]Non-fibrous carbohydrates, estimated according to Detmann & Valadares Filho (2010), where: NFC = 100 – (%NDFcp + %EE + %MM + %CP).

The treatments involved four experimental diets: 1. without forage palm (MFC) and without corn germ (treatment - CONT); 2. without MFC with the addition of corn germ (treatment - GIMEX); 3. with MFC and without corn germ (treatment - MFC); 4. with MFC and corn germ (treatment - MFC+GIMEX) (Table 2).

Table 2

Centesimal composition of ingredients, and chemical composition of experimental diets (based in DM, g kg^{-1} DM)

Ingredients	Treatments			
	CONT[1]	GIMEX[2]	MFC[3]	MFC+GIMEX[4]
Tifton-85, hay	600	600	300	300
Miúda, forage cactus (MFC)	0	0	300	300
GIMEX*	0	70	0	76
Maize	300	230	260	184
Soybean, bran	80	80	120	120
Mineral, salt[5]	10	10	10	10
Salt	10	10	10	10
TOTAL	1000	1000	1000	1000
Nutrients	**Composição da dieta (g kg^{-1} DM)**			
Dry matter (g kg^{-1} NM)	894.2	898.7	247.4	247.8
Mineral matter	51.1	50.7	76.0	75.6
Organic matter	938.9	939.3	903.8	904.2
Crude protein	116.4	117.7	120.3	121.6
Ethereal extract	29.3	62.5	27.8	63.9
Neutral detergent fiber	528.6	532.7	397.0	401.5
FDNcp[6]	474.3	478.0	357.0	360.3
CNF[7]	302.4	265.7	411.0	371.1
CHOT[8]	803.2	769.2	775.9	738.9

Note. *Extra fat whole corn germ. [1]Control; [2]Extra fat whole corn germ. [3]Miúda forage cactus. [4]Miúda forage cactus + extra fat whole corn germ. [5]Product warranty levels (nutrients/kg): Ca 218 g; S 20 g; P 20 g; Mg 20 g; K 28,2 g; Cu 400 mg; Co 30 mg; Cr 10 mg; Fe 2500 mg; I 40 mg; Mn 1350 mg; Mo 108 mg; Se 10 mg e Zn 1700 mg. [6]Neutral detergent fiber corrected for ash and protein. [7]Non-fibrous carbohydrates, estimated according to Detmann & Valadares Filho (2010), where: NFC = 100 – (%NDFcp + %EE + %MM + %CP). [8]Total carbohydrates, estimated according to Sniffen *et al*. (1992), where: CHOT = 100 – (%CP + %EE + %MM).

The Tifton-85 hay was grind to improve its apprehension and digestibility characteristics, passed through a 7 mm sieve and stored for 7 days. The MFC was grind daily using the MC3n electric stationary slicer (Laboremus®), before each feed offering, maintaining its natural and chemical characteristics and avoiding rotting due to storage. The corn and soybean meal had already been purchased in bulk form, speeding up the supply process by mixing them together. The diets were offered in two periods, one in the morning at 7am (60% of the total offered for the day, according to consumption calculated on the basis of the animals' weight), and at 4pm (40% of the total offered for the day), with clean, fresh water ad libitum in individual containers. The daily feed supply was adjusted daily, allowing for leftovers of 10-15% of what was offered based on dry matter (DM), as indicated by Romão et al. (2017).

Intake, and nutrients apparent digestibility

Nutrient consumption was calculated as the difference between the amount offered and the leftovers in the feeders. During all the collection periods, the ingredients and leftovers from the diet were sampled in order to obtain actual feed consumption and actual nutrient consumption. These samples were identified and stored in a freezer for later analysis. The samples were grouped proportionally for each period, thus obtaining composite samples for laboratory analysis.

To estimate the apparent digestibility of nutrients, total feces was collected on the 17th and 19th day of each experimental period using collection bags, with the animals having two days to adapt to the bags before the collection period, according to the methodology described by Cochran and Galyean (1994). The collection bags were emptied every four hours, within a 24-hour period, in order to avoid losses due to humidity or discomfort for the animals due to excess weight. The faeces were stored in plastic bags and, after the 24-hour period, they were weighed and homogenized, removing aliquots of 20 to 30% per animal to be stored frozen at -20 ºC and, at the end of the total collection period, the faeces samples were thawed to form composite samples and, of these, an aliquot of 10% of the total faeces was destined for pre-drying and analysis, following the guidelines proposed by Kitessa et al. (1999).

The samples made up of the ingredients supplied, leftovers and feces were pre-dried in a forced ventilation oven, model SL-102/1152I (SOLAB®), at a controlled temperature of 55 ºC, for 72 hours, according to the methodology described by Neumann et al. (2021). After pre-drying, all the material was ground in a Willey-type knife mill with 1 mm sieves (model SL-30, SOLAB®), for posthumous laboratory analysis to determine the dry matter (DM), mineral matter (MM), crude protein (CP), ether extract (EE), neutral detergent insoluble fiber (NDF) and neutral detergent insoluble fiber corrected for ash and protein (NDFap), determined according to the methodologies described by Krishna (2012) and Detmann et al. (2021).

The NFC content was estimated according to the equation proposed by Detmann & Valadares Filho (2010), where:

$$NFC = 100 - (\%NDFap + \%EE + \%MM + \%CP) \quad (2)$$

Where: NDFap = neutral detergent fiber corrected for ash and protein; EE = ether extract content; MM = mineral matter content; CP = crude protein content.

Total carbohydrates (CHOT) were calculated according to the equation proposed by Sniffen et al. (1992), where:

$$CHOT = 100 - (\%CP + \%EE + \%MM) \quad (3)$$

The apparent digestibility coefficient (ADC) of nutrients and DM was calculated according to the recommendations of Da Silva (2023), where:

$$ADC\ (g\ kg^{-1}) = \frac{intake\ nutrient\ (g) - nutrient\ lost\ in\ feces\ (g)}{Intake\ nutrient\ (g)} \quad (4)$$

The intake of total digestible nutrients (TDNI) of the diets was estimated according to the methodology recommended by Weiss (1999), as follows:

$$TDNI\ (g\ day^{-1}) = \%DCP + \%DNDF + \%DNFC + (2.25 \times \%DEE) \quad (5)$$

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With %DNDF and %DNFC corrected for ash and protein. Da Silva (2023), points out that the percentage of TDN is found using the formula:

$$TDN\ (\%) = \frac{TDN\ intake}{DM\ intake}\ x\ 100 \quad (6)$$

Statistical analysis

Statistical analyses were carried out using the SAS (2002) program (3.4, SAS Institute Inc., Cary, NC) using the MIXED program, as described by Stokes et al. (2012). The dependent variables were analyzed as a Latin square design, with 4 animals in each experimental period corresponding to the 4 treatments. The statistical model was generated through the statistical study:

$$Y_{ijk} = \mu + T_j + Ak_j + Pl + E_{jkl} \quad (7)$$

Where:

Y_{ijk} is the dependent response variable;

μ is the overall mean;

T_j is the fixed effect of the treatment (j = 1, 2, 3, 4);

Ak_j is the random effect of the animal within the treatment/square;

Pl is the random effect of the period;

E_{jkl} is the residual error.

The means were compared using Dunnett's test, with the effects considered significant at 5% probability (P<0.05).

3. RESULTS

With regard to nutrient intake, there was a statistical effect (P<0.05) for the variables dry matter (DMI), mineral matter (MMI), crude protein (CPI), ether extract (EEI), total carbohydrates (CHOTI), non-fibrous carbohydrates (NFCI) and total digestible nutrients (TDNI). It was observed that the diet containing (MFC+GIMEX) promoted higher dry matter intake (DMI) and other constituents, while the diet (GIMEX) promoted lower DMI, MMI, CPI, CHOTI and NFCI, but favored (P<0.05) higher EEI beside diet (MFC+GIMEX), as shown in Table 3.

Table 3

Intake values of dry matter and their constituents in sheep's subjects to experimental diets

Variables	Treatments (Intake in g day^{-1})				SEM[1]	*P*-value
	CONT[2]	GIMEX[3]	MFC[4]	MFC+GIMEX[5]		
Dry matter	1113.7^{ab}	955.0^{b}	1249.6^{ab}	1304.9^{a}	56.16	<0.05
DMI (% BW)	2.61	2.25	2.60	3.19	0.12	0.09
Organic matter	997.5	896.2	1023.0	1203.3	43.67	0.08
Mineral matter	70.3^{b}	58.7^{b}	113.7^{a}	122.1^{a}	6.80	<0.01
Crude protein	138.5^{ab}	119.9^{b}	147.3^{ab}	162.9^{a}	6.82	<0.05
Ethereal extract	36.8^{b}	70.6^{a}	36.7^{b}	77.8^{a}	4.19	<0.01
NDFap[6]	527.5	419.4	417.6	459.3	21.14	0.06
CHOT[7]	908.5^{ab}	709.1^{b}	953.9^{a}	945.5^{a}	42.60	<0.05
NFC[8]	371.4^{ab}	281.6^{b}	528.7^{a}	481.4^{a}	26.23	<0.01
TDN[9]	792.3^{ab}	666.1^{b}	791.7^{ab}	1024.8^{a}	41.22	<0.05

Note. [1]Standard error of the mean. [2]Control; [3]Extra fat whole corn germ. [4]Miúda forage cactus. [5]Miúda forage cactus + extra fat whole corn germ. [6]Neutral detergent fiber corrected for ash and protein. [7]Total carbohydrates. [8]Non-fibrous carbohydrates. [9]Total digestible nutrients. Means followed by distinct letters on the line differ by Dunnett's test.

The highest DMI was observed in the MFC and MFC+GIMEX diets, in which forage cactus was included ($P<0.05$), however, statistical analysis shows that there was a difference in consumption when MFC was mixed with GIMEX as a total diet, with the other treatments being similar in terms of consumption. This can be explained by the high palatability of the Miúda forage cactus, which makes it more acceptable to the animals, resulting in higher consumption, although consumption is reduced to a certain extent, since in terms of natural matter, the volume of cactus can be high, which results in limited consumption due to the limited space for food in the rumen (Oliveira et al., 2017). In addition, the rumen digestion rate of spineless cactus is high and, consequently, DM is degraded quickly, leading to a higher passage rate and, as a result, higher consumption, which is reflected in the data in Table 3.

Higher OM and MM intakes were found in the experimental diets in which forage cactus was present ($P<0.05$). This effect can be explained by the high concentrations of water (±900 g kg-1 DM) and minerals in this forage species. The variation in mineral values can occur according to the species analyzed, the place of cultivation and the physiological stage of the plant (Mayer and Cushman, 2019).

Higher intakes of EE were observed in the GIMEX and MFC+GIMEX diets, in which corn germ was included ($P<0.05$). This behavior can be explained by the germ's high fat content (Table 1), consequently, the inclusion of this ingredient in the experimental diets resulted in higher fat consumption by the animals. In these treatments, the level of fat consumed by the animals was 7.39 and 5.96% of the DMI, respectively.

With regard to dietary fiber, the control treatment was the one with the best ratio of fiber to the animals' dietary needs in relation to daily consumption, corresponding to 47.36% in relation to DMI and ±1.32% of their body weight. The other treatments resulted in low fiber, which is explained by the inclusion of MFC in the animals' diet. However, there was no difference (*P*>0.05) in the amount of fiber between the treatments.

In relation to the CHOT, NFC and TDN variables, higher intakes were observed in the treatments in which spineless cactus and germ were included (*P*<0.05). This can be explained by the high levels of NFC in forage cactus, which increased the animals' consumption of these nutrients (Oliveira et al., 2011). In addition, the germ, as it is a food rich in fat (Table 1), promotes a lower caloric increase in terms of digestive physiology, by increasing the TDN content of the diet; however, the experimental diet GIMEX expressed lower consumption of CHOT, NFC and TDN compared to the other treatments, due to the lower DMI in this diet.

The digestibility coefficients of DM, CP, EE and NDFap did not show significant results for the association of MFC with whole extra-fat corn germ (*P*>0.05), but the MFC+GIMEX treatment showed higher values for DM, CP and NDF digestibility than the other treatments, which shows that the association of germ with forage cactus generates an increase in nutrient digestibility and there is no negative effect on the same (Table 4).

Table 4

Digestibility values of dry matter and their constituents in sheep's subjects to experimental diets

Variables	Treatments (g kg^{-1} DM)				SEM[1]	*P*-value
	CONT[2]	GIMEX[3]	MFC[4]	MFC+GIMEX[5]		
Dry matter	689.9	654.3	721.8	720.1	10.21	0.06
Organic matter	703.3^{ab}	664.5^{b}	738.1^{ab}	742.7^{a}	10.20	<0.05
Crude protein	733.4	733.7	737.2	767.1	8.83	0.52
Ethereal extract	815.3	870.6	781.2	873.3	17.98	0.12
NDFap[6]	637.2	610.4	616.1	647.7	12.56	0.62
NFC[7]	769.2^{a}	657.1^{b}	838.8^{a}	798.4^{a}	14.62	<0.01

Note. [1]Standard error of the mean. [2]Control; [3]Extra fat whole corn germ. [4]Miúda forage cactus. [5]Miúda forage cactus + extra fat whole corn germ. [6]Neutral detergent fiber corrected for ash and protein. [7]Non-fibrous carbohydrates. Means followed by distinct letters on the line differ by Dunnett test.

The digestibility variables of the GIMEX experimental diet showed lower values for the DM, OM and NDFcp digestibility coefficients compared to the other treatments (Table 4). For the EE digestibility coefficient, the GIMEX treatment expressed higher values compared to the other experimental diets, however, there was no increase in TDN consumption as can be seen in Table 3. It is therefore possible to correlate the efficiency of nutrient consumption and digestibility when germ is associated with cactus, since the highest consumption values and nutrient digestibility coefficients in this study were observed more frequently when spineless cactus and germ were included in the form of TMR (Tables 3 and 4).

Significant effects (*P*<0.05) were observed for the digestibility coefficients of OM and NFC. The levels of NFC in the diet increased as they are easily degraded in the rumen and are eliminated quickly. This results in an increase in the supply of energy to the animal's rumen, which favors the growth of microorganisms and consequently improves the fermentative digestion process in the rumen. The increase in the amount of NFC was evident in the diets in which MFC was included, a fact explained by the high NFC content present in its composition (Table 1).

4. DISCUSSION

Only in the MFC+GIMEX treatment was the DMI in line with the recommendations of Da Silva (2021ab) and BR Caprinos e Ovinos (2024), for sheep with an average body weight of 38 kg in growth and a stipulated weight gain of 0.2 kg day^{-1}. Araújo Filho et al. (2024), also observed a linear increase in DMI in Santa Inês sheep as the MFC replaced Tifton hay by 100% and was included in up to 35. 10% of the total dry matter of the diet; however, according to the authors, this observed increase in consumption was still not enough to meet the sheep's DMI needs, suggesting that the higher proportion of cactus in the diets limits consumption due to distension of the digestive tract as a result of the high water content in diets with forage cactus included in up to 50% of the total dry matter. Other studies also confirm the data from the present study, in which the inclusion of cactus in the diet limits consumption and, consequently, animal performance (Albuquerque et al., 2020; Batista et al., 2020; Cordova-Torres et al., 2022). According to Savietto et al. (2014), DMI is one of the factors that most affects the productive performance of animals, since 60 to 90% of the variation in animal performance is due to DMI, since higher or lower consumption results in higher or lower nutrient intake and, consequently, their use for performance.

The ruminal degradability rate of cactus is high and, consequently, the dry matter is degraded quickly, resulting in a higher passage rate and greater consumption, which explains what happened in the treatments in which MFC was included (Paulino et al., 2021). Furthermore, in this study, the diets were provided as a total diet (TMR), so the spineless cactus, when processed, adds the other ingredients of the diet to its mucilage, forming a single mixture, which makes it difficult for the animals to select, mitigating the effects on DMI (Silva et al., 2024).

The higher MM intake observed in the inclusion cactus treatments is the result of the plant's higher mineral composition (Table 1); consequently, the MFC and MFC+GIMEX diets contained higher MM than the other diets (Table 2). Silva et al. (2024) also observed higher MM consumption in the treatments with cactus included in the diet; for these authors, the mineral composition of the plant and its inclusion in animal feed is important for the mineral balance in the animal organism, since excess minerals are excreted in the urine or can be harmful to animal health. Excess minerals or ratios between minerals, such as calcium and phosphorus, can maximize the manifestation of disorders in the animal body, such as urolithiasis in the presence of a Ca:P ratio greater than 6:1 (Pordeus Neto et al., 2016; Silva et al., 2023). Silva et al. (2024), warn that, given the composition of the cactus and the level of inclusion, the Ca:P ratio can be from 2:1 to >6:1.

With regard to CP, the higher intakes observed in the MFC and MFC+GIMEX treatments are not necessarily the result of the protein composition of these ingredients, but of the protein composition of the formulated diet. Even so, there was no effect of including cactus on CP intake; however, given the lower DMI in the GIMEX treatment, there was a lower protein intake in this treatment. Munhame et al. (2021), when evaluating different genotypes of spineless cactus resistants to the carmine mealybug in goat feed, observed CPI values similar to those of the present study; however, the animals reduced their DMI when cactus was included in the diet, which can be explained by rumen filling, which consequently reduced the CPI by the animals, although there was no significant effect, contrary to the statistical difference in this study between the treatments.

In the corn germ inclusion treatments, the EE content of the diet and, consequently, EE intake were higher (Table 3). Cardoso et al. (2019), evaluated different levels of cactus inclusion in sheep diets and observed an effect on EE consumption up to 300 g kg^{-1} DM of cactus inclusion, with consumption without palm and with 450 g kg-1

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DM being similar. What affects fat consumption by animals is the presence or absence of lipid sources in the animal's diet (Pereira et al., 2016), so the limitation of performance is imposed by the protein source, since there is a limit of lipids in ruminant feed to maintain rumen dynamics and homeostasis of the animal's digestive functions (Simionatto et al., 2024). Studies indicate that, for efficient fermentative digestion by rumen microorganisms, the level of lipids in the diet for ruminants should not exceed 7% of the total DM (Palmquist, 1994; Marín et al., 2013; Besharati et al., 2024); in the present study, lipid levels, represented by EE, were within the recommended limits, ranging from 2.78 to 6.39% between treatments and 2.94 to 5.96% between intakes, values similar to those found by Cardoso et al. (2019).

The fiber content of the diet, represented by NDFap, was in line with the daily dietary fiber recommendations of Einkamerer et al. (2025), who recommend that fiber should make up 40 to 60% of the total dry matter of ruminant diets and about 1.3 to 1.5% of NDF based on their body weight. In this study, fiber made up around 46.42% of the diet and 53.78% of intake, in line with the recommendations of Van Soest (1994) and Einkamerer et al. (2025). NDFap consumption was lower in the treatments in which there was a reduction in hay and the inclusion of cactus in the diet (Table 3), data corroborated by Godoi et al. (2024), who observed a reduction in fiber consumption in diets with cactus inclusion; however, these same authors evaluated fiber consumption in treatments with cactus and other fiber sources such as buffel grass silage (*Cenchrus ciliaris* L.), pornunça (Manihot spp.) and gliricidia (*Gliricidia sepium* L.) and observed that fiber intake increased in these treatments, a fact due to the fiber present in these ingredients and which helps with rumen dynamics, favoring digestion data and diet utilization.

The NFC content of the diets ranged from 26.57% to 41.10% based on the total DM of the diet, a value consistent with the recommendations of the National Research Council (2001) and Villalba et al. (2021). In turn, the average NFC intake was approximately 35.51%, which falls within the recommendations of these authors. Diets containing MFC exhibited higher NFC intake, as spineless cactus has high NFC concentrations and low NDF and lignin contents, resulting in high ruminal degradability of DM and low fiber effectiveness (Batista et al., 2009; Ribeiro et al., 2023). Consequently, sheep fed high levels of cactus may experience changes in DMI, as observed in this study (Gebremariam et al., 2006).

Due to the low effectiveness of fiber, an NFC:NDF ratio that maintains ruminal function in homeostasis is necessary. In this study, the NFC:NDF ratio was 1:1, which aligns with the findings of Pu et al. (2020), who reported that an ideal NFC:NDF ratio for fiber degradation rate and bacterial fermentation efficiency is 1.37:1. Lanzas et al. (2007) recommend an NFC content in ruminant diets of approximately 30 to 40% of total dry matter, with an NFC:NDF ratio between 1:1 and 1.5:1. Excessive NFC levels (>40%) lead to metabolic disorders such as subclinical ruminal acidosis, which negatively affect ruminal activity and, consequently, animal health. Conversely, a low NFC:NDF ratio (<1:1) results in poor animal productive performance (Agle et al., 2010; Ohtaki et al., 2020; Chen et al., 2022).

According to Savietto et al. (2014), 10 to 40% of animals' productive performance stems from nutrient digestibility. Diet digestibility is closely related to factors associated with ingredients and total mixture, the environment, and the animal, particularly regarding the health of the digestive system (Bruinenberg et al., 2002).

There was an effect only on OM and NFC digestibility, where the inclusion of GIMEX in the diet reduced nutrient digestibility in sheep. This phenomenon can be explained by the nutraceutical properties of extra-fat corn germ, due to a series of factors related to its composition and its effects on the ruminal microbiota, as well as its interaction with other dietary components (Montgomery et al., 2008).

Cardoso et al. (2019), reported digestibility coefficient values of 71.32%, 74.90%, 53.15%, and 88.32% for DM, CP, NDFap, and NFC, respectively, which are very similar to the data observed in this study. These same authors concluded that the inclusion of cactus pear in the diet has the potential to improve the digestibility of certain nutrients in the ruminal level.

Although this study shows promise as a combination for sheep feed, it has limitations in terms of the number of animals used and the duration of the experimental period. Therefore, we suggest that future research, including a larger experimental unit, a longer experimental period, and perhaps the effects of different sheep genotypes, be conducted to corroborate the data observed during this experiment.

5. CONCLUSIONS

The spineless cactus, regardless of its species and cultivars, is a plant of great importance to the Northeastern region of Brazil, due to its inherent characteristics that make it a fundamental ingredient in ruminant feed. Due to its importance, and its particularities as animal feed, the addition of concentrated ingredients mixed in the form of a total diet aims to increase production and productivity within the beef or milk production system.

In order to maximize energy consumption by the animals, ensuring greater weight gain and shorter time to slaughter, as well as not negatively influencing the digestibility of essential nutrients for the animals, it is recommended to use forage cactus cultivar Miúda (*Nopalea cochenillifera*) in association with extra-fat corn germ in the diet of feedlot finishing sheep.

The inclusion of Miúda forage cactus (Nopalea cochenillifera) with extra-fat corn germ increased dry matter intake and total digestible nutrients without affecting nutrient digestibility, suggesting its potential as an alternative energy source in feedlot sheep diets.

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The authors declare that they have no conflicts of interest.

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