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Effect of replacing corn with cactus pear on the performance and carcass traits and meat quality of feedlot finished lambs

Efeito da substituição do milho pela palma forrageira sobre o desempenho, características de carcaça e qualidade da carne de cordeiros terminados em confinamento

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Abstract
The aim was to evaluate the effect of replacing ground corn with spineless cactus from two species *Orelha de Elefante Mexicana-OEM (Opuntia stricta* Haw.) and *Gigante* (*Opuntia ficus-indica* Mill) in a total mixed ration for finishing lambs evaluating its effects on intake, ingestive behavior, performance, carcass traits, commercial cuts and physiochemical composition of the meat. Eighteen crossbred lambs with average body weight of 15.0 ± 2.32 kg were distributed in a completely randomized design with three treatments (OEM and *Gigante* spineless cactus and ground corn as control treatment) and six replications. Spineless cactus species replacing ground corn in lambs diets does not change the intake of dry matter (DMI), crude protein and neutral detergent fiber or time (min/d) of ingestion, rumination and idleness, or final body weight gain. Lambs fed with ground corn and "*Gigante*" cactus presented a higher total weigh gain (TWG) and average daily weight gain (ADG) when compared to OEM spineless specie. Ground corn diet promoted better hot and cold carcass yield in lambs receiving spineless cactus, regardless of species. Feed and total costs (kg/lamb) were higher for the ground corn diet. The replacement of ground corn with spineless cactus did not change moisture, protein, and ash meat contents, as well as water holding capacity, cooking loss, shear force, and a* color intensity. However, there was an effect for the meat lipid content, b* and L* color intensity and color index, where the species of cactus *Gigante* on ground corn presented the highest lipid content and yellowness (b*) intensity and lower L* color compared to OEM. Spineless cactus species *Gigante* can replace ground corn as a source of energy in diets for finishing lambs because it significantly improves the financial income for the producer without changing the ADG, DMI, ingestive behavior and yield of commercial cuts.
Keywords: cactus pear; carcass; color; shear force; ruminant
Resumo
Objetivou-se avaliar o efeito da substituição do milho moído por duas espécies de palma forrageira, *Orelha de Elefante Mexicana-OEM* (*Opuntia stricta* Haw.) e espécie *Gigante* (*Opuntia ficus-indica* Mill) em uma ração completa para terminação de cordeiros avaliando seus efeitos sobre consumo, comportamento ingestivo, desempenho, características de carcaça, cortes comerciais e composição físico-química da carne. Foram utilizados dezoito cordeiros sem padrão racial definido com peso corporal médio de 15,0 ± 2,32 kg e foram distribuídos em delineamento inteiramente casualizado com três tratamentos (OEM e palma Gigante e grão de milho como controle) e seis repetições. As duas espécies de palma forrageira em substituição ao milho moído na dieta de cordeiros não modificaram o consumo de matéria seca (CMS) proteína bruta e fibra em detergente neutro nem o tempo (min/dia) de ingestão, ruminação e ócio ou ganho corporal final. Cordeiros alimentados com milho moído e palma Gigante apresentaram maior ganho de peso total (GPT) e médio diário (GMD) em relação à espécie OEM. A dieta com milho moído promoveu melhor rendimento de carcaça quente e fria comparando cordeiros recebendo palma forrageira, independente da espécie. Os custos com ração e total (kg/cordeiro) foram maiores para a dieta com milho moído. A substituição do milho moído pela palma forrageira não alterou os teores de umidade, proteína e cinzas da carne, bem como a capacidade de retenção de água, perda por cozimento, força de cisalhamento e intensidade de cor a*. No entanto, houve efeito para o teor de lipídios da carne, índice de intensidade de cor b* e L*, sendo que a espécie de palma *Gigante* e o milho grão moído apresentou o maior teor de lipídios e intensidade de amarelo (b*) e menor cor L* em relação ao OEM. A espécie palma forrageira *Gigante* pode substituir o milho moído como fonte de energia em dietas para cordeiros em terminação, pois melhora significativamente o rendimento financeiro do produtor sem alterar o GMD, CMS, comportamento ingestivo e rendimento dos cortes comerciais.
Palavras-chave: carcaça; coloração; força de cisalhamento; palma; ruminante

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1. Introduction

Ground corn is one of the main energy feeds used in sheep diets, however, despite being widely used in the diet of monogastric and ruminants, it has a high cost. Among concentrate feeds, corn predominates in most feedlots in Brazil and, despite its high energy value, when used in mixed diets of roughage and concentrates, it can cause an adverse effect by reducing the digestibility of the dietetic fiber ([1]). The high nutritional value of ground corn, as a food product for human consumption, and the need for its use in the composition of monogastric animals' feeding, make its cost high, leading producers to search for alternative ingredients. Thus, byproducts rich in highly digestible fiber have been evaluated as alternative energy sources to replace starchy grains ([2]).

In this sense, the spineless cactus provides water and feed for animals and humans in areas with water scarcity ([1]). In its composition, the spineless cactus has a high content of water (80 to 90%) and organic matter (93%), but it has low dry matter-DM (± 10% as fed) and crude protein-CP (±3.5% in DM), being advised the added supply of a fiber source and a protein feed to prevent digestive problems when supplied alone ([3,4]). However, despite the low DM concentration, spineless cactus is an excellent source of ruminant dietary energy because of its high non-fiber carbohydrates-NFC (± 55% in DM) and total digestible nutrients (TDN) content ([4,5]). However, it is important to point out that spineless cactus should not be the only source of food in the animal's diet, as it has a low protein content. It is recommended that the spineless cactus be used in conjunction with other feed sources to ensure an adequate nutritional balance in the sheep diet ([6]).

Two species of spineless cactus are cultivated predominantly for animal feed, *Opuntia ficus-indica* Mill) or *Palma Gigante* (PG) is characterized by disease resistance, a determining characteristic in the selection of a cactus variety, and among these ([8]), the *Opuntia stricta* [Haw.] or *Orelha de Elefante mexicana* (OEM) species has shown resistance to carmine cochineal, an insect that has caused serious damage to producers on also has a lower requirement for soil fertility ([9]). However, it has many thorns, which can compromise its palatability and make it difficult to manage as a forage plant ([10]). Regarding *Opuntia stricta* [Haw.] specie, it has been used extensively due to high productivity, greater resistance to drought and greater susceptibility to carmine cochineal ([11]).

Veras et al. [12] observed that replacing up to 75% of corn bran by spineless cactus in sheep diets did not change the nutrient digestibility coefficient and TDN content. In contrast, Cavalcanti et al. [13] and Veras et al. [14] verified a reduction in dry matter digestibility and weight gain in sheep when substituting ground corn for spineless cactus.

Therefore, spineless cactus represents a promising alternative to corn in the diet of sheep, due to its high content of easily digestible carbohydrates and its capacity for rumen fermentation. These characteristics can enhance nutrient absorption and make it a more cost-effective option, particularly in regions where cactus is locally and extensively cultivated, leading to high yields per hectare and reduced feed production costs. Incorporating cactus pear into the diet may also improve animal productivity, as it is a source of high-quality energy that can facilitate weight gain and improve carcass quality. This research aimed to evaluate the effect of replacing ground corn by spineless cactus on intake, ingestive behavior, performance, commercial cuts, and carcass yield of lambs.

2. Material and methods

All animal handling practices followed the recommendations of the National Council for the Control of Animal Experimentation (CONCEA) for the protection of animals used for animal experimentation and other scientific purposes and were approved by the Ethics Committee on Animal Experimentation of the Federal University of Campina Grande, Paraiba state, Brazil (Protocol number 37/2020).

2.1 Location and facilities

The experiment carried out in the sheep and goat facilities of the Federal Institute of Education, Science and Technology, *Campus* Crato, in the town of Crato, Ceará. The geographic location is 7º12'25" South latitude, 39º26'48" West longitude and 271 m of average altitude in meters. The climate is tropical with an average temperature of 25.1 °C, and average annual rainfall of 1086 mm.

2.2 Animals, experimental design and diets

Eighteen uncastrated crossbred male lambs, at an average age of three months and initial body weight of 15.0 ± 2.32 kg were used. Before starting the experiment, the animals identified with earrings, weighed, dewormed, vaccinated against clostridium disease, in addition to application of ADE vitamin supplement and, after drawing lots, distributed in individual pens measuring 1.60 × 0.80 m, equipped with feeders and water drinkers. Lambs were distributed in a completely randomized design with three treatments (ground corn, and two diets replacing ground corn by two spineless cactus "*Palma Gigante*" and "*Orelha de Elefante Mexicana*" species and six replications per treatment. The experiment lasted 90 days, preceded by an adaptation period of 15 days.

The complete diets were formulated with a roughage: concentrate ratio of 40:60, using Tifton-85 hay in particles of approximately 5.0 cm as the roughage ingredient. The ingredients used in the concentrates were ground corn, soybean meal, soybean oil, and a mineral mixture (Table 1). The diets were formulated to meet the nutritional requirements for a weight gain of 200 g/day according to NRC ([15]) recommendations.

Table 1. Chemical composition and ingredient proportions of the experimental diets (% DM)

Item	Treatments		
	Ground corn	Spineless cactus "*Gigante*"	Spineless cactus OEM[1]
Ingredients (% DM)			
Tifton Hay-85	40.0	40.0	40.0
Ground corn	38.5	0.00	0.00
Spineless cactus "*Gigante*"	0.00	33.1	0.00
Spineless cactus OEM	0.00	0.00	32.9
Soybean meal	19.0	25.3	25.7
Urea	1.0	0.4	0.7
Soy oil	0.00	0.8	0.00
Mineral mixture[2]	1.5	0.4	0.7
Chemical composition of diets (% DM)			
Dry matter (% as fed)	87.9	27.0	24.9
Crud ash	5.74	8.75	7.44
Crude protein	16.5	16.4	16.5
Ether extract	1.86	2.10	1.60
Neutral detergent fiber$_{ap}$[3]	37.1	40.9	42.3
Non-fiber carbohydrates	38.8	31.8	32.1
Total digestible nutrients[3]	68.5	63.0	64.1

[1]OEM: *Orelha de Elefante Mexicana* species; [2]Assurance levels per kilogram of product: 220 g Ca, 163 g P, 12 g S, 12.5 g Mg, 2 mg Zn, 3500 mg Cu, 3640 mg Mn, 310 mg Co, 1960 mg Fe, 280 mg I, 9000 mg Zn, 1630 mg Fl, 32 mg Se. [3]Corrected for ash and protein [4]According to NRC equations ([21]).

The supply of experimental rations was carried out at 8:00 am and 4:00 pm, according to the pre-established treatments, with water permanently available to the animals in plastic containers. Before the morning supply, the leftovers of each experimental unit were collected, which after being weighed, recorded, and sampled, were stored under freezing at –10 ºC, together with samples of diets and ingredients for later formation of a weekly composite sample per animal, which at the end of the experimental period represented a total sample per animal/treatment. The amount of feed was adjusted daily to provide an *ad libitum* intake allowing for a 10% of leftover.

2.3 Chemical composition and calculations

The contents of dry matter (method 967.03), crude ash (method 942.05), crude protein (method 981.10), and ether extract (EE; 920.29) were determined, according to the AOAC ([16]). For the determination of neutral detergent fiber NDF, the methodologies described by Van Soest et al. ([17]) were used. For NDF analysis, three drops (50 µL) of α-amylase added per sample in the washing with the detergent, as well as in the water. The NDF content was corrected for ash and protein (NDF$_{ap}$), following the methodology described by Licitra et al. ([18]), where the neutral detergent residue was burned in a muffle furnace at 600 °C for 4 h, and the correction for protein was performed by discounting the insoluble protein in neutral detergent. Non-fiber carbohydrates (NFC) were calculated by the equation: NFC = 100 – [(CP – CP from urea + urea) + NDF + EE + Ash, considering the presence of urea in their constitution ([19]). Based on the composition of the evaluated feeds, the maintenance NDT values were estimated, according to NRC equations ([20]).

2.4 Ingestive behavior

The lambs were individually monitored by two observers positioned to interfere as little as possible with animal behavior. The monitoring during 24 hours at days 35 and 70 for 24 h at 5-min intervals. The nighttime observations were conducted using matte artificial lighting in which the animals were previously adapted. The relations obtained the variables referring to the ingestive behavior: EE = DMI/FT; RE = DMI/RT; TCT=FT + RT; NRB = RT/CMtb; CMnb = NRBCMnb, wherein, EE (g DM/h) is the eating efficiency; DMI (g DM/day) is dry matter intake; FT (h/day) is the feeding time; RE (g DM/h) is the rumination efficiency; RT (h/day) is the rumination time; TCT (h/day) is the total chewing time; NRB (Nº/day) is the number of rumen boli; CMtb (sec/ bolus) is the time of chewing per ruminal bolus (Polli et al., 1996); and CMnb (No./cake) is the number of chewing per bolus.

2.5 Growth Performance

The intake of nutrient obtained by the difference between the total of each nutrient offered in the diet and the total of each nutrient contained in leftovers. To carry out the chemical composition analyses, the samples pre-dried at 55°C for 72 hours, ground in a Willey-type mill (Tecnal, Piracicaba, São Paulo, Brazil) with a 1 mm sieve and stored in airtight plastic containers. For the performance, lambs weighed at the beginning and end of the experiment to determine the total weight gain (TWG) obtained by the difference between the final weight (FW) and initial weight (IW): TWG = (IW – FW). The estimate of average daily weight gain (ADG) obtained through the relationship between the WG and the total days referring to the feedlot period until slaughter: ADG = WG/75.

2.6 Slaughter, carcass characteristics and commercial cuts

After 75 days of experimental period, the lambs were subjected to 16 h of fasting, the animals were weighed and slaughtered. During the slaughtering procedure, the animals were stunned by electronarcosis (220 V, 1.5 A for

10 seconds; Dal Pino, Santo André, SP, Brazil), according to the guidelines of the Brazilian Department of Agriculture and Livestock (MAPA, Brazil) for the Federal Inspection Service ([21]). At slaughter, after bleeding, skinning and evisceration, the head and legs were removed, and the carcasses were weighed to obtain the hot carcass weight (HCW) and determination of the hot carcass yield [HCY = HCW/BWS (body weight at slaughter) × 100]. Then, the carcasses were cooled for 24 h in a refrigerated chamber at a temperature of 4ºC, being weighed to obtain the cold carcass weight (CCW). Weight loss due to chilling (LC) was calculated by the difference between LC = HCW – CCW/HCW × 100 and the cold carcass yield (CCY = CCW / BWS × 100). After the refrigeration period, the carcasses were sectioned in half, the half carcasses weighed and the left half carcass sectioned into five anatomical regions ([22]), originating commercial meat cuts: neck, shoulder, leg, loin, and chop. The individual weight of each cut was recorded.

The carcasses were transferred to a cold room at a temperature of 4°C for 24 h. then, the *Longissimus lumborum* muscle went through the toilet process, where the connective tissue and apparent fat were removed and finally the loin fractionation was carried out, which was conditioned in five polystyrene trays and sealed with a transparent PVC adherent film (Poliembalagens®, São Paulo, Brazil) and stored in a freezer at –18 °C during the storage period.

2.7 Physicochemical meat analyzes

Three samples of the *longissimus dorsis* (2.5 cm thick) were used to determine cooking weight loss ([23]). The weight of the samples were recorded before and after cooking. The subcutaneous fat of the samples were removed and cooked on an electric grill (Grill Mondial®, São Paulo, Brazil) at 170 °C and the temperature monitored by a portable digital thermometer (Incoterm®) until the moment when the internal temperature of the geometric center of the sample reached 71 °C. After cooking, the steaks were removed from the grill and weighed, and the difference between the initial and final weight of the sample was used to determine the cooking loss, expressed in %.

The water holding capacity (WHC) was determined by placing meat samples weighing approximately 100 mg inside previously weighed filter paper (P1), and pressed for five minutes, using a weight of 3.4 kg. After pressing, the samples were removed, and the paper was weighed again (P2). The calculation followed the formula: WHC (%) = (P2 – P1) /S × 100, where “S” represents the weight of the sample ([24]). Six cylindrical samples taken from each steak on a bench measuring approximately 1.12 mm in diameter. Shear force was determined with the Warner-Bratzler Shear Force ([25]) apparatus (GR Electrical Manufacturing Company, 25 kg).

After exposing the samples to the atmosphere for 30 minutes for myoglobin oxygenation, measurements related to color were performed in triplicate, using a Minolta CR-400 colorimeter (Konica Minolta, Osaka, Japan), and the CIE system (Commission Internationale de l'éclairage) L*, a*, b*, at the end obtaining an average of the variables. The parameters L* - luminosity (L* 0 = black; 100 = white), a* - red index and b* - yellow index were evaluated according to Miltenburg et al. ([26]). The determination of moisture content, dry matter, minerals, and crude protein of the meat followed the recommendations of the AOAC ([27]).

2.8 Economic analysis of the diets

The cost analysis considered the descriptive analysis of the diets cost during the 75 days of the experiment, with ingredients priced based on the current US$ dollar quotation (Dairy Farm International Holdings, Ltd.), as well as the profit with the sale of goat kid carcass (kg). Income over feeding costs (IOFC) was calculated using the following equation ([28]): *IOFC = Total Revenue (TR) - Total Feeding Costs (TFC)*, where: TR = revenue generated after the sale of cold carcasses, and TFC= feeding cost per diet × dry matter intake. The economic profitability (profit or loss) is presented in US$/animal.

2.9 Statistical analyzes

The experimental design completely randomized with three treatments and six replications per treatment. The data obtained analyzed using SAS 9.4 and the following statistical model used:

$$Y_{ij} = \mu + \tau_i + \varepsilon_{ij},$$

Yij= value observed in the experimental unit that received treatment i, repetition j;

μ= general mean common to all observations;

τi= effect of treatment i;

εij= random error with mean 0 and variance σ^2

The data were analyzed using the MIXED procedure in SAS (version 9.4); means were compared through Tukey’s test. A significance value of 0.05 was adopted as the critical value of the probability of type I and II errors. The statistical test chosen adequately controls the error rates per experiment and per comparison, preserving the nominal level of significance and essential control of type I and II errors and, therefore, was chosen for the studied variables.

3. Results

The replacement of corn by spineless cactus varieties did not influence the intake of DM, CP, and NDF (P >0.05), as well as the ingestive behavior (P >0.05) of feedlot lambs (Table 2). Most of the time was spent idling (704 min/day average) followed by rumination (514.33 min/day average), and less time eating (222 min/day average).

Table 2. Nutrient intake and ingestive behavior of lambs fed spineless cactus replacing ground corn

Variables	Treatments			SEM[2]	*P*-value[3]
	Ground corn	Spineless cactus "*Gigante*"	Spineless cactus OEM[1]		
Intake (g/day)					
Dry matter	924	1038	970	0.09	0.6898
Crude protein	176	158	142	0.01	0.1453
NDF	321	280	283	0.02	0.4255
Ingestive behavior (min/day)					
Rumination	495	510	538	15.6	0.6596
Eating	207	243	216	23.8	0.5530
Idling	738	687	686	50.1	0.7266
Efficiency (g/h)					
DM eating	293	263	278	34.8	0.8396
NDF eating	68.7	71.9	75.1	5.93	0.7571
DM rumination	110	121	111	8.76	0.6179
NDF rumination	35.4	32.9	32.4	35.4	0.6272
TCT (min/day)	703	754	754	49.9	0.7139

MS, dry matter; NDF, neutral detergent fiber; and TCT, total chewing time; [1]OEM: *Orelha de Elefante Mexicana* species; [2]SEM: standard error of the mean; [3]Mean values followed by different letters, in the same row, are significantly different by Tukey's test ($P \leq 0.05$).

Table 3. Performance, carcass characteristics of lambs and economic analysis of diets (R$) containing spineless cactus replacing ground corn

Variables	Treatments			SEM[2]	*P*-value[3]
	Ground corn	Spineless cactus "*Gigante*"	Spineless cactus OEM[1]		
Performance					
Initial weight (kg)	16.8	16.4	16.9	-	-
Final weight (kg)	30.1	30.2	29.0	2.13	0.8829
Total weight gain (kg)	13.3a	13.8a	12.1b	1.44	0.0243
Average daily gain (g/d)	177a	184a	161b	13.2	0.0243
Feed efficiency (g/g)	0.19	0.18	0.17	0.01	0.7473
Carcass characteristics					
Hot carcass weight (kg)	12.06	11.64	11.47	0.94	0.6592
Hot carcass yield (%)	45.59[a]	42.56[b]	43.93[b]	0.68	0.0220
Cold carcass weight (kg)	11.91	11.51	11.29	0.92	0.6447
Cold carcass yield (%)	45.06[a]	42.06[b]	43.26[b]	0.66	0.0186
Cooling weight loss (kg)	0.15	0.14	0.17	0.02	0.4821
Economic analysis of the diet (US$)[4]					
Feeding cost (kg DM/lamb)	0.42	0.22	0.22	-	-
Total feeding cost	29.32	17.22	16.28	-	-
Total carcass income	48.83	45.73	45.16	-	-
Results (profit or loss)	19.51	28.51	28.89		-

[1]OEM: *Orelha de Elefante Mexicana* species; [2]SEM: mean standard of the error. [3]Mean values followed by different letters, in the same row, are significantly different by Tukey's test ($P \leq 0.05$). [4]Revenue over feeding costs; Price in dollars quoted at US$ 5.35;

Regarding the performance and carcass characteristics of lamb, lambs fed with ground corn and "*Gigante"* cactus presented a higher total gain and ADG ($P = 0.0243$) compared OEM specie. Ground corn diet promoted higher HCY and CCY ($P < 0.05$) comparing lambs receiving spineless cactus, regardless of species (Table 3). There was no significant effect ($P > 0.05$) for final body weight, total weight gain, feed efficiency hot carcass weight and cold carcass weight.

Feed and total costs (kg/lamb) were higher for the ground corn diet (0.42 and 29.32). However, for the diet containing spineless cactus OEM, it provided a better cost and consequently a higher profit when compared to the other diets. The weights and yields of commercial cuts were not influenced ($P > 0.05$) by replacing ground corn with spineless cactus, (Table 4), except for breast yield ($P = 0.01$) which was higher for diet with "*Gigante*" species and OEM (9.37 and 9.30%).

Table 4. Commercial cuts of lambs fed diets containing spineless cactus replacing ground corn

Variables	Treatments			SEM[2]	*P*-value[3]
	Ground corn	Spineless cactus "*Gigante*"	Spineless cactus OEM[1]		
Weights (kg)					
½ Carcass	6.53	6.14	6.20	0.51	0.8472
Loin	0.82	0.75	0.72	0.06	0.4823
Leg	1.60	1.46	1.55	0.12	0.7351
Shoulder	1.15	1.09	1.04	0.07	0.4981
Ribs	1.20	1.14	1.18	0.13	0.9380
Brisket	0.49	0.57	0.58	0.05	0.4389
Flank steak	0.36	0.35	0.31	0.04	0.6782
Neck	0.91	0.78	0.81	0.08	0.5422
Yields					
Loin	12.77	12.20	11.58	0.45	0.2109
Leg	24.67	23.83	25.07	0.59	0.3376
Shoulder	17.86	17.69	16.93	0.45	0.3265
Ribs	18.00	18.4	18.95	0.63	0.5829
Brisket	7.44b	9.37a	9.30a	0.47	0.0166
Flank steak	5.47	5.74	4.98	0.30	0.2263
Neck	13.77	12.71	13.19	0.66	0.5233

[1]OEM: *Orelha de Elefante Mexicana* species; [2]SEM: standard error of the mean; [3]Mean values followed by different letters, in the same row, are significantly different by Tukey's test ($P \leq 0.05$).

The replacement of ground corn with spineless cactus did not change ($P > 0.05$) moisture, protein, and ash meat contents, as well as water holding capacity, cooking loss, shear force, and a* color intensity (Table 5). However, there was an effect for the meat lipid content (P = 0.001), b* (P = 0.001) and L* color intensity color index, which the species of cactus *Gigante* on ground corn presented the highest lipid content and yellowness intensity and lower L* color compared to OEM.

Table 5. Physicochemical characteristics of the *longissimus dorsi* muscle of sheep fed cactus pear.

Item	Treatments			SEM[2]	P-value[3]
	Ground corn	Spineless cactus "*Gigante*"	Spineless cactus OEM[1]		
Moisture (g/100 g meat)	74.29	74.26	74.21	0.33	0.1903
Dry matter (g/100 g meat)	25.71	25.74	25.79	0.33	0.1903
Protein (g/100 g meat)	21.23	22.19	23.10	0.61	0.0980
Lipid (g/100 g meat)	3.07a	2.32ab	1.44b	0.18	0.0123
Ash (g/100 g meat)	1.41	1.23	1.25	0.07	0.1770
Water holding capacity (%)	31.7	31.55	31.69	1.16	0.9948
Cooking weight losses (%)	68.91	77.03	77.00	3.39	0.1827
Shear force (kgf/ cm^2)	1.83	1.78	1.67	0.12	0.6040
Color indexes					
L* (Luminosity)	50.07b	51.88[b]	56.97[a]	0.87	0.0040
a* (Redness)	12.95	13.62	14.58	0.81	0.3872
b* (Yellowness)	13.18a	13.71a	11.06b	0.42	0.0012

[1]OEM: *Orelha de Elefante Mexicana* species; [2]SEM: standard error of the mean; [3]Mean values followed by different letters, in the same row, are significantly different by Tukey's test (*P* ≤0.05).

4. Discussion

DMI similar among lambs is directly related to the ingestive behavior of the animals as well as the similarity of the chemical composition of the diets, since the use of Tifton hay (fiber) provided similar rumination rates to the animals consuming cactus despite the lower DM content in the diets containing spineless cactus. According to Van Soest ([29]) and Maciel et al. ([30]), rumination activity in adult animals occupies around eight hours/day, varying from four to nine hours. The mean obtained in this study for rumination time was 8.5 hours (514 min), corroborating this statement. Diet composition influences animal behavior. According to ([7]), feed ingredients with higher proportions of fibrous material require a longer feeding and rumination time to meet their needs and a decrease in material particles to be better used by bacteria.

Costa et al. ([31]) observed that the total substitution of corn by cactus pear, despite leading to a reduction in weight gain, increased the DM intake and improved the ability of sheep to digest the nutrients and recommended cactus pear as part of the diet during the finishing of feedlot sheep.

Spineless cactus *Gigante* species as well as the ground corn promoted high weight gain which did not occur with the OEM species. The spineless cactus is a rich source of easily digestible carbohydrates and has a high rate of rumen fermentation, which can improve the absorption of nutrients by the animal ([11]). Compared to other feeds, the fiber content in spineless cactus is low, mainly the lignin-cellulose fraction, and the percentage of soluble carbohydrates is high ([31,32]). However, although soluble carbohydrates are rapidly and extensively fermented in the rumen, fermentation characteristics among spineless cactus differ, and are largely related to the presence of organic acids. Digestion of pectin, which is more present in spineless cactus, for example, results in less lactic acid production ([33,34]) than starch (soluble carbohydrate) present in large amounts in corn, which may explain the fact that spineless cactus OEM did not allow ADG like ground corn. HCY and CCY are within the range of values (40% to 50%) normally found for lambs ([35,36]).

The cost/kg/lamb of the diet with ground corn at the end of 75 experimental days showed a total cost of feeding 10% higher when compared to diets with cactus pear and OEM. However, diet containing OEM cactus species presented a better cost than the others. The cost of production with the OEM was promising, since the cost of feed was lower, because of the cost of kg of spineless cactus being lower than the ground corn, providing better profitability ([37]). There was a higher cost of the diet (10%) with ground corn for carcass production, compared to other diets (US$ 0.42 kg/DM).

There was no significant effect regarding replacing ground corn by spineless cactus species on the weight and yield of the main commercial carcass cuts (leg, loin and shoulder). This behavior may be due to the similarity of the body weight of the slaughtered animals. Breast yield was higher for diet with "*Gigante"* cactus compared OEM, demonstrating that the inclusion of spineless cactus in the diet influenced this cut characterized as third, providing more non-fiber carbohydrates and not compromising the quality of expensive cuts. In this way, the optimal weight for each cut will be the one in which its value is maximum, both for the producer and consumer, mainly in relation to the proportion of cuts that becomes a factor in determining its commercial value ([38]).

The b* content in the meat of animals fed with spineless cactus *Gigante* species as well as the ground corn reflects the greater weight gain in these animals, which promoted greater fat deposits. Lambs received a diet rich in energy and carotenoids, such as ground corn and *Gigante* spineless species ([41]) which is stored in the adipose tissue, intra and intramuscular in the meat, which, in turn, are mainly responsible for the yellow hue observed in lamb meat, explaining the increase in the b* parameter, showing that lamb meat with higher scores indicate that the red hue is closer to the yellow region ([42]). The meat color index is one of the most valued parameters at the time of purchase, representing an important sensory quality factor due to its association with the freshness of the meat ([39]). The values of luminosity (L*) differed between OEM and diets, which could indicate that the diets with this variety were more available, influencing this characteristic, since it is one of the factors that change the color of meat is the diet ([40]).

The instrumental parameters of water holding capacity (WHC), cooking weight loss (CWL) and shear force (SF) were not affected by the diet this occurred due to the pH values being normal in slaughter, obtaining average recommended values for lamb meat, which were 1.76 kgf/cm² SF, 31.64% for WHC and 74.31% for CWL ([41]). Therefore, based on this value the meat of the lambs in this study can be considered tender, as it is below 2 kgf/cm² which can result in high acceptance by the consumer ([42]). These results can be explained due to the higher levels of fat in the carcass, since they provide lower losses during cooking, resulting in more succulent meats, because the fat in the meat acts as a barrier to moisture loss ([43]).

5. Conclusion

Spineless cactus species *Gigante* can replace ground corn as a source of energy in diets for finishing lambs because it significantly improves the financial income for the producer without changing the ADG, DMI, ingestive behavior and yield of commercial cuts. Lambs fed spineless cactus *Orelha de Elefante Mexicana* species showed lower weight gain and meat lipid deposition yields when compared to *Gigante* and ground corn.

Conflict of interest

The authors declare no competing interests.

Author contributions

Conceptualization: K. A. Alencar; *Data curation*: K.A. Alencar and J.A.M.d Lima; *Investigation*: K.A. Alencar, T.C da Silva and M.L.R.Gomes; *Methodology*: K.A. Alves and C.de L. Brito: *Writing (revision and editing)*: M. R.G F. Costa, J.M.Pereira Filho, J.P.F de Oliveira, R.R do Nascimento and L.R.Bezerra.

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Data availability

The authors declare that all the data and materials used in this study comply with field standards and available on demand.

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