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Effects of replacing Tifton-85 hay by cactus pear *(Opuntia stricta Haw)* on the carcass traits and meat quality of crossbred Santa Inês lambs

Efeitos da substituição do feno de Tifton-85 por palma forrageira *(Opuntia stricta Haw)* nas características de carcaça e qualidade da carne de cordeiros mestiços Santa Inês

Graciliano Paiva Oliveira[1]*; Ivone Yurika Mizubuti[2]; Fernando Luiz Massaro Junior[3]; Francine Mezzomo Giotto[3]; Odimári Pricila Prado-Calixto[2]; Leandro das Dores Ferreira da Silva[2]; Juraci Marcos Alves Suassuna[4]; Angela Rocio Poveda-Parra[3]; Neila Lidiany Ribeiro[5]; Geovergue Rodrigues Medeiros[5]

Highlights

The ether extract of the meat increases with the inclusion of cactus pear in the diet.
Cactus pear can replace Tifton-85 hay in up to 900 g kg^{-1} DM in the diet.
The cactus pear in the diet do not change characteristics of meat.

Abstract

The objective of this study was to evaluate the carcass traits of crossbred Santa Inês lambs fed with increasing levels (0, 300, 600, and 900 g kg^{-1} on a dry matter basis) of cactus pear cv Mexican elephant ear (Opuntia stricta Haw) as a replacement for Tifton-85 hay. Forty-eight male lambs (noncastrated), averaging 21.0 ± 2.93 kg body weight (BW) at the beginning of the study, were used in this trial. Replacement levels of Tifton hay by cactus pear affected the hot carcass and cold carcass weights and the carcass compactness index linearly ($P < 0.05$), but did not influence the yield of hot carcass and cold carcass, the loin eye area, conformation, finishing, and subcutaneous fat thickness, the yield of commercial cuts and tissue composition of the leg ($P > 0.05$). The averages of tissue components yields were: muscle 64.94%, bone 16.92%, fat 14.92%, and other tissues 2.71%. There was also no effect ($P>0.05$) of treatments on other measurements in Longissimus

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[1] Prof. Dr., Instituto Federal do Maranhão, IFMA, Codó, MA, Brazil. E-mail: graciliano@ifma.edu.br
[2] Profs. Drs., Animal Science Department, Universidade Estadual de Londrina, UEL, Londrina, PR, Brazil. E-mail: mizubuti@uel.br, odimari@uel.br, leandro@uel.br
[3] PhD Animal Science, UEL, Londrina, Brazil. E-mail: massaro@uel.br; fgiotto@unr.edu; angelpov@gmail.com
[4] Prof. Dr., Animal Science Department, Universidade Federal da Paraíba, UFPB, Areia, PB, Brazil. E-mail: juracizootec@hotmail.com
[5] Drs., Instituto Nacional do Semiárido/MCT, INSA, Campina Grande, PB, Brazil. E-mail: neilalr@hotmail.com, geovergue.medeiros@insa.gov.br
* Author for correspondence

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dorsi. However, there was an increasing linear effect on ether extract content (P<0.05). It can be concluded that the Mexican Elephant Ear cactus pear can be used to feed finishing lambs, replacing up to 900 g kg-1 of the dry matter of the roughage, with a consequent increase in carcass weight, loin, shoulder, and leg, as well as, in the percentage of ether extract of the meat. However, it does not alter the other carcass traits and physical-chemical characteristics of the meat.

Key words: Carcass cuts. Carcass yield. Color meat. Lambs. Tissue composition.

Resumo

O objetivo deste trabalho foi avaliar as características de carcaça de ovinos mestiços Santa Inês alimentados com níveis crescentes (0, 300, 600 e 900 g kg^{-1} na matéria seca) de palma forrageira cv. Orelha de elefante Mexicana (Opuntia stricta Haw) como substituto para o feno de Tifton-85. Quarenta e oito cordeiros machos (não castrados), com média de 21,0 ± 2,93 kg de peso corporal (PC) no início do estudo, foram usados neste ensaio. Os níveis de substituição do feno de Tifton pela palma forrageira afetaram os pesos da carcaça quente e fria e o índice de compacidade da carcaça linearmente, mas não influenciaram o rendimento da carcaça quente e da carcaça fria, área de olho de lombo, conformação, acabamento, espessura de gordura subcutânea, rendimento dos cortes comerciais e composição do tecido da perna. As médias de rendimentos dos componentes do tecido foram: músculo 64,94%, osso 16,92%, gordura 14,92% e outros tecidos 2,71%. Também não houve efeito dos tratamentos nas outras medições no Longissimus dorsi. No entanto, houve um efeito linear crescente no teor de extrato etéreo. Pode-se concluir que a palma forrageira orelha de elefante mexicana pode ser utilizada na alimentação de cordeiros em fase de terminação, substituindo até 90% da matéria seca do volumoso, com consequente aumento do peso de carcaça, lombo, paleta e perna, bem como, na porcentagem de extrato etéreo da carne. No entanto, não altera as demais características de carcaça e as características físico-químicas da carne.

Palavras-chave: Composição de tecidos. Cordeiros. Cor da carne. Cortes de carcaça. Rendimento de carcaça.

Introduction

Within meat production, a way of evaluating what is being produced is through the quantitative and qualitative characteristics of the carcass, whose objective is to meet the needs of the consumer market (Cacere et al., 2014). With the increasing consumption of lambs meat, several alternatives have been researched to supply the market demand and reduce the feed production costs, the most expensive production system component. Through confinement, the intensification of animal production aims to shorten the production cycle and provide a faster economic return (Lima et al., 2019).

The cactus pear has stood out as a strategic food, mainly in the Semi-Arid region, where the production of other crops are almost innocuous, due to its adaptation to the edaphoclimatic conditions of the region (Pessoa et al., 2013). It has high forage production potential, contributing to the supply of alternative feed, especially during the dry season, making possible the confinement practice for small farmers (Abreu et al., 2019).

In addition, it is a source of water for animals, due to the high moisture content in its composition (Galvão, Silva, Morais, & Lima, 2014), an excellent source of energy, rich in non-fibrous carbohydrates (618 g kg^{-1}) and total digestible nutrients (620 g kg^{-1}) (Lima et al., 2018). It has low levels of dry matter - DM (251 g kg^{-1} of DM) and crude protein (41 g kg^{-1} of DM) and its use has been reported as a susbstitute for sugarcane with benefitial results in carcass traits of lambs (Lima et al., 2019). However, protein supplementation is recommended.

According to Frota, Carneiro, Carvalho, & Araujo (2015), supplementation with protein sources allows synchronization between energy and nitrogen supply for the ruminal microbiota.

The inclusion of cactus pear in the diet of ruminants provides an increase in the consumption of dry matter and the digestibility coefficient of dry matter, organic matter (OM), and total carbohydrates (TC) (Lima et al., 2019), in addition to reducing water consumption from animal (Costa et al., 2009).

In a study conducted by Costa el al. (2012), the use of cactus pear replacing partially (250, 500, 750 g kg^{-1}) or totally (1000 g kg^{-1}) corn in the diet for feedlot Santa Inês lambs provided quadratic behavior on adipose tissue, when the replacement level was 445.3 g kg^{-1}, reducing the muscle:fat ratio in tissue composition. The authors also observed that cactus pear can replace 1000 g kg^{-1} of the corn in the diet without compromising physical and sensory attributes of the meat.

In another study, Lima et al. (2019), observed that protein and intramuscular fat content were affected by the inclusion of spineless cactus, when replacing Tifton hay, showing that dietary treatments of 150 and 300 g kg^{-1} of replacement presented the highest values for those parameters. The authors also observed that up to 300 g kg^{-1} of spineless cactus can be used in lambs diet without compromising sensory attributes.

The objective of this study was to evaluate the effects of the levels (0, 300, 600 and 900 g kg^{-1} DM) of cactus pear variety Mexican Elephant Ear (*Opuntia stricta* Haw) replacing Tifton-85 grass hay in lambs' diet on carcass traits and meat quality.

Material and Methods

The experiment was carried out at the Experimental Station of the National Semi-Arid Institute (Campina Grande, Paraíba, Brazil) with the following geographical coordinates: latitude 7º 16'37" S and longitude 3º 58'07" W. The mean annual rainfall is 492.4 mm, and the mean temperature is 24.6 ºC. The study was approved by the Animal Ethics Committee of the Federal University of Paraiba-UFPB, Brazil, under protocol number 2305/14.

Forty-eight entire male of crossbred Santa Inês lambs (*n* = 12 by treatment) of 6 months of age and initial body weight (BW) of 21.0 ± 2.93 kg were used. At the beginning of the trial, experimental animals were identified, weighed, and treated against ectoparasites and endoparasites. Then, lambs were distributed in individual stalls (considering the average BW per treatment) with a cement floor measuring 1.0 m × 2.2 m and equipped with feeders and water trough. The experiment lasted 75 days, with 15 days of adaptation to the diets and facilities and 60 days of evaluation. Experimental lambs were slaughtered with 33.49±3.50 kg.

The experimental diets offered ad libitum at 08:00 h and 16:00 h were isoprotein composed of spineless cactus of the variety Mexican elephant ear (*Opuntia stricta* Haw), Tifton hay (*Cynodon dactylon*), ground corn, soybean meal, urea, limestone, and the vitamin and mineral premix. The spineless cactus was manually cut into slices of approximately five cm² and mixed with the other ingredients of the diet. The experimental diets consisted of four levels (0, 300, 600, and 900 g kg^{-1} on a dry matter basis) of spineless cactus in replacement of Tifton hay and met or exceeded the nutrient requirements for a BW gain of 250 g per day, as recommended by National Research Council [NRC] (2007). To formulate the diets, it was used chemical compositions of ingredients determined at the Animal Nutrition Laboratory (Tables 1 and 2), according to the methodologies described by Association of Official Analytical Chemists [AOAC] (2010). The dry matter (DM) (method AOAC 934.01), crude protein (Kjeldahl method, method AOAC 984.13), ether extract (method AOAC 920.39), neutral detergent fiber (method AOAC 2002.04), acid detergent fiber (method AOAC 973.18), and ashes content (method AOAC 942.05) were analyzed. Total carbohydrates were analyzed by capillary electrophoresis with ultraviolet radiation and derivatization pre-column with 250 mmolL^{-1} *p*-aminobenzoic acids (PABA) and 20% acetic acid 40 ºC. After the feed was offered, the leftovers were weighed to calculate the voluntary intake. The diet was daily adjusted based on the previous day's consumption, maintaining the leftovers at 10%.

Moreover, during the experiment, lambs were weighed at the beginning of the trial and the day before slaughter to obtain the initial and final live BW. Data obtained were used to calculate the daily average gain, the daily average feed intake, and the feed conversion ratio.

Table 1
Chemical composition of ingredients

Nutrient (g kg^{-1} of DM)	Ingredients			
	Cactus pear	Soybean meal	Tifton-85 hay	Ground corn
Dry matter (DM)	108	872	884	877
Organic matter	812	947	921	988
Crude protein	36.1	482	77.3	97.4
Ether extract	16.6	19.7	14.0	31.4
Neutral detergent fiber	300	160	750	142
Acid detergent fiber	240	121	460	36.6
Mineral matter	138	54.5	178	11.9
Total carbohydrates	809	843	730	859
Metabolizable energy (Mcal kg^{-1} of DM)	1.85	2.95	2.35	3.10

Table 2
Ingredients and nutrient composition of experimental diets

Ingredients (g kg^{-1} DM)	levels of Spineless cactus (g kg^{-1} of DM)			
	0	300	600	900
Cactus pear	0.00	300	600	900
Ground corn	303	287	271	256
Soybean meal	178	194	210	225
Tifton-85 hay	500	350	200	50
Urea	4.00	4.00	4.00	4.00
Mineral premix	15.0	15.0	15.0	15.0
Nutrient composition (g kg^{-1} of DM)				
Dry matter (DM - g kg^{-1} as feed)	882	425	280	200
Mineral matter	67.4	70.7	86.7	96.3
Crude protein	164	164	165	164
Ether extract	20.1	20.2	20.4	20.6
Neutral detergent fiber	446	379	312	244
Acid detergent fiber	262	230	199	167
Organic matter	932	929	913	903
Total carbohydrates	748	744	727	718
Metabolizable energy (Mcal kg^{-1} of DM)	2.39	2.46	2.53	2.61

All lambs were slaughtered the same day using standard commercial procedures following Brazilian welfare codes of practice (Ministério da Agricultura, Pecuária e Abastecimento [MAPA], 2000). Lambs were fasted at the farm for 8 h and transported to an accredited slaughterhouse. At the slaughterhouse, lambs had a 8 h rest period with full access to water but not to feed. Experimental animals were left unconscious by electrical stunning and slaughtered by bleeding for 3 min by carotid and jugular section. After slaughter, the carcasses were chilled at 4 ºC in a refrigerated chamber, where they remained for 24 h hanging from hooks by the Achilles tendon with the metatarsal joints spaced 17 cm apart.

The pH of the *Longissimus Dorsi* (LD) muscle was measured at 24 h *post mortem* using a digital potentiometer (DIGIMED, model pH 300 M, São Paulo, Brazil) equipped with a glass electrode. At the beginning of the measurements, the pH meter was calibrated using pH values 4 and 7 (Crison, Lainate, Italy) and was automatically calibrated for muscle temperature before each measurement. The right and left sides of the Longissimus Dorsi muscle were removed from each carcass, and samples (250 ± 25 g) were taken. The *Longissimus Dorsi* muscles were vacuum packed and placed in a freezer for 24 h for subsequent analysis. The right *Longissimus Dorsi* was reserved for color and physicochemical analysis, whereas the left *Longissimus Dorsi* was used for sensory studies.

All physicochemical analyses were performed in duplicate for each muscle sample. Before color measurements were conducted, LD samples were allowed to bloom directly in contact with air for 30 min. Objective measures of LD color (CIELAB space) including lightness (a more excellent L* value is indicative of a lighter color), redness (a greater a* value is indicative of a redder color), and yellowness (a more excellent b* value is indicative of more yellow color) were determined using a color-guide 45º/0º colorimeter (BYK-Gardner, USA).

For chemical composition analysis, muscle samples from the right LD from each carcass were cleaned, connective tissue removed and then, triturated in a domestic blender until a homogeneous mass was obtained. Moisture, protein, and ash content were determined according to AOAC (2010).

Cooking losses (CLs) were evaluated according to the methodology described by Wheeler, Cundiff and Koch (1993). Briefly, two steaks of 2.5 cm thickness were obtained from the LD muscle, with the cut being performed transversely to the direction of the muscle fibers. Steaks were thawed in a refrigerator for 24 h and weighed using a precision balance (SHIMADZU, model TX3202L, Kyoto, Japan). Then, samples were placed together in a griddle and baking sheet and roasted in an electric oven, preheated to 150 ºC (FISCHER, Star model, Brusque, Santa Catarina, Brazil) until the internal temperature of the samples reached 70 ºC. The internal temperature was monitored using K-type thermocouples inserted in the geometric center of the samples, and readings were performed with a digital reader (TENMARS, model TM-361, USA). Samples were cooled at room temperature until the samples reached an internal temperature of 25 ºC, measured using an insertion thermometer (TESTO, model 106, Melrose, MA, USA). Samples were then weighed to determine the weight loss, which was expressed as weight loss percentage.

A texture analyzer (G-R MANUFACTURING CO., Model 3000TAXT2, Stable Micro Systems, Godalming, UK) was used. Seven pieces of meat of 1 cm × 1 cm × 2.5 cm (height×width×length) were removed parallel to the muscle fiber direction. Samples were cut entirely using a Warner Bratzler shear blade with a triangular slot cutting edge (1 mm thickness) at a cut speed of 20 cm min^{-1}. As shown by the greater peak of the force-time curve, maximum shear force represented the maximum resistance of the sample to the cut.

The carcasses were individually weighed immediately after slaughter to obtain the hot carcass weight (HCW) and then cooled for 24 hours in a cold room at a temperature of 2ºC, then being weighed again to obtain the cold carcass weight (CCW). The hot carcass yield (HCY) and cold carcass yield (CCY) were estimated, calculated through the percentages of the HCW and CCW concerning the final body weight (FBW).

Before the linear measurements and the carcass section, a subjective evaluation was carried out to determine the degree of conformation by assigning scores from 1.0 to 5.0 (1.0 for the worst and 5.0 for the best conformation) and finishing with scores from 1.0 to 5.0 (1 to 2 = lower, 3 = medium, 4 = upper and 5 = extra), according to a methodology adapted from Muller (1980).

The carcasses were cut in half, and the half-carcasses were weighed. In the left half-carcass, the internal length was measured (distance from the anterior edge of the ischio-pubic symphysis to the anterior edge of the first rib); the depth of the breast (maximum distance between the sternum and the back of the carcass); the width of the breast (maximum width of the carcass at the level of the ribs); the length of the leg (distance between the greater trochanter of the femur and the tarsometatarsal junction); and the width of the croup (maximum width between the trochanters of both femurs) and the thoracic perimeter (Cezar & Sousa, 2007).

In the left half-carcass, a cross-section was performed in the section between the 12th and 13th ribs to measure the loin-eye area (LEA) of the Longissimus Dorsi muscle as recommended by Cezar and Sousa (2007). Still, in Longissimus Dorsi, the thickness of subcutaneous fat (TSF) covering over the muscle section (between the last thoracic and first lumbar vertebra) was measured at two-thirds of the total length of the loin-eye area (Muller, 1980).

The right and left half-carcasses were sectioned in six anatomical regions (commercial cuts), according to the methodology proposed by Cezar and Sousa (2007): shoulder, leg, loin, rib, breast and neck. The individual weights of each cut were recorded. The left legs were identified, packed in packaging, and stored in a cold room at -18 ° C for further dissection according to the methodology of Brown and Willians (1979). Before being dissected, the legs were thawed at 10 °C for 20 hours. Then, they were prepared for dissection by removing any extra tissue at the cranial end with a vertical cut to the end of the tensor muscles of the fascia latea and quadriceps femoris. With the aid of the scalpel, all the free fat inside the pelvic bone and the caudal vertebrae were removed, except for the first two. After the toilet, the clean legs were weighed, and, with the aid of a scalpel, the subcutaneous fat along the entire leg was removed and weighed. Subsequently, the muscles surrounding the femur (biceps femoris, semitendinosus, semimembranosus, adductor, and quadriceps femoris) were individually dissected. The other ham muscles were removed, dissected, and weighed together (tensor fascia lata, gluteus medius, deep, and accessory). The leg muscularity index (LMI) was determined using the formula described by Purchas, Davies and Abdullah (1991): $LMI = [\sqrt{(P5M/LF)}]/LF$, where P5M is the weight (g) of the five muscles that surround the femur (biceps femoris, semitendinosus, semimembranosus, adductor and quadriceps femoris) and LF is the length of the femur (cm).

Forty-eight male crossbreed lambs were distributed in a completely randomized design with four inclusion levels (0, 300, 600, and 900 g kg^{-1} on a dry matter basis) of spineless cactus in the diets. Data were subjected to analysis of variance (ANOVA), and the mean was compared by the Tukey test at 5% probability using the MIXED procedure of the SAS® program. Orthogonal contrasts were also performed to compare the control group (0 g kg^{-1} of DM) versus the spineless cactus-treated groups (300, 600, and 900 g kg^{-1} of DM) and the regression analysis, using the regression analysis was performed using PROC REG of Statistical Analysis System Software [SAS], (2009).

Results and Discussion

The morphometric measurements of the lamb carcass did not were influenced ($P > 0.05$) to the levels of spineless cactus in the diet (Table 3). The lambs carcass traits did not show any significant effect ($P > 0.05$) with up to 900 g kg^{-1} of DM of spineless cactus in the diet (Table 3). The HCW, CCW, weight of gastrointestinal content, empty body weight

(EBW), and assessment of pelvic-renal fat showed an orthogonal contrast effect. That is, the control value was different from the levels of spineless cactus in the diet. The values of HCW, CCW, EBW, and assessment of pelvic-renal fat increased with the levels of spineless cactus in the diet, but the opposite occurred with weight of gastrointestinal content.

The HCW, CCW, weight of gastrointestinal content, EBW, and fasting losses showed a linear effect, with HCW, CCW, EBW and fasting losses being linear increasing and the weight of gastrointestinal content was linear decreasing. Hot carcass and cold carcass weight increased 10% with the 900 g kg^{-1} of DM diet.

Table 3

Carcass traits and morphometric measurements of lambs fed different levels of forage palm Mexican Elephant Ear *(Opuntia stricta Haw)* replacing Tifton-85 hay in diets

Variables	levels of Spineless cactus (g kg^{-1} of DM)				SEM	P-value	
	0	300	600	900		Linear	Quadratic
Carcass traits							
IW (kg)	21.87	20.91	20.27	21.60	3.00	0.731	0.190
SW (kg)	30.59	32.27	32.22	33.01	3.49	0.120	0.681
FL (kg) *	1.35	1.32	1.53	1.52	0.25	0.032[1]	0.924
EBW (kg) *	27.50	27.70	28.60	29.40	2.05	0.010[2]	0.710
WGC (kg) *	4.82	4.52	3.60	3.55	0.93	<.0001[3]	0.559
HCW (kg) *	14.86	15.92	16.36	16.64	1.90	0.024[4]	0.486
CCW (kg) *	14.55	15.63	16.03	16.35	1.88	0.022[5]	0.494
HCY (%)	48.62	49.47	50.70	50.40	3.11	0.116	0.519
CCY (%)	47.63	48.58	49.68	49.52	3.09	0.100	0.532
Conformation	3.18	3.22	3.35	3.50	0.47	0.180	0.718
Finishing	3.38	3.32	3.25	3.70	0.58	0.238	0.121
TSF (mm)	1.57	1.68	1.94	1.95	0.65	0.100	0.776
LEA (cm^2)	10.18	10.38	10.05	11.29	5.57	0.061	0.464
Carcass morphometric measurements							
ICL, cm	57.45	58.27	58.20	58.16	3.02	0.605	0.634
LL, cm	38.54	40.04	39.41	39.83	2.33	0.303	0.458
BRD, cm	27.37	28.36	28.33	27.87	1.75	0.512	0.164
BRP, cm*	67.80	68.30	69.60	70.80	3.13	0.014[6]	0.723
BRW, cm	21.50	21.70	22.50	22.40	1.41	0.077	0.659
CRP, cm	61.45	62.09	63.20	62.16	5.01	0.627	0.559
CRW, cm	22.90	22.69	23.24	23.22	1.28	0.362	0.823

SEM- standard error means; IW- initial weight; SW- slaughter weight; FL - fasting losses; EBW - empty body weight; WGC - weight of gastrointestinal content; HCW - hot carcass weight; CCW - cold carcass weight; HCY - hot carcass yield; CCY - cold carcass yield; TSF- thickness of subcutaneous fat; LEA - loin eye area; ICL - internal carcass length; LL - leg length; BRD- breast depth; BRP- breast perimeter; BRW-breast width; CRP - croup perimeter; CRW- croup width. * Polynomial regression analysis. [1]$Y=1,33+0,002X$ ($R^2=0,71$); [2]$Y=16,92+0,02X$($R^2=0,98$); [3]$Y=4.74-0.02X$ ($R^2=0.89$); [4]$Y=15,08+0,02X$ ($R2=0,91$); [5]$Y=14,78+0,002X$ ($R2=0,91$); [6]$Y=67,6019+0,034185X$ ($R^2=0,97$).

The effects on carcass and meat quality from lambs-fed finishing diets containing spineless cactus replacing other roughages such as sugarcane (J. P. F. Oliveira et al., 2017) or wheat bran (Felix et al., 2016; Abreu et al., 2019) have been previously studied, concluding, respectively, that spineless cactus can replace up to 49.5% of sugarcane, and up to 58.7% of wheat bran without harming the carcass and meat quality.

In addition, recently, Ribeiro et al. (2016) have concluded that incomplete diets for sheep, Tifton hay associated with spineless cactus provides more significant BW gain, cold carcass muscularity, and organ weight when compared to those for animals fed corn silage as exclusive roughage. However, it is necessary to determine which level of spineless cactus is better as a supplement to Tifton hay diets (Lima et al., 2019).

The breast and croup perimeter had increases of 0.034 and 0.031 cm for each percentage unit in the level of forage palm in the diet, with the PRG having an average of 62.26 cm, higher than the 55.8 cm found by Sousa et al. (2019) in crossbred Morada Nova sheep with 29.3 kg of BW. Higher croup perimeter values indicate greater muscle performance in the posterior region of the animal, which is the region with the highest commercial value. These values can be considered very relevant considering that they are SRD animals. Such behavior may be related to the carcass weights, which also showed increasing linear behavior with the levels of palm in the diet.

The increase in EBW was inversely proportional to the weight of the gastrointestinal tract content. Diets containing forage palm showed lower NDF content and lower total carbohydrates content (Table 2), therefore more digestible and with a higher rate of passage through the animals' rumen, resulting in shorter residence time in the digestive tract the fasting period, sixteen hours, to which the animal was subjected. These results were confirmed by the fasting loss, which was around 1.35 to 1.52 kg for the levels of 0% to 90% of forage palm. Hot carcass yield (HCY) and cold carcass yield (CCY) yields averaged 49.8 and 48.9%. These yields can be considered satisfactory and are consistent with the carcass yields observed by Pinto et al. (2011) in diets with fodder palm replacing corn (0, 25, 50, 75, and 100%) for Santa Ines sheep slaughtered at 33 kg.

The absolute values of weight at the slaughter of the animals, in this research, were higher in animals of the treatments with higher levels of replacement of hay by forage palm, and the carcass weights (CCW and HCW) presented an increasing linear behavior. Probably these facts contributed to a more significant deposition of marbling fat, resulting in higher levels of EE in the meat (Longissimus Dorsi) of the animals receiving diets containing higher levels of forage palm. According to Fernandes et al. (2013), heavier animals deposit more fats. The average values of moisture and crude protein were similar to those found by Costa et al. (2012) in a study with Santa Inês lambs using diets containing forage palm instead of corn.

The loin eye area (LEA) is indicative of muscularity and had a behavior similar to that of carcass conformation. It is admitted that the carcasses maintained similarity in the pattern of muscularity and finish. Pinto et al. (2011) found an average of 10.35 cm2 in research with Santa Ines sheep weighing 33 kg at slaughter, fed diets containing Giant forage palm (Opuntia ficus indica) to replace corn. Thus, considering that the animals in this research were SRD, it is clear that the values are close to those of the more specialized breeds for cutting.

The color, physical and chemical characteristics, except for the ether extract, did not show any significant effect (P> 0.05) for the levels of forage palm in the lambs feed. The ether extract value was higher at the highest palm levels, showing orthogonal contrast and increasing linear behavior (Table 4). The value of the ether extract increased 18% with the level of 90% of forage palm in the lambs' feed.

Table 4

Physical and chemical parameters of lamb meat fed different levels of forage palm Mexican Elephant Ear *(Opuntia stricta Haw)* replacing Tifton-85 hay in diets

Variables	levels of Spineless cactus (g kg^{-1} of DM)				SEM	P-value	
	0	300	600	900		Linear	Quadratic
Instrumental color							
Lightness (L*)	38.37	38.32	39.14	37.87	3.07	0.852	0.482
Redness (a*)	17.16	17.54	17.16	17.57	1.91	0.731	0.953
Yellowness (b)*	7.39	7.88	7.66	7.47	1.41	0.984	0.427
Physical characteristics							
pH	5.42	5.39	5.41	5.48	0.20	0.512	0.494
Carc. Temp. (ºC)	8.12	8.21	8.25	8.27	0.28	0.184	0.693
Cooking loss (%)	18.57	17.74	20.28	17.62	1.06	0.816	0.981
Shear force (kgf $(cm^2)^{-1}$)	2.52	2.65	2.60	2.56	0.56	0.928	0.623
Chemical characteristics (g kg^{-1} DM^1)							
Moisture (g kg^{-1}MN)	73.72	73.52	73.68	73.82	1.17	0.758	0.628
Crude protein	22.99	22.92	22.78	22.89	0.34	0.745	0.764
Ether extract*	9.08b	10.54ab	10.79ab	12.00a	1.06	0.001^1	0.856
Mineral matter	4.04	4.17	4.18	3.95	1.95	0.546	0.093

DM-Dry matter; Quadr-Quadratic; SEM- standard error means; Different letters on the line differ by Tukey test at the level of 5% probability; * Polynomial regression analysis.
$^1\hat{Y}$= 9.24+0.03X (R^2=0.94).

The average pH 24 hours after death was 5.43 within the normal limits observed for lamb meat (ranging from 5.5 to 5.8) (Abreu et al., 2019), indicating that management and pre-slaughter were applied efficiently, avoiding the occurrence of stress and the probable existence of muscle glycogen reserves leading to the production of lactic acid and a decrease in pH, transforming the muscle into the meat. Lima et al. (2019) observed an average pH of 5.57 in the semimembranosus muscle of lambs fed up to 45% forage palm (Nopalea cochenillifera salm Dick) and concluded that the inclusion of cactus did not influence (P> 0.05) the pH. Bezerra et al. (2016) and Zhao et al. (2017), found no effect of the diet on the pH of the meat.

Several factors can influence the quality of the meat. However, consumers mainly use color as a primary selection criterion at the time of purchase, preferring bright red meat, and exclude the dark-colored meat they associate with older animals and that the meat is less tender (Calnan, Jacob, Pethick, & Gardner, 2016). The color parameters were within the range found by Sañudo, Alfonso, Sánchez, Delfa and Teixeira (2000), who reported values ranging from 30.0 to 49.5 for L * (verses 37.87 to 39.14 in the current study), from 8.2 to 23.5 for a * (verses 17.16 to 17.57 in the current study) and 3.4 to 11.1 for b * (against 7.39 to 7.88 in the current study). The L * value obtained in the present study (38.43 average) indicated an acceptable color for consumers since L * values equal to or greater than 34 are considered acceptable for lamb (Khliji, De Ven, Lamb, Lanza, & Hopkins, 2010). Lima et al. (2019) observed that the value of L * was 36.6 to 38.4, the value of a * was between 14.4 to 15.4 and 3.4 to 11.1 for b *, in the meat of lambs fed with forage palm, as well as not observed significant influence (P> 0.05) for the color variables in lamb meat receiving up to 45% of palm in the feeding. Abreu et al. (2019) also did not observe any influence of the inclusion of forage palm in the diet on the color characteristics of lamb meat.

Similar values obtained for pH and L * can explain the results found for b *, indicating probable similar content of myoglobin, iron concentrations, and oxidative capacity (Calnan et al., 2016; Lima et al., 2019). Under normal conditions, the color of fresh meat may vary depending on how myoglobin is found: reduced myoglobin, red-purple meat; oxygenated myoglobin, bright red meat; oxidized myoglobin, brown meat; and in what relative proportion these pigments are distributed. Cytochrome oxidase activity is increased at high pH due to the reduction in oxygen uptake and, as a consequence, a predominance of purple-red myoglobin. According to this research data, the pH level allowed the presence of oxygenated myoglobin, resulting in meat with a bright red color.

For tenderness values, Cezar and Sousa (2007) classified sheep meat as soft (2.27 kgf/cm2), mid soft (2.28 to 3.63 kgf/cm²), tough (3.64 to 5.44 kgf/cm²) and extremely hard (above 5.44 kgf /cm²). The meat evaluated in this work is classified as mid soft. The meats evaluated in this work are classified as soft or very soft. The values are more significant than 2.0 kgf $(cm^2)^{-1}$ found by Leão et al. (2012) in lambs meat-fed 60% roughage and 40% concentrate. However, lower than the average values of 4.9 kgf (cm^2) presented by Sousa et al. (2019) in a study with sheep, whole males, with 30 to 32 kg of body weight.

Carcass cuts, composition, and tissue yield of the leg did not have a significant effect (P> 0.05) with the levels of forage palm on lambs' feeding (Table 5). The muscle yield showed a decreasing linear regressive effect, decreasing with the levels of forage palm in the lambs' feed.

Table 5
Carcass cuts and tissue composition of the leg of lambs fed different levels of forage palm Mexican Elephant Ear *(Opuntia stricta Haw)* replacing Tifton-85 hay in the diets

Variables	levels of Spineless cactus (g kg^{-1} of DM)				SEM	P-value	
	0	300	600	900		Linear	Quadratic
Cut weight (kg)							
½ carcass	7.15	7.60	7.41	7.63	0.91	0.3555	0.7138
Neck	0.79	0.83	0.84	0.81	0.13	0.7843	0.4682
Shoulder	1.21	1.31	1.24	1.31	0.16	0.3536	0.8315
Rib	1.08	1.19	1.13	1.20	0.16	0.2370	0.6835
Breast	1.10	1.19	1.18	1.17	0.16	0.4143	0.4391
Loin	0.69	0.73	0.71	0.76	0.12	0.2979	0.9342
Leg	2.27	2.36	2.31	2.38	0.27	0.4798	0.9370
Tissue composition of the leg (g)							
RLW	2240	2300	2330	2400	0.27	0.103	0.933
Muscles	1510	1520	1517	1502	0.20	0.918	0.818
Bone	390	390	370	400	0.05	0.711	0.433
Fat	310	330	330	360	0.06	0.076	0.776
Tissue yield of the leg (%)							
Muscle*	67.16	65.80	64.59	62.09	5.07	0.015[1]	0.695
Bone	17.38	16.77	16.02	16.50	1.80	0.162	0.293
Fat	13.59	14.11	13.72	14.57	2.71	0.470	0.816
Other fabrics	2.45	2.72	2.73	2.94	0.93	0.219	0.922
LMI (kg cm^{-1})	0.40	0.39	0.40	0.40	0.02	0.760	0.209
muscle: fat	5.13	5.10	4.88	4.48	1.41	0.237	0.663
muscle: bone	3.92	3.97	4.07	3.78	0.50	0.613	0.237

SEM- standard error means; RLW- reconstituted leg weight; LMI - leg muscle index.
* Polynomial regression analysis. [1] $Y=67.39-0.05x$ ($R^2=0.96$).

The average yields found for these cuts amount to 58.13% and, although they are cuts of SRD animals, they are close to the average for sheep breeds with an aptitude for cutting, which is 60% (Oliveira et al., 2018). Considering only the leg and the shoulder, the yield was around 48.75%, values close to the 51.23% found by Pinto et al. (2011) in research with Santa Inês lambs fed diets containing forage palm of the Gigante variety in replacement of corn in the diet, as well as higher than the 41.73% presented by Cezar and Sousa (2007).

Conclusions

The morphometric, carcass, physical and chemical characteristics, cuts, and tissue composition of the leg were not affected by the levels of forage palm in the lambs' diet.

However, the ether extract was affected, showing the highest values in the meat of lambs fed diets containing 300 to 900 g kg^{-1} (DM) of palm, respectively. Therefore, forage palm can be included up to 900 g kg^{-1} DM in the finishing diet for lambs.

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