Carcass characteristics and meat quality of lambs fed high levels of spineless cactus in the diet

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Abstract

The objective was to evaluate the effect of increasing the dietary inclusion of spineless cactus (*Nopalea cochenillifera* Salm Dyck) on the carcass characteristics and meat quality of confined lambs. Thirty-two male Santa Inês lambs with an average age of 140 days and an initial body weight of 20.4 ± 2.60 kg were used in this study. The lambs were housed in individual stalls for 70 days and individually fed a ration with spineless cactus included at 0, 241, 519, or 753 g/kg of dry matter (DM). The lambs were slaughtered, and characteristics of the carcass and meat were recorded and analysed. Inclusion of spineless cactus had a quadratic effect on the bodyweight at slaughter and on the empty bodyweight of the lambs. The inclusion of 500 g/kg of spineless cactus provided the highest predicted cold carcass weight (16.03 kg). There was a quadratic effect of the inclusion of spineless cactus on the weight of meat cuts and leg composition of lambs. The inclusion of spineless cactus did not influence pH, tenderness, and water-retention capacity of the meat. However, the intramuscular fat content increased 1 mg for every 10 g/kg inclusion of spineless cactus in the diet. Quadratic effects were observed of the inclusion of spineless cactus on the weights of the liver, heart, rumen, blood, skin and internal fat of the lambs. Up to 500 g/kg of spineless cactus could be included in the diet of confined lambs.

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Introduction

The largest flocks of sheep are found in tropical areas (FAO, 2020), feeding mainly on native pasture. In these regions, variations in rainfall impose severe food restrictions on animals during drought (Salem, 2010). Therefore, the use of xerophyte forages, such as spineless cactus, appears to be a feed alternative for these flocks.

Spineless cactus produces 10 - 30 tons DM/ha/harvest. It has a proximate composition (g/kg, mean (SD)) of 108.7 (9.4) DM, 50.9 (6.2) crude protein, 244.7 (13.6) neutral detergent fibre, and 545.7 (10.7) non-fibrous carbohydrates (Lins *et al.*, 2016; Oliveira *et al.*, 2018; Silva *et al.*, 2019). Owing to high ruminal degradability, estimated to be 701.1 ± 8.4 g/kg DM (Batista *et al.*, 2009), spineless cactus is usually fed with other roughage to optimise the intake and digestibility of nutrients by ruminants (Siqueira *et al.*, 2017; Maciel *et al.*, 2019). However, it is necessary to establish the maximum level of inclusion of spineless cactus that improves the carcass characteristics and meat quality of sheep in confinement. In the diet of lambs for fattening, Cardoso *et al.* (2019) found a linear increase in weight gain and improvement in feed conversion with the inclusion of 450 g/kg of spineless cactus. Similarly, Moura *et al.* (2020) found a positive linear effect of the inclusion of 600 g/kg of spineless cactus on carcass fat covering, without negative effects on cold carcass weight and physicochemical characteristics of lamb meat. There is a need to study even higher

levels – greater than 600 g/kg – of spineless cactus in the diet of lambs being fattened for slaughter. Therefore, the effects of rising levels of inclusion of spineless cactus on the carcass characteristics and meat quality of lambs in feedlots were evaluated in this study.

Material and Methods

All procedures had been authorised by the Ethics Committee on the Use of Animals (CEUA), Rural Federal University of Pernambuco (licence 23082.012176/2014-51). The experiment was carried out at coordinates 8 ° 04 '03" S and 34 ° 55 '00" W with an average temperature of 25.8 ± 2.8 °C and annual precipitation of 18 cm.

Thirty-two male Santa Inês lambs with an average age of 140 days and an initial body weight of 20.4 ± 2.60 kg were allocated to individual stalls with feeders and drinking fountains. Water was available ad libitum. Initially, 14 days were provided for adaptation to the diets, facilities, and management. During adaptation, the animals were treated against endo- and ectoparasites. After adaptation, the animals were weighed and randomly assigned to one of four dietary treatments. The diets contained 0, 241, 519, and 753 g/kg spineless cactus on a DM basis. The feeding period was 56 days.

The treatment diets were formulated to meet the weight gain requirement of 200 g/day of growing lambs (NRC, 2007). The diets were composed of spineless cactus (*Nopalea cochenillifera* Salm Dyck), Tifton grass hay (*Cynodon* spp.), soybean meal, crushed corn grain, mineral salt, and urea (Tables 1 and 2). The spineless cactus was chopped in a disintegrating machine and the Tifton 85 grass hay was crushed in a forage machine with a 13 mm sieve. The rations were supplied as a complete mixture twice a day, with 60% being offered in the morning and 40% in the afternoon. The leftovers were weighed daily to adjust the supply so that it allowed approximately 15% of leftovers.

Table 1 Chemical composition of ingredients of experimental diets fed to lambs

Nutrient	Tifton hay 85	Spineless cactus	Corn grain	Soybean meal
Dry matter (DM), g/kg	918.17	100.00	881.69	890.69
Organic matter, g/kg DM	962.60	812.70	919.40	925.60
Mineral matter, g/kg DM	17.40	187.30	80.60	74.20
Ether extract, g/kg DM	17.10	16.90	41.60	13.80
Crude protein, g/kg DM	76.00	58.60	90.90	526.80
Neutral detergent fibre, g/kg DM	745.10	259.70	98.50	143.80
Acid detergent fibre, g/kg DM	356.40	150.80	76.80	25.00
Non-fibre carbohydrates, g/kg DM	144.40	477.50	688.40	241.40

Food offered to each animal and the leftovers were recorded weekly. All collected material generated individual composite samples, which were weighed, identified, pre-dried in an oven at 55 °C for 72 hours, ground in a mill with 1-mm sieve screens and stored in polyethylene pots.

AOAC (2000) methodologies were used to determine DM (method 934.01), mineral matter (method 942.05), crude protein (CP) (method 968.06), and ether extract (EE) (method 920.39), the contents of the feed and leftovers. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) was assessed according to Van Soest *et al.* (1991). Protein corrections followed Licitra *et al.* (1996). For quantification of total carbohydrates (TC), the equation:

$$TC = 100 - (\% CP + \% EE + \% Ash)$$

was used and the contents of non-fibrous carbohydrates in the diet was calculated as:

$$NFC = 100\% - ((CP\% - CP\% \text{ derived from urea} + \% \text{ urea}) + NDF\% + EE\% + Ash\%) \text{ (Hall, 2000).}$$

Table 2 Ingredients and chemical composition of diets containing increasing levels of spineless cactus

Ingredients	Inclusion level of spineless cactus			
	0 g/kg	241 g/kg	519 g/kg	753 g/kg
Tifton hay	774.0	530.0	253.0	0.0
Spineless cactus	0.0	241.0	519.0	753.0
Corn grain	89.2	67.6	44.9	24.3
Soybean meal	121.6	146.0	167.8	206.2
Mineral mix[1]	5.1	5.1	5.1	5.5
Urea	10.1	10.3	10.2	11.0
Chemical composition				
Dry matter (DM), g/kg	911.50	308.38	174.75	128.11
Organic matter, g/kg DM	939.62	903.30	861.91	825.17
Crude protein, g/kg DM	159.27	166.49	170.63	185.76
Ether extract, g/kg DM	18.62	17.97	17.28	16.58
Neutral detergent fibre, g/kg DM	602.98	484,81	351,86	227.58
Acid detergent fibre, g/kg DM	285.74	233.90	176.09	120.57
Non-fibre carbohydrates, g/kg DM	202.53	273.53	355.80	426.08
Total digestible nutrients	721.10	753.60	731.80	670.50
Metabolisable energy, Mcal/kg DM	2.60	2.71	2.64	2.42

[1]Provided per kg: calcium: 140 g, phosphorus: 70 g, magnesium: 1320 mg, iron: 2200 mg, cobalt: 140 mg, manganese: 3690 mg, zinc: 4700 mg, iodine: 61 mg, selenium: 45 mg, sulfur: 12 g, sodium: 148 g, fluorine: 700 mg

At the end of the 56-day feeding period, the animals were fasted for 16 hours. After that time, they were weighed again to obtain bodyweight at slaughter (BWS). The slaughtering process started with a stunning brain concussion, followed by bleeding from the fission of the carotid arteries and jugular veins (Brasil, 2000). The blood was collected in a tarred container and then weighed. The carcass was and eviscerated, skinned, the head, feet, and tail were removed, and hot carcass weight (HCW) was recorded. The gastrointestinal tract was weighed full and empty to determine the empty bodyweight (EBW). The weight of the contents of the gastrointestinal tract was quantified as the difference between the weights of the full and empty tract. The non-constituent components of the carcass were separated into organs, viscera and slaughter by-products (Bezerra *et al.*, 2010) and weighed.

The carcasses were hung individually on hooks by the tarsus-metatarsal joints and refrigerated at 4 ºC for 24 hours. After cooling, each carcass were weighed again to determine the cold carcass weight (CCW) and cooling loss was calculated as:

$$CL\ (\%) = (CCW\text{-}HCW/HCW) \times 100\ (\text{Gonzaga Neto } et\ al.,\ 2006)$$

Subsequently, yields of hot (HCY) and cold carcass (CCY) were calculated relative to BWS, and the true yield was calculated as:

$$TY\ (\%) = HCW/EBW \times 100\ (\text{Cezar \& Souza, 2007})$$

Morphometric measurements were made on the cold carcass. The carcass compactness index (CCI) was calculated as:

$$CCI\ (kg/cm) = CCW/\text{internal length carcass (Cezar \& Souza, 2007)}$$

Each cold carcass was cut in half and the half-carcasses were weighed. The left half-carcass was divided into six commercial cuts (Cezar & Sousa (2007), namely shoulder, leg, loin, rib, belly, and neck, which were weighed individually, and their weights recorded. Owing to the weight loss, because of the evaporation and exudation processes that the cuts undergo during shredding, the yields were estimated in relation to the reconstituted CCW, which is obtained from the weight of all the cuts in the half-carcass. The

legs and loins of each animal were identified, vacuum-packed in polyethylene bags and frozen in a freezer (-18 °C) to assess tissue composition and physical-chemical analysis.

the left half of the carcass was split between the 12th and 13th thoracic vertebrae to measure the *Longissimus* muscle area. After the *Longissimus dorsi* muscle had been exposed, a transparent plastic film was placed on it, the outline of the muscle was traced, and its area was later measured with a digital planimeter.

The loins (*Longissimus dorsi* muscle) were used for physical-chemical analysis. The samples were removed from the freezer, and thawed at 4 °C for 18 hours. Then the colour of the muscle was determined with a Minolta colorimeter (Chroma Meter CR-400, Konica Minolta Sensing Americas, Inc., Ramsey, New Jersey, USA) operating in the CIELAB system. After the *Longissimus dorsi* had been exposed to air for 30 minutes under refrigeration at 4 °C to allow the superficial oxygenation of the myoglobin, three measurements were made at different points of the muscle, noting the average values (Ramos & Gomide (2009).

Ten-gram samples of the muscle were obtained. Each sample was crushed and diluted with 150 ml distilled water and stirred until the particles were suspended uniformly, then the pH was measured.

The samples, which were composed of slices approximately 1.5 cm thick, 3.0 cm long and 2.5 cm wide, were weighed, distributed in a container covered with aluminium foil, then roasted in a preheated oven at 200 °C until they reached 70 °C in the geometric centre. Then the samples were cooled to room temperature and weighed again. The losses during cooking were calculated as the difference in weight of the samples before and after being roasted and were expressed as a percentage (Duckett *et al.*, 1998).

Shear force was measured (Ramos & Gomide, 2009) using three cylindrical samples of the roasted meat, 1.27 cm in diameter, taken parallel to the direction of the muscle fibres. The force required to cut each cylinder was measured with Warner-Bratzler shear force (GR Electric Manufacturing, Manhattan, Kansas, USA) with the result expressed as newtons (N).

Water-holding capacity (WHC) was determined by placing a meat samples weighing approximately 30 grams were placed between two pieces of weighed filter paper and pressing it for five minutes with a 3.4 kg weight. Then, the samples were removed, and the papers were weighed again. The WHC consisted of the difference between the weights of the filter paper after and before pressing, with the difference being expressed as a percentage of the sample weight (Sierra, 1973).

Dissection of the leg (see Cesar & Souza, 2007) to determine tissue composition started with its removal from the freezer and thawing the cut for 24 hours at 4 °C. Subcutaneous fat (located between the skin and the masses of muscle tissue) was removed, intermuscular fat, muscles (after removal of all adhered fat), bones (ischium, ilium, pubis, sacrum, femur, tibia, fibula, calcaneus, and metatarsus) and other tissues (tendons, lymph nodes, nerves, and blood vessels) were weighed, and the percentage of tissue components was calculated based on the reconstituted weight of the leg, because of weight loss from evaporation and exudation. The ratios of muscle to bone and of muscle to fat were calculated. The five main muscles surrounding the femur (*Biceps femoris, Semimembranosus, Semitendinosus, Quadriceps femoris,* and *Adductor*) were removed in full, the length of the femur (cm) was measured and the leg muscle index was calculated (Purchas *et al.*, 1991):

$$LMI = \sqrt{\frac{P5M}{LF}} / LF$$

where: LMI = leg muscle index, P5M = weight of the five muscles (g), and LF = length of the femur (cm).

The chemical composition of the *Semimembranosus* muscle was determined after dissection of the leg. The samples were homogenised in a blender and then lyophilised to assess moisture, CP, EE, and ash (AOAC, 2000).

The analysis of variance was conducted using a randomised block design according to this model:

$$Y_{ij} = \mu + B_i + T_j + e_{ij}$$

where: Y_{ij} = a response variable, B_i = the effect if the ith block, T_j = the effect of the jth treatment, and e_{ij} = the residual error.

Treatments were compared by decomposing the sum of squares into orthogonal contrasts. Contrast A compared the diet containing 0 g/kg spineless cactus with the average of the diets containing cactus. Contrasts B and C evaluated the linear and quadratic effects of the levels of spineless cactus in the diets. SAS software version 9.1 (SAS Institute, Inc., Cary, North Carolina, USA) was used to analyse the data.

Results and Discussion

The digestible organic matter intake (DOM) intake, metabolisable energy (ME) and digestible crude protein (DCP) intake behaved in a quadratic effect (P <0.01) owing to the increasing inclusion of spineless cactus in the diet (Table 3). With the exceptions of gut fill and CCY, these quadratic effects implied a maximum value that was intermediate relative to the dietary treatments. The control was the most fibrous and produced the highest amount of gut fill. Cold carcass yield was maximised for lamb. fed 753 g/kg spineless cactus. The inclusion of spineless cactus in the diet also produced quadratic responses (P <0.01) for EBW, CCW and CCY.

Table 3 Intake of nutrients, weight and carcass yields of lambs fed increasing levels of spineless cactus

	Inclusion of spineless cactus, g/kg				SE	Contrast P-values		
	0	241	519	753		A	B	C
DOM intake, g/d	620.2	934.4	926.8	733.3	65.50	<0.05	<0.05	<0.01
DCP intake, g/d	127.0	187.4	172.5	141.8	10.17	<0.05	ns	<0.01
ME intake Mcal/kg	2.85	4.20	4.20	3.19	0.56	<0.05	ns	<0.01
Slaughter weight, kg	27.2	32.9	32.6	28.9	1.19	<0.05	ns	<0.01
Empty body weight, kg	20.7	27.6	28.1	25.9	1.04	<0.05	<0.01	<0.01
Gut fill, kg	6.16	5.25	4.89	2.99	0.19	<0.05	<0.01	<0.05
Hot carcass weight, kg	11.3	15.3	15.6	14.4	0.63	<0.05	<0.01	<0.01
Cold carcass weight, kg	10.9	14.9	15.3	14.0	0.60	<0.05	<0.01	<0.01
Cooling loss, %	3.7	2.9	2.8	2.7	0.23	<0.05	ns	ns
Hot carcass yield, %	41.9	46.5	47.5	49.8	0.67	<0.05	<0.05	ns
Cold carcass yield, %	40.5	45.2	46.2	48.5	0.65	<0.05	<0.05	<0.05
Biological yield, %	54.3	54.6	55.9	55.5	0.68	ns	ns	ns
Longissimus muscle area, cm²	7.1	10.4	10.3	9.7	0.53	<0.05	<0.01	<0.01
Carcass compactness, kg\cm	0.18	0.24	0.25	0.23	0.01	<0.05	<0.01	<0.01

DOM: digestible organic matter, DCP: digestible crude protein, ME: metabolisable energy A: control (0 g/kg spineless cactus) versus treatments that contained spineless cactus, B: linear effect of spineless cactus inclusion, C: quadratic effect of spineless cactus inclusion

All meat cuts showed a quadratic response (P <0.01) to the level of spineless cactus included in the diet before slaughter (Table 4). The maximum weights of the individual cuts were from lambs fed the intermediate levels of spineless cactus, namely 241 g/kg and 519 g/kg. The inclusion of spineless cactus did not influence (P >0.05) the percentages of the meat cuts in the carcasses except for the loin.

The leg represented about 34% of the CCW and the composition of this cut in muscle, fat, and bone was influenced (P <0.01) by the inclusion of spineless cactus in the diet (Table 5). the responses to the level of spineless cactus included in the diet were quadratic in the dissected leg, except for the percentage of muscle and the mass of other tissues. The percentages of muscle and fat were maximised, and the percentage of bones was minimised in the leg from lambs that were fed the intermediate levels of spineless cactus.

Inclusion of spineless cactus did not influence (P >0.05) the lightness (L*), redness (a*), pH and shear force of the meat of the lambs (Table 6). However, it influenced the yellowness (b*) of the meat in a quadratic way (P <0.05). This might be the result of the quadratic effect for the percentage of fat. Inclusion of spineless cactus had a quadratic influence (P <0.05) on cooking loss from the meat. However, this effect seemed to be related to the inexplicably high value for lambs fed 519 g/kg of spineless cactus.

Table 4 Weight of meat cuts from lamb carcasses fed with increasing levels of spineless cactus

Cut of meat	Inclusion of spineless cactus, g/kg				SE	Contrast *P*-values		
	0	241	519	753		A	B	C
Shoulder	1.1	1.5	1.5	1.4	0.05	<0.01	<0.01	<0.01
Neck	0.5	0.7	0.8	0.7	0.05	<0.01	<0.05	<0.01
Ribs	0.9	1.2	1.3	1.2	0.06	<0.05	<0.01	<0.01
Belly	0.6	0.9	0.9	0.8	0.05	<0.05	<0.05	<0.01
Leg	1.9	2.6	2.6	2.4	0.09	<0.01	<0.01	<0.01
Loin	0.4	0.6	0.6	0.5	0.04	<0.01	<0.05	<0.01

A: control (0 g/kg spineless cactus) versus treatments that contained spineless cactus, B: linear effect of spineless cactus inclusion, C: quadratic effect of spineless cactus inclusion

Table 5 Tissue composition of the leg of lambs fed with increasing levels of spineless cactus

Components	Inclusion of spineless cactus, g/kg				SE	Contrast P-values		
	0	241	519	753		A	B	C
Reconstituted leg, g	1777	2432	2435	2268	92.95	<0.01	<0.01	<0.01
Muscle, g	1208	1642	1666	1509	67.60	<0.01	<0.01	<0.01
Muscle, %	68.1	68.1	68.8	66.9	0.62	ns	ns	ns
Bones, g	406.5	496.0	482.8	484.3	11.88	<0.01	<0.01	<0.01
Bones, %	23.4	20.8	20.1	21.5	0.66	<0.01	ns	<0.01
Fat, g	105.3	212.0	206.1	173.8	15.56	<0.01	<0.01	<0.01
Fat, %	5.8	8.7	8.6	7.7	0.51	<0.01	<0.05	<0.01
Other tissue, g	50.3	58.5	60.0	86.3	6.65	<0.05	<0.01	ns
Other tissue, %	2.9	2.4	2.5	3.9	0.31	<0.05	<0.05	<0.01
Muscle to bone ratio	2.9	3.3	3.5	3.1	0.12	<0.05	ns	<0.01
Muscle to fat ratio	12.7	8.3	8.1	8.9	0.87	<0.01	<0.01	<0.01
Leg muscle index, g/cm	0.36	0.42	0.40	0.39	0.01	<0.05	ns	<0.01

A: control (0 g/kg spineless cactus) versus treatments that contained spineless cactus, B: linear effect of spineless cactus inclusion, C: quadratic effect of spineless cactus inclusion

Table 6 Physico-chemical characteristics of meat *(Longissimus dorsi)* from lambs fed increasing levels of spineless cactus

	Inclusion of spineless cactus (g/kg)				SE	Contrast *P*-values		
	0	241	519	753		A	B	C
Lightness, L*	37.8	37.6	38.6	36.8	0.57	ns	ns	ns
Redness, a*	14.2	13.6	13.1	13.6	0.29	ns	ns	ns
Yellowness, b*	7.8	9.1	8.0	7.8	0.28	<0.05	ns	<0.05
pH	5.1	4.8	4.7	4.8	0.11	ns	ns	ns
Shear force, kg/cm²	14.7	15.7	15.7	16.7	1.13	ns	ns	ns
Cooking losses, %	32.3	31.0	39.9	30.6	1.41	<0.05	ns	<0.05
Water-holding capacity, %	33.8	34.7	33.6	33.5	0.79	ns	ns	ns

A: control (0 g/kg spineless cactus) versus treatments that contained spineless cactus, B: linear effect of spineless cactus inclusion, C: quadratic effect of spineless cactus inclusion

The inclusion of spineless cactus in the diet did not affect the moisture, protein, and mineral contents of lamb meat (Table 7). The EE content increased linearly ($P <0.01$).

Table 7 Composition of meat *(Semimembranosus)* from lambs fed increasing levels of spineless cactus

	Inclusion of spineless cactus (g/kg)				SE	Contrast *P*-values		
	0	241	519	753		A	B	C
Moisture, %	76.5	75.8	75.4	75.3	0.51	ns	ns	ns
Ashes, %	1.2	1.4	1.3	1.4	0.10	ns	ns	ns
Ether extract, %	1.7	2.1	2.3	2.4	0.16	<0.01	<0.01	ns
Crude protein, %	17.7	18.1	18.2	18.2	0.42	ns	ns	ns

A: control (0 g/kg spineless cactus) versus treatments that contained spineless cactus, B: linear effect of spineless cactus inclusion, C: quadratic effect of spineless cactus inclusion

The inclusion of spineless cactus resulted in quadratic effects ($P <0.01$) on heart, spleen, kidney and liver weights (Table 8). The highest liver weight (0.59 kg) was observed when the animals consumed 500 g/kg of spineless cactus. Quadratic effects ($P <0.01$) due to the level of spineless cactus in the diet were also detected for blood, skin, feet, head, and internal fat weights owing to the increasing inclusion of spineless cactus.

Table 8 Non-carcass components of lambs fed increasing levels of spineless cactus

Component, kg	Inclusion of spineless cactus (g/kg)				SE	Contrast *P*-values		
	0	241	519	753		A	B	C
Heart	0.11	0.15	0.14	0.13	0.004	<0.05	ns	<0.01
Spleen	0.04	0.06	0.06	0.07	0.02	<0.05	<0.01	0.3310
Liver	0.40	0.51	0.61	0.57	0.00	<0.05	<0.01	<0.05
Pancreas	0.04	0.05	0.06	0.06	0.00	ns	ns	ns
Kidneys	0.078	0.098	0.103	0.098	0.02	<0.05	<0.01	<0.01
Rumen	0.608	0.681	0.654	0,535	0.01	ns	ns	<0.01
Reticulum	0.109	0.127	0.115	0,120	0.01	ns	ns	ns
Omasum	0.069	0.099	0.079	0,071	0.00	<0.05	ns	<0.01
Abomasum	0.101	0.130	0.111	0,101	0.04	ns	ns	ns
Small intestine	0.654	0.682	0.740	0,695	0.02	ns	ns	ns
Large intestine	0.300	0.330	0.315	0.346	0.06	ns	ns	ns
Blood	1.066	1.289	1.374	1.259	0.11	<0.05	<0.05	<0.01
Skin	1.706	2.335	2.643	2.376	0.02	<0.05	<0.01	<0.01
Feet	0.724	0.819	0.851	0.868	0.05	ns	<0.01	ns
Head	1.592	1.817	1.842	1.756	0.14	<0.05	ns	<0.01
Internal fat	0.742	1.393	1.179	0.868	0.004	<0.05	ns	<0.01

A: control (0 g/kg spineless cactus) versus treatments that contained spineless cactus, B: linear effect of spineless cactus inclusion, C: quadratic effect of spineless cactus inclusion

The empty body weight of the lambs had quadratic response to the inclusion of the spineless cactus in the diet possibly because the intake of metabolisable energy and digestible protein of the animals was also quadratic. The greater energy and protein supply provided by the diet increased the flow of nutrients for the deposition of carcass and other components in the animals' EBW. Cardoso *et al.* (2019) found that the

inclusion of up to 450 g/kg of spineless cactus increased the flow of glucose and microbial protein synthesis in lamb linearly.

A quadratic effect of the dietary level of spineless cactus was observed for CCW with up to 500 g/kg spineless cactus in the diet producing higher CCW of the animals. Thus, spineless cactus could possibly provide up to half of the DM fed to lambs being fattened in confinement. This value – 500 g/kg – was recommended by Knupp *et al.* (2019) to optimise dry matter intake and weight gain of lambs fed on spineless cactus. The CCY was also increased by the inclusion of spineless cactus.

By inference, the linear reduction in gut fill and increased CCI are associated with the rise in the CCY. The decreased gut fill was believed to be because of the increased rate of digestion of ruminal dry matter from the feeding of spineless cactus (Siqueira *et al.*, 2017). The increase in CCI reflected an increase in muscle mass of the carcasses, mainly in the shoulder and leg (Silva *et al.*, 2019).

All meat cuts had quadratic responses following those of EBW and the carcass weight variables. Oliveira *et al.* (2018) also found quadratic effects to the inclusion of spineless cactus on the weights of the leg, shoulder, loin and belly. The meat cuts of the carcass grow at the same speed as the EBW of fattening lambs (Furusho-Garcia *et al.*, 2006). However, no effects of the dietary inclusion of spineless cactus on the proportions of shoulder (19.92% ± 0.37), neck (9.90% ± 0.21), rib (16.55% ± 0.62), belly (11.40% ± 0.43), and leg (34.12% ± 0.51) were observed in the present study, possibly because of the similarity in physiological maturity of the lambs at the time of slaughter (Bonvillani *et al.*, 2010).

The inclusion of spineless cactus in the diet resulted in quadratic effects on the weights of muscle, fat, and bone. Thus, the inclusion of 420 to 450 g/kg of spineless cactus in the diet generated more muscular greasy carcasses with lighter bones, that is, carcasses with more edible tissues. Moura *et al.* (2020) also observed a decrease in the proportion of bones and an increase in the proportion of leg fat as the dietary level of spineless cactus fed to sheep increased. Specifically for adipose tissue, which in deposited later in the leg of fattening sheep Oliveira *et al.* (2018) the inclusion of spineless cactus had a quadratic influence on the proportion of fat, particularly adipose tissue. Blanco *et al.* (2012) also found that the proportion of fat in the lambs' shoulder increased with an increment in CCW, similar to the authors' observation in the present study.

Increasing the contribution of spineless cactus to the diet did not influence the pH, tenderness, water retention and colour (lightness and redness), parameters of the meat. Possibly the similarity in the pH values (4.84 ± 0.17) of the meat provided a similar physical-chemical environment for fibrillar proteins, without effects on lightness (37.72 ± 0.72), redness (13.63 ± 0.44), shear force (15.69 ± 0.70), and WHC of the meat (33.69 ± 0.54). Abreu *et al.* (2019) did not verify the effect of the inclusion of spineless cactus on the pH, colour, shear force and WHC of lamb meat. Yellowness (b*), however, was influenced by the inclusion of spineless cactus. Thus, the increase in the yellowness (b*) of the meat may be related to the increase in the intramuscular fat content of the meat of the lambs. Oliveira *et al.* (2019) also found quadratic performance for marbling and the b* of goat meat fed dehydrated spineless cactus in the diet.

There was a linear increase in the intramuscular fat content of lambs' meat with rising levels of spineless cactus. Possibly the greater energy supplied by the diets with intermediate amounts of spineless cactus, as reflected in the ME content of the diets, resulted in greater fatty acid synthesis in muscle adipocytes, which has been associated with increases in the levels of propionate and rumen butyrate (Lins *et al.*, 2016). Plasma glucose is the main precursor of fatty acids in ruminant intramuscular adipocytes (Laliotis *et al.*, 2010). Its level has been reported to increase with the inclusion of spineless cactus in the diet (Maciel *et al.*, 2019; Cardoso *et al.*, 2019).

The increase in the energy level in the diet could be responsible for the increase in the weights of the heart, liver, and kidneys of the lambs fed with spineless cactus. Ribeiro *et al.* (2017) reported an increase in the weight of the heart, liver, and kidneys of lambs with the inclusion of spineless cactus in the diet. These organs are a priority in the metabolism of animals and grow according to the energy level of the diet. Garcia *et al.* (2014) found that the organs grew faster than the EBW of growing lambs. Santos-Cruz *et al.* (2009) also found a positive allometric relationship between EBW and the weight of viscera and by-products of the slaughter of the lambs in fattening. Thus, the effects observed in the present study for blood, skin, feet, head and internal fat weights are because of the observed increases in EBW of lambs fed with rising levels of inclusion of spineless cactus. Oliveira *et al.* (2018) also found a quadratic effect of the inclusion of spineless cactus on the weight of the internal fat of lambs.

Conclusion
Inclusion of spineless cactus influenced slaughter bodyweight, carcass weight and yield, leg tissue composition and lamb meat chemical composition with the best performance for many traits being obtained

when feeding less than 753 g/kg. It is therefore acceptable to include 500 g/kg of spineless cactus in the diet of confined lambs as an alternative source of forage.

Authors' Contributions
         SBLB (ORCID 0000-0003-2267-5327), DBC (ORCID 0000-0002-7137-534X) and MVM (ORCID 0000-0002-6483-224X) participated in designing the study, laboratory analysis, and manuscript writing. RMLV (ORCID 0000-0003-0081-9596), AMVB (ORCID 0000-0001-6133-2795) and AG (ORCID 0000-0002-6589-9104) were involved in drafting and revising the manuscript for intellectual content. FFRC (ORCID 0000-0001-9211-0263), DMLJ (ORCID 0000-0002-1154-8579) and MVM carried out data analysis and interpretation and were involved in the preparation and revision of the manuscript. FFRC, SBLB, DMLJ contributed to the acquisition, analysis and interpretation of data.

Conflict of Interest Declaration
         The authors declare that they have no conflict of interest.

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