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Bean meal and cactus pear in Santa Inês lamb rations for meat production: Intake, digestibility, performance, carcass yield, and meat quality

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Abstract

Aim of study: The objective of this study was to evaluate the intake, digestibility, performance, carcass yield, and meat quality parameters in Santa Inês lambs fed cactus pear and bean meal.

Area of study: NW Brazil

Materials and methods: 32 intact Santa Inês male lambs were distributed in a completely randomized design with 4 treatments (diets): control diet (concentrated feed containing corn and soybean meal as energy and protein ingredients); diet containing bean meal as a protein source; diet containing cactus pear as an energy source and; diet containing bean meal and/or cactus pear), using 8 animals per treatment. At the end of the experimental period, lambs were slaughtered with an average body weight of 32.78 kg.

Main results: Animal fed cactus pear and bean meal/cactus pear had a higher intake and digestibility for non-fibrous carbohydrates ($p<0.05$). Lambs fed cactus pear diet had greater water intake via diet and lower neutral detergent fibre digestibility compared to other evaluated diets ($p<0.05$). Cactus pear and bean meal/cactus pear diets promoted lower water intake concerning to control and bean meal diets ($p<0.05$). The lower feed conversion was observed for animals that received control diet ($p<0.05$). Carcass characteristics and meat quality were not affected for the diets ($p>0.05$). Bean meal can be used as a source of protein concentrate in combination with cactus pear promoting a reduction in the use of corn and soybean in diets for small ruminants. The use of cactus pear in the diets promoted a water supply to the animals.

Research highlights: Diets containing cactus pear and bean meal/cactus pear provided higher non-fibrous carbohydrates intake.

Additional key words: agro-industrial residues; by-products; Cactaceae; small ruminants

Abbreviations used: apparent digestibility coefficient (ADC); acid detergent fibre (ADF); average daily gain (ADG); acid detergent insoluble nitrogen (ADIN); body weight gain (BWG); biological yield (BY); carcass compaction index (CCI); cold carcass weight (CCW); cold carcass yield (CCY); cooking loss (CL); crude protein (CP); dry matter (DM); empty body weight (EBW); external carcass length (ECL); ether extract (EE); feed conversion (FC); hot carcass weight (HCW); hot carcass yield (HCY); hemicellulose (HEM); hind perimeter (HP); hind width (HW); internal carcass length (ICL); leg length (LL); leg perimeter (LP); mineral matter (MM); neutral detergent fibre (NDF); neutral detergent fibre corrected for ash and protein (NDFap); neutral detergent insoluble nitrogen (NDIN); non-fibre carbohydrates (NFC); non-protein nitrogen (NPN); rib eye area (REA); slaughter body weight (SBW); shear force (SF); total carbohydrates (TC); thorax depth (TD); total digestible nutrients (TDN); thorax width (TW); water intake (TWI).

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Introduction

In dryland regions, where grazing occurs seasonally, confinement of lambs is a viable alternative that guarantees less mortality, better sanitary and nutritional management, especially in the period of feed scarcity, resulting in animals slaughtered early and with high quality in carcasses (Leite *et al.*, 2017). However, feed represents, on average, more than 50% of the total cost of a feedlot, with the concentrate fraction of diets being the most expensive part, as it represents about two thirds of that value (Zanine *et al.*, 2020).

The use of agro-industrial residues can play an important role in the diet of small ruminants, especially when the availability, nutritional value and cost of the residues allow their inclusion in the formulation of diets in partial or total replacement to the traditional concentrates commonly used, such as corn and soybean, according to Ferro *et al.* (2018). To Castro *et al.* (2019), and Zanine *et al.* (2020), the use of agro-industrial residues in the feeding of small ruminants presents advantages such as the possibility of negotiating prices with consequent cost optimization because they do not present themselves as commodities, and also contributes, in a sustainable manner, to the reduction of environmental pollution.

Bean (*Phaseolus vulgaris* L.) is widely cultivated in Brazil, with considerable regional availability. According to Oliveira JT *et al.* (2020), the total area of bean cultivation in the year 2019-2020 was 2.909 million hectares, with a production of 3.022 million tons, with 19% of this being produced in semiarid region of the country (Santos *et al.*, 2019), which resulted in an average grain yield of 1,039 kg/ha (Oliveira JT *et al.*, 2020). Bean meal is a feed derived from agro-industrial processing that represents from 3 to 4% of the total bean that reaches agro-industries and is available in several Brazilian states (Magalhães *et al.*, 2008). Being an economical source of nutrients, mainly of protein, the bean meal has been object of scientific studies, in which it has been tried to know its chemical composition (Ferro *et al.*, 2017), as well as identifying the acceptability behavior by ruminants (Magalhães *et al.*, 2019), given that bean have antinutritional factors in their composition, such as protein inhibitors (inhibitors of trypsin, chymotrypsin and amylase), lectins, phytates and tannins, which can interfere with the consumption and digestibility of nutrients by animals (Espinosa-Páez *et al.*, 2017).

An alternative for the replacement of corn in diets for small ruminants in the Brazilian semiarid is the cactus pear (Knupp *et al.*, 2019; Oliveira *et al.*, 2019). From the Cactaceae family, cactus pear (*Opuntia ficus-indica* L. Miller) is a feed alternative for small ruminants in drought periods, for it has high yield of fresh biomass (163 tons/ha; Sá *et al.*, 2018) and 12.46 tons/ha of dry matter (Borges *et al.*, 2019). This productive capacity occurs due to its photosynthetic metabolism of the Crassulacean Acid Metabolism (CAM), which captures CO_2 at night, making the cactus pear efficient in water use (100-150 kg water/kg dry matter) (Edvan *et al.*, 2020; Jardim *et al.*, 2020).

In an estimate that considers about 18 million heads of goats and sheep in the Brazilian semiarid region, associated with an average intake of 3 L/head·day, 54 million liters of water/day would be needed. Thus, due to the low water availability of fresh water in periods of drought, and so that there is a greater availability of fresh water for human consumption, there is an interest in evaluating new forms of water supply for small ruminants, such as water supply via foods (Campos *et al.*, 2019).

The use of succulent forage in animal feed can be an excellent alternative as a water supply strategy. Studies have observed a reduction in water consumption from water sources with the supply of cactus pear in the composition of the diet (Matias *et al.*, 2020; Silva *et al.*, 2021). In addition to the high-water content, characteristics as a high energetic value, rich in non-fibrous carbohydrates, low cell wall constituents, combined with the high dry matter digestibility coefficients (Albuquerque *et al.*, 2020; Souza *et al.*, 2020) make the cactus pear an essential feed ingredient in the production systems of small ruminants in the Brazilian semiarid. Thus, we hypothesized that the use of bean residue and cactus pear could replace the use of traditional concentrates, such as corn and soybean, in diets for confined lambs without affecting the productive performance of the animals.

The objective of this study was to evaluate the intake, digestibility, performance, carcass yield, and meat quality parameters in Santa Inês lambs fed cactus pear and bean meal.

Material and methods

Description of the study site

The experiment was conducted at the Senator Paulo Guerra Agricultural Exhibition Park, Garanhuns, PE, Brazil (8º53'25''S, 36º29'34''W and 896 masl). The climate is tropical type Aw', according to Köppen-Geiger (1928), characterized by hot and dry summers and mild and humid winters. The annual average rainfall is 828 mm, relative humidity 79% and average annual maximum and minimum temperatures 27.2 and 25.5ºC, respectively (INMET, 2019). All the animals were cared in accordance with guidelines of the National Council for the Control of Animal Experimentation (CONCEA, 2008).

Animals, treatments, and experimental diets

Thirty-two intact Santa Inês male lambs (5 months old and 19.76 ± 1.80 kg body weight) were distributed in individual stalls (1.5×2.0 m), equipped with drinking and feeding troughs. The experiment lasted 61 days, preceded by 12 days of animal adaptation to the experimental diets. At the beginning of the adaptation period, the animals were identified, weighed, treated against endo- and ecto-parasites, and randomly allocated to the stalls previously identified according to the treatment.

The experimental design was a completely randomised design, with four treatments (diets) and eight animals per treatment. Treatments consisted of four experimental diets: control diet (concentrated feed containing corn and soybean meal as energy and protein ingredients); diet containing bean meal as a protein source (partial replacement of the soybean meal with 36.5% bean meal); diet containing cactus pear as an energy source (partial replacement of corn meal by 59.6% cactus pear), and; diet containing bean meal and cactus pear in its composition (partial replacement of soybean meal by 29.6% bean meal and corn meal by 45.4% cactus pear).

Diets were composed of cactus pear (*Nopalea cochenillifera* - Salm Dyck), bean meal (*Phaseolus vulgaris* L.), tifton 85 hay (*Cynodon nlemfluensis*), corn meal, soybean meal, urea, ammonium sulfate, limestone, mineral premix (Ovinofós, Tortuga, São Paulo, Brazil) and vitamin premix (Table 1). The cactus pear used came from a plantation of cactus pear Muída variety, established 5 years ago in the field. Cladodes were collected manually. Cactus pear were processed daily before being offered to the animals. Processing was performed through a stationary forage (PP-35, Pinheiro Máquinas, Itapira, São Paulo, Brazil) chopper to an average particle size of ~2.0 cm. Bean residue was purchased from a grain processor in Garanhuns, PE, Brazil, and consisted of damaged grains of types: integers (crushed, wrinkled, stained, without pellicle and others), and broken, from the mixture of carioca, black and red cultivars, without predominance of any given variety. The material was ground in a knife mill (Wiley mill, Marconi, MA-580, Piracicaba, Brazil), using 8 mm sieves. Tifton 85 was harvested manually, cut at 10 cm from the ground. Haying was carried out in the field, where all the material was dehydrated for 48-h until reaching the point of hay, being collected and stored in a dry place.

Diets were formulated to be isoproteic for weight gains of 200 g/day (Table 2) following the National Research Council recommendations (NRC, 2007).

Intake and apparent digestibility

Food was provided twice a day, at 8:00 am and 5:00 pm, and water ad libitum. The leftovers were collected and weighed to determine intake and adjust the dry matter intake (DMI) in order to allow 10% leftovers of the total offered. Samples of the food supplied and leftovers were collected weekly for further laboratory analysis.

The daily dry-matter intake was estimated by the difference between the total DM of feed intake and the total leftovers' DM. Nutrient intake was determined as the difference between the total nutrients present in the feed intake and the total leftover's nutrients, on a total DM basis. A digestibility test was performed across 10 days in the final third' of the experimental period: 5 days for adaptation and 5 days for collection. The animals were distributed in metabolism cages provided with feeders and drinking

Table 1. Chemical composition of the ingredients used in experimental diets

Items (g/kg dry matter)	Ingredients				
	Tifton 85 hay	Soybean meal	Bean meal	Cactus pear	Corn meal
Dry matter (g/kg of fresh matter)	844.9	872.3	858.9	192.7	830.1
Organic matter	915.4	936.1	943.4	893.2	979.8
Mineral matter	84.6	63.9	56.6	106.8	20.2
Ether extract	17.1	18.3	16.3	14.4	30.1
Crude protein	91.5	484.4	243.3	40.0	82.6
Non-protein nitrogen	4.7	13.5	11.9	1.3	3.5
Neutral detergent insoluble nitrogen	9.5	35.9	24.5	3.0	13.7
Neutral detergent fiber	678.1	159.4	247.9	281.0	151.6
Acid detergent fiber	369.1	102.0	189.9	142.8	56.8
NDFap	631.7	117.3	200.5	191.8	133.5
Lignin	82.9	6.1	31.8	35.8	10.7
Non-fiber carbohydrates	165.2	316.1	483.2	650.1	733.6
Total carbohydrates	806.9	433.4	683.7	838.8	867.1
Total digestible nutrients	553.9	807.9	726.9	693.4	857.5

NDFap: neutral detergent fibre corrected for ash and protein

Table 2. Chemical composition of the experimental diets

Proportion of ingredients (g/kg DM)	Diet			
	Control	Bean meal	Cactus pear	Bean meal / Cactus pear
Tifton 85 hay	599.4	593.6	530.8	545.6
Soybean meal	130.2	31.3	64.9	25.9
Bean meal	0.0	148.4	0.0	134.5
Cactus pear	0.0	0.0	279.7	206.5
Corn meal	253.4	205.9	97.1	63.4
Urea	0.0	4.2	10.0	7.1
Mineral premix[1]	12.5	12.5	12.5	12.5
Limestone	3.5	3.1	3.0	2.5
Ammonium sulfate	0.0	0.0	1.0	1.0
Vitamin premix[2]	1.0	1.0	1.0	1.0
Chemical composition (g/kg DM)				
Dry matter (g/kg of fresh matter)	847.2	847.1	434.7	498.5
Organic matter	921.6	921.0	905.4	907.9
Mineral matter	78.4	79.0	94.6	92.0
Ether extract	20.2	19.3	17.2	16.9
Crude protein	138.9	134.5	131.6	133.0
Non-protein nitrogen	5.4	7.6	9.2	8.9
Neutral detergent insoluble nitrogen	13.9	13.2	9.5	10.9
Neutral detergent fiber	465.9	475.9	464.0	464.4
NDFap	428.1	436.3	409.9	423.1
Acid detergent fiber	249.2	262.4	248.2	262.9
Lignin	53.2	56.4	55.5	57.8
Non-fibrous carbohydrates	334.3	338.5	366.9	350.0
Total carbohydrates	762.4	774.7	776.9	773.5
Total digestible nutrients	654.7	639.1	625.6	620.4
Metabolizable energy (MJ/kg)	23.67	23.11	22.62	22.43

[1] Guaranteed levels provided by the manufacturer (per kg in active elements): calcium, 120 g (minimum); phosphorus, 87 g (min); sodium, 147 g (min); sulfur, 18 g (min); copper, 590 mg (min); cobalt, 40 mg (min); chromium, 20 mg (min); iron, 1,800 mg (min); iodine, 80 mg (min); manganese, 1,300 mg (min); selenium, 15 mg (min); zinc, 3,800 mg (min); molybdenum, 10 mg (min); fluorine, 870 mg (max); phosphorus solubility in 2% citric acid, 95% (min). [2] Guaranteed levels provided by the manufacturer (UI/kg): Vitamin A, 4×109; Vitamin D3, 1×109; Vitamin E, 3×104. DM: dry matter. NDFap: neutral detergent fibre corrected for ash and protein.

fountains in a roofed area. Faeces were sampled using collection bags fixed to the animals, attached to the animals before the sampling period. The bags were weighed and emptied twice daily (8: 00 am and 3:00 pm). A subsample of 10% of the total faeces amount was collected for further analysis. Samples were stored in a freezer at -20°C.

Water intake

Water intake was evaluated daily. Water was weighed before being supplied in buckets and weighed again 24-h later. The water lost through evaporation was considered when calculating water intake. This variable was estimated using buckets arranged randomly around the experimental shed, with the same amount of water available for each treatment, and the difference in weight over 24-h was determined. Water intake via diet was obtained by the difference between the intake of natural matter and the intake of dry matter in the diets. Total water intake (TWI) was evaluated by the following equations: TWI (kg/day) = Consumed water (Supplied water – Evaporated water) + Water from the diet.

Chemical analyses

Samples of the food offered, leftovers and faeces were pre-dried in a forced-air oven at 55ºC for 72-h and ground to 1-mm particles in a knife mill (Wiley Mill, Marconi, MA-580, Piracicaba, Brazil). The analyses were performed using the methods described by AOAC (2016) to determine the contents of dry matter (DM; method 967.03), mineral matter (MM; method 942.05), crude protein (CP; method 981.10), ether extract (EE; method 920.29), and acid detergent fibre (ADF; method 973.18). The neutral detergent fibre corrected for ash and protein (using sodium sulfite thermostable alpha-amylase) (NDFap) was determined by Licitra *et al.* (1996) and Mertens (2002). Neutral detergent fibre (NDF) was determined using the methodology described by Van Soest *et al.* (1991) and lignin was determined by treating the ADF residue with 72% sulfuric acid (Silva & Queiroz, 2006). Hemicellulose (HEM) was calculated using the following equation: HEM = NDF – ADF. The NDF correction for nitrogen compounds and the estimation of the contents of neutral detergent insoluble nitrogen (NDIN), acid detergent insoluble nitrogen (ADIN) and non-protein nitrogen (NPN) was performed according to Licitra *et al.* (1996).

Total carbohydrates (TC) were estimated with the equation proposed by Sniffen *et al.* (1992): TC = 1000 – (CP + EE + MM). The non-fibre carbohydrates content (NFC) in diets containing urea in their composition were calculated as proposed by Hall (2003): NFC = 1000 – [(CP – (CP urea + urea)) + NDF + EE + MM]. In urea-free diets, NFC were obtained according to Weiss (1993): NFC = TC – NDFap.

The apparent digestibility coefficient (ADC) of nutrients was calculated as described by Silva & Leão (1979): ADC = {[Nutrients ingested – Nutrients excreted in the faeces]/Nutrients ingested} * 100. Total digestible nutrients (TDN) were estimated on the basis of the data of apparent digestibility, and calculated according to Sniffen *et al.* (1992). TDN of the diet was converted into metabolizable energy (ME) using the following equation (NRC, 2001): Digestible energy (DE) = (TDN/100) × 4.409; ME = DE × 0.82.

Productive performance

The animals were weighed at the experimental period beginning and at the end of the experimental period, after a solid-food deprivation period of 12-h (with water access). The following equations were used to assess average daily gain (ADG), body weight gain (BWG) and feed conversion (FC): ADG = BWG/days in confinement, BWG = Initial body weight – Final body weight; FC = DMI/ADG.

Slaughter and carcass evaluation

Lambs were slaughtered at the end of the study period. Before slaughter, the animals were deprived of solid food, according to animal welfare standards (CONCEA, 2008). After this period, the animals were weighed to determine slaughter body weight (SBW). Animals were previously stunned by cerebral concussion and immediately slaughtered by bleeding through the section of the carotid arteries and jugular veins, according to the current rules of the Brazilian Regulation on Sanitary and Industrial Inspection of Animal Products (Brazil, 2017).

Animals were skinned and the head was separated from the carcass through the cervical vertebrae at the atlanto-occipital joint and the limbs separated by the section of the carpometacarpal joints (forelimbs) and the tarsometatarsal joints (hindlimbs). Evisceration was carried out through a section along the abdominal midline to remove non-carcass components. These non-carcass components were weighed filled and emptied to determine the empty body weight (EBW).

Carcasses were weighed with kidneys and kidney fat to obtain hot carcass weight (HCW) and hot carcass yield (HCY = (HCW/SBW) 100). Carcasses were transferred to a cold room at ± 4°C for 24-h. After this period, carcasses were weighed to obtain the cold carcass weight (CCW) and cold carcass yield (CCY= (CCW/SBW) ×100), cooling losses ([(HCW – CCW)/HCW] ×100) (Silva Sobrinho *et al.*, 2005) and biological yield (BY; BY = (HCW/EBW) ×100) (Sañudo & Sierra, 1986). Kidneys and pelvic-renal fat were removed from the chilled carcasses, weighed and the values obtained were subtracted from the HCW and CCW.

Commercial cuts

Carcasses were cut length wise and the left half carcass was weighed. The left half carcass was divided into six commercial cuts (leg, shoulder, loin, rib, breast and flank and neck) according to Colomer-Rocher *et al.* (1988). The cuts were weighed separately and then the yields of each cut were calculated in relation to the left half carcass weight. In the left half carcass, a cross section was made between the 12th and 13th ribs to measure the rib eye area (REA) of the Longissimus dorsi muscle using transparency sheets for tracing its outline which was measured with the aid of the AutoCAD® software (Autodesk, Inc., San Rafael, CA, USA). The subcutaneous fat thickness was measured with a digital calliper (FG8331, Franca, SP, Brazil).

Meat quality

After obtaining commercial cuts, the loins (*Longissimus lumborum*) were identified, individually wrapped in aluminum foil and stored at -20º C, for further dissection to remove subcutaneous fat and qualitative analyses. Meat samples were thawed for 12-h under refrigeration. The pH of the meat was measured with a portable digital pH meter (TESTO-205, Testo SE & Co. KGaA, Campinas, SP, Brazil), inserted at the center of the samples (AOAC, 2016).

For color evaluation, samples were exposed to oxygen for 30 min before readings. Meat color was analyzed using a colorimeter (Konica® Minolta CR-300, Osaka, Japan). The CIELAB system was used to read brightness (L*; black/white), red intensity (a*; green/red) and yellow intensity (b*; blue/yellow), with illuminant D65 and 10° for standard observation. From these trichromatic coordinates, the colorimetric coordinates were calculated, which assess the hue (H*) and color saturation (C*). The Hue angle was calculated (H* = tan−1 (b*/a*)) according to Calnan *et al.* (2016), with values from 0° to 360° representing a color based on a color circle, where 0 (=360) is red, 90 is yellow, 180 is green, and 270 is blue. The Chroma was calculated as, $C* = \sqrt{((a*)^2 + (b*)^2)}$, where higher values represent ideal flesh color meat (Calnan *et al.*, 2016).

Cooking loss (CL) was quantified following Wheeler *et al.* (1995). Loin samples ~ 1.5 cm thick, 3.0 cm long, and 2.5 cm wide, were weighed and cooked in a digital water bath (TECNAL, Piracicaba, SP, Brazil) at 170°C, until the internal meat temperature reached 71°C, measured using a copper-constant thermocouple equipped with a digital reader. These samples were then cooled to ambient temperature and reweighed. CL was calculated by the difference in weight before and after heat treatment.

Shear force (SF) were determined according to the methodology described by Wheeler *et al.* (1995). The samples for this analysis were those cooked in the CL, which were cooled (8ºC) for 24 h. Samples were cut into 1 cm^3 samples parallel to muscle fibers and evaluated on a texturometer (GR Manufacturing Co model 3000, Manhattan, KS, USA) equipped with a Warner-Bratzler shear blade with load of 25 kgf (kilogram-force) and a cutting speed of 20 cm/min. Results expressed in kgf/cm^2.

Statistical analyses

The analyzed variables were tested by analysis of variance (ANOVA). Data were analyzed by the PROC GLM procedure of SAS 9.2, considering as significant probability values those below 5% according to the Tukey's test. The statistical model used was: $Yij = \mu + Ti + eij$, where Yij = observed value of the dependent variable; μ = average; Ti = treatment effect; and eij = experimental error

Results

Table 3 shows that there was no effect of diets on DM, OM, CP, NDF, and TDN intakes ($p>0.05$). Diets containing cactus pear and bean meal/cactus pear provided higher NFC intake ($p<0.001$) than others diets. Diets containing cactus pear and bean meal/cactus pear in their composition promoted lower water intake via trough ($p<0.001$) than other diets. Cactus pear diet showed higher water intake via diet ($p<0.001$) than other diets. There were no differences in DM, OM and CP apparent digestibility coefficients of the evaluated diets ($p>0.05$). NDF digestibility coefficient was lower for the cactus pear diet ($p=0.001$) in relation to the other diets. NFC digestibility coefficients were higher in cactus pear and bean meal/cactus pear diets ($p<0.001$) in relation to the other diets. No differences were observed in the growth performance ($p>0.05$; Table 3) which presented an average daily weight gain of 215 g/day. The lowest feed conversion was observed for animals that received the control diet based on corn and soybean meal ($p<0.001$).

Weights, yields, and cooling loss of carcass were not affected ($p>0.05$; Table 4) for the diets tested. The diets did not affect ($p>0.05$) fat thickness and REA in the carcasses (Table 4). Percentage of commercial yields cuts were not affected ($p>0.05$) for the diets tested (Table 5). The pH, brightness, redness, yellowness, chroma and hue angle, cooking loss, and shear force of the loin were not affected ($p>0.05$) for the diets tested (Table 6).

Discussion

Dry matter intake is an important factor in the performance of lamb in confinement, being considered the determining point of the supply of nutrients necessary to meet the requirements of maintenance and weight gain of the animals (Araújo *et al.*, 2019). The average DMI was 1111.00 g/animal·day. This average intake value was higher than that reported by the NRC (2007), which suggests the intake of 820g/animal·day; this confirms the good acceptability of the diets by the lambs, as they did not affect the nutrient intake and the animals' needs were met, which allowed daily gains above the established during the formulation of the diets (215.75 g/day). This demonstrates that even using an agro-industrial residue with similar characteristics to those of common use, such as soybean, it is possible to balance diets in order to overcome the nutritional differences between them, obtaining a good animal performance and carcass yield.

The intake and digestibility of NFC was positively influenced by chemical composition of the cactus pear, which has a high NFC content (650.1 g/kg DM) when compared to bean meal (483.2 g/kg DM) (Table 1), and due to the presence of the high NFC content (366.97 g/kg DM) which probably increased ruminal degradation and nutrient digestion. The increasing NFC in the diets might favor rapid degradation in the rumen, quickly absorbing

Table 3. Intake, apparent digestibility of nutrients and growth performance of Santa Inês lambs fed diets cactus pear basis and bean meal in replacing corn and soybean meal.

Item	Diets				SEM	*p* value
	Control	Bean meal	Cactus pear	Bean meal / Cactus pear		
		Intake (g/day)				
Dry matter	1117	1083	1144	1100	38.6	0.71
Organic matter	1030	998	1034	998	34.9	0.81
Crude protein	158	149	151	148	5.4	0.54
Neutral detergent fibre	485	484	486	475	17.5	0.97
Non-fibrous carbohydrates	403b	394b	463a	429ab	13.8	<0.001
Total digestible nutrients	673	666	716	698	14.3	0.73
		Water intake (kg/day)				
Water intake via trough	2.7a	2.4a	1.3b	1.7b	0.13	<0.001
Water intake via diet	0.2c	0.2c	1.7a	1.3b	0.04	<0.001
Total water intake	2.9	2.6	3.0	3.0	0.15	0.20
		Digestibility (g/kg)				
Dry matter	631	636	626	641	0.6	0.39
Organic matter	645	650	651	662	0.6	0.24
Crude protein	621	603	632	622	0.9	0.14
Neutral detergent fibre	454a	467a	401b	454a	1.1	0.001
Non-fibrous carbohydrates	796b	815b	858a	855a	0.9	<0.001
		Performance				
Initial weight, kg	20.2	19.8	19.0	19.4	0.67	0.82
Body weight gain, kg	14.0	13.1	13.2	12.4	0.56	0.12
Average daily gain, g/day	234	213	216	200	9.2	0.12
Feed conversion	4.8b	5.1ab	5.4a	5.5a	0.10	<0.001

SEM: standard error of the mean. Means followed by different letters in the same row differ statistically by the Tukey test ($p<0.05$).

Table 4. Carcass characteristics of Santa Inês lambs fed diets cactus pear basis and bean meal in replacing corn and soybean meal.

Item	Diets				SEM	*p* value
	Control	Bean meal	Cactus pear	Bean meal / Cactus pear		
Slaughter body weight, kg	34.2	32.9	32.2	31.8	1.06	0.39
Empty body weight, kg	27.5	25.9	25.5	24.9	0.97	0.27
Hot carcass weight, kg	15.4	14.6	14.7	14.2	0.55	0.50
Hot carcass yield, %	45.2	44.9	46.4	45.8	0.57	0.26
Cold carcass weight, kg	14.9	14.2	14.2	13.8	0.53	0.48
Cold carcass yield, %	43.9	43.5	44.9	44.4	0.56	0.31
Biological yield, %	55.9	56.6	57.5	57.2	0.50	0.15
Chilling loss, %	3.0	3.0	3.2	3.1	0.12	0.51
Fat thickness, mm	2.0	2.0	2.1	1.9	0.13	0.80
Rib eye area, cm^2	10.8	10.4	10.3	10.8	0.41	0.73

SEM: standard error of the mean.

Table 5. Weights and yields of commercial meat cuts of Santa Inês lambs fed diets cactus pear basis and bean meal in replacing corn and soybean meal.

Item	Diets				SEM	*p* value
	Control	Bean meal	Cactus pear	Bean meal / Cactus pear		
Left half carcass, kg	7.2	6.9	6.9	6.6	0.27	0.58
Leg, %	32.7	32.2	32.2	32.4	0.33	0.69
Shoulder, %	17.6	17.4	17.6	17.3	0.29	0.93
Loin, %	10.2	10.3	10.2	10.4	0.26	0.97
Rib, %	16.9	16.8	16.7	17.8	0.38	0.17
Breast and flank, %	11.1	10.6	11.6	10.5	0.32	0.08
Neck, %	11.8	12.6	11.7	11.6	0.27	0.40

SEM: standard error of the mean.

and increasing energy support and favoring microbial growth and digestion (Albuquerque *et al.*, 2020).

Greater NFC intake after being rapidly fermented in the rumen, promote a sharp drop in ruminal pH, an increase in passage rate and, consequently, a reduction in cellulolytic activity and, consequently, the fiber digestibility (Pinho *et al.*, 2018), a fact that was observed in the present study, where the highest NFC intake (463 g/day) induced a reduction in NDF digestibility (Table 3). A similar result was observed by Magalhães *et al.* (2019), who observed higher NFC intake and less digestibility of NDF for lamb that received diets containing cactus pear in its composition.

Diets containing cactus pear in its composition reduced water intake via water trough. This behavior is due to the amount of water that the cactus pear has due to its low DM content (192.7 g/kg fresh matter; Table 1) and, consequently, high moisture content, which provided a greater intake of the diet, thus reducing the search for drinking water by animals. Therefore, the inclusion of the cactus pear also provides a water supply to the animals, being considered a strategic resource during periods of drought in arid and semiarid areas where water is scarce and can be a limiting factor for animal production (Pinho *et al.*, 2018; Moura *et al.*, 2020).

The animals obtained an average total water intake of 2.88 L water/day, higher than that recommended by the NRC (2007), which suggests 0.800 L water/day for lamb. Thus, the present study highlights that, for diets that contained cactus pear, considering only water intake via diet, there was a higher water intake than necessary for the functioning of the animals' physiological functions (NRC, 2007). Corroborating our findings, Andrade *et al.* (2016), Neto *et al.* (2016), and Magalhães *et al.* (2019), also obtained greater water intake via food when including cactus pear in natura in the animals' diet.

The use of bean meal and cactus pear or the combination of these two ingredients in the diets promoted a greater feed conversion compared to the control diet (Table 3). Therefore, for the purpose of recommendation and to the best of our knowledge, further studies are needed using cactus pear associated with different levels of bean meal in diets for confined lambs.

Table 6. Meat quality parameters of Santa Inês lambs fed diets cactus pear basis and bean meal in replacing corn and soybean meal.

Item	Diets				SEM	*p* value
	Control	Bean meal	Cactus pear	Bean meal / Cactus pear		
pH	5.9	5.9	6.1	5.9	0.02	0.06
Brightness, L*	37.8	35.9	36.5	37.5	1.00	0.54
Redness, a*	12.6	13.8	13.6	12.4	0.73	0.45
Yellowness, b*	7.9	8.3	7.2	8.3	0.43	0.29
Chroma, C*	15.0	14.9	14.6	13.7	1.16	0.19
Hue angle, H*	0.56	0.54	0.56	0.59	0.44	0.35
Cooking loss, %	35.4	34.6	40.6	43.7	3.74	0.13
Shear force, kgf/cm^2	1.6	1.5	1.5	1.7	0.16	0.81

SEM: standard error of the mean.

The fact that the diets promoted equal nutritional value for the animals resulted in similar weights and carcass and commercial cut yields between the evaluated treatments. Similar behaviors were obtained by Lima *et al.* (2021) when evaluating the carcass characteristics of Santa Inês lamb fed diets with different levels of cactus pear and by Eynipour *et al.* (2019) when studying the effect of diets with different levels of bean residues on the carcass of lambs. The absence of significant effects of diets on weights and yields reinforces the law of anatomical harmony cited by Andrade *et al.* (2017), by stating that, in carcasses of similar weight and amount of fat, almost all body regions are found in similar proportions, regardless of the conformation and genotypes tested.

The pH values measured in Santa Inês lamb meat were around 5.98, similar to the pH values found by Madruga *et al.* (2020), after 24-h for lamb meat (between 5.97 and 6.04), indicating that pre-slaughter management techniques were efficiently applied avoiding the occurrence of stress for the proper establishment of rigor mortis and the transformation of muscle into meat (Lima *et al.*, 2019). According to Moura *et al.* (2020), the increase in NFC intake with the addition of forage cactus in the diets may be related to the high glycogen synthesis and the ideal pH of the lamb meat. However, the pH values of the lamb meat evaluated were similar in the different treatments. Thus, we can infer that diets did not affect muscle glycogen stores and its conversion to lactate and H + was similar between treatments (Souza *et al.*, 2020). Despite pH response, there was no effect of cactus pear addition on the yellowness or other color characteristics of the lamb meat in this study. Probably, the variation in meat pH was not enough to provide deep changes in the structure of muscle fibers, which is the factor that most influences meat color (Neethling *et al.*, 2017).

Since the diets did not influence the pH of the meat, the color, CL and SF also did not show differences between treatments. These parameters are among the most important characteristics of the meat as the main attributes considered at the time of purchase.

In the present study, the color parameters were within the range found by Sañudo *et al.* (2000), who reported values for lamb meat color parameters ranging from 30.0 to 49.5 for lightness, from 8.2 to 23.5 for red intensity and from 3.4 to 11.1 for yellow intensity. Although there was no effect of diets, we can infer that the meat analyzed in this study was clear, a fact also observed by Oliveira FG *et al.* (2020) who, when evaluating the meat quality of Santa Inês sheep, had lighter meat and lower intensities of a* and b*. The light color of the meat is a positive factor, as it is associated by consumers with meat from young animals (Venturini *et al.*, 2020).

C* and H* are positively related to metmyoglobin concentration and meat discoloration (Hernández *et al.*, 2016). The results found for C* are lower than those found by Belhaj *et al.* (2020; 20.18-23.45) when evaluating the meat quality of Beni-Guil sheep. However, these authors found red intensity values higher than those observed in the present study, a fact that may have contributed to the superiority of the results obtained. Regarding H*, Lima *et al.* (2019), when analyzing the meat of lambs fed diets containing different levels of cactus pear, observed H* values ranging from 0.50 to 0.54, results similar to those found in the present study.

Cooking loss was not influenced by the studied diets, with CL between 34.3 and 43.7%. According to Mendonça Júnior *et al.* (2016), variations in CL are mainly influenced by differences in cooking time and temperature, genotype, slaughter weight, muscle used in the analysis, pH and fat thickness, rather than feed management. As observed in our results, the fat thickness being minimal (1.9-2.1 mm), allowed a lower water retention capacity, causing a greater cooking loss. Bezerra *et al.* (2021) when analyzing also the effect of diets containing cactus pear on the quality of lamb meat, did not verify the effect of diets on this parameter.

The diets had no effect on the SF, probably because this parameter is more related to the age, breed and sex of the animal than in relation to the diets themselves. Since the animals were of the same sex, similar race and age, no difference was observed. According to the classification of Cezar & Sousa (2007), when fillets of meat do not resist cutting under pressure of less than 2.27 kgf/cm^2 they indicate that the meat is soft. Thus, the samples analyzed in this study, that presented SF values between 1.5 to 1.7 kgf/cm^2, were considered soft in all treatments.

Based on the observed results, the use of cactus pear and bean meal is a viable and low-cost alternative for use in diets for lambs in feedlots, as they provide good productive performance of the animals, and carcass yield. These results are relevant since the combination of these ingredients in the lamb's diet, in addition to increasing nutrient intake can reduce the water demand of animals, an important factor in arid and semiarid regions. In experimental conditions, bean meal can be used as a source of protein concentrate in combination with cactus pear without affecting productive performance, carcass characteristics and the technological meat quality, promoting a reduction in the use of corn and soybean in the preparation of diets, and reducing feed costs. The use of cactus pear in the diets promoted a water supply to the animals, reducing the intake of water offered. A future study on cost analysis of diets containing residues from the agro-industry (such as bean meal) in total or partial replacement to traditional ingredients, such as soybeans, commonly used in diets for ruminants, is also recommended.

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