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Carcass characteristics and meat quality of sheep fed buffelgrass silage to replace corn silage

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Abstract

The aim of the study was to evaluate the carcass characteristics, proximate composition, and sensorial attributes of meat from sheep fed diets in which buffelgrass silage replaced corn silage. Thirty-two intact male crossbred Santa Inês sheep with an average live weight of 20.09 ± 2.0 kg were housed in individual stalls and allotted at random to four treatments in which corn silage was replaced by buffelgrass silage at the levels of 0 (control), 33.3%, 66.6%, and 100%. After an adaption period of 10 days, the sheep were fed for an additional 61 days. Feed was offered ad libitum and corn silage comprised 60% of the diet for the control group. Carcass characteristics, non-carcass components and meat quality were evaluated. Hot carcass yield, cold carcass yield, true carcass yield, trimmings, fat weight, and mesenteric and omental fat weight were highest for the control group (P <0.05). Loin eye area had a quadratic response (P =0.02), with the largest areas being observed in animals fed the diet containing 66.6% buffelgrass silage. Liver weight (P <0.01), luminosity of the meat (P <0.05), and cooking loss (P <0.05) likewise had nonlinear responses to the concentration of buffelgrass silage in the diet. The treatments did not have significant negative influence on the nutritional and organoleptic characteristics of the meat.

Keywords: animal products, diets, sensory analysis, small ruminants
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Introduction

In the semi-arid Caatinga eco-region of north-eastern Brazil, cacti, thick-stemmed plants, thorny brush and arid-adapted grasses provide forage for grazing. Forage production is influenced to a large extent by the rainy and dry seasons. During the rainy season, which lasts for about three months, forage is abundant, and has good nutritional quality. In the dry season, the availability and quality of forage are reduced because of cell wall lignification and decreased crude protein content (Bodner & Robles, 2017). To manage this situation better, researchers have sought nutritional regimes to increase productivity during periods of drought (Araújo *et al*., 2017). Among the forages in the Caatinga, buffelgrass (*Cenchrus ciliaris* L.) stands out because of its adaptation to the adverse climate and its resistance to drought. Buffelgrass produces from 2 to 8 tonnes dry matter (DM)/ha in the region (Bruno *et al*., 2017) making it an excellent option for silage that is less expensive to produce than corn.

Sheep production is an important enterprise in the Caatinga. The acceptance of sheep meat by consumers results from a combination of its flavour, juiciness, texture, softness, and appearance. The degree to which individual consumers are satisfied with sheep meat depends on their psychological and sensory responses to it. However, its production may be evaluated from the point of view and interest of each producer, downstream industry and the consumer (Sohaib *et al*., 2017). Thus, the aim of the study was to evaluate the carcass characteristics, proximate composition, and sensory attributes of meat from sheep fed buffelgrass silage (BGS) to replace corn silage (CS).

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Material and methods

This research was evaluated and approved by the Ethics and Deontology Committee for Studies and Researches of the Federal University of São Francisco Valley under the protocol number 0007/131014. It was conducted in the Animal Metabolism Sector of the Experimental Field of Caatinga, which belongs to the Brazilian Agricultural Research Corporation (Embrapa Semiarid), Petrolina, Brazil. The local average annual precipitation is 570 mm and average annual maximum and minimum temperatures are 33.5 °C and 20.9 °C (Embrapa 2011).

Thirty-two six-month-old intact male crossbred Santa Inês sheep weighing 20.09 ± 2.0 kg were used in the experiment. Before the experiment began, the animals were weighed, dewormed, and randomly allotted to individual stalls (0.80 × 1.20 m). Each stall was equipped with feed and water toughs. A 10-day period of adaption preceded the 61-day feeding trial. The sheep were weighed every 15 days.

The experimental design was completely randomized, with four treatments and eight replications. Corn (*Zea mays* variety Caatingueiro), which was harvested approximately 90 days after planting, and buffelgrass (*Cenchrus ciliaris* L., variety Biloela), which was harvested about 120 days after germination, were made into silages in 200 L barrel silos applying 600 kg/m^3 to compact the forage material. In formulating the experimental diets, the silages were augmented with concentrate mixtures that were composed primarily of corn and soybean meal. Samples of the feedstuffs were dried for 72 hours at 55 °C and ground to 1-mm particles (Wiley Mill, Marconi, MA-580, Piracicaba, Brazil). Dry matter (method 967.03), mineral matter (method 942.05), crude protein (CP) (method 981.10) and ether extract (EE) (method 920.29) were determined (AOAC 2016). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were assesses (Van Soest *et al*., 1991). Total carbohydrates (TC) were calculated with the equation proposed by Sniffen *et al*. (1992). Non-fibrous carbohydrate (NFC) content was calculated as proposed by Hall (2003). Total digestible nutrient content was calculated using the equation of Harlan *et al.* (1991). Proximate analyses of the silages, corn grain and soybean meal that were used in formulating the diets are shown in Table 1.

Table 1 Proximate analysis of ingredients used to formulate experimental diets for sheep fed diets in which various levels of corn silage were replaced by buffelgrass silage

	CS	BGS	Ground corn	Soybean meal	C1	C2	C3	C4
Dry matter (DM), g/kg fresh matter	225.6	506.4	893.7	908.5	889.7	889.4	890.2	892.9
Constituent, g/kg DM								
Organic matter	857.8	844.7	975.3	919.9	946.1	946.4	946.3	942.4
Mineral matter	142.2	155.3	24.7	80.1	53.9	53.6	53.7	57.6
Ether extract	15.3	19.0	64.2	17.9	38.6	38.4	34.0	34.0
Crude protein	60.7	53.0	99.3	498.9	290.9	310.0	320.8	352.5
Neutral detergent fibre	533.6	688.1	213.9	186.1	216.3	218.9	219.0	221.8
Acid detergent fibre	292.3	419.9	37.9	135.8	96.1	100.2	103.2	111.3
Non-fibrous carbohydrates	248.2	84.6	597.3	217.0	400.3	379.1	372.5	334.1
Total digestible nutrients	621.7	531.9	800.8	731.9	759.8	757.0	754.8	749.1

CS: corn silage; BGS: buffelgrass silage; C1, C2, C3 and C4: concentrate mixtures used in formulating diets varying in CS and BGS contents

Four diets were formulated from these silages and the concentrate mixtures that were characterized in Table 1 (Table 2) Buffelgrass silage replaced CS to produce T1: 100% CS, T2: 66.6% CS and 33.3% BGS, T3: 33.3% CS and 66.6% BGS, and T4: 100% BGS. Each diet was balanced to provide for a projected growth rate of 200 g/day when fed at a roughage to concentrate ratio of 60 to 40 (dry matter basis) (NRC, 2007). The animals were fed twice a day at 08h30 and 15h30 and the orts were collected and weighed to determine consumption. The feed offered was adjusted to allow for 10% orts.

Table 2 Formulation and proximate analysis of the experimental diets fed to sheep

Ingredients, g/kg dry matter	T1	T2	T3	T4
Corn silage (CS)	600.0	399.9	199.9	
Buffelgrass silage (BGS)		199.9	399.9	600.0
Ground corn	240.0	224.0	209.0	194.0
Soybean meal	159.0	175.0	190.0	205.0
Limestone	0.3	0.3	0.3	0.3
Common salt	0.5	0.5	0.5	0.5
Premix mineral[1]	0.2	0.2	0.2	0.2
Proximate analysis				
Dry matter, g/kg fresh matter	491.2	547.2	603.7	661.0
Organic matter, g/kg dry matter	893.1	890.4	887.8	883.8
Mineral matter, g/kg dry matter	106.9	109.4	112.0	116.2
Ether extract, g/kg dry matter	24.6	25.3	24.3	25.0
Crude protein, g/kg dry matter	152.8	158.9	161.6	172.8
Neutral detergent fibre, g/kg dry matter	406.7	438.5	469.4	501.6
Acid detergent fibre, g/kg dry matter	213.8	240.9	267.6	296.5
Non-fibrous carbohydrates, g/kg dry matter	309.0	267.8	232.4	184.4
Total digestible nutrients, g/kg dry matter	677.0	657.7	638.9	618.8

[1] Phosphorus: 45 g, calcium: 90 g, chloride: 240 g; sodium: 156 g, sulfur: 10 g, magnesium: 8 g, zinc: 2800 mg, iron: 300 mg, manganese: 2300 mg, copper: 150 mg, iodine: 40 mg, cobalt: 35 mg, selenium: 15 mg, fluorine: 450 mg, BGS: buffelgrass silage, CS: corn silage
T1: 100% CS, T2: 66.6% CS and 33.3% BGS, T3: 33.3% CS and 66.6% BGS, T4: 100% BGS

The sheep were slaughtered at the end of the study period. Before slaughter, the animals were fasted for 16 hours. The animals were then weighed to determine slaughter weight (SW). At slaughter the animals were first stunned, causing cerebral concussion, and then bled by severing the jugular vein and carotid artery in accordance with the Regulation for Inspection of Industrial Sanitation for Products of Animal Origin (Brazil, 2017). After that, the animals were skinned and eviscerated to remove non-carcass components. These components were weighed separately, and percentages were calculated relative to SW.

The carcasses were weighed to determine hot carcass weight (HCW) and hot carcass yield (HCY). The gastrointestinal tract namely stomach and intestines, was separated, and each compartment was weighed full and empty to estimate empty bodyweight (EBW) and true carcass yield (TCY) (Silva Sobrinho *et al*., 2005).

The carcasses were refrigerated for 24 hours at 4 °C on hooks to maintain 17 cm between the tarsometatarsal joints. After chilling, the carcasses were weighed for cold carcass weight (CCW), cold carcass yield (CCY), and chilling loss (CHL). Kidneys and pelvic kidney fat were removed from the chilled carcasses, weighed, and their weight was subtracted from HCW and CCW.

The carcasses were split longitudinally at the midline. The left half-carcass was weighed and cut into six anatomical regions, namely neck, shoulder, rib, loin, leg and breast and flank (Silva Sobrinho *et al*., 2005). The cuts were weighed (Cezar & Souza, 2007) immediately to determine their yields relative to half-carcass weight (Colomer-Rocher, 1987). A cut was made between the 12th and 13th ribs of the right side of the carcass to expose the *Longissimus* muscle. The loin eye area (LEA) was traced on a transparent plastic film, which was then measured with AutoCAD® software (Autodesk, Inc., San Rafael, California, USA).

The pH of the meat was measured 24 hours after slaughter with a portable pH meter (Mettler Toledo International Inc., Columbus, Ohio, United States) (AOAC, 2016). The evaluation of meat colour was conducted on the back section using a transverse cut, and the meat was exposed to the atmosphere for 30 min before the oxygenated myoglobin level was read. Then, after 30 min, the colour values were measured at three points on the inner surface of the muscle, and the average of triplicate measures was calculated separately for each animal, namely L*, the index related to luminosity (L* = 0, black; = 100, white); a*, the index that ranges from green (−) to red (+); and b*, the index that ranges from blue (−) to yellow (+) (Miltenburg *et al*., 1992). These measurements were performed with the CIELAB system, which considers the L*, a* and b* coordinates responsible for brightness (black/white), red content (green/red) and yellow content (blue/yellow), respectively, with a Minolta CR-10 (Konica® Minolta, Osaka, Japan) colorimeter calibrated from a white ceramic plate with the C illuminant at 10° for standard observation, being operated with an open cone.

Samples of the *Longissimus thoracis* muscle were collected from the dorsal-lumbar region at the 10th to 13th ribs. These samples were then packaged individually and stored at -20 °C for subsequent analyses. Before being analysed, the samples were thawed under refrigeration (8 °C) and then dissected with a scalpel to remove the subcutaneous fat. Cooking loss (CL) was determined with samples from the loin that were approximately 1.5 cm thick, 3.0 cm long, and 2.5 cm wide (Duckett *et al*., 1998). Samples were weighed and cooked in a preheated oven at 170 °C until the internal meat temperature reached 71 °C, as measured with a copper constant thermocouple equipped with a digital reader. They were then cooled to ambient temperature and reweighed. Cooking loss was determined as the difference in weight of the sample before and after being cooked.

Shear force (SF) was determined according to Wheeler *et al*. (1995). The samples for this analysis had been cooked after being held at 8° C for 24 hours. Two cores were removed from each slice of meat using a 1.27 cm diameter cork borer that was inserted parallel to the muscle fibres. Each core was sheared perpendicular to the muscle fibres and shear force was measured with a texturometer (GR Manufacturing Co model 3000, Trussville, Al) equipped with a Warner-Bratzler shear blade with a load of 25 kgf (kilogram force) and a cutting speed of 20 cm/min. Shear force was expressed as kgf/cm^2.

Water-holding capacity (WHC) was measured by placing 0.5 g samples of the muscle on a 10 x 10 cm² piece of filter paper (Whatman No. 1) between two plexiglass plates, and the sandwich was pressed with a weight of 5 kg (71.12 psi) for five minutes. The sample was then reweighed and WHC was expressed as a percentage of the initial weight (Wierbicki & Deatherage, 1958; Honikel & Hamm, 1994).

The composition of the *Longissimus thoracis* was determined by thawing the muscle samples for 24 hours at 4 ± 1 °C. Then the samples were ground for approximately five minutes with a food processor (Mondial, Sao Paulo Brazil) until they became homogenous. Moisture, ash, and protein were measured (AOAC, 2016) with methods 985.41, 920.153 and 928.08. Total lipids were determined in an extractor apparatus (ANKOM Technology, Macedon, New York, USA) (AOCS, 2017).

Sensory evaluation of the meat was performed by a panel of 64 untrained people in a single day. Samples of the *L. thoracis* muscle of each treatment were cut parallel to the muscular fibres into 2.0 cm cubes (Lyon *et al*., 1992). These samples were baked in a preheated oven at 170 °C until the temperature of the geometric centre of the meat cube reached 71 °C, which took on average six minutes. The meat was then wrapped in aluminium foil and maintained in a water bath at 65 °C ± 2 °C. No condiments and salt were added to the meat. The tasting was performed in individual booths under a controlled temperature and adequate lighting conditions. Each evaluator received one cube of each treatment, totalling four samples, which were. were identified by three random digits. The participants were offered water and a cracker to remove residual flavour between samples. The samples were served according to sample position balancing (MacPhie *et al*., 1999). The colour, aroma, texture, juiciness, and flavour of each attribute were evaluated on an unstructured 9-cm scale (Campos *et al*., 2017). The anchor points were from extremely light (1) to extremely dark (9) for colour; from extremely weak (1) to extremely strong (9) for aroma; from extremely soft (1) to extremely hard (9) for texture; from extremely dry (1) to extremely succulent (9) for juiciness; from extremely mild (1) to extremely strong (9) for flavour; and from extremely disgusting (1) to extremely liked (9) for the global assessment.

Statistical analyses were performed using the general linear model procedure of SAS (SAS institute Inc., Cary, North Carolina, USA). The data were submitted to one-way analysis of variance and linear and quadratic regression analysis. Probability levels of $P < 0.05$ were considered to indicate real differences. The Kruskal-Wallis nonparametric test (Pimentel-Gomes, 1990) was used to analyse the sensory characteristics of meat.

Results and Discussion

Consumption of EE (P = 0.006) and NFC (P = 0.001) decreased linearly as more BGS was included in the diet. However, the diets did not affect intake (in g/day) of DM (P =0.18), CP (P =0.21), NDF (P =0.15), ADF (P =0.13), TC (P =0.22), and TDN (P = 0.27) (Table 3). The equation was:

$$EE = 28.67 - 2.38x$$

where x = the level of BGS in the diet, which explained 26% of the variation in consumption of EE. The mean daily weight gain was 140.16 g/day (Table 3).

Table 3 Daily consumption of nutritional components and daily weight gain in sheep fed buffelgrass silage to replace corn silage

Item	T1	T2	T3	T4	SE	L	Q
Dry matter, g/day	768.04	878.06	835.61	701.02	34.22	0.694	0.180
Crude protein, g/day	168.52	195.30	184.83	161.75	6.92	0.503	0.211
Ether extract, g/day	26.30	25.27	21.77	18.53	1.08	0.006	0.656
Neutral detergent fibre, g/day	236.99	305.93	311.44	284.06	13.86	0.145	0.058
Acid detergent fibre, g/day	144.10	161.29	177.29	171.81	7.67	0.134	0.558
Total digestible nutrients, g/day	649.68	724.64	740.58	538.92	32.66	0.267	0.164
Daily weight gain, g/day	135.83	144.40	155.00	125.42	8.66	0.513	0.299
Feed conversion	5.93	6.27	5.47	5.73	0.24	0.605	0.976

BGS: buffelgrass silage, CS: corn silage; T1: 100% CS, T2: 66.6% CS and 33.3% BGS, T3: 33.3% CS and 66.6% BGS, T4: 100% BGS included in the diet, L: *P*-value for linear substitution effect, Q: *P*-value for quadratic substitution effect

Hot carcass yield (*P* =0.002), cold carcass yield (CCY) (*P* =0.002), and TCY (*P* =0.012) decreased linearly as the percentage of buffelgrass silage increased in the diets (Table 4). Equations that described these effects were:

$$HCY = 51.05 - 1.98x \qquad CCY = 49.14 - 2.35x \text{ and } \qquad TCY = 57.76 - 1.45x$$

where x = the level of BGS in the diet and the equations explained 39%, 40% and 18% of the variation in the traits. The treatment effects caused no significant differences in SW (*P* =0.22), EBW (*P* =0.15), HCW (P =0.07), CCW (P = 0.08), CHL (P = 0.38), and yield of the commercial cuts (*P* >0.05) (Table 4). The LEA was affected (*P* =0.02) by the diets, with a maximum value of 11.14 cm^2 in animals fed T3 (Table 4). The equation that described the quadratic response in LEA was:

$$LEA = 8.54 + 2.51x - 0.59x^2$$

where x = the level of BGS in the diet. This equation explained 29% of the variation in LEA. The diets had no effect (*P* >0.05) on carcass conformation score or the degree of finish (Table 4).

Data for the non-carcass components of the lambs are presented in Table 4. Liver weight had a quadratic response (*P* <0.01) to the increasing level of BGS, being relatively higher in lambs fed T2, and markedly lower in lambs fed T4. Fat trim (*P* =0.05) and mesenteric and omental fat (*P* =0.056) decreased linearly as the level of BGS increased. Equations describing these effects on liver weight (LVR), weight fat trim and weight (FT) of the mesenteric and omental fat (IF) were:

$$LVR = 0.32 + 0.17x - 0.04x^2 \qquad FT = 0.15 - 0.05x \text{ and } \qquad IF = 0.85 - 0.04x$$

where x = the level of BGS in the diet and the equations explained 43%, 20%, and 30% of the variation in the traits. The other non-carcass components were not affected by these treatments (*P* >0.05).

The treatments influenced (*P* <0.05) L* of the *Longissimus thoracis*, CL, SF, and its moisture content (MC) (Table 5). Equations that described these effects were:

$$L^* = 38.22 - 0.11x + 0.001x^2 \qquad CL = 34.62 - 0.20x + 0.002x^2 \qquad SF = 1.61 + 0.008x \text{ and } \quad MC = 72.84 + 0.18x$$

where x = the level of BGS in the diet and the equations explained 94%, 98%, 85%, and 94% of the variation in the traits.

Table 4 Carcass characteristics and non-carcass components of sheep fed diets in which buffelgrass silage replaced corn silage

Carcass characteristic	T1	T2	T3	T4	SE	L	Q
Slaughter weight, kg	26.80	29.15	29.29	25.08	0.93	0.224	0.537
Empty bodyweight, kg	23.29	24.96	24.66	20.67	0.84	0.151	0.539
Hot carcass weight, kg	13.11	13.52	13.59	10.98	0.46	0.073	0.555
Cold carcass weight, kg	12.54	12.84	12.93	10.47	0.45	0.079	0.592
Hot carcass yield, %	48.80	46.47	46.38	43.82	0.52	0.002	0.366
Cold carcass yield, %	46.66	44.16	44.10	41.76	0.50	0.002	0.333
True yield, %	56.27	55.08	54.32	53.24	0.51	0.012	0.332
Chilling loss, %	4.41	5.07	4.79	4.67	0.15	0.380	0.854
Carcass conformation score	3.35	3.39	3.37	3.00	0.08	0.189	0.602
Degree of finish	3.39	3.28	3.21	3.00	0.12	0.675	0.583
Ribs, %	14.94	14.80	15.01	14.55	0.36	0.898	0.369
Neck, %	8.93	9.04	9.25	8.57	0.30	0.716	0.356
Shoulder, %	18.74	18.27	18.37	19.88	0.27	0.062	0.151
Loin, %	8.58	9.26	9.32	8.16	0.27	0.254	0.722
Leg, %	29.14	30.51	29.79	30.71	0.61	0.819	0.627
Breast and flank, %	10.42	9.29	9.27	9.22	0.44	0.722	0.149
Loin eye area, cm^2	10.48	10.70	11.14	8.86	0.36	0.422	0.022
Liver, kg	0.46	0.50	0.48	0.36	0.02	0.254	0.007
Trimmings fat, kg	0.22	0.20	0.15	0.08	0.02	0.047	0.174
Mesenteric + omental fat, kg	0.80	0.65	0.56	0.33	0.06	0.046	0.149

BGS: buffelgrass silage, CS: corn silage
T1: 100% CS, T2: 66.6% CS and 33.3% BGS, T3: 33.3% CS and 66.6% BGS, T4: 100% BGS included in the diet, L: *P*-value for linear substitution effect, Q: *P*-value for quadratic substitution effect

Table 5 Mean values of the physical-chemical characteristics of *Longissimus thoracis* muscle of sheep fed with various levels of replacement of corn silage by buffelgrass silage

Variable	T1	T2	T3	T4	SE	L	Q
pH at 24 hours post mortem	4.04	4.42	4.47	4.34	0.16	0.09	0.35
Luminosity (L*)	38.08	36.34	35.61	38.74	0.45	0.76	0.01
Redness (a*)	12.60	12.80	11.92	12.46	0.30	0.64	0.78
Yellowness (b*)	10.36	10.03	9.60	10.17	0.19	0.55	0.23
Cooking loss, %	34.82	30.12	33.0	39.64	1.17	0.11	0.02
Shear force, kgf/cm^2	1.63	1.75	2.37	2.36	0.11	0.01	0.75
Water-holding capacity, %	77.67	78.10	79.21	76.83	0.55	0.77	0.21
Moisture content, %	73.02	73.21	73.91	74.76	0.16	0.01	0.31
Ash, %	1.1	1.1	1.2	1.1	0.09	0.89	0.93
Protein, %	24.83	24.18	25.39	24.23	0.26	0.81	0.63
Lipid content, %	2.62	2.57	2.08	2.09	0.15	0.12	0.94

BGS: buffelgrass silage, CS: corn silage; T1: 100% CS, T2: 66.6% CS and 33.3% BGS, T3: 33.3% CS and 66.6% BGS, T4: 100% BGS included in the diet, L: *P*-value for linear substitution effect, Q: *P*-value for quadratic substitution effect

No difference (P >0.05) was detected for any of the sensory attributes (Table 6).

Table 6 Sensory attributes of *Longissimus thoracis* muscle of sheep fed various levels of buffelgrass silage to replace corn silage*

Sensory attribute	T1	T2	T3	T4	SE	*H*-statistic
Colour	3.74	3.65	3.37	3.14	0.222	5.69
Aroma	3.54	3.40	2.98	3.14	0.117	4.07
Softness	6.69	6.60	5.76	6.13	0.321	7.30
Juiciness	4.41	4.39	4.59	4.80	0.199	1.33
Flavour	4.76	4.34	3.88	3.95	0.249	6.63
Global assessment	5.69	6.05	5.87	5.90	0.414	1.99

*Evaluated by 64 judges
BGS: buffelgrass silage, CS: corn silage
T1: 100% CS, T2: 66.6% CS and 33.3% BGS, T3: 33.3% CS and 66.6% BGS, T4: 100% BGS included in the diet,

The sheep grew more slowly than was anticipated, based on the formulations of the nutritionally similar diets that were used in this study. However, similar final and carcass weights were obtained from all of the treatments.

Decreases in carcass yield could be attributed to diet constituents. Oliveira *et al*. (2018) observed that animals fed diets that were high in fibre and had low digestibility usually promoted lower carcass yield than those that contained less fibre and had higher digestibility. These effects were attributed to differences in gut fill at slaughter, despite the animals have been fasted for the same time. Healthy well-fed animals with high body condition score shave a higher yield because of greater deposition of fat tissue in the carcass (Díaz-López *et al*., 2017).

The increased amount of BGS in the diet reduced true carcass yield. Leg and loin have the highest commercial values and are thus 'prime' or 'first-class' cuts, given the relatively high proportion of muscle and tenderness (Esteves *et al*., 2018). However, in this experiment relative amounts of the various cuts were unaffected. Silva Sobrinho *et al*. (2005) observed that the sum of the leg, loin, and shoulder yields should be above 60% in meat-producing breeds of sheep. In this study, these yields averaged 57.68%. Breast and flank are known for a small amount of muscle and greater amounts of bone and fat. This greater fat deposition slows the thickening of these cuts. The later growth of these cuts is explained because of their anatomical location whereby a greater fat accumulation is observed in the abdominal region (Andrade et al., 2017). Therefore, the relatively greater amounts of fat trim and mesenteric plus omental fat in CS-fed animals might be because these sheep were fed the diet that was highest in energy (Maciel *et al.*, 2015). Knapik *et al*. (2017) found that higher energy intake stimulates lipogenesis and hence visceral fat deposition. The similar chilling losses may be because the diets promoted a similar deposition of external fat, preventing weight loss in the carcasses because of evaporation during the refrigeration period.

The observed pH for sheep meat was around 4.32 (Table 2). This is less than is desired for sheep meat (Gois *et al*., 2017) since pH values should range from 5.5 to 5.8 at 24 hours after slaughter. This may happen because of the exposure of high-metabolic rate animals to stressful situations, as often occurs before slaughter. Stressed animals often present accelerated metabolism before slaughter and a rapid drop in pH soon afterwards to the point of compromising meat quality (Kim *et al*., 2014).

The main meat attributes in the evaluation of meat quality are colour (associated mainly with the decision to buy the meat), softness and aroma and flavour (related to satisfaction of consumption) (Berrighi *et al*., 2017). Factors that influence colour are related to diet, myoglobin concentration, muscle tissue type, pH, and intramuscular fat concentrations (Jacob & Pethick, 2014). The diets that were evaluated in this study did not modify the intensity the red colour of the meat. Confinement of the experimental animals possibly favoured lower values of redness since the animals were less active, favouring a lower myoglobin synthesis because of a lower muscle oxygenation, leading to a meat with a less intense colour (Campos *et al*., 2017). Meat luminosity (L*) values ranged from 35.61 to 38.74, in accordance with the results in other studies, with values higher than 30.0 for sheep meat (Araújo *et al*., 2017; Berrighi *et al*., 2017; Campos *et al*., 2017). These results were possibly influenced by the diets, with less luminous meat being obtained from sheep fed intermediate levels of BGS. However, a rationale for this observation was not apparent. Cooking loss (CL) is a parameter for evaluating meat quality since it is associated with the product yield as it is prepared for consumption and influences juiciness and tenderness of the meat (Lima *et al*., 2018). As with luminosity, cooking loss was lower for meat from sheep fed the intermediate levels of BGS. Shear force of the meat declined linearly as the level of BGS inclusion in the diet increased. The CS-based diet produced meat that would be classified as most tender and the diets that contained more BGS resulted in meat of medium softness (Cezar & Souza, 2007). The consumer panel did not detect differences in softness that could be attributed to diet.

Higher levels of intra- (marbling) and inter-muscular fat lead to lower CL and hence softer and juicier meat since the meat fat acts as a barrier against moisture loss (Frank *et al*., 2016). Perceptible sensory differences in sheep meat are caused by variations in fat content (de Lima Junior *et al*., 2016), as are the characteristic odour and flavour (Kosowska *et al*., 2017). Generally, as fat deposit increases and the amount of water in the muscle decreases, meat has reduced luminosity and becomes softer (Calnan *et al*., 2014; Listrat *et al*., 2016). In the present study, the meat with the highest fat content had a more intense aroma and flavour. The juiciness score increased with the level of BGS in the diet. In the overall assessment, inclusion of BGS in the diet for feeding lambs did not compromise the overall assessment by the panellists.

Conclusions

Replacing some or all of the CS with BGS in diets for confined Santa Inês sheep did not compromise their carcass characteristics or the nutritional and organoleptic aspects of the meat. Therefore buffelgrass silage could be used as a food source for sheep in semi-arid production systems.

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Authors’ Contributions

EGS, TMBS, GCG, FS, and AFP participated in designing the study, laboratory analysis, and writing the manuscript. GGLA, EMS, JSO, SMY, and OLR drafted and revised the manuscript for intellectual content. EGS, TMBS, GCG, FSC, and SMY carried out data analysis and interpretation and were involved in the preparation and revision of the manuscript. EGS, TMBS, GCG, SMY contributed to the acquisition, analysis and interpretation of data.

Conflict of Interest Declaration

The authors have no conflicts of interests relative to this project.

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