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Influence of diets with silage from forage plants adapted to the semi-arid conditions on lamb quality and sensory attributes

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ABSTRACT

Quality and sensory attributes of meat from 32 mixed-breed Santa Inês lambs fed diets composed of four silages with old man saltbush (*Atriplex nummularia* Lind), buffelgrass (*Cenchrus ciliaris*), Gliricidia (*Gliricidia sepium*), and Pornunça (*Manihot* sp.) were evaluated. Meat from lambs fed diet containing old man saltbush silage ($P < 0.05$) showed greater values for cooking loss. Of the sensory attributes evaluated in the *Longissimus lumborum* muscle of the lambs, color and juiciness did not differ ($P > 0.05$). However, the silages led to differences ($P < 0.05$) in aroma, tenderness, and flavor values. The meat from animals fed the pornunça and Gliricidia silages was tenderer. Flavor scores were higher in meat from lambs that consumed old man saltbush silage and lower in the meat from those fed buffelgrass silage. Diets formulated with buffelgrass silage for sheep reduce meat production. Based on the results for carcass weight and meat quality, old man saltbush and pornunça are better silages for finishing sheep.

1. Introduction

Ruminant livestock in tropical and subtropical countries have most of their dietary requirements met by native pastures and crop residues, which are usually low in nutritional quality (Tikam et al., 2014). According to these authors, smallholder farmers commonly face scarcity of good-quality forages that are not available or are overly expensive during the dry season. Thus, in order to maintain adequate feed supply, forage can be preserved using surplus crops during the rainy season as hay or silage during food shortage.

Studies investigating meat sensory analysis are complex, costly, and require personnel with high training and coordination, in addition to many participants to obtain representative data. According to Martinez-Cerezo et al. (2005), in spite of all the difficulties, consumer preferences are undoubtedly one of the main factors determining purchasing trends, and their expectations and perceptions can be used in studies to improve the meat quality. Research on the evaluation of lamb sensory traits by consumers is therefore essential.

As stated by Khan, Jo, and Tariq (2015), one of the major costs in animal production are animal feed sources, which define the formulation of the animal diet in different types of production systems. The diet can modify the carcass conformation and physicochemical characteristics and organoleptic parameters of meat quality such as proximate composition, fatty acid profile, tenderness, and color (Franco, Crecente, Vázquez, Gómez, & Lorenzo, 2013; Li, Zhu, Wang, He, & Cao, 2014; Ramirez-Retamal & Morales, 2014).

The importance of feeding on production and general characteristics of the meat from small ruminants justifies the need for studies investigating the influence of the diet on the quality of these animals (Gusha, Halimani, Ngongoni, & Ncube, 2015; Pereira et al., 2016). In addition, according to these authors, these studies are aimed at discovering alternative feeding systems adaptable to the rearing conditions of arid and semi-arid regions.

As mentioned before and described by Milewski et al. (2014), the type of silage offered to animals may influence the quality of their end products, e.g., milk and meat. Thus, the use of silage instead of hay is more suitable for arid and semiarid regions, since this choice implies reduced water requirement by ruminants. The use of silages made from forage plants adapted to the semi-arid conditions can yield satisfactory results regarding quantitative and qualitative traits of meat from

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feedlot-finished lambs, as observed by Sen, Santra, and Karim (2004). Pinho et al. (2013) evaluated the ensiling of buffelgrass and found that it is possible to obtain high-quality silage when this grass is harvested at a height of 50 cm.

Pornunça is a *Manihot* species like cassava, which presents high soluble carbohydrate contents in leafs and thin stems that result and good-quality silages. Despite not being well preserved as silage due to its low soluble carbohydrate content and high buffering capacity, Gliricidia has a high crude protein content. If Gliricidia silage is provided alone, the animal performance declines. On the other hand, if Gliricidia silage is offered in a complete diet, animal performance rates may increase. Van Man and Wiktorsson (2002) compared the quality of cassava and Gliricidia silages and observed that the former was better preserved than the latter, yet both had a high nutritive value.

Based on specific characteristics of each forage plant, it is necessary to compare all of them in a feedlot system to identify how the fermentation process during ensiling affects the nutritional value of the silage and consequently the performance of an animal and its meat quality. This is the way to define the most appropriate forage source for semi-arid conditions. Thus, the aim of the present study was to compare diets containing silages from forage plants adapted to the semi-arid conditions on the quality of meat from feedlot-finished lambs by determining the physicochemical, proximate, and sensory properties of their meat.

2. Materials and methods

The experiment was developed in accordance with the recommendations described in CONCEA (Guide of the National Council for the Control of Animal Experimentation). The protocol was approved by the Committee of Ethics in Animal Experiments of the Federal University of Bahia, Bahia State, Brazil (Permit Number: 05-2016).

2.1. Location

The experiment was conducted on an experimental Caatinga biome field, at the Metabolism Unit of the Brazilian Agricultural Research Corporation (Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA), located in Petrolina-PE, Brazil, where the average annual precipitation is 570 mm and maximum and minimum temperatures are 33.5 and 20.9 °C, respectively.

2.2. Animals and feeding management

Thirty-two uncastrated, mixed-breed Santa Inês male lambs at five months of age, with an initial live weight of 17.6 ± 2.6 kg, were used in the experiment. The experiment lasted 59 days, including 10 days for acclimation. Lambs were weighed every seven days to monitor their weight development. The animals were initially vaccinated against clostridial diseases and dewormed against ecto- and endoparasites, and then distributed into individual 1.0 × 1.2 m cages with free access to feeders and drinkers.

The experimental design was completely randomized, with four treatments and eight replications. Experimental diets were composed of four silages (treatments): old man saltbush (*Atriplex nummularia* Lind), buffelgrass (*Cenchrus ciliaris*), Gliricidia (*Gliricidia sepium*), and pornunça (*Manihot* sp.) plus a concentrate based on corn, soybean meal, urea, a mineral mixture, calcitic limestone, and ammonium chloride (Table 1). To produce the silages, the old man saltbush, Gliricidia, and pornunça plants were harvested from the experimental field of Embrapa Semiarid, selecting plant shoots with young leaves and stems with an average height of 1.5 m. The buffelgrass was harvested at the Agricultural Research Company of Paraíba State (*Empresa Estadual de Pesquisa Agropecuária da Paraíba* S.A. - EMEPA), cut 10 cm above the soil before the inflorescence period, with approximately 60 cm in height. All materials were processed to an average particle size of 2.0 cm and stored in plastic drum silos with 200 L capacity, applying a compaction density of 600 kg/m^3. For the buffelgrass, however, because of its high DM content (40%), a compression density of approximately 400 kg/m^3 was necessary at the moment of harvest.

Table 1
Chemical composition of ingredients used in experimental diets.

Item (%DM)	Old man saltbush silage	Buffelgrass silage	Gliricidia silage	Pornunça silage	Ground corn	Soybean meal
DM[a]	36.4	40.5	26.3	32.0	87.1	84.6
MM	17.1	13.6	9.8	7.1	1.6	6.1
CP	7.0	8.4	15.7	16.7	13.1	52.7
EE	1.6	1.6	2.9	4.6	2.4	0.7
NDFap	53.6	64.1	46.4	44.3	10.2	10.7
NDF	61.5	72.0	54.6	55.2	14.0	14.6
ADF	39.0	45.3	40.0	42.6	8.3	7.0
iNDF	45.1	32.8	31.4	28.0	1.5	2.1
NDIN[b]	24.8	24.5	25.0	37.8	9.5	4.9
ADIN[b]	19.1	20.2	19.7	25.7	3.8	2.8
Cellulose	29.9	43.3	27.8	27.9	3.6	8.4
Hemicellulose	22.5	26.7	14.6	12.6	9.4	6.1
Lignin	14.2	5.2	13.4	19.9	1.2	1.3
TC	74.3	76.4	71.6	71.6	83.0	40.5
NFCap	20.7	12.3	25.3	27.3	74.5	30.0

DM = dry matter, MM = mineral matter, CP = crude protein, EE = ether extract, NDFap = neutral detergent fiber corrected for ash and protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, iNDF = indigestible neutral detergent fiber, NDIN = neutral detergent insoluble nitrogen, ADIN = acid detergent insoluble nitrogen, TC = total carbohydrates, NFCap = non-fibrous carbohydrates corrected for ash and protein.
[a] In % fresh matter.
[b] In % total nitrogen.

Table 2
Composition of experimental diets.

	Old man saltbush	Buffelgrass	Gliricidia	Pornunça
Centesimal composition of ingredients (%)				
Silage	50.0	50.0	50.0	50.0
Ground corn	37.2	39.3	46.8	45.1
Soybean meal	9.0	7.0	0.0	1.3
Urea	0.9	0.7	0.0	0.4
Mineral mix[a]	1.7	1.7	1.9	1.9
Calcitic limestone	0.4	0.4	0.4	0.4
Ammonium chloride	0.8	0.8	0.8	0.8
Chemical composition of diets (% DM)				
DM[b]	61.7	66.7	55.2	57.6
MM	11.6	9.9	8.4	7.1
CP	15.5	15.0	15.0	15.1
EE	1.8	1.8	2.5	3.4
NDFap	31.6	36.8	28.0	26.9
NDF	45.9	50.0	40.0	40.0
ADF	22.2	25.1	21.9	23.3
iNDF	25.1	18.6	18.1	15.4
NDIN[c]	14.6	14.3	16.0	21.5
ADIN[c]	11.8	12.3	12.8	15.2
Cellulose	17.1	23.0	15.7	16.1
Hemicellulose	23.7	24.9	18.1	16.7
Lignin	7.4	3.0	7.2	10.4
TC	71.1	73.3	75.1	73.4
NFCap	39.5	36.5	47.1	46.5

[a] Provides per kg in active elements: calcium - 120 g; phosphorus - 87 g; sodium - 147 g; sulfur - 18 g; copper - 590 mg; cobalt - 40 mg; chromium - 20 mg; iron - 1800 mg; iodine - 80 mg; manganese - 1300 mg; selenium - 15 mg; zinc - 3800 mg; molybdenum - 10 mg; maximum fluoride - 870 mg; minimum 2% citric acid phosphorus (P) solubility - 95%.
[b] In % fresh matter.
[c] In % total nitrogen, DM = dry matter, MM = mineral matter, CP = crude protein, EE = ether extract, NDFap = neutral detergent fiber corrected for ash and protein, NDF = neutral detergent fiber, ADF = acid detergent fiber, iNDF = indigestible neutral detergent fiber, NDIN = neutral detergent insoluble nitrogen, ADIN = acid detergent insoluble nitrogen, TC = total carbohydrates, NFCap = non-fibrous carbohydrates corrected for ash and protein.

Diets were formulated with a roughage:concentrate ratio of 50:50 and were balanced so as to provide an average weight gain of 200 g/day, following NRC (2007) recommendations (Table 2). Feed and water were provided ad libitum. The feed was supplied twice daily, at 08h30 and 15h30, and leftovers were collected and weighed on the next day to determine the intake and to adjust the dry matter (DM) intake so as to allow for 10% as leftovers in the trough.

Samples of silage, ingredients of the concentrate, and leftovers were analyzed for the evaluation of feed intake and digestibility. Laboratory analyses were conducted at the Laboratory of Animal Nutrition of Embrapa Semiárido, where the DM (method 967.03), ash (method 942.05), crude protein (CP; method 981.10), and ether extract (EE; method 920.29) were determined as described by AOAC (1990). Concentrations of neutral detergent fiber corrected for ash and protein (NDFap; Mertens, 2002; Licitra, Hernandez, & Van Soest, 1996), and acid detergent fiber (ADF) were obtained as described by Van Soest, Robertson, and Lewis (1991). Lignin was determined by treating the acid detergent fiber residue with 72% sulfuric acid (Silva & Queiroz, 2002).

The total carbohydrates (TC) were obtained by following the recommendations of Sniffen, O'Connor, Van Soest, Fox, and Russell (1992). Non-fibrous carbohydrates (NFC) concentrations were calculated using the methods of Detmann and Valadares Filho (2010). Total digestible nutrients (TDN) were estimated by using the formula proposed by Weiss (1999). The indigestible neutral detergent fiber (iNDF) in the feeds was obtained after in situ incubation for 288 h (method INCT-CA F-009/1; Detmann et al., 2012).

2.3. Slaughter and carcass evaluation

To evaluate performance, monitor the weight evolution, and determine the daily weight gain, animals were weighed individually at the start of the experimental period, after being fasted for solids for approximately 16 h. The intake of nutritional components was estimated over the course of 49 days as the difference between the total amounts of each component contained in the feed supplied and in the leftovers, with values expressed in kilograms per period (kg/period).

The lambs were slaughtered at the end of the trial period, and their average weights were 29.2, 24.3, 27.4, and 27.7 kg for those fed the diets containing old man saltbush, buffelgrass, Gliricidia, and pornunça silages, respectively. The overall mean was 27.2 ± 3.63 kg. Prior to slaughter, animals were fasted for solids and received a water-only diet for 16 h, according to animal welfare norms. The slaughter method adopted was stunning by brain concussion followed by bleeding, skinning, and evisceration. Carcasses were weighed (Portable Electronic Balance WALMUR, capacity: 50 kg, Porto Alegre, RS, Brazil) for hot carcass weight (HCW) and hot carcass dressing percentage (HCD = (HCW/SBW) × 100), and then chilled at 4 °C for approximately 24 h. After the postmortem chilling period, the cold carcass weight (CCW) and cold carcass dressing percentage (CCD = (CCW/SBW) × 100) were determined.

2.4. Meat quality assessment

Samples of the *Longissimus lumborum* muscle of the dorsal-lumbar region were collected from the 10th to the 13th ribs. Next, samples were individually wrapped, labeled, and stored at −20 °C until analyses. Loins were thawed under refrigeration (8 °C) in the night prior to the beginning of analyses and dissected with a scalpel to remove the fat cover of the samples.

The pH values of the meats were measured at 0 and 24 h after slaughter using a portable pH meter coupled to a penetration electrode previously calibrated with buffer solutions of pH 4.00 and 7.00 inserted in the center of the samples. The pH meter was calibrated to room temperature (25 °C) before each measurement at every time point. Meat color was evaluated using a Minolta CR300 colorimeter (Minolta, 1998) operating in the CIE (L*, a*, b*) system, in which L* represented lightness, a*, the intensity of the color red, and b*, the intensity of the color yellow. The colorimeter was calibrated with a white ceramic plate and illuminant C, 10°, for standard observation, and it was operated using open cone. Before analysis, samples were exposed to room temperature for 30 min for the formation of oxymyoglobin, the main pigment responsible for the meat bright red color (Cañeque & Sañudo, 2000). After this time, and as described by Miltenburg, Wensing, Smulders, and Breukink (1992), the L*, a*, and b* coordinates were measured in three distinct points of the internal muscle surface, and the average of the triplicates of each coordinate was calculated per animal sample.

Cooking loss (CL) was determined in each loin sample with approximately 1.5 cm thickness, 3.0 cm length, and 2.5 cm width. Raw samples were weighed, placed in an aluminum-coated tray, and cooked in a pre-heated oven at 170 °C until the center of the meat reached a temperature of 70 °C, measured using a copper-constantan thermocouple equipped with a digital reader. Samples were subsequently cooled at room temperature and re-weighed. Cooking losses were calculated as the weight difference before and after heat treatment (Duckett, Klein, Dodson, & Snowder, 1998). The meat texture was determined by the shear force (SF), by adopting the method described by Wheeler, Koohmaraie, and Shackelford (1995), expressed in N/cm^2.

Samples of the *L. lumborum* muscle for analysis of proximate composition were ground and homogenized in a blender. Moisture, ash, and protein contents were evaluated according to the methodology described by AOAC (2000) methods 985.41, 920.153, and 928.08, respectively. Total lipids were extracted according to the methodology described by Folch, Less, and Stanley (1957), using a chloroform:methanol (2:1) solution followed by solvent evaporation in an oven at 105 °C.

2.5. Sensory analysis

The quantitative-descriptive analysis test for sensory evaluation was applied using a panel of 84 judges, which was carried out during three consecutive days. Samples of the *L. lumborum* muscle were cut parallel to the orientation of the muscle fibers into 2.0 cm-sided cubes (Lyon, Francombe, & Hasdell, 1992). Before being cooked, samples were dissected, and the subcutaneous fat was removed. Then, the samples were roasted in a pre-heated oven at 170 °C until the temperature of their geometric center reached 71 °C. After roasting, the meat was wrapped in aluminum foil and kept in a water bath at 65 °C ± 2 °C. No salt or condiments were added. The tests were performed in individual cubicles under controlled temperature and lighting conditions. At each session, each evaluator received one cube of each treatment, identified by three random digits. Samples were tasted following the sample testing order proposed by Macfie, Bratchell, Greenhoff, and Vallis (1989).

The intensity of each attribute was evaluated on a non-structured 9-cm scale (Costa et al., 2011) anchored at the extremities with terms expressing intensity. Each attribute was scored on a scale of 1 to 9, in which 1 corresponded to the least favorable and 9 to the most favorable condition for the following sensory parameters: color (color observed in evaluated samples), aroma (intensity of smell associated with the ovine species), tenderness (tenderness felt as the meat was chewed with the molars), juiciness (overall juiciness perceptible during chewing), and flavor (intensity of flavor associated with the ovine species).

2.6. Statistical analysis

A completely randomized design with four treatments and eight replicates was adopted. The MIXED procedure of SAS (version 9.2) was used to analyze effects of treatment on meat quality traits, with the animal serving as the experimental unit, according to the following statistical model:

$$Yij = \mu + ti + eij$$

where Yij = value for dependent variable observed with diet i; μ = overall mean; ti = effect of diet i, in which i = old man saltbush, buffelgrass, Gliricidia, and pornunça; and eij = residual error associated with each observation with j replications (n = 8). Although the MIXED procedure was used, only fixed effects influenced the main variables, except for the sensory analysis. All means were compared by Tukey's test at the 5% probability level using SAS software (version 9.2).

Sensory data were analyzed using the MIXED procedure. Diet was the only fixed effect, whereas panelists (n = 84) and sessions (n = 3) were considered random effects. Each session was carried out with 28 judges, totaling 84 at the end. Sensory data were interpreted by principal component analysis (PCA), in which values obtained in the sensory analyses composed a set of multivariate data that were arranged in a matrix (256 × 10).

3. Results

3.1. Feed intake

Lambs fed diets containing old man saltbush had a higher CP intake ($P < 0.05$), while lower intakes for this component were observed ($P < 0.05$) in animals fed diets containing buffelgrass and Gliricidia silages. Diets with silage from forage plants adapted to the semi-arid conditions affected ($P < 0.05$) the ether extract intake, which was higher ($P < 0.05$) for lambs that consumed pornunça and lower ($P < 0.05$) for the animals fed the diet with buffelgrass silage. The NDF intake was also influenced by the diets, with higher values found in animals fed diets with buffelgrass and lower values for the lambs consuming diets containing Gliricidia and pornunça silages, whereas the diets with old man saltbush were in an intermediate position for this parameter. The NFC intake was higher for the lambs fed diets with old man saltbush and pornunça silages and lower for those that received buffelgrass silage. Animals fed buffelgrass had a lower TDN intake compared with those fed diets with old man saltbush, Gliricidia, and pornunça silages (Table 3).

3.2. Carcass characteristics

As shown in Table 4, no difference was observed ($P > 0.05$) for dressing percentage among the diets. The average hot and cold carcass dressing percentages were 42.6% and 41.6%. The hot and cold carcass weights, expressed in kilograms, varied according to the silages present in the diets ($P < 0.05$); higher values were obtained with diets containing old man saltbush, pornunça and Gliricidia, whereas lower values were found for lambs fed the diet with buffelgrass silage (Table 4). Moreover, the carcass weights of lambs fed buffelgrass silage did not differ from those of animals fed the diet containing Gliricidia silage.

Table 3
Intakes of dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE), neutral detergent fiber corrected for ash and protein (NDFap), non-fibrous carbohydrates (NFC), and total digestible nutrients (TDN) of lambs fed diets with silage from forage plants adapted to semi-arid conditions.

Item (kg[a])	Silages				SEM	*P*-value
	Old man saltbush	Buffelgrass	Gliricidia	Pornunça		
DM	53.2a	36.1c	42.2bc	48.4ab	1.098	<0.001
OM	47.5a	32.3c	38.8bc	45.0ab	0.931	<0.001
CP	9.6a	4.7c	5.5c	8.0b	0.141	<0.001
EE	1.0b	0.5c	0.9bc	1.50a	0.086	<0.001
NDFap	12.7ab	13.81a	10.0b	11.1b	0.393	0.041
NFC	24.4a	11.9c	20.4b	24.2a	0.352	<0.001
TDN	36.3a	22.7b	30.3a	33.5a	0.639	<0.001

P = probability, considering $P < 0.05$.
[a] Period lasted 49 days.

3.3. Physical-chemical and proximate composition

Diets did not affect ($P > 0.05$) pH evaluated immediately and 24 h after slaughter, which was approximately 5.7 (Table 5), or the L* (meat lightness) values (Table 5). The same response was noted for the redness (a*) and yellowness (b*) values, which were not influenced ($P > 0.05$) by the diets composed of tropical silages.

On the other hand, differences between diets were observed ($P < 0.05$) for cooking losses (CL), which ranged from 40.6 to 32.0%, with the highest values found in the meat from lambs consuming the diets containing old man saltbush silage (40.6%), and the lowest in lambs fed diets with pornunça silage (32.0%). The meat shear force was affected ($P < 0.05$) by the diets, with the highest values obtained with diets containing Gliricidia and pornunça silages and the lowest with old man saltbush and buffelgrass silages (Table 5).

3.4. Sensory analysis

There was a difference ($P < 0.05$) between the silages used in the lamb diets for the percentage of moisture, whose mean values ranged from 74.6 to 76.5, and the percentage of protein, which averaged 23.6%. Higher values were found in the meat from animals that consumed old man saltbush silage and lower values were detected in those fed the buffelgrass and pornunça silages (Table 6). No effect was observed ($P > 0.05$) between the diets for percentages of ash and lipids in the meat, whose mean values remained between 1.1 and 2.5%, respectively, suggesting that they were influenced negatively by the diets containing different silages.

In the sensory analysis, there was no effect ($P > 0.05$) of panelists or sessions. Additionally, no differences were observed ($P > 0.05$) for the sensory parameters color, juiciness, or overall-assessment evaluated using the 9-point hedonic scale (Table 7). Meat tenderness showed differences ($P < 0.05$) between the diets, as the meat from lambs fed pornunça silage showed the highest mean values for the scores assigned by the tasters. For the flavor attribute, the highest mean (4.6) was found in meat from animals fed old man saltbush silage. The meat from animals fed buffelgrass silage had its sensory quality affected ($P < 0.05$) by the diets. Lambs fed this silage received lower aroma scores by the tasters in relation to those consuming Gliricidia and old man saltbush, which had the highest scores. The same trend was observed for the flavor attribute. On the other hand, the highest tenderness scores were assigned to the meat from lambs fed old man saltbush, pornunça, and buffelgrass in comparison with the animals that were offered Gliricidia silage.

A trend towards separation of samples from animals receiving the four different silages was observed when variables were evaluated using principal component analysis. The first principal component (PC_1), responsible for explaining 59.34 of the variance of the data (horizontal axis of Fig. 1), discriminated the two groups (Table 8 and Fig. 1). Samples located in the lower part of the figure represent those with lowest mean values assigned by the judges, and thus of lowest scores in relation to principal component 2. The sensory analysis was discriminant for the separation of the silages.

The principal component analysis for distinguishing the silages based on sensory analysis showed a trend of formation of homogeneous groups. Regarding the principal components of the sensory traits (Table 8; Fig. 1), we observed that principal components 1 and 2 explained 93.2% of the variation of the total dataset. Therefore, the sensory traits present in both components may be used in lieu of the original variables without information losses.

Table 4
Carcass characteristics of lambs fed diets with silage from forage plants adapted to semi-arid conditions.

Item	Silages				SEM	*P*-value
	Old man saltbush	Buffelgrass	Gliricidia	Pornunça		
Body weight at slaughter (kg)	29.2a	24.3b	27.4ab	27.7ab	0.91	0.006
Empty body weight (kg)	23.4a	17.4b	19.2ab	21.8ab	0.68	0.008
Hot carcass weight (kg)	13.0a	9.6b	11.2ab	12.7a	0.45	0.025
Cold carcass weight (kg)	12.7a	9.4b	10.9ab	12.4a	0.43	0.007
Hot carcass yield (%)	44.8	39.6	40.8	45.9	0.03	0.786
Cold carcass yield (%)	43.4	38.7	39.6	44.9	0.03	0.323

P = probability, considering $P < 0.05$. Means followed by the same letter do not differ statistically by Tukey test at 5% probability.

4. Discussion

4.1. Carcass characteristics

The pH values of the meats were within the range of 5.5 to 5.8 considered normal for sheep meat 24 h after slaughter, according to Della Malva et al. (2016). It should be stressed that normal pH values suggest that other parameters indicative of the meat quality, such as color and tenderness, will have good results, as they will be influenced by pH (Bonagurio, Perez, & Garcia, 2003).

Even though dressing percentage did not vary between diets, in sheep, hot carcass dressing percentages usually range from 40 to 50% (Silva Sobrinho, 2001), which involves the development and profile of muscle mass and the quantity and distribution of subcutaneous fat. Addressing cold carcass dressing, Silva Sobrinho (2001) reported 46% in this animal species. Given the above information, the lamb carcasses in this study had dressing percentages within the recommended range for this genetic group.

4.2. Physicochemical and proximate composition

The variation in red content (a*) may be related to the ability of the genetic group or of the diet to influence the proportion between the forms of myoglobin (deoxymyoglobin and oxymyoglobin). This was not observed in the present study, probably because of the similarity between animals and diets and the adopted production system, since feedlot animals are less susceptible to development of physical activities. As a consequence, myoglobin synthesis is reduced because of the lower need for oxygenation of the muscle; this in turn promotes a less intense meat color, which is normally pinkish (Urrutia et al., 2016).

The b* value found in this study was similar among the diets. According to Leão et al. (2012), diets with low concentrations of carotenoids, e.g., grains, hay, and silage, lead to a reduction of the yellow color of the meat fat due to the dilution of the fat color. These researchers also reported that the intensity of light absorption by the carotenoid stored in the fat of feedlot lambs is negatively correlated with the feedlot period; this effect is probably mediated by the dilution of white-colored fat. Because the forage used to make the silage did not have a high carotenoid concentration and the ingredients were the same for all diets, this similarity was expected.

It is also important to emphasize that, among the carotenoids, lutein is the only one stored in the fat tissue of this animal species (Yang, Larsen, & Tume, 1992; Prache, Priolo, & Grolier, 2003a; and Prache, Priolo, & Grolier, 2003b), and that lambs reared on pasture have 5.5 times more carotenoids in the blood and 3.2 more lutein in the perirenal fat as compared with animals reared in feedlots (Prache & Theriez, 1999; Prache et al., 2003a; and Prache et al., 2003b). Thus, it can be stated that the b* value observed in this study was not influenced by the silages, probably because of the low lutein concentration in the feedstuffs that made up the diets, since it was used a roughage:concentrate ratio of 50:50. The results obtained in this study agree with values reported in the literature for sheep meat, e.g., 30.0 to 49.5 for L*, 8.2 to 23.5 for a*, and 3.4 to 11.1 for b* (Bressan, Prado, Pérez, Lemos, & Bonagurio, 2001; Warris, 2003).

According to Khliji, van de Ven, Lamb, Lanza, and Hopkins (2010), the acceptable limit for L* in lamb is 34–35, which is lower than the values found in this study. However, L* values may differ depending on whether the cone is open or closed. Values obtained in this study for lamb meat color are in agreement with those mentioned by Kerr and Hopkins (2010), who used a Minolta colorimeter with open cones for coordinates L*, a*, and b*. As noted by these authors, the type of cone can influence meat color and, therefore, lead to different results between studies.

Cooking loss is an important parameter in the evaluation of meat quality, as it is associated with yield in the preparation for consumption and influences the juiciness and tenderness of the meat.

The lack of effects on meat pH can be justified, since the diets probably did not affect the concentration of muscular glycogen reserves and, consequently, their conversion into lactate and H^+ ions. Moreover, lambs were subjected to the same pre-slaughter fasting period, which also explains the lack of a significant effect on pH values. The results found in this study corroborate Silva et al. (2011), who mentioned that the amount of glycogen in ruminant carcasses can be influenced by the diet as well as by pre- and post-slaughter procedures.

In this study, the values found for initial pH were close to those obtained by Cunha, Bueno, Santos, Roda, and Otzuki (2001) and Oliveira,

Table 5
Qualitative characteristics of the *L. lumborum* muscle of lambs fed diets with silage from forage plants adapted to semi-arid conditions.

Item	Silages				SEM	*P*-value
	Old man saltbush	Buffelgrass	Gliricidia	Pornunça		
pH_0 [a]	6.7	6.7	6.8	6.7	0.02	0.382
pH_{24} [b]	5.6	5.6	5.6	5.6	0.04	0.561
Color						
L*	39.6	36.0	42.3	39.1	0.69	0.438
a*	14.3	12.7	13.4	14.7	1.31	0.174
b*	9.9	8.2	10.5	9.8	0.10	0.753
CL	40.6a	36.9a	35.0ab	35.0b	0.02	0.046
SF	11.3b	11.4b	12.7a	13.0a	0.04	0.028
Newton/cm^2						

L* = lightness; a* = red intensity; b* = yellow intensity; CL = cooking loss; SF = shear force; SEM = standard error of the mean. P = probability, considering $P < 0.05$. Means followed by different letters in the row do not differ ($P < 0.05$) by Tukey's test.

[a] pH_{24} = pH after 24 h of cooling storage.

[b] pH_0 = pH immediately after slaughter.

Table 6
Proximate composition (%) of the *L. lumborum* muscle of lambs fed diets with silage from forage plants adapted to semi-arid conditions.

Item (%)	Silages				SEM	*P*-value
	Old man saltbush	Buffelgrass	Gliricidia	Pornunça		
Moisture	74.6b	76.5a	74.8ab	74.7b	0.15	0.018
Ash	0.9	1.0	1.2	1.3	0.27	0.065
Protein	24.8a	23.0b	23.8ab	23.0b	0.06	0.019
Lipids	2.7	2.5	2.3	2.5	0.28	0.071

P = probability, considering $P < 0.05$. Means followed by common letters do not differ at the 5% probability level by Tukey's test; SEM = standard error of the mean.

Table 7
Results for sensory evaluation of meat from lambs fed diets with silage from forage plants adapted to semi-arid conditions.

Item	Silages				SEM	*P*-value
	Old man saltbush	Buffelgrass	Gliricidia	Pornunça		
Color	4.5	4.3	4.0	4.4	0.15	0.163
Aroma	4.2a	3.6b	4.6a	4.0ab	0.46	0.037
Tenderness	7.1ab	6.7bc	6.3c	7.6a	0.44	0.033
Juiciness	5.1	4.7	4.9	4.7	0.33	0.179
Flavor	4.6a	3.6b	4.5ab	4.0ab	0.47	0.046
Overall assessment	6.2	6.0	5.8	6.1	0.37	0.084

Mean values for scores on a scale of 1 to 9. P = probability, considering $P < 0.05$. Means followed by common letters do not differ statistically at the 5% probability level by Tukey's test.

Silva, Freitas, Tortelly, and Paulino (2004), which varied from 6.50 to 6.60. Because it is a trait indicative of the meat quality, it is important to emphasize the detection of normal values of pH decline, as it can affect other characteristics such as color, tenderness, and cooking weight loss (Leão et al., 2012).

The results for pH evaluated 24 h after slaughter are acceptable, considering that values between 5.4 and 5.9 are desirable, because despite having satisfactory tenderness, meats with pH values above 6.0 are considered unsuitable for sale due to reduced shelf life (Devine, Graafhuis, Muir, & Chrystall, 1993; Zapata, Seabra, & Nogueira, 2000; Silva Sobrinho, Purchas, Kadim, & Yamamoto, 2005). Furthermore, Bonagurio et al. (2003) observed an average cooking loss of 36.1% in male lambs, which was in general very similar to the values found in lambs fed diets with buffelgrass, Gliricidia, and pornunça silages in this study.

Concerning the tenderness aspect, the samples analyzed in this study showed a shear force between 11.3 and 13.0 N/cm^2 and can thus be considered tender, according to the classification of Cezar and Sousa (2007), who indicated that meat steaks that do not withstand a cut under a pressure lower than 22.3 N/cm^2 can be classified as tender. In this regard, all diets likely provided energy for fat deposition and maintenance of meat tenderness, showing nutritional similarity among the diets.

The chemical composition of sheep meat can be influenced by how the animals are fed and finished (Ahmed et al., 2015). This was confirmed in the current study, in which the results were similar to those described in the literature. According to Madruga et al. (2006), it is known that the chemical composition of sheep meat includes mean values of 75% moisture, 19% protein, 4% fat, and 1% mineral matter, with possible variations in these levels depending on the animal age,

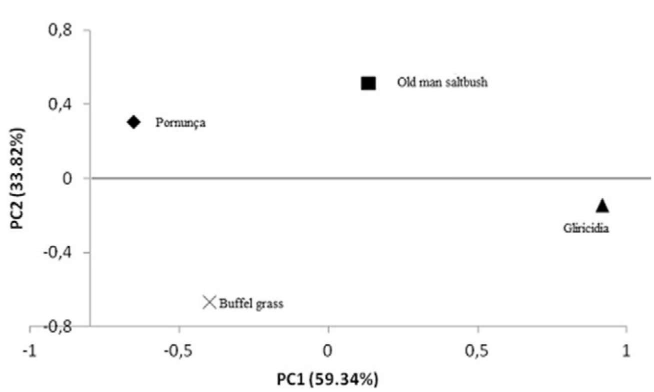

Fig. 1. First two principal components for four silages (old man saltbush (■), buffelgrass (X), Gliricidia (▲), and pornunça (♦)) evaluated for sensory attributes of lamb meat, expressed by PC1 + PC2 = 93.16%.

Table 8
Estimate of eigenvalues associated with sensory attributes of meat from lambs fed diets with silage from forage plants adapted to semi-arid conditions.

I	Principal components (PC_i)	Eigenvalues λ_i	Proportion of variance (%)	Accumulated proportion (%)
1	PC_1	0.4809	59.34	59.34
2	PC_2	0.2740	33.82	93.16
3	PC_3	0.0554	6.84	100.00
4	PC_4	0.0000	0.00	100.00
5	PC_5	0.0000	0.00	100.00
6	PC_6	0.0000	0.00	100.00

genotype, sex, castration, pre- and post-handling procedures, and diet (Tshabalala, Strydo, Webb, & Kock, 2003).

Another important factor is the improved nutritional content of the diets; more specifically, the protein content, which may provide significant increases in animal performance, since the concentration and quality of the protein can affect feed intake, carcass characteristics, and the chemical composition of muscle tissues. Given these facts, despite not having the highest CP content, the diet containing old man saltbush provided the highest CP intake ($P < 0.05$), which is associated with the greater DM intake observed with this diet and consequently with the greater protein percentages in the meat. Results lower than those found here were reported by Moreno et al. (2011) — 20% — in a study on the effects of genotype and dietary protein on lamb quality. Our findings corroborate Atti, Rouissi, and Mahouachi (2004), who evaluated the effect of dietary crude protein (10, 13, and 16%) on the composition of the carcass and meat from native goats and also found 20.5% CP.

Moreno et al. (2014) studied the concentration of old man saltbush hay and concentrate in diets for lambs and observed an increase in mineral content as this roughage was increased, which did not occur in the present study, because the mineral content in the diets was adjusted. According to Masters, Norman, and Barrett-Lenard (2005), the voluntary feed intake of animals fed saltbush forage is limited by salt accumulation, as approximately 200 g of salt are ingested per day by sheep.

The fat content found in this study ranged from 2.3 to 2.7%, which, according to Bezerra et al. (2016), characterizes the meat as lean, as it has <5% fat. The low fat contents found in the meat of the lambs from this study are probably due to their age, which also influences their fat content, because, as they were young animals, at approximately seven months of age (27.2 kg) at slaughter, they were still under muscle development. In other words, they had less fat in their muscle composition, which is desirable from the consumer-nutrition perspective. On the other hand, all diets resulted in similar fat contents, which led to their similar nutritional values. The fat content could be increased by augmenting the concentrate level in the diets or by extending the duration of the finishing phase, but probably without differences among diets.

4.3. Sensory analysis

According to Thompson et al. (2005), the meat palatability is generally described in terms of tenderness, juiciness, and flavor scores. As stated by Batcher, Brant, and Kunze (1969), the consumer can accept or reject cooked lamb based solely on its flavor and aroma, whereas the acceptability of other meats such as beef and pork is also determined by tenderness and juiciness.

The aroma, which may be understood as the characteristic smell of sheep meat, or "ovine" smell, was more evident in the meat from animals fed Gliricidia silage, whose average score was 4.6. The more evident aroma of these animals is possibly directly related to the use of legumes in their diet. Limited literature is available on the inclusion of legumes in ruminant diets and how it could influence the meat tenderness, because flavor and juiciness are the most important sensory attributes in acceptability by consumers.

The effects of legume inclusion in the diet on flavor characteristics of beef and lamb are ambiguous, but the effect of forage type on flavor appears to be more pronounced in lamb than in beef. Schreurs, Lane, Tavendale, Barry, and McNabb (2008) showed that meat from sheep fed red clover or lucerne alone had a more intense and unacceptable flavor than meat from grass-fed sheep. Differences due to legume consumption have been attributed to the proportion of legumes in diets and its consequent effect on the 18:3 n − 3 concentrations in meat. This compound is associated with lower oxidative stability and with odoriferous compounds stored in fat depots (Moloney, 2016).

Despite the lack of differences for meat lipids, their composition could have been altered when lambs were fed different diets. Thus, the fatty acids profile in meat lipids might have influenced the meat flavor. Pearce, Norman, and Hopkins (2010) mentioned that there are some indications that lamb quality may be changed if the animal is fed saltbush, e.g. oxidative products of polyunsaturated fatty acids such as linolenic acid (C 18:3). Meat from animals fed saltbush has a lower polyunsaturated fatty acid content (Pearce et al., 2008), which may decrease the susceptibility of the meat to oxidative processes that affect compounds available for fat deposition (Cramer, 1983). This response probably occurred when lambs were fed diets with other silages.

Some types of forage may be responsible for undesirable flavor and smell in the meat, leading to low acceptability by consumers. Notter, Kelly, and Berry (1991) detected a rancid taste in meat from lambs finished on a legume pasture. Legume silages have a high content of undesirable fermentation products such as ammonia and some amines that can be absorbed in the rumen. As stated by Ferrão et al. (2009), some diets may change the fat composition and consequently the meat flavor. Silage-based diets may lead to differences in flavor and aroma in sheep meat compared with animals reared on pasture.

Our results indicate that the old man saltbush and pornunça silages benefited the sensory traits of the sheep meat, since the highest scores for the established parameters were assigned to the meat from animals that consumed these silages. All samples had good overall acceptance, and the degree of satisfaction was evaluated considering the set of attributes as a whole; i.e., some evaluators might have appreciated the less intense aroma and flavor of the lamb, while others preferred meat with greater tenderness and juiciness. Despite the significant differences for some sensory aspects, samples were well accepted by the evaluators, according to their overall acceptance.

Flavor and aroma stand out among the important sensory traits of sheep meat due to the difficulty to distinguish between one another at the moment of consumption. According to Elmore et al. (2005), some types of forage can be responsible for unpleasant flavor and aroma in sheep meat and lead to low acceptability by consumers; however, these results may vary in terms of acceptability of the meat, which varies from region to region. The terpenes, derived from chlorophyll via fermentation in the rumen, can also contribute to the flavor and aroma of sheep meat (Utsumi et al., 2013; Urrutia et al., 2016).

The results of this study suggest that the use of silages from different forage plants in the finishing of young sheep in the feedlot can be an interesting alternative to standardize the supply of good-quality lamb, since this is one of the major obstacles of the sheep-meat production chain. This is especially important in the semi-arid region of Brazil, where the lack of standards for sheep meat directly affects the consumer market.

5. Conclusion

Sheep diets formulated with buffelgrass silage reduce carcass weight. This silage is not recommended, as it may lead to economic losses. Based on meat production and meat quality results, old man saltbush and Pornunça are better silages for finishing sheep.

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