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PAPER

Meat quality of lambs fed different saltbush hay (*Atriplex nummularia*) levels

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Abstract

Climate changes have increased soil and water salinity, compromising animal production especially in dry areas where scientists have become more interested in halophyte plants, like saltbush. The effects of saltbush hay levels (30, 40, 50 and 60%) were evaluated based on physical-chemical, nutritional and sensory parameters of Santa Inês lamb meat. Thirty-two 8-month-old castrated Santa Inês lambs, with initial weights of 22±1.97 kg were used; they were slaughtered after 60 days in the feedlot. The pH, colour, moisture, protein and cholesterol contents did not differ among treatments. Panelists observed a greater intensity of lamb smell and flavour (P=0.0035) in the meat of animals that received more concentrate in the diet. An increase in the inclusion of saltbush increased ash percentage (P=0.0232), total saturated (P=0.0035) and polyunsaturated (P=0.0287) fatty acids and reduced the lipids (P=0.0055) and the n-6:n-3 ratio (P=0.0058) of the meat. Therefore, saltbush hay can be used as a feeding resource in regions with problems of water and soil salinity because it does not impair the physical-chemical, nutritional and sensory quality of sheep meat.

Introduction

Soil salinization is an expanding process in several countries of the world, especially in arid and semi-arid regions, where evaporation is greater than precipitation. It is estimated that 2% of the Brazilian soils have saline, solodic or sodic properties, and around 60% of them are in the semi-arid region of northeastern Brazil, which corresponds to 91,000 km^2 (Ribeiro *et al*., 2003). Several authors have been considering salinity as the major soil degradation factor in many areas (as in the northeast of Brazil), and also an important agent of desertification (Cavalcanti *et al*., 1994; Leprun and Silva, 1995).

Climate changes that are occurring in the last decades are leading to a global warming and a reduction in rainfall, especially in arid and semi-arid regions, which could significantly increase soil and water salinities and expand the size of affected areas (Iannetta and Colonna, 2011). High concentrations of salt in the soil and/or in the water negatively affect plant and animal production. Therefore, the need of identifying forage species adapted to such environments emerges to enable animal production without compromising sustainability and the balance of such fragile ecosystems. Saltbush (*Atriplex nummularia* Lindl.) is a native shrub from Australia, and it has been used in many arid and semi-arid places as an important source in diets for sheep. It can provide feed supply in feedlots and assure a sustainable meat production. Because feedlots increase production costs, especially those related to feeding, the use of alternative feeds adapted to each region may reduce those costs and increase the competition and the income of the farmers, and also favor the sustainability of the animal production systems (Van Niekerk *et al*., 2009; El Shaer, 2010; Meneses *et al*., 2012).

The saltbush shrub is adapted to saline soils and it may be productive in the feeding of sheep in places where other species would not survive. The use of saltbush in the diets of sheep, goats and cattle was the objective of several studies (Francote *et al*., 2009; Ben Salem *et al*., 2010; El Shaer, 2010; Pearce *et al*., 2010); however, the studies which evaluate its use as the only source of forage associated with grains in the finishing phase of feedlot sheep and its effect on meat quality are scarce, especially regarding the profile of fatty acids, chemical and sensory meat characteristics.

In addition to the nutritional importance, the knowledge of factors affecting the sensory quality of sheep meat as well as its acceptance or rejection in the different consumer markets is relevant (Muela *et al*., 2010). Animal production systems, cooking habits and the cultural aspects of each country and/or region influence the acceptability of such meat by their consumers (Font I Furnols *et al*., 2006; Sañudo *et al*., 2007). Because of the large expanse of the Brazilian territory, systems of sheep production differ among regions, in accordance with their particular characteristics, such as climate, breed or crossbreed, handling and especially, to feed availability, whether quantitative or qualitative (Ferraz and Felício, 2010; Montossi *et al*., 2013). Those factors linked to the age and weight at slaughter, castration and finishing system (pasture or feedlot) directly affect the quality of the produced sheep meat (Guerrero *et al*., 2013). The objective of this study was to determine the physical-chemical, nutritional and sensorial qualities of the meat of sheep fed 30, 40, 50 and 60% of saltbush hay concentrate.

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Materials and methods

Local animals and experimental diets

The experiment was carried out at the Brazilian Agricultural Research Corporation (Embrapa Tropical Semi-Arid) in Pernambuco

(09º 23' 55'' S; 40º 30' 03'' W), Brazil. The qualitative analyses of sheep meat were conducted at the Technology Laboratory of Animal Products of the Faculty of Agrarian and Veterinarian Sciences - FCAV/Unesp, Jaboticabal, State of São Paulo (21º 15' 22'' S; 48º 15' 58'' O). Thirty-two castrated male Santa Inês lambs with initial weights of 22±1.97 kg and at 8 months of age were used. Animals were identified, treated for worms, vaccinated and randomly distributed to the various treatments, considering 20 days for adaptation to the experimental diets and to the facilities. Animals were allotted to individual pens.

Treatments consisted of diets containing 30, 40, 50 and 60% of saltbush hay added to the concentrate with different forage:concentrate ratios. The concentrates were composed of ground corn and soybean meal, and the diets were calculated to be isoprotein [12.0% of crude protein (CP)] and to contain the requirements preconized by the National Research Council (2007), aiming for a daily weight gain of 200 g/animal (Table 1). For hay confection, saltbush plants were cut and ground before being exposed to the sunlight, laid on a cement surface, revolved twice daily and packaged after three days of exposure when they were dry to the touch. Fine and medium thickness (approximately 1.0 cm) leaves, branches and stems were used for the confection of the hay.

Animals were fed at 9:00 h and 16:00 h with a daily control of the amount offered to the animals, considering 20% of leftovers. A 60-day feedlot period was adopted, and animals were weighed at the beginning (initial body weight) and at the end of the trial (final body weight).

Slaughter procedures

After 60 feedlot days, animals were weighed before and after a fasting of 18 hours. They were stunned with a 330V electrical discharge for 12 seconds, and the jugular veins and the carotid arteries were sectioned. Forty-five minutes after the beginning of slaughter, the pH of the meat (pH_{45min}) was measured in triplicate in the *Longissimus lumborum* muscle between the 12th and 13th ribs by using a pH meter (Testo® 205). After the measurements, the carcasses were weighed and transferred to a cold chamber at 4°C for 24 hours where they were hung by the gastrocnemius tendons on hangers fitted to keep them 17 cm apart. The cold carcasses were weighed, and the cold carcass yield and drip losses were obtained. The cross sections of the 13th rib for maximum width (A: maximum distance from the medial border to the lateral extremity of *Longissimus lumborum*) and depth (B: maximum distance perpendicular to the width) of the *Longissimus lumborum* were measured with a calliper, and ribeye area was calculated ((A/2)×(B/2)×π).

Some data on the performance of the animals during the experimental period are shown in Table 2. All experimental procedures were approved by the Commission on Ethics and Animal Welfare (CEBEA) of the Faculty of Agrarian and Veterinary Sciences (process no. 008403-08).

Chemical and physical analyses of the meat

At 24 h *post-mortem* at 4°C, *Longissimus lumborum* muscles were removed from the two half-carcass, weighed, vacuum packaged, stored at -20°C and shipped to Sao Paulo, where the evaluations of meat quality were performed. The left loins were used in the physical-chemical analyses and the right loins in the sensory analyses. The pH (pH_{24h}) was measured again in triplicate on the *Longissimus lumborum* between the 12th and 13th ribs. For the colour measurements, the muscle was air exposed for 30 minutes between the 12th and 13th ribs (loin) for proper myoglobin oxygenation. Instrumental meat colour expressed as L* (lightness), a* (redness), and b* (yellowness) according to CIElab system (Commission International de l'Eclairage, 1976) was measured with a Minolta CR-200 colour (Minolta Camera Co., Osaka, Japan) on samples after exposure to air for 1 h at 2°C (Boccard *et al*., 1981). The colorimeter was calibrated before analyzing the samples against white and black standards. Triplicate readings were made for each sample and average values were recorded. To determine the water-holding capacity (WHC) of the meat, 500±20 mg of the meat was placed on a filter paper between two acrylic plates, and a 10-kg weight was placed over those plates for 5 minutes. Then, the samples were weighed and the water-holding capacity was calculated by the following equation: WHC=final weight/initial weight x100, in accordance with Hamm

Table 1. Chemical composition and fatty acid content of the experimental diets.

	Level of saltbush hay, %			
	30	40	50	60
Ingredient, % of DM				
Saltbush hay	30	40	50	60
Corn meal	59.15	49.50	39.90	30.30
Soybean meal	9.60	9.60	9.60	9.60
Urea	1.25	0.90	0.50	0.12
Nutrient, g/kg DM				
Dry matter	892.1	891.6	891.5	890.5
Ash	71.9	86.7	101.5	116.3
Crude protein	125.7	124.6	123.5	122.3
Ether extract	37.0	32.9	28.9	24.8
Neutral detergent fibre	317.7	358.9	400.2	441.5
Acid detergent fibre	178.3	213.5	248.7	283.9
Total digestible nutrients	702.6	670.6	591.6	550.0
Na	18.8	24.9	31.0	37.1
Cl	22.8	30.2	37.8	45.2
P	6.2	6.0	5.8	5.7
Ca	3.4	4.1	4.7	5.4
Mg	2.2	2.4	2.7	2.9
K	11.5	12.2	12.8	13.4
Fatty acid, % total				
C14:0	0.44	0.57	0.70	0.83
C16:0	22.18	24.74	27.31	29.88
C18:0	2.99	3.19	3.40	3.61
C20:0	1.13	1.28	1.44	1.59
C16:1	0.36	0.44	0.51	0.58
C18:1n-7	1.71	2.04	2.38	2.72
C18:1n-9	26.04	24.09	22.15	20.22
C18:2n-6	36.43	33.51	30.60	27.70
C18:3n-3	4.13	5.06	5.99	6.92

DM, dry metter

(1960).

Cooking losses were calculated by the weight of samples before and after cooking in a pre-heated industrial oven at 170°C until the internal temperature of the sample reached 72°C, which was then removed from the oven and cooled at room temperature. Cooking losses were calculated by the equation: 100 – (weight of the baked samplex100/raw sample weight).

After this, Warner-Bratzler shear force was measured on *Longissimus lumborum* samples using a texture meter (Texture Analyser TA-XT2i; Stable Micro Systems Ltd., Godalming, UK), which measures the necessary pressure to cut the portion of the muscle. Six cylindrical meat cores 1.0 cm in diameter were removed from each sample parallel to longitudinal orientation of muscle fibres and sheared perpendicularly to the fibre. The results are expressed in kgf/cm^2.

Moisture, intramuscular fat, ash and CP were assessed according to AOAC procedures (AOAC, 1995), after 36h thawing at 4°C. The ether extract do a Soxhlet extraction preceded from a acidification step.

Cholesterol in the loin was determined in accordance with Bragagnolo and Rodriguez-Amaya (1992), after to lipid extraction using a 2:1 chloroform:methanol ratio. Absorbance readings were taken using a spectrophotometer at a wavelength of 490 nm. A calibration curve for the cholesterol was constructed using 0.01 g of cholesterol p.a. diluted in 50 mL of hexane from which aliquots of 40, 80, 120, 160 and 200 mg/mL were removed.

Sensory analyses

For the sensory analysis, the samples of *Longissimus lumborum* were thawed by 24h at 4°C, baked in a pre-heated oven at 170°C until the internal temperature of the meat reached 72°C, and it was continuously monitored with a MAUX thermocouple. Then, subcutaneous fat was removed and samples were obtained from a parallel cut parallel to the muscular fibres, in cubes (Lyon *et al*., 1992), and served to each panelist in individual booths. Before tasting a sample, panelists consumed bottled water and breadsticks. Within a sensory analysis laboratory (ISO 8589:1988; ISO, 1988), panelists received samples in individual booths under controlled environmental conditions and red light.

Eight sessions were performed in which panelists consumed four samples (one sample from each treatment), raffled and identified with 3-digit random numbers, totaling 32 samples (8 animals/treatment). Ten trained panelists from southeastern Brazil participated in the trial. The characteristics evaluated for sheep meat were lamb odour (odour intensity of cooked lamb), lamb flavour (flavour intensity of cooked lamb), salty flavour (taste of salt in the meat), juiciness (liquid expelled by the sample, during chewing), tenderness (facility of chewing with the molars) and whole acceptation (whole hedonic acceptation of the product by panellists). Salty flavour was evaluated to determine a possible effect from the high level of sodium in the saltbush hay, which could have been stored in the muscular tissue and resulted in a natural effect of a salty meat. However, no salt was added in any of the treatments during the sensory analysis. A quantitative and descriptive analysis was used with a non-structured 8-cm scale, where the extremes indicate the intensity of each evaluated characteristic, ranging from 1 (minimum grade) to 9 (maximum grade). Each panelist marked a vertical trace on this scale in the grade that best described the intensity of the feeling for each tasted sample, taking into account the extremes of each attribute described during the training. Data were obtained by measuring with a ruler the distance that the panelist marked over the line from the left extreme of the scale (Dutcosky, 1996). A free space for considering and writing observations was provided to allow the panelists to express their particular considerations about each tasted sample.

Fatty acid composition of the meat

To determine the fatty acid composition of the fresh meat, samples of the transversal section from the *Longissimus lumborum* muscle were collected and frozen for lipid extraction and methylation. The fatty material was extracted using a mixture of chloroform–methanol, as reported by Bligh and Dyer (1959), and the fatty acid methyl esters were obtained by the ISO 5509 method (ISO, 1978). Qualitative and quantitative measurements of fatty acid content were performed by gas chromatography using a chromatograph (Model GC-14B with a Communication Bus Module-CBM 102; Shimadzu, Kyoto, Japan) with a detector of flame ionization and fused with a silica capillary column (30 m x 0.25 mm, Omegawax 250), with a film thickness of 0.25 m (Supelco SP-24136). Helium was used as a carrier gas at a flow of 1 mL/min. A 1- L aliquot of the sample was injected into a *split* at a ratio of 1/100 at 250°C. The temperature of the oven was programmed to remain at 100°C for 2 min and then increase to 220°C at 4°C/min for 25 min, while the detector was at 280°C. The peak areas were determined by integrator-processor GC-300, and the identification and quantifica-

Table 2. Estimates for 30% of saltbush hay and slopes of linear regression of dietary saltbush hay level, productive performance and carcass traits of Santa Inês sheep.

Parameter	30% saltbush hay		Slope parameter			R^2	RMSE
	Estimate°	SE#	Slope	SE§	P^		
Initial weight, kg	22.11	0.62	0.001	0.03	0.969	0.1741	2.05
Final live weight, kg	36.17	1.36	-0.16	0.07	0.040	0.9950	4.52
Daily weight gain, g	196.69	15.69	-2.27	0.85	0.013	0.9683	52.10
Dry matter intake, kg/day	1.32	0.06	-0.005	0.003	0.093	0.7841	0.19
Feed conversion	6.89	0.74	0.10	0.04	0.016	0.9622	2.44
Cold carcass weight, kg	15.95	0.51	-0.11	0.03	0.0003	0.9913	1.71
Cold carcass yield, %	49.50	0.82	-0.12	0.05	0.017	0.9122	2.86
Drip losses, %	4.09	0.46	0.014	0.02	0.569	0.0152	1.51
Fat thickness, mm	1.84	0.02	-0.002	0.001	0.011	0.9120	0.06
Ribeye area, cm^2	11.86	0.42	-0.06	0.02	0.014	0.9999	1.39

RMSE, root mean square error. °Estimate for 30% of saltbush hay inclusion in the diet; #standard error of the intercept (*a*) estimate; §standard error of the slope (b) estimate; ^P value of complete model.

tion of the methyl esters of the fatty acids was achieved by a comparison between the retention times and the concentrations of methyl esters of standard fatty acids (Sigma Chemical Co., St. Louis, MO, USA).

The atherogenicity index (AI), used to estimate the quality of the lipidic fraction was calculated from the fatty acid composition of the meat in accordance with the equation proposed by Ulbricht and Southgate (1991), where AI=C12:0+(4xC14:0)/[monounsaturated fatty acid (MUFA)+polyunsaturated fatty acid (PUFA)].

Statistical analysis

A completely randomized design with four treatments and eight replicates was used. Data were analyzed considering the level of saltbush hay inclusion in the diet as a continuous variable using PROC GLM of SAS software suite (SAS, 2002). As the quadractic and cubic effect of saltbush hay incorporation in the diet were not significant, the models retained only the linear effect (first order linear regression models). In the tables, the estimate and standard error for the first level of saltbush inclusion (30%) is presented as well as the slope parameters of the linear regressions.

The PROC GLM in SPSS 14.0 (2005) was used for the meat sensorial analysis where the effects of the panelists were observed; and because there was no interaction between the panelists and the treatments, a mean was calculated for each attribute of each animal individually assessed by the panelist. This new spreadsheet with the means of the grades given by the panelists was used to in tests of comparisons of the means, considering each animal as a replicate.

Results and discussion

Chemical and physical analyses of the meat

An increase in the level of saltbush hay in the diet did not alter the pH and the colour of the sheep meat (Table 3).

The mean value of the final pH (5.46) shows that the biochemical transformations responsible for the conversion of muscle into meat occurred normally and that there was no accentuated stress before slaughter. In addition, the pH value indicates a good final quality of the meat, and it predicts that other parameters such as water holding capacity, colour and flavour are within the quality standards recommended for sheep meat. Furthermore, Al-Owaimer *et al.* (2008) did not find any difference in the final pH of Najdi sheep meat fed two *Atriplex* species or their combination with a mean value of 5.67.

Significant differences in lightness (39.47), redness (18.16), or yellowness (5.55) of the *Longissimus lumborum* muscle were not observed (Table 3), probably because the animals were from the same breed and sex, or because they were slaughtered at similar ages and an adequate final pH was observed. According to Warris (2003), sheep meat usually present values from 30.03 to 49.47 for L*; from 8.24 to 23.53 for a* and from 3.38 to 11.10 for b*; thus, the values obtained in this study are consistent with those described in the literature.

Osório *et al*. (2009) reported that diets containing a higher amount of forage may result in a darker meat; however, this information should be further assessed after the different feedings pass through intense transformations in the rumen, which could influence the colour of the meat. Pearce *et al*. (2005) observed more redness (greater a* value) and brightness (greater content of L*) at 4 or 5 days of maturation from sheep grazing on saltbush.

There was a significant effect only for shear force, and the meat got tougher as the level of forage increased (Table 3). The lower percentage of subcutaneous fat (Table 2) and of intramuscular fat (Table 4) in the meat of animals fed a higher level of saltbush may have contributed to a greater shear force. Furthermore, less fat deposition with a consequent greater deposition of muscle may have been responsible for the higher shear force, because the force required to cut muscle is greater than that required to cut adipose tissue.

The mean values for cooking weight loss (CWL) and water-holding capacity (WHC) were 37.69 and 62.78%, respectively (Table 3). There is a relationship between the WHC of the meat and betain, which is an osmorregulator and has been studied as a potential reducer of water loss in the muscle of humans (Craig, 2004). Due to the high level of betain in saltbush (30 g betain/kg dry basis; Storey *et al*., 1977), this amino acid may have influenced the maintenance of WHC in the *Longissimus lumborum* in all the studied levels of hay. These results are in contrast to those reported by some authors, who affirmed that with an increase in the level of concentrate in the diets, the WHC of the meat also increases (Puolanne and Halonen, 2010). Although no significant difference was observed, the WHC was 11% higher in the meat of animals fed diet with a higher amount of saltbush hay, and this could be due to the activity of betain.

The ash content increased and the intramuscular fat content decreased in the meat as

Table 3. Estimates for 30% of saltbush hay and slopes of linear regression of dietary saltbush hay level, pH, colour, cooking weight loss, water-holding capacity and shear force of the *Longissimus lumborum* of Santa Inês sheep.

Parameter	30% saltbush hay		Slope parameter			R^2	RMSE
	Estimate°	SE#	Slope	SE§	P^		
pH (45 min)	6.27	0.03	0.006	0.002	0.001	0.9195	0.10
Ultimate pH	5.45	0.03	0.0002	0.002	0.919	0.0122	0.11
Colour							
L*	39.36	0.73	0.013	0.04	0.752	0.0399	2.43
a*	18.25	0.39	-0.008	0.02	0.706	0.0032	1.29
b*	5.64	0.27	-0.003	0.015	0.814	0.0118	0.89
CWL, %	38.04	1.16	-0.039	0.063	0.535	0.2160	3.85
WHC, %	60.99	1.19	0.146	0.064	0.031	0.5245	3.95
SF, kgf/cm^2	2.58	0.25	0.031	0.013	0.029	0.8182	0.82

RMSE, root mean square error; L*, lightness; a*, redness; b*, yellowness; CWL, cooking weight loss; WHC, water-holding capacity; SF, shear force. °Estimate for 30% of saltbush hay inclusion in the diet; #standard error of the intercept (*a*) estimate; §standard error of the slope (*b*) estimate; ^P value of complete model.

the level of saltbush hay increased in the diet (Table 4). However, there was no effect on moisture (74.50%), protein (21.15%) and cholesterol in the meat (36.76 mg/100 g). Probabily, the slight increase of ash is a consequence of less fat.

The average content of protein (21.15%) indicates that the sheep meat fed saltbush hay and concentrate is nutritionally desirable, and it linearly reduced the amount of intramuscular fat and increased the ash when this forage was included in the diet. These results could be further studied and used as marketing tools in the systems of sheep meat production using saltbush as forage, showing an improvement in the nutritional quality of this meat due to a reduction in fat content. Some initiatives have already been implemented in some regions in Australia aiming at these objectives (Hocquette *et al*., 2010).

The different levels of forage and concentrate affected all fat storage depots, including subcutaneous (Table 2), visceral (Moreno, 2011) and intramuscular (Table 4). A higher proportion of the concentrate in the diet increased the percentage of the intramuscular fat, which was also observed by other authors (Luciano *et al*., 2013; Majdoub-Mathlouthi *et al*., 2013). However, other results regarding the effect of different forage: concentrate ratios on the chemical composition of the sheep meat are contradictory (Zeola *et al*., 2004; Lanza *et al*., 2011; Camilo *et al*., 2012; Joy *et al*., 2012).

Sensory analyses

High levels of saltbush hay reduced the intensity of the typical flavour of the sheep meat, and meat was considered softer in the treatments with a higher amount of forage (Table 5).

In Australia, sheep farmers along with the meat industry and the retailers state that the sheep meat from lambs fed saltbush has a higher sensory quality (Anon, 1996). Those empirical statements have not been proven yet by the few studies carried out on the sensory analyses of the meat from sheep receiving saltbush in the diet. Pearce *et al.* (2010) affirm that the improvement in the sensory aspects of this meat may be related to the antioxidant action of the vitamin E present in the saltbush, which would inhibit the development of rancidity odour and taste, especially in the aged meat, which is very common in Australia. The greatest ratings for flavour intensity of sheep meat were observed in this work with a lower proportion of saltbush in the diet; however, other studies have demonstrated that the opposite also occurs; the meat may present a greater flavour intensity in animals fed more forage in the diet or in the pasture (Resconi *et al*. 2009).

The greater flavour intensity may result from a greater amount of fat in the meat of animals fed more concentrate in the diet (Table 4). Lipids are the precursors of most volatile compounds that by the action of the heat contribute to the flavour, pallatablity and characteristic meat taste (Resconi *et al*., 2012). The main contributors in the formation of the flavour and odour in meat are the branched-chain fatty acids (isobutyric, isovaleric, 2-methyl-butyric, 4-methyl-octanoic and 4-methyl-nonanoic). These fatty acids originate from the rumen propionate as derivatives of hepatic gluconeogenesis. High levels of propionate in the rumen lead to the production of branched-chain fatty acids, and the production of propionate is higher when animals are fed high proportions of concentrate (Resconi *et al*., 2009; Luciano *et al*., 2013; Majdoub-Mathlouthi *et al*., 2013), which may have occurred in this experiment. The low energy content of saltbush may have also resulted in a lower formation of propionate and, consequently, a lower content of branched-chain fatty acids that would be involved in the formation of odour and flavour in the assessed meat.

It is known that consumers in Southeast Brazil, especially in São Paulo State, prefer sheep meat with a softer flavour from young lambs (from 4 to 6 months of age) with a low fat content, as opposed to most consumers in northeastern and southern Brazil, who prefer animals slaughtered later. The sensory panel of this study was made up only by panellists from the Southeast region of Brazil, which could explain the results obtained in the study, and this was also observed in other studies (Osório *et al.,* 2009). Nevertheless, the differences between the ratings for taste were not sufficient to reduce the whole acceptance of the meat in the different treatments. The preferences of the panelists are related to their culinary and cultural habitats and by their personal characteristics; moreover, the sensory characteristics are a very important tool to discern the acceptability of the offered meat to a potential consumer market.

Regarding the juiciness, consumers stated that a more juicy meat is a better meat, and this quality is mostly related to the content of intramuscular fat, water and protein (muscle). Therefore, a lamb may present a less juicy meat because it has not completely reached intramuscular fat deposition (Osório *et al.,* 2009), however, the amount of water in muscle of young animals can also promote greater sense of meat juiciness. Naturally, there is a large amount of water in muscle tissue, since fat and water are inversely proportional. In this study, even though the amount of intramuscular fat have reduced with the inclusion of saltbush hay, there was no difference to the meat juiciness, which may be associated with a higher relative amount of muscle and water, rather than the relative amount of fat. Pearce *et al*. (2011) affirm that even though the characteristics of the myowater in general must be expected to contribute to juiciness, there is only limited knowledge of how these characteristics and the temperature induced changes in these characteristics during cooking affect the sensory properties of meat.

Table 4. Estimates for 30% of saltbush hay and slopes of linear regression of dietary saltbush hay level, chemical composition and cholesterol concentration of the *Longissimus lumborum* of Santa Inês sheep.

Parameter	30% saltbush hay		Slope parameter			R^2	RMSE
	Estimate°	SE#	Slope	SE§	P^		
Moisture, %	74.08	0.28	0.03	0.015	0.058	0.3589	0.94
Protein, %	21.45	0.28	-0.016	0.015	0.292	0.6662	0.93
Fat, %	3.83	0.24	-0.05	0.01	0.0004	0.9525	0.81
Ash, %	0.03	1.99	0.155	0.11	0.161	0.9862	6.60
Cholesterol, mg/100 g of meat	37.32	3.18	0.010	0.17	0.952	0.6558	10.57

RMSE, root mean square error. °Estimate for 30% of saltbush hay inclusion in the diet; #standard error of the intercept (*a*) estimate; §standard error of the slope (*b*) estimate; ^P value of complete model.

Animals with more subcutaneous (Table 2) and intramuscular fat (Table 4) in this work also presented meat with a lower shear force (Table 3), although the panelists had not found those differences in the tenderness (Table 5). Hopkins and Nicholson (1999) studied the quality of lamb meat grazing saltbush and supplemented with hay or oat, or fed only hay (control). These researchers found that there was a difference only in the flavour intensity, while the meat of animals fed saltbush, regardless the type of supplement, presented more flavour intensity in relation to the animals fed only hay. However, Pearce *et al.* (2008) did not obtain feeding effects with the use of saltbush in any of the parameters assessed in the sensory analyses of the lamb meat, with average ratings of 4.8, 6.0, 6.2 and 6.3 for intensities of odour, tenderness, juiciness and whole acceptation, respectively, by using a 1–10 scale.

Fatty acid composition

The fatty acids found at a higher concentration in this study were the following: saturated palmitic acid (C16:0) and stearic acid (C18:0), and monounsaturated oleic acid (C18:1n-9) (Table 6).

Myristic (C14:0) and palmitic (C16:0) acids are considered as hypercholesterolemic; however, the stearic acid (C18:0), which represents from 10 to 20% of the fat produced by the ruminants do not show this property (FAO, 2010). The inclusion of saltbush hay in the diet has contributed to the reduction of myristic acid and it did not increase palmitic acid, which is an interesting result with regards to its benefits for human health.

Conjugated linoleic acid (CLA; isomer C18:2*c*9*t*11) was reduced as the level of saltbush hay increased in the diet, contradicting some authors who reported an increment in CLA when animals were fed higher proportions of forage or pastures (Nuernberg *et al*., 2008;

Table 5. Estimates for 30% of saltbush hay and slopes of linear regression of dietary saltbush hay level and of eating quality from meat of Santa Inês sheep.

Parameter	30% saltbush hay		Slope parameter			R^2	RMSE
	Estimate#	SE§	Slope	SE^	P$		
Lamb odour	5.71	0.28	-0.025	0.015	0.118	0.8216	0.83
Lamb flavour	5.48	0.30	-0.052	0.016	0.004	0.9899	0.87
Salty taste	1.94	0.08	0.005	0.004	0.274	0.7635	0.23
Juiciness	6.13	0.17	-0.001	0.009	0.315	0.7570	0.51
Tenderness	6.75	0.27	-0.02	0.014	0.230	0.6179	0.79
Overall liking	6.00	0.21	0.014	0.011	0.227	0.4271	0.63

RMSE, root mean square error. °Parameters are calculated based on different scales: lamb odour, lamb flavour and salty taste (1=not detected to 9=very intense), juiciness (1=very dry to 9=very juicy), tenderness (1=very tough to 9=very tender), overall liking (1=very bad to 9=very good); #estimate for 30% of saltbush hay inclusion in the diet; §standard error of the intercept (*a*) estimate; ^standard error of the slope (*b*) estimate; $P value of complete model.

Table 6. Estimates for 30% of saltbush hay and slopes of linear regression of dietary saltbush hay level and fatty acid composition of the *Longissimus lumborum* of Santa Inês sheep.

Parameter	30% saltbush hay		Slope parameter			R^2	RMSE
	Estimate°	SE#	Slope	SE§	P^		
SFA							
C10:0 capric	0.12	0.008	-0.0001	0.0004	0.728	0.1500	0.02
C12:0 lauric	0.08	0.006	-0.0001	0.0003	0.705	0.0681	0.02
C14:0 myristic	2.22	0.096	-0.011	0.005	0.038	0.9648	0.28
C16:0 palmitic	24.13	0.50	-0.044	0.027	0.111	0.5672	1.47
C17:0 margaric	1.12	0.07	-0.004	0.004	0.295	0.3551	0.22
C18:0 stearic	14.77	0.61	0.167	0.03	<0.0001	0.9949	1.78
C20:0 arachidic	0.08	0.004	0.0001	0.0002	<0.0001	0.6922	0.01
MUFA							
C14:1 myristoleic	0.08	0.001	-0.0008	0.0005	0.155	0.6459	0.03
C16:1 palmitoleic	2.01	0.08	-0.014	0.004	0.002	0.9703	0.23
C18:1n-9 oleic	47.04	0.73	-0.13	0.04	0.003	0.9269	2.13
C20:1n-9 gadoleic	0.10	0.005	-0.0003	0.0002	1.000	0.3556	0.01
PUFA							
C18:2n-6 linoleic	2.89	0.23	0.03	0.01	0.028	0.7517	0.67
C18:3n-3 α-linolenic	0.11	0.01	0.004	0.0008	<.0001	0.8223	0.04
C18:3n-6 γ-linolenic	0.10	0.006	0.001	0.0003	0.0008	0.7360	0.02
C20:2 eicosadienoic	0.26	0.05	0.005	0.003	0.074	0.6098	0.14
C20:4n-6 arachidonic	0.97	0.14	0.02	0.007	0.024	0.8527	0.40
CLA (C18:2c9t11)	0.49	0.04	-0.006	0.002	0.022	0.6751	0.12
Eicosapentaenoic acid	0.09	0.02	0.003	0.001	0.001	0.8091	0.07
Docosahexaenoic acid	0.01	0.01	0.001	0.0007	0.128	0.1022	0.04

RMSE, root mean square error; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids. °Estimate for 30% of saltbush hay inclusion in the diet; #standard error of the intercept (*a*) estimate; §standard error of the slope (*b*) estimate; ^P value of complete model.

Table 7. Estimates for 30% of saltbush hay and slopes of linear regression of dietary saltbush hay level, fatty acid sum and ratios, and atherogenicity index of the *Longissimus lumborum* of Santa Inês sheep.

Parameter	30% saltbush hay		Slope parameter			R^2	RMSE
	Estimate°	SE#	Slope	SE§	P^		
Total SFA	42.87	0.60	0.10	0.03	0.003	0.9715	1.77
Total MUFA	52.04	0.70	-0.16	0.04	0.0002	0.9834	2.04
Total PUFA	5.09	0.47	0.06	0.02	0.029	0.7491	1.37
Total UFA	57.13	0.60	-0.11	0.03	0.003	0.9685	1.77
UFA/SFA	1.33	0.03	-0.005	0.002	0.004	0.9426	0.09
MUFA/SFA	1.21	0.03	-0.006	0.001	0.0005	0.9057	0.08
PUFA/SFA	0.12	0.01	0.001	0.0006	0.103	0.1159	0.03
n6	4.13	0.38	0.05	0.02	0.021	0.8111	1.11
n3	0.21	0.05	0.009	0.002	0.002	0.7832	0.14
n-6:n-3	19.08	1.30	-0.21	0.07	0.006	0.7833	3.80
Atherogenicity index	0.23	0.01	-0.0006	0.0006	0.329	0.0432	0.03

RMSE, root mean square error; SFA, saturated fatty acids (calculated as C10:0+C12:0+C14:0+C15:0+C16:0+C17:0+C18:0+C20:0); MUFA, monounsaturated fatty acids (calculated as C14:1+C16:1+C17:1+C18:1n7+C18:1n9+C20:1n9); PUFA, polyunsaturated fatty acids (calculated as C18:2 n6+C18:2c9, t11+C18:3n3+C18:3n6+C20:2+C20:3n3+C20:3n6+C20:5 n3); UFA, unsaturated fatty acids (calculated as C14:1+C16:1+C17:1+C18:1n7+C18:1n9+C18:2 n6+C18:2 c9, t11+C18:3n3+C18:3n6+C20:1n9+C20:2+C20:3 n3+C20:3n6+C20:5 n3); n6, omega-6 fatty acids (calculated as C18:2n6+C18:3n6+C20:3n6); n3, omega-3 fatty acids (calculated as C18:3n3+C20:3n3+C20:5n3). °Estimate for 30% of saltbush hay inclusion in the diet; #standard error of the intercept (*a*) estimate; §standard error of the slope (*b*) estimate; ^P value of complete model.

Jacques *et al*., 2011; Ekiz *et al.*, 2013; Paim *et al*., 2014). Diets with greater forage contents would favor higher concentrations of CLA, especially in animals with a completely developed rumen, once the main precursor of CLA, vaccenic acid (Campo, 2009), is formed in this environment. This was not observed in this study. An explanation it the reason for CLA decreasing with increasing of saltbush hay, are low PUFA intake and lower intramuscular fat (Table 4). The amount of CLA deposited in the muscles depends mostly of the rumen outflow of C18:1 trans-11 formed by incomplete biohydrogenation of dietary C18 PUFA, and of the endogenous conversion of C18:1 trans-11 into C18:2 cis-9, trans-11 (CLA) in the tissues (Wood *et al*., 2008). There was an increase of linoleic acid (C18:2 n-6) with the inclusion of saltbush hay in the diet. The increase in linoleic with saltbush hay is directly related with lower intramuscular fat, and thus higher relative proportion of phospholipids.

Eicosapentaenoic (EPA, C20:5 n-3) and docosahexaenoic (DHA, C22:6 n-3) acids are PUFA derivatives of linolenic acid, moreover, they are more propitious to oxidation than oleic or linoleic acids (Elmore *et al*., 2000). Some studies reported a greater proportion of linolenic acid and its derivatives in the fat of grazing sheep than those fed concentrate diets, consistent with the results of this work (Woods and Fearon, 2009; Oliveira *et al*., 2013). Although the most studies usually find higher biohydrogenation in forage fed animals than in concentrate fed animals, another authors reports lower biohydrogenation in the rumen when the diet is composed of a higher level of forage (Antongiovanni *et al*., 2003; Abidi *et al.,* 2009; Buccioni *et al*., 2009).

The total amount of saturated (SFA) and unsaturated fatty acids (UFA) (*i.e.* MUFA and PUFA) and their main ratios are described in Table 7. The increase in the level of saltbush hay in the diet increased the total SFA and PUFA, corroborating the results found by Gallo *et al*. (2007) and Nuernberg *et al.* (2008), who observed an increase in the concentration of these fatty acids in the meat of sheep fed a greater amount of forage.

There was an decrease of the n-6:n-3 ratio with the inclusion of saltbush hay in the diet. In a FAO (2010) revision about fats and fatty acids in human nutrition, there is no a rational specific recommendation for n-6:n-3 ratio, if intakes of n6 and n3 fatty acids lie within the recommendation established. Therefore, the usefulness of the ratio in human nutrition is very questionable and controversial (Griffin, 2008; Harris, 2006; Salter, 2013).

The greater incorporation of n3 PUFA in animals fed more forage in the diet is also associated with a greater level of α-tocopherol (vitamin E) present in the forage, which accumulates in the adipose tissue once it is a liposoluble vitamin (Delgado-Pertíñez *et al.*, 2013; Hou *et al.*, 2013). This fact allows for less oxidation of n-3 PUFAs which are susceptible than n-6, favoring the preservation of the final product (Campo, 2009). Considering that saltbush is rich in vitamin E (139.0 mg of α-tocopherol/kg DM; Pearce *et al*., 2005), more studies are warranted to address this potential to improve the final quality of the meat and its preservation.

Conclusions

Saltbush provides a good quality sheep meat with a low fat content and a high ash content. The saltbush hay did not cause negative effects in the sensory quality of the meat, and its percentage in the diet altered the perception of lamb's flavour intensity by the panelists. The inclusion of saltbush reduced the n-6:n-3 ratio and increased the total PUFA of meat, which are important for human health. Diets composed by saltbush hay may be used in Santa Inês finishing lambs as long as they are associated with other diets, especially energy diets, aiming to potentiate the voluntary intake and to promote a greater weight gain of the animals.

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