

ORIGINAL ARTICLE

Which is the shear force that defines the lamb's sensory acceptance?

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Abstract

The lamb meat tenderness acceptance threshold has been little studied and has never been evaluated for the Brazilian population. So, this study aimed to find the maximum acceptable shear force for Brazilian lamb meat consumers. Three muscles were previously tested and chosen *Longissimus thoracis et lumborum* (LTL), *psaos major* and *semimembranosus* muscles received different treatments in the post-slaughter period (Hot deboning followed by cooling on ice, Standard carcass cooling and Ageing), aiming to create samples with varying levels of tenderness, which were evaluated by acceptance tests and descriptive analysis of tenderness by a trained team. Sarcomere length, myofibril fragmentation index, proximate composition, weight loss and pH analyses were performed to observe the biochemical phenomena in each treatment's meats. Variations caused in samples by treatments were more significant than differences inherent to the different muscles. Pearson and Multiple Factor correlation analyses indicated positive correlations between sarcomere length, myofibril fragmentation index and the scores assigned in sensory tests by 140 panelists and a trained team. Both groups noted that the differences between the meats in terms of tenderness and the sarcomere length also influenced the perception of juiciness observed by the groups. The maximum shear force indicated as acceptable for lamb meat was 44.1 N. The results obtained are important to guide the lamb meat producer for certain practices in the post-slaughter moments, avoiding actions that lead to sarcomere shortening and encouraging the production of aged meats.

Keywords: Lamb tenderness; Quantitative descriptive analysis; Sarcomere length; Myofibril fragmentation index; Acceptance; Post-slaughter practices.

Highlights

- Positive correlations were observed between sarcomere length, myofibril fragmentation index, and sensory scores related to tenderness and juiciness
- Maximum acceptable shear force for Brazilian lamb meat consumers was determined as 44.1 N
- Treatments in the post-slaughter period had a greater impact on tenderness than differences between muscles



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1 Introduction

Appearance, tenderness, juiciness and flavor are among the factors that most influence meat acceptance, with tenderness being considered decisive for the commercial value of the product (Chambers & Bowers, 1993). Tenderness can be defined by the easiness with which meat is chewed and is very variable (Osório et al., 1998). Recently, lamb meat tenderness acceptance thresholds have been studied, correlating sensory methods to intramuscular fat concentration (Hopkins et al., 2013; Pannier et al., 2014; Lambe et al., 2017; Realini et al., 2021) and shear force (Bickerstaffe et al., 2001; Hopkins et al., 2006).

Shear force measurement is the primary method used as an objective measure to quantify red meat tenderness (Holman & Hopkins, 2021) and is commonly performed by the Warner-Bratzler shear force (WBSF) method (Holman et al., 2016). However, no study has described the minimum lamb meat tenderness range acceptable for consumers in Brazil.

In the country, lamb meat consumption is around 0.6 kg/inhabitant/year, but with a growth trend (Empresa Brasileira de Pesquisa Agropecuária, 2019). Meat quality consumption and perception depend on sociodemographic issues, and the population of the state of São Paulo is one of the most interested in the consumption of lamb meat in the country, as well as in places where consumption is more traditional, like South and Northeast regions (Battagin et al., 2021). The relative importance of each of the meat properties that influence acceptance varies for different populations from different places (Miller, 2020) and in Brazil, there is lack of studies on the preference of lamb meat consumers in relation to tenderness. Thus, it is important to search for information on tenderness thresholds for the species.

Intramuscular fat concentration affects tenderness (Hopkins et al., 2013), which can be affected by other pre-slaughter factors such as race, connective tissue content, age, sex and slaughter weight, and post-slaughter conditions, with *postmortem* glycolysis being the most significant (Lawrie, 1985). After slaughter, biochemical and physicochemical changes in the skeletal muscle determine the establishment of *rigor mortis* and the stage of ageing. Tenderness is inversely related to the rate of *postmortem* pH reduction and directly to the time until the onset of *rigor mortis* (Veiseth et al., 2004; Lawrie, 1985) and temperature directly influences the rate of pH reduction at this time (Bendall, 1973). Soon after slaughter, the muscle is extensive and elastic and there are few connections between contractile proteins actin and myosin, but when all the muscle glycogen is used, actin and myosin bridges are formed, causing less extensibility and elasticity in the muscle and this process extends to the end of *rigor mortis* period (Lawrie, 1985).

When the muscle is submitted to very low temperatures (less than 10 °C) in the first 10 hours after slaughter, when *rigor mortis* has not yet been established, there is an acceleration of muscle metabolism and muscle tissue contraction, with shortening of fibers, an event called cold shortening, which reduces meat tenderness (Olsson et al., 1994; Osório et al., 2008).

On the other hand, to increase tenderness, the ageing process stands out, with the effect of calcium-dependent enzymes on meat. Calpain is responsible for part of *postmortem* proteolysis and induces a progressive increase in meat tenderness (Koochmaraie et al., 1989) and calpastatin is a calpain-specific proteinase inhibitor (Cong et al., 1998). Thus, with the release of Ca^{2+} ions from the sarcoplasmic reticulum in the *postmortem* period, there is greater stimulus of calpains and consequent increased meat tenderness during the ageing process.

Thus, handling the meat after slaughter can cause changes in tenderness, causing the production of more or less tender meats. Therefore, meat with different treatments were produced in this research: Hot deboning followed by cooling on ice, Standard carcass cooling and ageing. This study aimed to evaluate these three different lamb meat treatments in the post-slaughter period and present them to the consumer to find the maximum acceptable lamb meat shear force, that is, the sensory acceptance threshold in relation to tenderness.

2 Material and methods

2.1 Sample preparation

Preliminary tests were carried out with 33 animals slaughtered according to standards (Brasil, 2000) and good manufacturing practices, and subsequently, 48 male lambs (Santa Inês x Dorper breeds), confined at the Fernando Costa Campus, USP, Pirassununga, São Paulo, were used for the study. Animals had an initial age of 80 ± 10 days, an initial body weight of 30 ± 5 kg, and were kept in confinement for a period of 50 days, with shade and water *ad libitum*. The slaughter weight was 47 ± 5 kg, with an average daily weight gain of 0.340 kg. The lambs, from birth to weaning, had access to milk and concentrate from the creep feeding system and during confinement nutrition was provided by a total diet. Feeding was standardized with 20% corn silage and 80% concentrate with ground corn (70%), soybean meal (25%) and minerals (5%). To generate different tenderness degrees (different shear forces measured by the WBSF method), loins (*Longissimus thoracis et lumborum* - LTL), tenderloins (*Psoas major*) and topsides (*Semimembranosus*) of these animals were used, submitting them to three different treatment strategies after slaughter:

- **Hot deboning followed by cooling on ice:** to obtain fewer tender samples, a procedure was carried out to shorten the sarcomere, in which muscles were removed from the carcass soon after slaughter, packaged, identified and transferred to a cooler with water and ice at 0 °C, where they remained for 2 hours before being frozen;
- **Standard carcass cooling:** to obtain intermediate tenderness samples, carcasses were deboned and kept in a cold chamber at 3.0 ± 1.0 °C for 24 hours after slaughter;
- **Ageing:** cuts were aged at 4 °C for a period of 14 days to obtain tenderer samples. The 14-day period was chosen for presenting a significant difference from the other treatments, which did not occur with only 7 days of ageing in the cuts of animals used in preliminary tests.

At the time of deboning, covering fat and collagenous tissues were removed and after the production of meat with the different treatments, all cuts were vacuum packed, frozen and stored at -18 °C until the time of physicochemical and sensory analyses. The right and left sides of the animals were packaged and frozen separately; the left side was designated for physicochemical analyses and the right side for sensory ones.

Treatments selected to be submitted to physicochemical and sensory analyses were chosen based on the shear force measured by the SFWB method, as they have significant differences from each other and fall into one of the ranges sought:

- Range of 20 N: lamb meat samples with SF value below 23 N;
- Range of 30 N: lamb meat samples with SF value between 26 and 33 N;
- Range of 40 N: lamb meat samples with SF value between 36 and 43 N;
- Range of 50 N: lamb meat samples with SF value between 46 and 53 N;
- Range of 60 N: lamb meat samples with SF value above 56 N.

2.2 Physicochemical analysis

All physicochemical analyses took place after thawing samples for 24 hours at 4 °C. Initially, the pH was measured (pHmeter Hanna HI 99163) in triplicate, followed by the calculation of weight loss due to cooking. For this, samples were weighed and baked in an electric oven (Philco model PFE48P) at a temperature of 180 °C until reaching an internal temperature of 72 °C at the geometric center. Meats were removed from the oven and left at room temperature until reaching 24 °C, when they were weighed again.

Soon after, to measure the shear force, cooked samples were cut into 10 parallelepipeds parallel to muscle fibers (10 replicates), avoiding nerves and collagenous tissues, with a cross-sectional area of 1 cm², and analyzed using the TA.XT Plus texture meter (Stable Micro Systems, Surrey, England), coupled to a probe

in the shape of a stainless steel blade with a cutting angle of 60°, the thickness of 1.01 mm, length of 64.94 mm and width of 44.90 mm, moving at speed of 250 mm/min in the downward direction until complete sample rupture in the direction perpendicular to fibers. The shear force was determined by the maximum force (N) of the curve generated by the software.

To calculate the proximate composition, the official AOAC methodology (Association of Official Analytical Chemists, 2007) was used to determine moisture (950.46), fixed mineral residue (920.153) and proteins (928.08). The lipid content was determined by the method of Bligh & Dyer (1959). All analyzes were performed in triplicate.

2.3 Sarcomere length

The analysis of the sarcomere length, by laser diffraction, was performed according to Cross et al. (1981) and Koolmees et al. (1986). The blade with fibers was placed under the laser and 6 sarcomere lengths of each fiber were recorded.

2.4 Myofibril fragmentation index

The myofibril fragmentation index (MFI) was determined according to Culler et al. (1978) with modifications: protein concentration was determined by the biuret method (Gornall et al., 1949). An aliquot of the myofibril suspension was diluted with the extraction solution to obtain a protein concentration of 0.5 ± 0.05 mg/mL. The diluted myofibril suspension was shaken and placed in a cuvette to read the optical density at 540 nm in a spectrophotometer (Biospectro SP-22). The myofibril fragmentation index was obtained according to Culler et al. (1978).

2.5 Sensory analysis

The project was approved by the Research Ethics Committee at FZEA/USP (CAAE 90291818.6.0000.5422) and was carried out with two sensory analysis methods: Descriptive Analysis of the tenderness, with a trained panel (Stone & Sidel, 1993), and acceptance test with lamb meat consumers (Meilgaard et al., 1991). The method of sample preparation for sensory evaluation was identical to that described for the calculation of weight loss due to cooking and analysis of shear force. In the cases of sensory analyses, the temperature of the meat for all the tests was 60 °C (American Society for Testing and Materials, 2010).

2.5.1 Descriptive analysis of tenderness

The only requirement for the pre-selection of panelists to be part of the team of Descriptive analysis of tenderness was to be a lamb meat consumer. The sensory test applied to individuals of this initial recruitment was the paired comparison test in an individual booth with a red light. For this, samples from preliminary tests carried out to evaluate the possible treatments that would be applied in the study were used: tenderloins with standard treatment and loins with standard boning, with shear forces of 28.0 ± 7.5 and 38.2 ± 11.7 N, respectively. Two samples were simultaneously presented, one from each treatment, randomly coded with three-digit numbers, asking the panelists to distinguish the softest sample. Four replicates were applied for each panelist in individual booths, inverting the order of presentation of samples with AB and BA permutations. The candidate with a performance higher than 67% was selected for the training stage due to the good discriminatory ability for the attribute (Stone & Sidel, 1993).

The selected panelists underwent training with the Network Method (Moskowitz, 1983), in which samples with 3 different tenderness degrees were served in pairs and the panelist, in an individual booth under red light, was led to describe the similarities and differences between them. First, the sample considered less tender (65.9 ± 14.5 N) was served together with that of intermediate tenderness (37.7 ± 13.5 N); then, samples with intermediate tenderness and the highest tenderness (22.2 ± 10.2 N) were presented together and, finally, samples with the lowest and highest tenderness. These samples were, respectively, loins exposed to ice, Loins

with standard carcass cooling and Aged loins. Then, two-group sessions were conducted by the team leader to familiarize panelists with the descriptive terms individually raised in the previous step, where the descriptive terminology for the attribute of interest (tenderness) was defined and the use of the 9-cm unstructured scale for later use was discussed (Stone & Sidel, 1993).

For the final selection of members of the trained team, in an individual booth with a red light, three lamb meat samples with different tenderness degrees were evaluated by pre-selected panelists, according to standard procedures of Stone & Sidel (1993). The three samples were presented in a monadic and random way, coded with three-digit number in three sessions. The tenderness intensity was evaluated in each sample by an unstructured linear 9-cm scale, with intensity terms anchored at its extremes, with minimum values on the left and maximum values on the right. The results of each panelist were statistically treated in the SAS program (Statistical Analysis System, SAS Institute, Inc., Cary, NC, USA) by means of a two-way analysis of variance (ANOVA) with two sources of variation (sample and replicate). The selection criteria were the ability to discriminate samples ($p < 0.50$ for the sample factor), good repeatability ($p < 0.50$ for the repetition factor) and consensus with the rest of the team.

Finally, for the analysis of samples with different tenderness levels (the same available by the physicochemical analyses), the same unstructured linear 9-cm scale was used and, in three sessions, the final trained team evaluated the tenderness of samples in individual booth with red light.

2.5.2 Acceptance

Acceptance analysis was performed by 140 panelists, with convenience sampling, in the city of Pirassununga, SP, Brazil. The only requirement for recruitment was being a lamb meat consumer. Samples were produced under the same conditions as the physicochemical and Descriptive analyses and served at 60 °C. Loins exposed to ice (range of 60 N), Topsides with standard carcass cooling (50 N), Loins with standard carcass cooling (30 N), and Aged loins (20 N) were used. Panelists evaluated samples for appearance, juiciness and tenderness in a monadic and randomized way. Samples were served in disposable cups coded with 3 random digits and panelists consumed water and cream crackers between samples. For evaluation, a 9-point hedonic scale was used (1 = disliked it very much; 2 = disliked it much; 3 = disliked it moderately; 4 = disliked it slightly; 5 = neither liked it nor disliked it; 6 = liked it slightly; 7 = liked it moderately; 8 = liked it much; 9 = liked it very much) (Meilgaard et al., 1991).

2.6 Statistical analysis

Analyses of variance were performed to compare the results of all physicochemical and sensory analyses of the different treatments. Interactions between results of the different physicochemical and sensory analyses were evaluated by Pearson's Correlation Analysis and Multiple Factor Analysis (MFA), using the XLSTAT Sensory software (Addinsoft).

2.7 Calculation of the maximum lamb meat shear force acceptable by the consumer

Point 7 on the 9-point hedonic scale, described as "liked it moderately", was considered the minimum value for acceptance (Teixeira et al., 1987; Dutcosky, 2007). The shear force value related to this score was sought by fitting a straight-line equation with shear force values and acceptance test scores.

3 Results and discussion

3.1 Physicochemical and biochemical analyses

When applying the different treatments to the three muscles studied, it was not possible to produce meat with a tenderness level close to 30 N. Furthermore, in preliminary tests, different treatments for different muscles generated samples that would fit within the same range. For example, tenderloins (*Psoas maior*)

with standard carcass cooling and aged tenderloins fit in the same tenderness range as aged loins (20 N). As the loins are larger and there was less variation in shear force between repetitions, it was decided to use only the loins for this range. Treatments selected to evaluate the maximum shear force acceptable by the consumer (Table 1) involved only loins (LTL) and topsides (*Semimembranosus*), as the other possibilities tested were not successful in generating samples with different tenderness levels.

Table 1. Selected treatments for sensory assessment.

Samples n=12	Treatments	Tenderness range	WBSF (N)
LCS	Loins exposed to ice	60 N	65.9 ± 14.5 ^a
CS	Topsides with standard carcass cooling	50 N	47.9 ± 11.5 ^b
LS	Loins with standard carcass cooling	40 N	37.7 ± 13.5 ^{b,c}
LM	Aged loins	20 N	22.2 ± 10.2 ^c

LCS: Loins exposed to ice; CS: Topsides with standard carcass cooling; LS: Loins with standard carcass cooling; LM: Aged loins. ^{a,b,c} Means with different superscripts in the same column indicate significant differences ($p < 0.05$; Tukey's test).

The pH values (Table 2) were not significantly different from each other and presented variation range similar to that observed by other authors, from 5.41 to 5.69 for LTL of lambs after *rigor mortis* establishment (Knight et al., 2019; Oliveira et al., 2019, 2020; Rant et al., 2019), even after ageing.

Table 2. pH, weight loss due to cooking, sarcomere length and myofibril fragmentation index of samples.

Samples n=12	pH	Weight loss due to cooking (%)	Sarcomere length (μm)	Myofibril fragmentation index
LCS	5.47 ± 0.11	24.01 ± 4.98 ^a	1.16 ± 0.05 ^a	30.50 ± 4.70 ^a
CS	5.53 ± 0.06	32.22 ± 3.16 ^b	1.30 ± 0.08 ^b	36.15 ± 1.36 ^b
LS	5.52 ± 0.08	21.20 ± 3.82 ^a	1.35 ± 0.08 ^b	39.55 ± 2.18 ^b
LM	5.44 ± 0.14	25.72 ± 4.16 ^a	1.34 ± 0.06 ^b	64.67 ± 4.95 ^c

LCS: Loins exposed to ice; CS: Topsides with standard carcass cooling; LS: Loins with standard carcass cooling; LM: Aged loins. ^{a,b,c} Means with different superscripts in the same column indicate significant differences ($p < 0.05$; Tukey's test).

Weight loss due to cooking did not differ significantly between different loin samples ($p \leq 0.05$), as other results obtained in studies with the Santa Inês breed, from 20% to 25% (Fernandes et al., 2010; Oliveira et al., 2019). However, these results are lower than those presented by Bressan et al. (2001), around 29% for Santa Inês and Bergamácia *Longissimus dorsi* and by Oliveira et al. (2020), close to 40% for Santa Inês. This may be related to differences in genotype, age and slaughter weight of animals, pre- and post-slaughter management, type of equipment used in the analysis, temperature and cooking time. The value calculated for topside samples; however, showed a significant difference in relation to loins and the weight loss due to cooking was greater for this muscle.

As for the sarcomere length measurement, the only treatment with a measurement significantly smaller than the others was LCS. The same was observed for *Biceps femoris* (Fausto et al., 2017) and *Longissimus* (Geesink et al., 2000) muscles from lamb. The exposure of meat to lower temperatures after hot deboning promoted the phenomenon called sarcomere shortening (Locker & Hagyard, 1963; Olsson et al., 1994) and consequent meat hardening, that is, greater shear force. As expected, for the matured treatment (LM) there was no significant difference in sarcomere length when compared to standard carcass cooling treatments, as maturation promotes the degradation of structural proteins (desmin, titin and nebulin), but the contractile proteins actin and myosin are not affected (Koochmaraie, 1994).

The MFI results also occurred as expected, as the degree of degradation of myofibril proteins increases as a function of ageing (Veiseth et al., 2004). Treatment with ageing presented higher MFI values than the standard treatment for both muscles and these, in turn, had higher mean than treatment with sarcomere shortening. Positive correlations were found between sarcomere length and myofibril fragmentation index, which agrees with Fausto et al. (2017).

The proximate composition (Table 3) of raw samples was very similar, even comparing topsides and loins submitted to the same treatment. This similarity indicates that there is no impact of the *postmortem* process on composition, as described in the literature (Bonagurio et al., 2004; Oliveira et al., 2019, 2020). The lipid content is very low due to the removal of all fat covering when boned, leaving mostly intramuscular fat.

Table 3. Proximate composition of samples.

Samples n=12	Humidity	Proteins	Lipids	Ashes
LCS	75.24 ± 0.88 ^a	23.71 ± 0.30	0.56 ± 0.11	0.28 ± 0.14
CS	74.38 ± 0.74 ^{a,b}	23.62 ± 1.47	0.50 ± 0.06	0.35 ± 0.00
LS	73.68 ± 0.17 ^b	24.64 ± 0.27	0.42 ± 0.05	0.27 ± 0.06
LM	73.37 ± 0.28 ^b	23.94 ± 2.22	0.51 ± 0.10	0.43 ± 0.04

LCS: Loins exposed to ice; CS: Topsides with standard carcass cooling; LS: Loins with standard carcass cooling; LM: Aged loins. ^{a,b,c}Means with different superscripts in the same column indicate significant difference ($p < 0.05$; Tukey's test).

3.2 Sensory analysis

The final team selected for the Descriptive Analysis of tenderness consisted of eight panelists aged 19-35 years, five females and three males. The team defined tenderness as “easiness to chew, related to characteristics of chewability, fibrousness and shear force” and scores assigned to samples (Table 4) indicated that the different treatments caused significant differences.

Table 4. Descriptive Analysis of tenderness results.

Treatments	Tenderness ¹
LCS	0.60 ^a
CS	5.31 ^b
LS	5.60 ^b
LM	7.13 ^c

LCS: Loins exposed to ice; CS: Topsides with standard carcass cooling; LS: Loins with standard carcass cooling; LM: Aged loins. ¹ 19-cm unstructured linear scale, ranging from “slightly tender” to “very tender”. ^{a,b,c}Means with different superscripts in the same column indicate significant differences ($p < 0.05$; Tukey's test).

LCS sample had a significantly lower score than the others and LM had a higher score, showing that the sarcomere shortening by cold, with consequent sample hardening, was as perceivable as the consequences of ageing. Among the different muscles that underwent the same treatment, no significant difference was identified by the team. Thus, the Descriptive Analysis of tenderness results corroborate those of physicochemical analyses.

Regarding other studies on lamb meat tenderness evaluated by the quantitative descriptive analysis method in Brazil, Venturini et al. (2020) reported a score of 6.98, using a 9-cm scale for meat from Corriedale lambs with the shear force of 23.7 N, which values are comparable to the score of 7.13, assigned by the team to aged loins with 22.2 N. Bonacina et al. (2011) reported scores between 4.98 and 5.38 (varying with sex and finishing system) for *Longissimus dorsi* from 70-day-old Texel x Corriedale lambs slaughtered and kept until analysis in the same way as the standard treatment given to CS and LS samples, which had scores of 5.31 and 5.60, respectively.

In Norway, for LTL from Norwegian White Sheep and Norwegian Spel lambs, using a 9-point scale, the trained team in the study by Bhatti et al. (2020) reported scores of 5.22 and 5.39, respectively. In Uruguay, male Corriedale lambs aged 9-10 months, evaluated using the 10-cm scale, received scores between 5.90 and 6.32, varying with different diets (Resconi et al., 2009). In general, it can be observed that, for lambs of different breeds slaughtered using recognized animal welfare and deboning procedures 24 hours after slaughter, even with variations related to diet and sex, the scores attributed by the trained team vary around 5 and 6 for a 9-cm scale. Thus, the results obtained for Dorper x Santa Inês lambs indicate convergence with those of other lamb breeds.

In the case of the acceptance analysis (Table 5), the results were similar. The test carried out in the state of São Paulo with 140 panelists, had 115 male and 25 female consumers aged 18-57 years. For appearance and juiciness, only the LCS sample had lower acceptance. For the tenderness attribute, not only the least tender treatment (LCS) had significantly different score, but also the one with the highest tenderness (LM), with greater acceptance.

Table 5. Results of the acceptance test with 140 panelists in the state of São Paulo.

Treatments	Appearance	Juiciness	Tenderness
LCS	6.5 ^a	6.3 ^a	5.8 ^a
CS	7.3 ^b	7.1 ^b	7.2 ^b
LS	7.3 ^b	7.2 ^b	7.2 ^b
LM	7.4 ^b	7.4 ^b	8.0 ^c

LCS: Loins exposed to ice; CS: Topsides with standard carcass cooling; LS: Loins with standard carcass cooling; LM: Aged loins. ^{a,b,c}Means with different superscripts in the same column indicate significant differences ($p < 0.05$; Tukey's test).

As well as the trained team, consumers were able to perceive variations generated in samples according to post-slaughter treatments received, reinforcing the need for cooling carcasses 24 hours before deboning and suggesting that ageing is a differential for good acceptance by consumers. Comparing the tenderness scores by the acceptance test with those of other studies with Brazilian consumers scores around 7.0 were observed by Fernandes et al. (2014) and Rodrigues et al. (2018) for loins with shear forces in the ranges of 40 and 30 N, respectively. For loins in the range from 20 to 30 N, Fregonesi et al. (2014) reported scores close to 7.4. Thus, the values observed are similar to those previously reported. In the Pearson correlation analysis, as there were only four treatments, only very high correlations were significant and, the analysis indicated very high correlations between shear force and tenderness assessment by the trained panel ($r = -0.941$, $p = 0.059$) and between shear force and acceptance test results ($r = -0.967$, $p = 0.033$), so the lower the shear force, the higher the tenderness score.

In addition, sarcomere length influenced the juiciness perception observed by consumers ($r = 0.974$, $p = 0.026$) and tenderness by the trained team ($r = 0.964$, $p = 0.036$), so that people attributed higher scores to these attributes in samples with greater sarcomere length.

All factors evaluated by consumers are correlated with each other: appearance acceptance is associated with tenderness ($r = 0.956$, $p = 0.044$) and juiciness acceptance ($r = 0.993$, $p = 0.007$), and the greater the tenderness acceptance, the greater the juiciness acceptance ($r = 0.972$, $p = 0.028$). A positive correlation was also observed between tenderness acceptance attributed by consumers and that observed by the trained team ($r = 0.989$, $p = 0.011$). It is noteworthy that, as the trained team performed the test in individual booth under red light, it was not influenced by sample appearance, and even so, correlation was observed between results of the two tenderness evaluation methods.

Similar conclusions can be made when analyzing the results found by the Multi-Factor Analysis (Figure 1), in which the F1 and F2 axes represent 87.8% of the total variability between treatments. The inverse behavior of the shear force compared to the tenderness perceived by panelists and by the Descriptive Analysis of the

tenderness team is evident. Likewise, the last two factors are similar to the sarcomere length measure and perception of the other attributes evaluated by consumers, which are positively correlated.

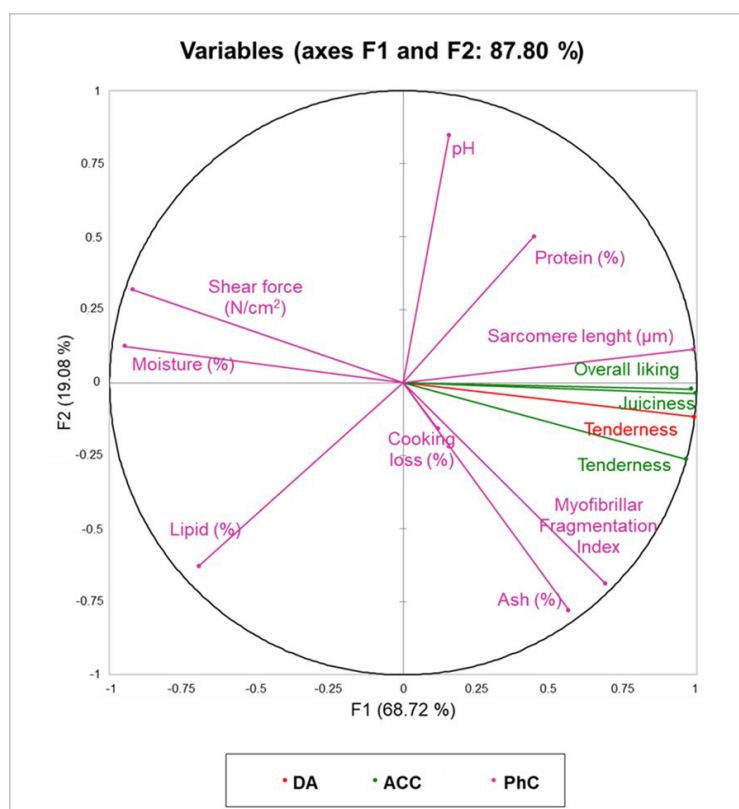


Figure 1. Multi-Factor Analysis Graph (DA: Descriptive Analysis results; Acceptance: Acceptance test results; PhC: Physicochemical analyses results).

As for the global analysis of samples (Figure 2), it was observed that variations caused in samples by treatments were more significant than differences inherent to the different muscles, that is, there is greater homogeneity between the characteristics of loins and topsides with the same treatment than between different treatments for the same muscle (loin).

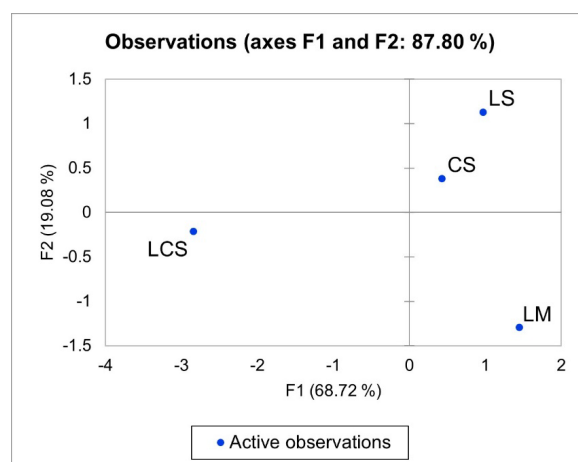


Figure 2. Graph of the global analysis of samples (LCS: Loins exposed to ice; CS: Topsides with standard carcass cooling; LS: Loins with standard carcass cooling; LM: Matured loins).

These observations are following data previously found by the analysis of variance in relation to each parameter under study, in which, for all biochemical and sensory analyses, there were no significant differences between loins and topsides with standard treatment and greater variation occurred between loins with sarcomere shortening and other treatments. The same can be found for results obtained by the two sensory analysis methods.

3.3 Determination of the tenderness acceptance threshold

Finally, to find the tenderness acceptance threshold, it was necessary to indicate a maximum shear force value related to minimum lamb meat acceptance in relation to the tenderness parameter. As the Pearson correlation analysis performed indicated that there was a linear correlation between tenderness acceptance (M) and shear force (SF), the relationship of these parameters can be expressed by the linear equation $M = -0.0463 \cdot SF + 9.0415$, where $R^2 = 0.9346$ (Figure 3).

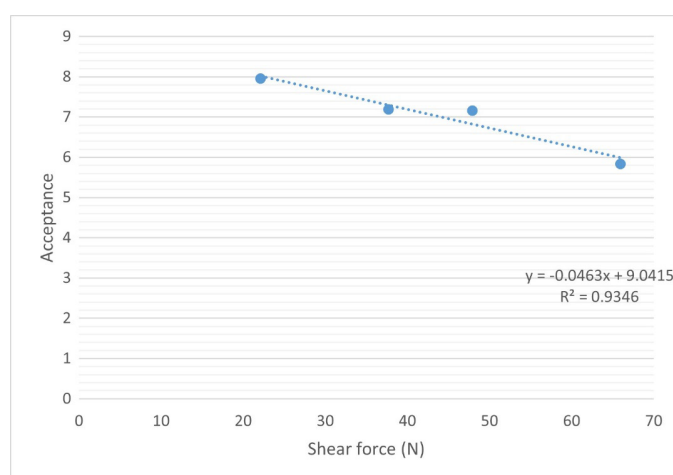


Figure 3. Linear interaction between shear force and the tenderness score attributed by consumers.

Considering the minimum value of 7 on the 9-point hedonic scale as the sensory acceptance threshold, for $M=7$, the shear force found is 44.1 N. In other words, this shear force value is the maximum acceptable by panelists and it would be interesting for lamb meat producers to maintain animal and meat handling methods to ensure that their products have, at most, this shear force.

In Figure 3, it is clear that the point referring to topsides with standard treatment is farther from the straight line and, even with shear force a little higher than that considered acceptable, it received a score greater than 7 by panelists. Thus, it could be concluded that to reach the desired minimum tenderness value, lambs must be deboned 24 hours after slaughter, with no need for ageing, but this procedure will make the meat even tenderer, which will be better accepted.

Deboning before the recommended time or packaging carcasses at a temperature lower than that recommended may generate changes that lead to sarcomere shortening and consequent discomfort to consumers. Although rapid cooling is related to a reduction in the proliferation of microorganisms, it is also associated with the phenomenon called cold shortening, in which exposure to low temperatures promotes muscle contraction when *rigor mortis* has not yet been established (Marsh, 1977). In the *postmortem* period, muscles lose their ability to contract due to cold over time, and sarcomere shortening is avoided when bridges are formed between actin and myosin filaments before muscle temperature reaches 10 °C or less (Marsh, 1977; Olsson et al., 1994; Osório et al., 2008). Thus, it is recommended to wait for *rigor mortis* to be established and only then expose carcasses to lower temperatures, which can be performed in such a way that the muscle temperature is not lower than 10 °C in the first 10 hours after bleeding (which is also related to pH=6.0 and 50% of the initial amount of ATP) (Marsh, 1977).

It is also necessary to reaffirm that, in this study, procedures related to animal welfare during the transport of lambs to the slaughterhouse were taken into account, as well as good practices at the time of slaughter, and disregarding these factors can also cause undesirable changes in meat tenderness.

The result found as the maximum shear force acceptable by consumers is close to that observed in other studies, of 50.0 N for New Zealand consumers (Bickerstaffe et al., 2001) and 49.0 N for Australian consumers (Hopkins et al., 2006), and for the latter group, the maximum shear force of 27.0 N is desirable, a value that approximates the tenderness range of aged loin, the sample best evaluated by consumers who participated in this study. These variations are common when studying populations from different countries and even between regions within the same country, as is the case of Brazil.

Regarding Brazilian lamb meat consumers, it is known that they give varying degrees of importance to the various meat quality attributes according to their income, education level and age, but for most, color, appearance of freshness, price and ease of preparation are decisive factors at the time of purchase (Battagin et al., 2021). Tenderness is a factor verified only after purchase, only when meat is ready for consumption, but it could be linked to factors such as marbling and ageing at the time of choice by the consumer at the place of purchase. However, the species is not among the most consumed in the country, being associated with consumption on commemorative dates and high prices (Andrade et al., 2016) and, possibly, consumers have difficulty even choosing the product because they do not have the habit of consuming it.

Thus, it was observed that, for the expansion of the lamb meat market in Brazil, in addition to the care of meat producers to produce meat of adequate quality and tenderness, commercial establishments need to highlight the meat characteristics to call the consumer's attention. Thus, it is necessary to educate consumers so that they know how to evaluate the product at the time of purchase so that it becomes a more common dish in everyday meals.

4 Conclusion

The correlations under study indicated the relevance of proper handling of carcasses in post-slaughter moments and allowed suggesting which parameters should be adopted in the production of lamb meat so that the meat producer can use them with the confidence that these processes guarantee minimum consumer acceptance. All factors evaluated by consumers are shown to be correlated with each other: appearance, tenderness and juiciness. Sarcomere length has been shown to influence perceptions of juiciness and tenderness. The maximum shear force acceptable by the studied population was 44.1 N.

The study was carried out in the state of São Paulo and is the first to describe the tenderness threshold for a sample in Brazil; however, as the population was chosen for convenience and there are variations in consumer preferences from different Brazilian regions, similar studies should be carried out to assess acceptance differences in different locations, where thresholds may be different.

References

- American Society for Testing and Materials – ASTM. (2010). *ASTM E1871: Standard guide for serving protocol for sensory evaluation of foods and beverages*. West Conshohocken, PA: ASTM International.
- Andrade, J. C., Sobral, L. A., Ares, G., & Deliza, R. (2016). Understanding consumers perception of lamb meat using free word association. *Meat Science*, 117, 68-74. PMID:26946479. <http://doi.org/10.1016/j.meatsci.2016.02.039>
- Association of Official Analytical Chemists – AOAC. (2007). *Official methods of analysis of AOAC International* (18th ed.). Gaithersburg: AOAC.
- Battagin, H. V., Panea, B., & Trindade, M. A. (2021). Study on the lamb meat consumer behavior in Brazil. *Foods*, 10(8), 1713. PMID:34441493. <http://doi.org/10.3390/foods10081713>
- Bendall, J. R. (1973). Postmortem changes in muscle. In G. H. Bourne (Ed.), *The structure and function of muscle* (pp. 243-309). New York: Academic Press. <http://doi.org/10.1016/B978-0-12-119102-3.50012-4>.
- Bhatti, M. A., Gaarder, M. Ø., Steinheim, G., Hopkins, D. L., Horneland, R., Eik, L. O., & Ådnøy, T. (2020). Lamb or hogget meat: A different sensory profile? Extending the fresh meat season in Norway. *Small Ruminant Research*, 185, 106086. <http://doi.org/10.1016/j.smallrumres.2020.106086>
- Bickerstaffe, R., Bekhit, A. E. D., Robertson, L. J., Roberts, N., & Geesink, G. H. (2001). Impact of introducing specifications on the tenderness of retail meat. *Meat Science*, 59(3), 303-315. PMID:22062785. [http://doi.org/10.1016/S0309-1740\(01\)00083-3](http://doi.org/10.1016/S0309-1740(01)00083-3)

Which is the shear force that defines the lamb's sensory acceptance?

Battagin, H. V. et al.

- Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, 37(8), 911-917. PMID:13671378. <http://doi.org/10.1139/o59-099>
- Bonacina, M. S., Osório, M. T. M., Osório, J. C. S., Corrêa, G. F., Hashimoto, J. H., & Lehmen, R. I. (2011). Sensory evaluation of meat lambs from males and females Texel × Corriedale finished in different systems. *Revista Brasileira de Zootecnia*, 40(8), 1758-1766. <http://doi.org/10.1590/S1516-35982011000800020>
- Bonagurio, S., Pérez, J. R. O., Furusho-Garcia, I. F., Santos, C. L. D., & Lima, A. L. (2004). Meat centesimal composition of purebred Santa Ines lambs and its crosses with Texel, slaughtered at different weights. *Revista Brasileira de Zootecnia*, 33(6), 2387-2393. <http://doi.org/10.1590/S1516-35982004000900027>
- Brasil. Ministério da Agricultura, Pecuária e Abastecimento. (2000). Regulamento técnico de métodos de insensibilização para abate de animais de açougue (Instrução normativa nº 3, de 17 de janeiro de 2000). *Diário Oficial [da] República Federativa do Brasil*, Brasília. Retrieved in 2024, July 26, from <https://www.defesa.agricultura.sp.gov.br/legislacoes/instrucao-normativa-sda-3-de-17-01-2000,661.html>
- Bressan, M. C., Prado, O. V., Pérez, J. R. O., Lemos, A. R. S. C., & Bonagurio, S. (2001). Efeito do peso ao abate de cordeiros Santa Inês e Bergamãcia sobre as características físico-químicas da carne. *Food Science and Technology*, 21(3), 293-303. <http://doi.org/10.1590/S0101-20612001000300008>
- Chambers, E. N., & Bowers, J. R. (1993). Consumer perception of sensory quality in muscle foods. *Food Technology*, 47(11), 116-120.
- Cong, M., Thompson, V. F., Goll, D. E., & Antin, P. B. (1998). The bovine calpastatin gene promoter and a new N-terminal region of the protein are targets for cAMP-dependents protein kinase activity. *The Journal of Biological Chemistry*, 273(1), 660-666. PMID:9417129. <http://doi.org/10.1074/jbc.273.1.660>
- Cross, H. R., West, R. L., & Dutson, T. R. (1981). Comparison of methods for measuring sarcomere length in beef semitendinosus muscle. *Meat Science*, 5(4), 261-266. PMID:22056091. [http://doi.org/10.1016/0309-1740\(81\)90016-4](http://doi.org/10.1016/0309-1740(81)90016-4)
- Culler, R. D., Parrish-Jr, F. C., Smith, G. C., & Cross, H. R. (1978). Relationship of myofibril fragmentation index to certain chemical, physical and sensory characteristics of bovine Longissimus muscle. *Journal of Food Science*, 43(4), 1177-1180. <http://doi.org/10.1111/j.1365-2621.1978.tb15263.x>
- Dutcosky, S. D. (2007). *Análise sensorial de alimentos*. Curitiba: Champagnat.
- Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA. (2019). *Atualização das demandas de pesquisa em ovinos de corte no Brasil Central*. Retrieved in 2024, July 26, from <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/202196/1/CNPC-2019-Boletim-CI-n8.pdf>
- Fausto, D. A., Lima, M. A., Ramos, P. M., Pertile, S. F. N., Susin, I., & Delgado, E. F. (2017). Cold shortening decreases the tenderization of *Biceps femoris* muscle from lambs. *Revista Brasileira de Saúde e Produção Animal*, 18(1), 16-25. <http://doi.org/10.1590/s1519-99402017000100003>
- Fernandes, M. A. M., Monteiro, A. L. G., Poli, C. H. E. C., Barros, C. S. D., Almeida, R. D., & Ribeiro, T. M. D. (2010). Composição tecidual da carcaça e perfil de ácidos graxos da carne de cordeiros terminados a pasto ou em confinamento. *Revista Brasileira de Zootecnia*, 39(7), 1600-1609. <http://doi.org/10.1590/S1516-35982010000700029>
- Fernandes, R. P. P., Freire, M. T. A., Paula, E. S. M., Kanashiro, A. L. S., Catunda, F. A. P., Rosa, A. F., Balieiro, J. C. C., & Trindade, M. A. (2014). Stability of lamb loin stored under refrigeration and packed in different modified atmosphere packaging systems. *Meat Science*, 96(1), 554-561. PMID:24018275. <http://doi.org/10.1016/j.meatsci.2013.08.005>
- Fregonesi, R. P., Portes, R. G., Aguiar, A. M. M., Figueira, L. C., Gonçalves, C. B., Arthur, V., Lima, C. G., Fernandes, A. M., & Trindade, M. A. (2014). Irradiated vacuum-packed lamb meat stored under refrigeration: Microbiology, physicochemical stability and sensory acceptance. *Meat Science*, 97(2), 151-155. PMID:24583322. <http://doi.org/10.1016/j.meatsci.2014.01.026>
- Geesink, G. H., Bekhit, A. E. D., & Bickerstaffe, R. (2000). Rigor temperature and meat quality characteristics of lamb longissimus muscle. *Journal of Animal Science*, 78(11), 2842-2848. PMID:11063307. <http://doi.org/10.2527/2000.78112842x>
- Gornall, A. G., Bardawill, C. J., & David, M. M. (1949). Determination of serum proteins by means of the biuret reaction. *The Journal of Biological Chemistry*, 177(2), 751-766. PMID:18110453. [http://doi.org/10.1016/S0021-9258\(18\)57021-6](http://doi.org/10.1016/S0021-9258(18)57021-6)
- Holman, B. W. B., & Hopkins, D. L. (2021). The use of conventional laboratory-based methods to predict consumer acceptance of beef and sheep meat: A review. *Meat Science*, 181, 108586. PMID:34098380. <http://doi.org/10.1016/j.meatsci.2021.108586>
- Holman, B. W. B., Fowler, S. M., & Hopkins, D. L. (2016). Are shear force methods adequately reported? *Meat Science*, 119, 1-6. PMID:27107727. <http://doi.org/10.1016/j.meatsci.2016.03.032>
- Hopkins, D. L., Hegarty, R. S., Walker, P. J., & Pethick, D. W. (2006). Relationship between animal age, intramuscular fat, cooking loss, pH, shear force and eating quality of aged meat from sheep. *Australian Journal of Experimental Agriculture*, 46(7), 879-884. <http://doi.org/10.1071/EA05311>
- Hopkins, D. L., Lamb, T. A., Kerr, M. J., & van de Ven, R. J. (2013). The interrelationship between sensory tenderness and shear force measured by the G2 Tenderometer and a Lloyd texture analyser fitted with a Warner-Bratzler head. *Meat Science*, 93(4), 838-842. PMID:23305834. <http://doi.org/10.1016/j.meatsci.2012.11.052>
- Knight, M. I., Linden, N., Ponnampalam, E. N., Kerr, M. G., Brown, W. G., Hopkins, D. L., Baud, S., Ball, A. J., Borggaard, C., & Wesley, I. (2019). Development of VISNIR predictive regression models for ultimate pH, meat tenderness (shear force) and intramuscular fat content of Australian lamb. *Meat Science*, 155, 102-108. PMID:31102991. <http://doi.org/10.1016/j.meatsci.2019.05.009>
- Koohmaraie, M. (1994). Muscle proteinases and meat ageing. *Meat Science*, 36(1-2), 93-104. PMID:22061455. [http://doi.org/10.1016/0309-1740\(94\)90036-1](http://doi.org/10.1016/0309-1740(94)90036-1)
- Koohmaraie, M., Crouse, J. D., & Mersmann, H. J. (1989). Acceleration of postmortem tenderization in ovine carcasses through infusion of calcium chloride: Effect of concentration and ionic strength. *Journal of Animal Science*, 67(4), 934-942. PMID:2654112. <http://doi.org/10.2527/jas1989.674934x>

Which is the shear force that defines the lamb's sensory acceptance?

Battagin, H. V. et al.

- Koolmees, P. A., Korteknie, F., & Smulders, F. J. M. (1986). Accuracy and utility of sarcomere length assessment by laser diffraction. *Food Microstruct*, 5, 71-76.
- Lambe, N. R., McLean, K. A., Gordon, J., Evans, D., Clelland, N., & Bunger, L. (2017). Prediction of intramuscular fat content using CT scanning of packaged lamb cuts and relationship with meat eating quality. *Meat Science*, 123, 112-119. PMID:27701028. <http://doi.org/10.1016/j.meatsci.2016.09.008>
- Lawrie, R. A. (1985). *Meat science* (4th ed.). Oxford: Pergamon Press.
- Locker, R. H., & Hagyard, C. J. (1963). A cold shortening effect in beef muscles. *Journal of the Science of Food and Agriculture*, 14(2), 787-793. <http://doi.org/10.1002/jsfa.2740141103>
- Marsh, B. B. (1977). Symposium the basis of quality in muscle foods: The basis of tenderness in muscle foods. *Journal of Food Science*, 42, 295. <http://doi.org/10.1111/j.1365-2621.1977.tb01485.x>
- Meilgaard, M. C., Civille, G. V., & Carb, B. T. (1991). *Sensory evaluation techniques*. Boca Raton: CRC Press.
- Miller, R. (2020). Drivers of consumer liking for beef, pork and lamb: A review. *Foods*, 9(4), 428. PMID:32260287. <http://doi.org/10.3390/foods9040428>
- Moskowitz, H. R. (1983). *Product testing and sensory evaluation of foods: Marketing and R&D approaches*. Westport: Food and Nutrition Press. 605 p.
- Oliveira, F. G., Sousa, W. H., Cartaxo, F. Q., Batista, A. S. M., Ramos, J. P. F., & Cavalcante, I. T. R. (2020). Quality of meat from Santa Inês sheep with different biotypes and slaughtering weights. *Revista Brasileira de Saúde e Produção Animal*, 21, 1-13. <http://doi.org/10.1590/s1519-994020210732020>
- Oliveira, G. M., Rocha, Y. J. P., Gallo, S. B., Trindade, M. A., Souza, G. M., & Delgado, E. F. (2019). Toughness in Santa Inês lamb meat has negative impact on consumer evaluation. *Revista Brasileira de Saúde e Produção Animal*, 20, 1-13. <http://doi.org/10.1590/s1519-9940200372019>
- Olsson, U., Hertzman, C., & Tornberg, E. (1994). The influence of low temperature, type of muscle and electrical stimulation on the course of rigor mortis, ageing and tenderness of beef muscles. *Meat Science*, 37(1), 115-131. PMID:22059417. [http://doi.org/10.1016/0309-1740\(94\)90149-X](http://doi.org/10.1016/0309-1740(94)90149-X)
- Osório, J. C. S., Astiz, C. S., Osório, M. T. M., & Alfranca, I. S. (1998). *Produção de carne ovina, alternativa para o Rio Grande do Sul* (166 p.). Pelotas: Editora da Universidade Federal de Pelotas.
- Osório, M. T. M., Osório, J. C. S., & Sobrinho, A. G. S. (2008). Avaliação instrumental da carne ovina. In A. G. Silva Sobrinho, C. Sañudo, J. C. S. Osório, M. M. Campo Arribas & M. T. Osório (Eds.), *Produção de carne ovina* (pp. 129-176). Jaboticabal: Funep.
- Pannier, L., Gardner, G. E., Pearce, K. L., McDonagh, M., Ball, A. J., Jacob, R. H., & Pethick, D. W. (2014). Association of sire estimated breeding values and objective meat quality measurements with sensory scores in Australian lamb. *Meat Science*, 96(2 Pt B), 1076-1087. PMID:23968666. <http://doi.org/10.1016/j.meatsci.2013.07.037>
- Rant, W., Rant, A. R., Swiatek, M., Niznikowski, M., Szymanska, Z., Bednarczyk, M., Orłowski, E., Villavicencio, A. M., & Slezak, M. (2019). The effect of aging and muscle type on the quality characteristics and lipid oxidation of lamb meat. *Archiv für Tierzucht*, 62(2), 383-391. PMID:31807649. <http://doi.org/10.5194/aab-62-383-2019>
- Realini, C. E., Pavan, E., Johnson, P. L., Font-i-Furnols, M., Jacob, N., Agnew, M., Craigie, C. R., & Moon, C. D. (2021). Consumer liking of *M. longissimus lumborum* from New Zealand pasture-finished lamb is influenced by intramuscular fat. *Meat Science*, 173, 108380. PMID:33288363. <http://doi.org/10.1016/j.meatsci.2020.108380>
- Resconi, V. C., Campo, M. M., Font i Furnols, M., Montossi, F., & Sañudo, C. (2009). Sensory evaluation of castrated lambs finished on different proportions of pasture and concentrate feeding systems. *Meat Science*, 83(1), 31-37. PMID:20416726. <http://doi.org/10.1016/j.meatsci.2009.03.004>
- Rodrigues, I., Trindade, M. A., Palu, A. F., Baldin, J. C., Lima, C. G., & Freire, M. T. A. (2018). Modified atmosphere packaging for lamb meat: Evaluation of gas composition in the extension of shelf life and consumer acceptance. *Journal of Food Science and Technology*, 55(9), 3547-3555. PMID:30150813. <http://doi.org/10.1007/s13197-018-3280-1>
- Stone, H., & Sidel, J. L. (1993). *Sensory evaluation practices* (2nd ed.). London: Academic Press.
- Teixeira, E., Meinert, E. M., & Barbetta, P. A. (1987). *Análise sensorial de alimentos*. Florianópolis: UFCS.
- Veiseth, E., Shackelford, S. D., Wheeler, T. L., & Koohmaraie, M. (2004). Factors regulating lamb longissimus tenderness are affected by age at slaughter. *Meat Science*, 68(4), 635-640. PMID:22062540. <http://doi.org/10.1016/j.meatsci.2004.05.015>
- Venturini, R. S., Carvalho, S., Nalério, E. S., Giongo, C., Argenta, F. M., Pellegrin, A. C. R. S., Moro, A. B., Martins, A. A., Simões, R. R., & Lopes, J. F. (2020). Instrumental and sensory evaluation of meat from lambs and hoggets fed high-concentrate maize or sorghum diets. *Semina: Ciências Agrárias*, 41(5), 1679-1690. <http://doi.org/10.5433/1679-0359.2020v41n5p1679>

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