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Carcass and Meat Quality of Lambs From Intensive Grazing Systems Differing in the Age of Slaughter

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Abstract: Ninety lambs reared on pastures were slaughtered for 2 y corresponding to 3 ages of slaughter: at weaning with 4 mo of age (4M), at 6–7 mo of age (6M), and at 12 mo of age (12M; last treatments were weaned at 4 mo). With the purpose of deseasonalizing high-quality meat lamb production in the year, the present work aimed to achieve hot carcass weight (HCW) of 18–20 kg on average in each lamb group. Hot carcass weight, carcass yield (CYd), subcutaneous tissue depth, leg, frenched rack, and loin weights were determined. After meat ageing for 7 and 14 d from the 3 groups of lambs, instrumental color, Warner-Bratzler shear force (WBSF), consumer sensory analysis ($n = 200$), and fatty acid profile of intramuscular fat (IMF) were determined on *longissimus lumborum* muscle. Lambs of 12M resulted in greater HCW ($P < 0.05$). The young lambs (4M) presented a greater subcutaneous fat coverage and CYd ($P < 0.05$). Lambs of 12M presented a greater proportion of legs ($P < 0.05$) regarding HCW. Meat color from 4M lambs was lighter (greater L^* values) when aged for 7 and 14 d and showed lower WBSF values with 14 d of ageing ($P < 0.05$). A greater proportion of IMF ($P < 0.05$) was observed in 12M and 4M lambs, but the latter presented a greater proportion of conjugated linoleic acid ($P < 0.05$) and polyunsaturated fatty acid to saturated fatty acid ratio ($P < 0.05$). Older lambs (12M) showed a lower n6/n3 fatty acid ratio ($P < 0.05$) and a greater concentration of α-tocopherol ($P < 0.05$). Meat from the 3 groups of lambs was scored positively (i.e., at least between "I like moderately" and "I like slightly") for overall liking when evaluated by consumers. Although significant differences were observed among the 3 groups of lambs, slaughter age in lambs until 12M seems to have a minor effect on product quality from a practical standpoint.

Key words: de-seasonalize, meat quality, pasture-based systems
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Introduction

In Uruguay, lambs represented 60% on average of the total sheep slaughtered from 2010 to 2019 (INAC, 2020). One of the main concerns of the Uruguayan lamb industry lies in the slaughter of lambs, which is markedly seasonal. These animals are raised mainly on native pastures (Piaggio et al., 2014). Production of lambs based on intensive grazing systems allows for slaughter weights (SW) being reached earlier than in traditional pastoral systems, but little is known about the magnitude of the effect of age at slaughter on meat quality when maintaining similar SW. Thus, maintaining a lamb meat supply consistently throughout the year is of greatest importance. The Uruguayan Heavy Lamb Program accepts animals of any breed, whether male or female, if the requirements in terms of SW (34–45 kg), body condition score (between 3 and 4 on a 5-point scale), and age (milk teeth) are met (Azzarini, 2003).

Lamb carcass and meat quality are affected by many factors, among which the age at slaughter has been studied (Sañudo et al., 1998; Budimir et al., 2018). Pannier et al. (2018) suggest that lamb slaughter age has an impact on low-quality cuts compared to high-quality cuts. Della Malva et al. (2016) reported that the age of slaughter affected the nutritional value, physical characteristics, and sensory attributes of meat, and presented in younger animals it had a better meat fatty acid profile. On the other hand, it has been reported that following good animal handling practices and processing conditions, it should be possible to produce lamb meat with satisfactory tenderness with animals up to 20 mo of age (fed with a pelleted diet), although it would depend on the cut (Pethick et al., 2005).

With the purpose of de-seasonalizing lamb production, the aim of this work was to study the effect of different grazing production systems whose lambs differed in the age of slaughter on carcass and meat quality characteristics. Our interest was to evaluate the production of a typical heavy lamb (10–12 mo old) reared in Uruguay from a dual-purpose breed compared to crossbreed lambs (with meat sheep breeds) that are usually used in more intensive fattening systems and slaughtered at a younger age. Therefore, the present study was not focused on the assessment of factors such as diet and genetics that are intrinsic to the production system.

The hypothesis of the study was that beyond genetics, the lamb's age of slaughter up to 12 mo old in pastoral systems and at similar kill weight has a minor effect on carcass and meat quality attributes.

Materials and Methods

Experimental treatments

For 2 y, three groups of 30 male and female lambs were slaughtered each year: at weaning at 4 mo of age (4M), at 6–7 mo of age (6M), and at 12 mo of age (12M). Lambs ($n = 90$) slaughtered at 4M and 6M were a crossbreed Texel x Corriedale Pro® (25% East Friesian, 25% Finnish Landrace and 50% Corriedale) while 12M lambs were from the dual-purpose breed Dohne Merino. Lambs were slaughtered at 36–40 kg of average live weight to achieve a carcass weight of 18–20 kg. Lambs and their dams during gestation grazed in a pastoral sheep intensive unit that included pastures such as red clover (*Trifolium pratense*), perennial ryegrass (*Lolium perenne*), *Lotus pedunculatus*, and dactylis (*Dactylis glomerata*), with a rotational grazing system of 4–7 d of occupation of the paddocks. The lambs at 6–7 mo of age after weaning grazed red clover (*Trifolium pratense*) and *Lotus pedunculatus* and performed hourly grazing of forage sorghum during the summer. The 12M lambs grazed fodder sorghum after their weaning during winter season, and then they were placed in a natural grassland paddock, and in the final phase of fattening they grazed restrictively (on hourly basis) oats (*Avena sativa L.*) and ryegrass (*Lolium multiflorum*).

Carcass and meat measurements

Lambs were humanely slaughtered in a commercial meat packing plant according to the Uruguayan legislation. Live weight at slaughter (SW), hot carcass weight (HCW), and carcass yield (CYd: (HCW/SW) × 100) were determined. After slaughter, carcasses were kept in a cooler for 24 h at 2–4°C. Subsequently, subcutaneous tissue depth (GR site) was determined on the 12th rib at 11 cm from the midline of the carcass (Kirton and Johnson, 1979). At the deboning room, right and left frenched racks (FR), loins, and legs (boneless, chump-on) were weighed. The FR is a bone-in cut obtained from the dorsal part of the half carcass. Its cranial and caudal limits are the 6th and 13th ribs, respectively, and its ventral limit is approximately 7.5 cm from the costovertebral joint; muscles are removed to the portion of the ribs that remain in their last 5 cm. The loin (boneless) originated from the dorsal region of the half carcass; its cranial limit is the 1st lumbar vertebrae, and the caudal limit is the joint between the lumbar spine and the sacrum. Boneless leg is obtained from a cut in the 6th lumbar vertebrae and subsequent extraction of its bone base (Robaina, 2002). The left and right *longissimus lumborum* muscles were removed from each carcass, which was vacuum packaged and transported to the Meat Laboratory of Instituto Nacional de Investigación Agropecuaria (INIA) in Uruguay.

The right *longissimus lumborum* muscle was aged for 7 d, and the left was aged for 14 d at 0–2°C. For both loins, samples were obtained in the cranial-caudal direction for the following determinations: an 8 cm portion for consumer panel and a 5 cm portion for instrumental meat color and Warner-Bratzler shear force (WBSF). Before meat ageing, a 4 cm portion was removed from the caudal ending of the *longissimus lumborum* muscle for vitamin E content determination (from the right loin) and for fatty acid composition assessment (from the left loin). Both portions were cut into small pieces to be subsequently frozen at −80°C and pulverized using a Robot Coupe R2 (Robot Coupe®, Montceau-les-Mines, France). After homogenization, each sample was packed in individual sterile whirl-pack bags (Nasco, Fort Atkinson, WI, USA) and placed into a −80°C freezer until analysis was performed. After ageing, samples were removed from the vacuum packaging bags to allow 45 min of blooming prior to lean color determination. Color was measured on the caudal surface of the *longissimus lumborum* portion intended for this measurement and WBSF. Lean color was measured in triplicate in each sample with a Minolta chromameter CR-400 (Konica Minolta Sensing Inc., Japan) using a C illuminant, a 2° standard observer angle and 8 mm aperture size and calibrated with a white tile before use. Meat color was measured through the CIEL*a*b* system (L^*: lightness, a^*: redness, and b^*: yellowness; King et al., 2023). Subsequently, meat samples were weighed using an electronic scale (EP-41KA, A&D Company, Tokyo, Japan) before being cooked in a preheated clam shell style grill (GRP100 The Next Grilleration, Spectrum Brands, Inc., Miami, FL, USA) until the internal temperature measured with a thermometer (Comark N9094, Norwich, Norfolk, UK) in the geometric center reached 71°C (AMSA, 2016). After the pieces were cooked and cooled, they were weighed again to determine the cooking losses (CL) from the interaction between lamb age at slaughter and ageing period as follows: [(raw weight − cooked weight)/raw weight] × 100. After this, 6 cores (1.27 cm diameter) were removed from each meat sample parallel to the longitudinal orientation of muscle fibers, and shear force was assessed with a TA.XT Plus texturometer (Stable Micro Systems, Godalming, Surrey, UK) fitted with a Warner Bratzler V-shaped blade (WBSF). Individual shear force values were averaged to assign a mean peak WBSF value to each sample (AMSA, 2016).

Intramuscular fat (IMF) proportion was determined gravimetrically as a percentage. The lipid extraction was carried out following the chloroform-methanol method according to the procedure of Bligh and Dyer (1959). Fatty acids were cold methylated with methanolic potash (IUPAC, 1987), and the analysis was carried out by gas chromatography (Konik HRGC 4000B, Barcelona, Spain) using a 30 m DB-WAX capillary column (0.25 mm internal diameter and 0.25 μm film thickness, Agilent, Santa Clara, USA). The carrier gas used was nitrogen with a flow of 1 mL/min. The injection volume was 1 μL, and a flame ionization detector (FID) was used. Fatty acid identification was carried out by comparing the retention times with those of a standard (FAME Supelco TM 37, Sigma, St. Louis, USA). Fatty acids were expressed as a percentage of the total fatty acids identified.

Vitamin E (α-tocopherol) content was analyzed following the procedure described by Molino et al. (2012). Briefly, 0.2 g of meat sample was lyophilized (Alpha 1-4LD Plus, Christ, Osterode am Harz, Germany), placed in an Eppendorf tube with 0.4 mL of ethyl alcohol, and vortexed for 2 min. Subsequently, 1 mL of hexane was added and vortexed for 15 min and then centrifuged at 3500 rpm for 5 min (IEC™ Multi-RF, Themo Scientific, MA, USA). The extraction was performed in triplicate, and lipophilic layers were pooled and evaporated under a stream of nitrogen. The dry residue was dissolved in 1 mL of acetonitrile/methanol/dichloromethane (75/15/10) and transferred to a vial from which 80 μL was injected into the HPLC (UltiMate® 3000, Thermo Scientific Dionex, Boston, MA, USA) fitted with a DAD detector. To separate the analyte a C18 chromatographic column of 250 mm × 4.6 mm × 5 μm was used (BDS-Hypersil, Thermo Scientific, Boston, MA, USA). The mobile phase used was a mixture of acetonitrile/methanol/dichloromethane/ammonium acetate 0.05M in water (75/10/10/5) at a flow of 1.5 mL/min with an oven temperature of 35°C. Quantification of α-tocopherol was performed at 292 nm using a 5-point calibration curve performed with the standard (α-tocopherol, Sigma, St. Louis, MO, USA), and results were expressed as μg/g muscle.

Consumer sensory analysis

Consumer sensory analysis was conducted according to the guidelines of the Declaration of Helsinki (the code of ethics of the World Medical Association) for experiments involving humans.

After ageing for 7 and 14 d, the *longissimus lumborum* portions were frozen −20°C for 3 mo until the consumer sensory analysis was performed. Consumers ($n = 200$) evaluated samples from the 3 groups of lambs and from both ageing times (6 samples in total). The consumer sensory analysis was designed following procedures to reduce the effects of order of presentation and first order carry-over effects (Macfie et al., 1989). On the days of consumer testing, the loin portions were previously thawed at 2°C for 24 h. Loin samples of 8 cm intended for sensory evaluation were wrapped with aluminum foil and then grilled as previously described to reach an internal temperature of 71°C. After cooking, external fat and connective tissue were removed, and samples were cut into 10 pieces which were wrapped with aluminum foil, coded, and placed in a heater to avoid them cooling down. The samples were placed in a heater maintained at 49°C for no more than 15 min, following the protocol recommended by AMSA (2016), in which this temperature did not affect the sensory properties of the sample. Characteristics of the consumers (gender, age, and frequency of meat consumption) that participated in the panel are presented in Tables 1 and 2.

Table 1. Sociodemographic characteristics of consumers ($n = 200$)

Variable	Frequency relative (%)
Gender	
Female	37
Male	63
Age	
<30 y	19
30–50 y	63
>50 y	18

Table 2. Frequency of consumers ($n = 200$) consumption for pork, beef, chicken, and sheep meat

	Frequency of consumption (%)			
Variable	Less than once a month	Once a month	Every 2 weeks	Every week
Pork	23	47	20	10
Beef	—	4	8	88
Chicken	1	10	34	55
Sheep	19	44	21	16

Each consumer was asked to assess tenderness liking, flavor liking, and overall liking on 8-point category scales: like extremely (1), like very much (2), like moderately (3), like slightly (4), dislike slightly (5), dislike moderately (6), dislike very much (7), and dislike extremely (8). Consumers were seated in individual sensory booths where unsalted crackers and natural drinking water were available to cleanse their palates between samples.

Statistical analysis

The experimental design was completely randomized. The variables were analyzed using a mixed linear model using the MIXED procedure of the Statistical Analysis System (SAS Institute, Cary, NC, version 9.4). The model included the lamb group as a fixed effect, while the animal and the year were considered as random effects. Data from the panel consumer sensory panel were analyzed as 3 × 2 factorial design in which the group of lambs (4M, 6M, and 12M) and ageing times (7 and 14 d) were considered as fixed effects and consumer, meat sample, and year were considered as random effects. Homogeneity of variance and normality for all data were evaluated using studentized residuals plots. Kenward-Roger approximation was used to calculate denominator degrees of freedom for different covariance structures for adjustment of the F-statistic. After ANOVA, least-squares means were calculated for treatment comparisons with a significance level of $\alpha = 0.05$, using the PDIFF option of LSMEANS adjusted by Tukey, when F-tests were significant ($P < 0.05$).

Results

Carcass and meat quality

Oldest lambs (12M) showed a greater ($P < 0.05$) SW and a greater HCW ($P < 0.05$) compared to 6M and 4M lambs (Table 3). The 4M lambs had a greater ($P < 0.05$) tissue depth at the GR point and CYd than the other 2 groups of lambs (Table 3).

Leg presented a greater ($P < 0.05$) proportion of the HCW in 12M lambs compared to 4M and 6M lambs. However, FR presented a greater ($P < 0.05$) proportion of the HCW in 4M and 6M lambs than lambs slaughtered at 12 mo of age (Table 3). Lambs slaughtered at 12M and 4M ($P < 0.05$) of age showed a greater proportion of loin compared to 6M lamb.

Regarding meat quality traits, no significant differences ($P > 0.05$) were found among the 3 groups of lambs for WBSF when meat was aged for 7 d. Nevertheless, 4M lambs showed lower ($P < 0.05$) WBSF values than the other 2 groups of lambs in meat aged for 14 d (Table 3). No significant differences ($P > 0.05$) were found among the 3 groups of lambs for CL of meat aged for 7 and 14 d. Lean color of 4M lambs was lighter (greater L^* values; $P < 0.05$) than 6M and 12M lambs when meat was aged for 7 and 14 d. In addition, lambs of 6M of age presented greater ($P < 0.05$) L^* values than 12M lambs in both ageing times. The a^* value (redness) of lean from 12M lambs was greater ($P < 0.05$) than the other 2 groups and greater ($P < 0.05$) than 6M lambs when meat was aged for 7 and 14 d, respectively (Table 3). Lambs slaughtered at 4M of age showed greater ($P < 0.05$) b^* values (yellowness) of meat when aged for 7 d compared to 6M and 12M lambs, and they had values greater ($P < 0.05$) than 12M lambs in meat aged for 14 d.

Lambs slaughtered at 4M and 12M of age showed greater ($P < 0.05$) IMF proportion than 6M lambs (Table 4). In our study, the younger lambs (4M) presented a greater ($P < 0.05$) proportion of the saturated fatty acids (SFA) C14:0 and C16:0 compared to 6M and 12M (Table 4). The oldest lambs (12M) had the greatest ($P < 0.05$) proportion of the oleic acid (C18:1-n9) compared to the other 2 groups. The proportion of linoleic (C18:2-n6) was significantly higher

Table 3. Least-squares means ± standard error of carcass and meat quality characteristics of lambs slaughtered at 4M, at 6M, and at 12M

	Treatments[1]			
	4M	6M	12M	*P* value
Carcass traits				
SW[2] (kg)	36.9 ± 0.58[c]	39.9 ± 0.58[b]	43.5 ± 0.59[a]	<0.0001
HCW[3] (kg)	18.0 ± 0.25[c]	19.0 ± 0.25[b]	20.9 ± 0.26[a]	<0.0001
GR[4] (mm)	12.4 ± 1.88[a]	10.6 ± 1.88[b]	7.1 ± 1.88[c]	<0.0001
CYd[5] (%)	48.7 ± 0.48[a]	47.7 ± 0.48[b]	47.2 ± 0.48[b]	0.0018
Leg (%HCW)	19.2 ± 0.20[b]	18.9 ± 0.20[b]	20.2 ± 0.20[a]	<0.0001
Frenched rack (% HCW)	5.2 ± 0.11[a]	5.1 ± 0.11[a]	4.8 ± 0.11[b]	<0.0001
Loin (% HCW)	3.2 ± 0.04[a]	3.0 ± 0.04[b]	3.3 ± 0.04[a]	<0.0001
Meat quality traits—7 d ageing				
WBSF[6] (kgf)	2.09 ± 0.11	2.29 ± 0.11	2.14 ± 0.11	0.1221
CL[7] (%)	25.4 ± 1.10	24.3 ± 1.12	23.6 ± 0.93	0.4434
Lightness (*L)**	41.0 ± 0.55[a]	38.9 ± 0.55[b]	34.4 ± 0.55[c]	<0.0001
Redness (*a)**	19.5 ± 0.37[b]	19.4 ± 0.37[b]	20.1 ± 0.36[a]	0.0048
Yellowness (*b)**	8.8 ± 0.15[a]	8.0 ± 0.15[b]	7.7 ± 0.15[b]	<0.0001
Meat quality traits—14 d ageing				
WBSF[6] (kgf)	1.58 ± 0.09[a]	2.02 ± 0.09[c]	1.76 ± 0.09[b]	<0.0001
CL[7] (%)	24.4 ± 1.01	25.7 ± 1.11	23.9 ± 1.30	0.4434
Lightness (*L)**	41.0 ± 0.49[a]	39.3 ± 0.49[b]	35.2 ± 0.49[c]	<0.0001
Redness (*a)**	19.6 ± 0.66[a]	19.0 ± 0.66[b]	19.7 ± 0.66[a]	0.0026
Yellowness (*b)**	8.9 ± 0.31[a]	8.6 ± 0.31[a]	7.3 ± 0.31[b]	<0.0001

[a–c]LS means with different superscripts in the same row differ significantly ($P < 0.05$).

[1]4M: lambs with 4 mo of age; 6M: lambs with 6–7 mo of age; 12M: lambs with 12 mo of age.

[2]SW: slaughter weight.

[3]HCW: hot carcass weight.

[4]GR: total tissue depth over the 12th rib at 11 cm from the midline of the carcass.

[5]CYd: carcass yield = (HCW/SW) × 100.

[6]WBSF: Warner-Bratzler shear force.

[7]CL: cooking loss.

($P < 0.05$) in the IMF of 4M and 6M lambs than 12M, while the proportion of conjugated linoleic acid (CLA) and linolenic (C18:3-n3) was greater ($P < 0.05$) in 4M lambs compared to the other 2 groups of lambs (Table 4). No significant differences ($P > 0.05$) were observed among the 3 groups of lambs on proportion of SFA. The oldest lambs (12M) presented a greater ($P < 0.05$) proportion of monounsaturated fatty acids (MUFA) compared to 4M and 6M lambs. Younger lambs (4M) showed a greater ($P < 0.05$) proportion of polyunsaturated fatty acids (PUFA) and PUFA to SFA ratio (PUFA/SFA) than the other 2 groups of lambs (Table 4). Regarding the proportion of omega 6/omega 3 fatty acids (n6/n3), meat from 4M and 6M lambs showed a greater ($P < 0.05$) ratio than 12M lambs. The oldest lambs (12M) presented the greatest ($P < 0.05$) concentration of vitamin E (α-tocoferol) on the *longissimus lumborum* muscle, while 4M lambs showed the lowest ($P < 0.05$) concentration (Table 4).

Consumer sensory analysis

Meat from 4M lambs was scored higher ($P < 0.05$) for tenderness liking than 6M and 12M lambs (Table 5). Flavor liking and overall liking was greater ($P < 0.05$) for 4M lambs than 12M lambs, while 6M lambs did not differ ($P > 0.05$) from these 2 groups (Table 5). It is important to highlight that the 3 groups of lambs were scored positively (i.e., as at least "I like slightly") for the 3 attributes. Meat ageing time (7 vs. 14 d) did not show an effect ($P > 0.05$) on any attribute evaluated by consumers, and no interaction ($P > 0.05$) was observed between lamb age at slaughter and ageing period (data not presented).

Discussion

Hot carcass weight and degree of fatness are important characteristics associated to the value of

Table 4. Least-squares means ± standard error of intramuscular fat content, fatty acid composition (% of the total fatty acids identified), and α-tocopherol concentration of the *longissimus lumborum* muscle of lambs slaughtered at 4M, at 6M, and at 12M

Variable	Treatments[1] 4M	6M	12M	*P* value
Intramuscular fat (IMF, %)	4.92 ± 0.70[a]	4.21 ± 0.69[b]	4.98 ± 0.70[a]	0.0011
Fatty acids (%)				
C14:0 (*myristic*)	5.18 ± 0.25[a]	3.13 ± 0.25[b]	1.98 ± 0.25[c]	<0.0001
C16:0 (*palmitic*)	28.6 ± 1.50[a]	27.2 ± 1.50[b]	24.4 ± 1.50[c]	<0.0001
C18:0 (*stearic*)	14.5 ± 0.93[c]	18.1 ± 0.93[b]	21.6 ± 0.93[a]	<0.0001
C20:0 (*arachidic*)	0.37 ± 0.05[a]	0.31 ± 0.05[b]	0.35 ± 0.05[a]	<0.0001
C14:1 (*myristoleic*)	0.20 ± 0.11[c]	0.26 ± 0.11[b]	0.32 ± 0.11[a]	<0.0001
C16:1 (*palmitoleic*)	1.79 ± 0.04[a]	1.32 ± 0.04[b]	1.24 ± 0.04[b]	<0.0001
C18:1-n9 (*oleic*)	37.8 ± 0.33[b]	38.4 ± 0.33[b]	42.2 ± 0.33[a]	<0.0001
C18:2-n6 (*linoleic*)	3.89 ± 0.24[a]	3.77 ± 0.24[a]	2.71 ± 0.24[b]	<0.0001
CLA (*conjugated linoleic*)	1.56 ± 0.15[a]	1.13 ± 0.15[b]	1.06 ± 0.15[b]	<0.0001
C18:3-n3 (*linolenic*)	2.18 ± 0.11[a]	1.86 ± 0.11[b]	1.40 ± 0.11[c]	<0.0001
C18:3-n6 (*linolenic*)	0.09 ± 0.008[b]	0.09 ± 0.008[b]	0.13 ± 0.008[a]	<0.0001
C20:2-n6 (*eicosadienoic*)	0.07 ± 0.032[c]	0.11 ± 0.033[b]	0.13 ± 0.032[a]	<0.0001
C20:3-n3 (*eicosatrienoic*)	0.21 ± 0.041[b]	0.28 ± 0.041[a]	0.19 ± 0.041[b]	<0.0001
C20:3-n6 (*DGLA*)	0.21 ± 0.021[b]	0.23 ± 0.021[ab]	0.26 ± 0.032[a]	<0.0001
C20:4-n6 (*arachidonic*)	1.20 ± 0.08[a]	1.27 ± 0.07[a]	0.78 ± 0.07[b]	<0.0001
C20:5-n3 (*eicosapentaenoic*)	0.74 ± 0.056[a]	0.68 ± 0.056[ab]	0.62 ± 0.056[b]	0.0481
C22:5-n3 (*docosapentaenoic*)	0.55 ± 0.030[a]	0.59 ± 0.030[a]	0.49 ± 0.030[b]	0.0007
C22:6-n3 (*docosahexaenoic*)	0.14 ± 0.016[a]	0.13 ± 0.016[ab]	0.12 ± 0.016[b]	0.0094
SFA[2] (%)	48.7 ± 0.85	48.7 ± 0.85	48.3 ± 0.85	0.4181
MUFA[3] (%)	39.8 ± 0.39[b]	40.0 ± 0.39[b]	43.8 ± 0.39[a]	<0.0001
PUFA[4] (%)	11.5 ± 0.28[a]	10.4 ± 0.29[b]	7.8 ± 0.28[c]	<0.0001
PUFA/SFA ratio	0.24 ± 0.009[a]	0.21 ± 0.009[b]	0.16 ± 0.009[c]	<0.0001
n6/n3[5] ratio	1.88 ± 0.20[a]	1.91 ± 0.20[a]	1.69 ± 0.20[b]	0.0002
***α*-tocoferol (*μ*g/g muscle)**	1.443 ± 0.571[c]	1.826 ± 0.571[b]	3.125 ± 0.571[a]	<0.0001

[a–c]LS means with different superscripts in the same row differ significantly ($P < 0.05$).

[1]4M: lambs with 4 mo of age; 6M: lambs with 6–7 mo of age; 12M: lambs with 12 mo of age.

[2]SFA: saturated fatty acids, ∑ C14:0 + C16:0 + C18:0 + C20:0.

[3]MUFA: monounsaturated fatty acids, ∑ C14:1 + C16:1 + C18:1n9.

[4]PUFA: polyunsaturated fatty acids, ∑ C18:2n6 + C18:3n6 + C18:3n3 + CLA + C20:2n6 + C20:3n3 + C20:3n6 + C20:4n6 + C20:5n3 + C22:5n3 + C22:6n3.

[5]n-6: omega 6 fatty acids, ∑ C18:2n6 + C18:3n6 + C20:2n6 + C20:3n6 + C20:4n6. n-3: omega 3 fatty acids, ∑ C18:3n3 + C20:3n3 + C20:5n3 + C22:5n3 + C22:6n3.

the lamb (De Brito et al., 2016). In our study, 12M lambs showed a greater HCW than the other 2 groups, and these results agree with the study of Mashele et al. (2017), in which lambs slaughtered at 14 mo old presented heavier HCW than lambs slaughtered at 5 mo old. The tissue depth at the GR point was also greater in 4M lambs, probably associated to animal biotype effect (Ye et al., 2019), but it also could be due to a higher energy concentration during breastfeeding. It has been stated that lambs slaughtered at weaning probably had a higher growth rate because of milk intake prior to slaughter, which would result in greater muscle development and fat deposition (Ye et al., 2020a). In addition, the greater CYd of 4M lambs could be explained by the gastrointestinal tract, including the rumen, that would not yet be fully developed (Baldwin and Connor, 2017). Cifuni et al. (2000) reported that CYd decreases as the slaughter age of young lambs increases. With increasing carcass weight, greater muscle proportions can be achieved and consequently an increase in the weight of valuable cuts (Cruickshank et al., 1996; Parilo et al., 2007; Yakan and Ünal, 2010). As for the high-valuable cuts, 12M lambs presented a greater proportion of legs and lower proportion of FR than 4M and 6M lambs. As for the loins, the 12M and 4M lambs had higher proportions. Borton et al. (2005)

Table 5. Least-squares means ± standard error for tenderness liking, flavor liking and overall liking scores of meat from lambs slaughtered at 4M, at 6M, and at 12M averaged over ageing time (7 and 14 d) evaluated by a consumer panel ($n = 200$)

	Treatments[1]			
Variable	4M	6M	12M	*P* value
Tenderness liking[2]	2.11 ± 0.15^{a}	2.51 ± 0.15^{b}	2.66 ± 0.15^{b}	<0.0001
Flavor liking[2]	2.94 ± 0.17^{a}	3.08 ± 0.18^{ab}	3.19 ± 0.18^{b}	0.0388
Overall liking [2]	2.84 ± 0.08^{a}	3.03 ± 0.08^{ab}	3.23 ± 0.08^{b}	0.0005

[a–c]Means within a row with different superscripts differ ($P < 0.05$).

[1]4M: at weaning with 4 mo of age, 6M: at 6-7 mo of age, 12M: at 12 mo of age.

[2]8-point category scales: like extremely (1), like very much (2), like moderately (3), like slightly (4), dislike slightly (5), dislike moderately (6), dislike very much, (7) and dislike extremely (8).

did not find significant differences in the proportion of FR and loins as for the HCW in heavy lambs at 2 slaughter end weights, 52 and 77 kg. Cañeque et al. (1999) reported that in light lambs slaughtered at 3 live weights (10, 12, and 14 kg) the leg cuts represented approximately 33% of the carcass weight, but in our study, legs represented between 18% and 20% of the HCW since our lambs were heavier.

Tenderness is one of the most important attributes of meat quality, being affected by animal age (Maltin et al., 2003), breed, alterations in the myofibrillar structure, content and solubility of the connective tissue and the type of muscle (Harris, 1976; Silva et al., 1993; Obuz and Dikeman, 2003; Fayemi and Muchenje, 2019). In the present study, WBSF was evaluated with 2 ageing times. No differences in WBSF were detected among the 3 groups of lambs when meat was aged for 7 d. Although Starkey et al. (2015) suggest that ageing lamb meat for more than 7 d would not improve the shear force of *longissimus* muscle, we considered it interesting to evaluate whether there would be an effect of the age of slaughter when ageing was extended to 14 d. Meat of the 4M lambs aged for 14 d had lower WBSF than older lambs, although shear force values were in all cases below 2.5 kg, which would indicate very tender meats (Shorthose et al., 1986; Sañudo et al., 2003; Holman and Hopkins, 2021). This was confirmed to some extent by consumers since tenderness liking mean scores of the 3 groups of lambs were between “I like very much” to “I like moderately”. Safari et al. (2001) found that a WBSF value range between 3 and 4 kg would be needed to achieve a tenderness score above 50 on a 100-point scale in lamb loins evaluated by trained panelists. More recent research conducted by Hopkins et al. (2006) suggested that loins must have a shear force value of about 27 N (2.75 kg) or less to achieve the mean overall liking score of 63 on a 100-point scale.

Meat color is the main characteristic on which consumers base their purchase decision (Faustman and Cassens, 1990; Mancini and Hunt, 2005; Faustman and Suman, 2017). Meat cuts that do not have a good appearance and color are poorly accepted by consumers and end up losing their commercial value (Li and Liu, 2012). Meat color of 4M lambs was lighter (greater L^* values) than 6M and 12M lambs. These results agree with the findings of Hopkins et al. (2007), where greater L^* values were observed on lambs slaughtered at 4 mo of age compared to those slaughtered at 22 mo. Lean color of the loins aged for 7 d from the 12M lambs presented greater values of a^* (redness), which could be attributed to a greater myoglobin content that occurs as age increases, influencing a greater oxidative capacity (Gardner et al., 2007; Hopkins et al., 2007; Warner et al., 2007). Khliji et al. (2010) reported that if the L^* and a^* values are equal or above 34 and 9.5, respectively, on average, consumers will consider the meat color acceptable in Australia. Our results showed values of L^* (lightness) and a^* (redness) close to or above that benchmark. In the present study, the b^* values were greater on meat of 4M lambs aged for 7 d, while for 14 d of ageing, the 4M and 6M lambs presented greater values. We expected greater b^* values on meat of the oldest lambs (12M) since grass-fed animals present higher concentrations of carotenoid pigments in IMF (Yang et al., 1992), but probably the myoglobin redox state plays also an important role affecting the b^* coordinate of meat color (Mancini and Hunt, 2005).

Intramuscular fat contributes to the nutritional value, palatability, and consumer acceptability, influencing meat juiciness, flavor, and tenderness (Thompson, 2004; Fowler et al., 2020). Meat of 4M and 12M lambs presented the greatest proportions of IMF. Nevertheless, it was observed that lambs slaughtered at 4 and 6–8 mo of age did not differ between them (IMF: 2.92% and 2.89%, respectively) and had lower IMF proportion than those slaughtered at 12 mo (3.52%) fed on mixed pasture (Ye et al., 2019), and similar results were also reported by Mashele et al. (2017). Intramuscular fat proportions in all 3 groups of lambs were in the range of 4.21%–4.98%. Hopkins et al. (2006) reported that an IMF content close to 5% was required to achieve the mean overall liking score when meat was tasted by consumers. However, these authors indicated that IMF explained only 3% of the variation in overall liking.

Meat fatty acid composition is relevant for consumers in terms of the nutritional value and its impact on human health, but it also influences meat characteristics such as flavor and shelf life (Wood et al., 2003). Regarding SFA, 4M lambs had a greater proportion of C14:0 and C16:0 than 6M and 12M lambs, which agreed with Bas and Morand-Fehr (2000), who observed that milk-fed lambs had a higher composition of myristic (C14:0) and palmitic (C16:0) fatty acids in tissues. Oleic acid is another important fatty acid, which interferes with the oxidative stability of muscles and firmness, thus influencing the flavor, color, and juiciness of the meat (D'Alessandro et al., 2015). In this experiment, 12M lambs showed higher oleic acid (C18:1-n9), which agrees with the Uruguayan heavy lambs slaughtered at 12–13 mo reported by Díaz et al. (2005). The proportions of linoleic acid were higher in 4M and 6M lambs, while the proportions of CLA and linolenic acid were higher in 4M lambs compared to the other 2 groups of lambs. Fatty acid composition of IMF is influenced by ewe milk (Joy et al., 2012) in suckling lambs, and because these lactating animals do not have a fully developed rumen fatty acid biohydrogenation is inefficient (Osorio et al., 2007; D'Alessandro et al., 2012). As a result, a higher proportion of PUFA was found in the younger lambs, which is attributed to the milk ingested from pasture-fed sheep (Gonzales-Barron et al., 2021). Intramuscular fat of 12M lambs presented a greater MUFA proportion compared to the other 2 groups of lambs, while 4M lambs presented a greater percentage of PUFA than 6M and 12M lambs. Agreeing with our results, Ye et al. (2020b) found a greater proportion of MUFA in Merino lambs slaughtered at 12 mo of age than those of the composite breed slaughtered at 4 mo of age, and in addition, a lower proportion of PUFA was found in Merino lambs compared to lambs slaughtered at 4 and 6–8 mo of age. The omega 6/omega 3 ratio in the 3 groups of lambs was below the maximum value of 4, recommended by the Department of Health (1994) of the United Kingdom. This Department (1994) also recommended a PUFA/SFA ratio greater than 0.45, although this value was not achieved by any group of lambs, even in the 4M group. However, the 4M lambs presented a greater ratio, most likely because of lower biohydrogenation. The PUFA are bio-hydrogenated in the rumen by the action of bacteria, which determines a low PUFA/SFA ratio (Harfoot and Hazlewood, 1997; Banskalieva et al., 2000).

Antioxidants such as α-tocopherol are essential in muscle tissue to protect both lipid and myoglobin from oxidation, contributing to extend meat shelf life (Arnold et al., 1993; Faustman et al., 1998). Previous studies have reported concentrations of α-tocopherol necessary to delay oxidative processes and deterioration of lamb meat color, which range from 3.1 to 4.0 mg/kg of muscle (Ponnampalam et al., 2012; Jose et al., 2016; Ponnampalam et al., 2021). In our study, 12M lambs presented the greatest concentration of α-tocopherol in muscle since those lambs grazed for a longer time. Green pastures have high concentrations of α-tocopherol (Li and Liu, 2012) that resulted in concentrations above 3 μg/g of muscle. However, 6M lambs presented a lower α-tocopherol content of 1.8 μg/g of muscle, which agrees with that reported by Petron et al. (2007) in lambs that grazed ryegrass and were slaughtered with the same age. As it was expected, the lowest concentration of α-tocopherol was observed in 4M lambs that were slaughtered after weaning and had a smaller contribution of the pastures in their diets, which could have a detrimental effect on meat shelf life.

Consumer acceptability of meat is affected by cultural aspects, consumption habits, and previous experiences, and furthermore, preferences of sensory attributes are not homogenous among consumers (Font-i-Furnols and Guerrero, 2014). It has been stated that evaluations with consumers are important to understand how their preferences are generated (Font i Furnols et al., 2009; Realini et al., 2009; Chong et al., 2020). Tenderness, juiciness, and flavor represent the main characteristics of meat palatability that are linked to consumer satisfaction (Maltin et al., 2003; Garmyn, 2020). In our study, tenderness liking, flavor liking, and overall liking of meat from 4M lambs were preferred by consumers rather than meat from 12M lambs. Meat of the 6M lambs did not differ from either of the other 2 groups of lambs in the score of its flavor liking and overall liking. It is important to note that the 3 groups of lambs were rated with positive scores, i.e., at least between "like moderately" and "like slightly". Previous research has shown that legs from 15-mo-old sheep was as acceptable as that from 5-mo-old lambs by consumer taste panel in terms of tenderness, flavor, and juiciness (Kirton et al., 1974). Payne et al. (2020) suggested that the age of the animal is less significant than the type of cut in terms of eating quality. Wiese et al. (2005) found no difference in the scores for overall liking assessed by consumers among meat aged for 4 d from lambs with milk teeth, partial eruption of permanent teeth, or both permanent teeth fully erupted. However, these authors also observed that the oldest lambs were scored higher for tenderness and juiciness than the youngest ones. Furthermore, Pethick et al. (2005) found no differences in the consumer overall liking scores between 8.5- mo-old lamb and 20-mo-old sheep for the *biceps femoris* and *longissimus lumborum* muscles. These authors pointed out that when sheep meat is denuded of subcutaneous and intermuscular fat, the flavor becomes less evident and thus the age effect is less relevant.

Results from our experiment showed no differences in tenderness liking, flavor liking, and overall liking scores because of the ageing period (7 vs. 14 d). These findings indicated that extending the ageing period from 7 to 14 d did not affect consumer perception of eating quality attributes of lamb meat.

It is important to recognize that differences observed mainly between 4M and 6M compared to 12M lambs could also be due to a different diet and genetics. Therefore, there would be a confounding effect of diet and genetics implicit in the production system and thus at the age of slaughter.

Conclusions

Results from the present study showed that 12M lambs produced heavier carcasses. Youngest lambs (4M) presented greater fat thickness and CYd. Regarding meat quality, WBSF values of the 3 groups of lambs (4M, 6M, and 12M) would allow us to assert that tender or very tender meats were produced in all cases, which was positively evaluated by the consumer panel. Youngest lambs (4M) presented lighter meat (greater L^* values). A greater PUFA/SFA ratio of IMF and a lower concentration of vitamin E would determine that 4M lamb meat would be more susceptible to lipid and protein oxidation having a negative impact on its shelf life. Overall liking of the meat evaluated by consumers from the 3 types of lambs were scored positively (i.e., at least "I like slightly").

Although some differences in meat quality were observed in lambs up to 12 mo of age, they do not seem to be of such a magnitude as to profoundly affect the quality of the product.

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