The effects of age, sex, and hot carcass weight on cooked lamb flavor and off-flavor in four muscle cuts

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ABSTRACT: The present study used 48 lambs originating from three different locations in the Western United States (16 lambs per location; 8 ewes and 8 wethers per location). Each consisting of similar breed composition (Suffolk cross) that were selected to represent weight by age at harvest treatments: light weight carcasses at 5 mo (**LW5**, 31.81 ± 1.88 kg), light weight carcasses at 12 mo (**LW12**, 35.09 ± 4.45 kg), heavy weight carcasses at 12 mo (**HW12**, 57.89 ± 4.70 kg) with different carcass weight compositions. Older heavy weight lambs (HW12) had greater ($P \leq 0.01$) hot carcass weight, ribeye area, backfat and body wall thickness, and yield grade compared with light weight lamb carcasses (LW5 and LW12). The longissimus thoracis *longissimus thoracis* (**LT**) from older lamb carcasses (LW12 and HW12) had a greater ($P \leq 0.01$) total lipid percentage compared with younger lamb carcasses (LW5). Across harvest weight and age treatments, wether carcasses had greater ($P \leq 0.05$) total lipid percentage compared with ewe carcasses. Slice shear force values were greater ($P \leq 0.01$) for both the LT and *semimembranosus* from older lambs (LW12 and HW12) compared with LW5 lambs, with no differences between ewes and wethers. Lamb flavor intensity was greater ($P \leq 0.05$) for the LT of LW12 lambs and tended ($P = 0.08$) to be greater for HW12 lambs, compared with the LT from LW5 lambs. The off-flavor intensity of the LT was greater ($P \leq 0.01$) for older lambs (LW12 and HW12) compared with LW5 lambs. Interestingly, the lamb flavor and off-flavor intensity scores of the ground shoulder exhibited a treatment × sex interaction. Lamb flavor intensity of LW12 lamb was greater ($P \leq 0.05$) from ewes compared with wethers, whereas wethers had a greater ($P \leq 0.05$) lamb flavor intensity compared with ewes for HW12 lambs, and LW12 ewe lambs had a greater ($P \leq 0.05$) off-flavor intensity compared with all other treatment × sex treatment combinations. Overall, lambs in the present study possessed a mild lamb flavor, typically with greater lamb flavor and off-flavor intensities for older animals; while slice shear force and LT lipid percentage increased as animal age increased at the time of harvest.

Key words: lamb, lamb flavor, meat quality, slice shear force

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INTRODUCTION

The inconsistency of lamb quality in the United States results from the wide range of production management systems including variation

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of breed, diet, and animal age at time of harvest (slaughter endpoints), which in turn affects body composition. Meat palatability consists of three factors: tenderness, flavor, and juiciness. Consumer eating satisfaction of lamb is most commonly influenced by lamb flavor or taste (Hoffman et al., 2016); and therefore, is the most important meat quality factor influencing the consumer's willingness to purchase lamb (Font i Furnols et al., 2009; Oltra et al., 2015).

Sheep meat possesses a distinctive, species-specific flavor profile occasionally referred to as "mutton" when these observed species-specific flavors are greater or more intense. However, the majority of American consumers prefer a mild flavor when consuming lamb (Field et al., 1983). Medium branched-chain fatty acids, 4-methyloctanoic acid, 4-methylnonanoic acid, and 4-ethyloctanoic acid, deposited in the adipose tissue of lambs, have been identified as the primary contributors for the unique species-specific lamb flavor (Wong et al., 1975a; 1975b; Brennand et al., 1989) and have been reported to increase with animal age (Watkins et al., 2010). In the United States, sheep producers and feeders are able to increase their potential profits and revenue by marketing sheep with heavier live body weights; however, a greater body weight results in body composition changes comprised of a greater proportion of fat relative to lean muscle (Ferrell et al., 1979).

For this study, we hypothesized a greater deposition of fat due to a greater body weight at harvest would lead to a greater deposition of these species-specific compounds and increase the lamb flavor intensity of the meat. Therefore, this research aims to investigate the effects of body weight, animal age at harvest, and sex of lambs on instrumental sheep meat quality characteristics and consumer ratings for sheep meat flavor.

MATERIALS AND METHODS

Animal procedures were approved by the Institutional Animal Care and Use Committee (IACUC protocol number 2015A00000023) of The Ohio State University and animal care followed guidelines recommended in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010).

Animals and Treatments

Forty-eight lambs raised in lots from three different Western U.S. states (16 lambs per location; 8 ewes and 8 wethers per location) and similar breed composition (Suffolk × Polypay or Sulffolk × Rambouillet) were randomly selected at the packing plant (JBS; Greeley, CO) to represent weight by age at harvest treatments. Treatments included the following: light weight at 5 mo (**LW5**, 29.03–35.79 ± 1.88 kg), light weight at 12 mo (**LW12**, 24.77–42.23 ± 4.45 kg), heavy weight at 12 mo (**HW12**, 47.17–65.54 ± 4.69 kg) with different carcass weight compositions. Lambs used in the present study were intended to represent different production systems and market channels in the U.S. Lambs obtained from Montana were born in February 2015 and represented a production system with accelerated growth rates, where lambs were raised on a high concentrate-based diet after weaning and harvested at 5 mo of age at a typical market body weight (LW5). Lambs from Utah were born in June 2014 and represented a production system with slower growth rates, where lambs were raised on a forage-based diet after weaning before being finished with a high concentrate-based diet and were harvested at 12 mo of age at a typical market body weight (LW12). Lambs obtained from Wyoming were born in June 2014 and were raised on a concentrate-based diet until being harvested at 12 mo of age and at a heavy body weight (HW12). Location of sourced lambs was considered treatments, with comparisons among and within lamb age and weight at harvest assessed in the present study. Lambs were harvested on the same day in July 2015 at a USDA inspected facility utilizing electrical stimulation (JBS; Greeley, CO), while carcass measurements were determined and recorded by trained personnel from Colorado State University. Carcasses containing spool joints were not awarded a USDA quality grade and one carcass did not have flank streaking or a USDA quality grade recorded. Lamb carcasses were fabricated into wholesale cuts (rack, whole bone-in shoulder, and whole bone-in lamb leg), and vacuum packaged before being shipped via a refrigerated truck to The Ohio State University Meat Science Laboratory (Columbus, OH) for further fabrication, processing, and research analysis.

Carcass Fabrication

At 14 d post-harvest, fresh wholesale cuts were fabricated to yield individual muscle cuts. The *Longissimus thoracis* (**LT**) was removed from the lamb rack (IMPS 204, NAMP) and all subcutaneous fat was removed. A 2.54-cm-thick chop was cut from the posterior end of the LT, butterflied, and allowed

to bloom for 20 min prior to instrumental color assessment. A Model CR-410 Minolta Chroma Meter (Minolta Corp. Ramsey, NJ) fitted with a 50-mm diameter aperture and using a D65 illuminant standardized against a white tile, was used to assess LT lightness (L*), redness (a*), and yellowness (b*). The remaining LT samples and butterflied chop samples were labeled for carcass identification, vacuum packaged and frozen at −25 °C for future lipid, pH, shear force, and sensory evaluation.

Fresh bone-in square cut shoulders (IMPS 207, NAMP) were deboned, ground through a 0.95-cm course plate, and frozen at −25 °C for ground shoulder (**GS**) patty sensory analysis and lipid extraction. The *Gluteus medius* (**GM**) was removed from the lamb leg sirloin boneless roast (IMPS 234G, NAMP) and the *Semimembranosus* (**SM**) was removed from the lamb leg top boneless roast (IMPS 234E, NAMP), and muscles were denuded of external fat. The entire GM and SM muscle cuts were vacuum packaged, and frozen at −25 °C until sensory analysis and shear force testing.

Lipid Extraction

Total lipid extraction was conducted on the butterflied LT lamb chop and GS samples following the methods of Fisher et al. (2013). Samples were finely ground into powder with the use of liquid nitrogen and a mortar and pestle. Two replicates per sample of 2 g powdered tissue were placed inside of double sheeted filter paper for lipid extraction, while the remaining powdered LT samples were held in freezer at −25 °C until pH analysis was conducted. Samples were labeled and weighed within two sheets of folded filter papers to obtain raw weights. Sample packets were freeze dried using a Labconco Freezedryer-6 (Labconco, Kansas City, MO) for 22 to 24 h to remove any moisture present within the samples. After freeze drying, samples were weighed once again to determine moisture percentage. Samples were then placed into Soxhlet glassware for lipid extraction by conducting soxhlet extraction. Each cylinder contained one liter of 87:13 (vol/vol) solution of chloroform:methanol and was allowed to run for 12 h. Samples were allowed to vent under a fume hood for 30 min and subsequently placed into a drying oven set at 100 °C to ensure samples were free of moisture. Finally, samples were weighed again and total extractable lipid percentage was determined using the following equation: ([freeze dried weight – oven dried weight]/ground tissue weight [on a wet basis]) × 100% = % total lipid extracted.

Determination of Muscle pH

Ten grams of ground (powdered) LT muscle, from the butterflied chop frozen at 14 d postmortem, was put into a micro centrifuge tube and a solution containing 5 mM sodium iodoacetate and 150 mM KCL (pH 7.0) at a 1:8 (wt/vol) ratio was added to each sample and homogenized (Bendall, 1973). Samples were centrifuged for 5 min at 12,000 *g* and placed in a heating block set at 25 °C until pH was measured using a pH meter with a Accumet Basic semi-micro pH glass electrode (Fisher Scientific, Waltham, MA). The pH probe was cleaned between sample use and the meter was calibrated daily.

Cooking Procedure

Samples from the LT, GS, GM, and SM were randomly allocated by treatment to cooking and sampling day. The LT, GM, and SM muscle samples were thawed overnight at 0 to 4 °C. The following day, whole muscle samples were removed from packages and trimmed of any remaining external fat and connective tissue. Ground shoulder samples were formed into patties using a burger press template (Weber 6483 Original Burger Press) with patties weighing approximately 227 g prior to cooking. Samples were weighed to determine raw weight and cooked using a clamshell cooking instrument (George Foreman GRP99 Next Generation Grill with nonstick removable plates), at a preheated surface temperature of 190 °C. The internal temperature of samples was monitored using a ThermaData Thermocouple Logger KTC (2 External K type mini-connector inputs) with thermocouple probe (mini needle probe, 8.5 cm, 1.016 mm diameter Type K). A thermocouple probe was inserted into the geometric center of each sample for internal temperature readings. Prior to cooking, the internal temperature was recorded to obtain the initial internal temperature. Pull and peak temperatures of samples were recorded when whole muscle samples were removed at an internal temperature of 65 °C, while shoulder patties were removed at an internal temperature of 71 °C. Cooked weight was recorded on each sample. Cooking loss percentage was calculated by the equation: ([raw weight – cooked weight]/raw weight) × 100.

Slice Shear Force Procedure

Slice shear force (**SSF**) was determined using a modified version of the protocol developed by

Shackelford et al. (2004). Due to the muscle size, shape, and thickness consistency, SSF determination was only performed on the LT and SM muscles and not the GM muscle. Cooked whole muscle LT and SM samples were cut into 2.5 cm chops using a cut box as a template. A minimum of two chops were obtained from each LT sample, while SM muscles were large enough to obtain multiple chops. Cuts were made on each lateral end of the chops to determine muscle fiber orientation, placed in a slice box, and centered to match the 45° cutting slots of the slice box. Using a double-bladed knife, a cut was made parallel to the muscle fibers to obtain a 1 cm thick by 2.54 cm width slice from LT samples and 1 cm thick by 5.0 cm width slice from the SM samples. Furthermore, to achieve the same slice length (5 cm) as previously reported with beef LT (Shackelford et al., 1999a, 1999b), a second slice shear sample from the second chop was laid side by side, matching muscle fiber orientation of the first slice, in the shearing apparatus. Each sample was sheared with a flat, blunt-end blade using the electric testing machine (Model TA. XT 2^{plus}), making sure the shearing blade cut perpendicular to the muscle fibers. The crosshead speed was set at 500 mm/min. Peak force was recorded and measured in kilograms.

Taste Panel Procedure

Muscle samples from the LT, GS, GM, and SM were used for sensory testing. After cooking samples and obtaining shear force slices from only the LT and SM, samples were cut into 1.5 cm cubes for sensory analysis. Cubed sensory samples were placed into individual Ziploc freezer bags and held in a water bath maintained at 65 °C until consumed by panelists.

The decision to use a consumer panel reflected the intent to garner perceptions of Midwest lamb consumers. Specifically, for lamb flavor intensity, an indicator of the "innate" flavor profile, and off-flavor intensity, a possible indicator of the "undesirable," and potentially "off-putting" flavor profiles that could discourage future purchases of lamb products. The consumer taste panel was comprised of graduate students, staff, and faculty from The Ohio State University, Department of Animal Sciences (Columbus, OH). Taste panelists had prior experiences eating lamb and were identified as not being aversive to lamb.

Taste panels for LT and shoulder patty samples were both conducted over an 8-d period, while GM and SM were each conducted over a 2-d period. Taste panels were conducted three times a day at 0900, 1200, and 1500 h offering each panelist eight cooked samples in a session, and with a random order of dissemination. Before testing, panelists were provided instructions for the sensory evaluation process and were asked to not eat for 1 h prior to testing sessions. Panelists were provided a record sheet for each sample, and a set of palate cleansers including unsalted crackers, distilled water, and apple juice. Panelists were instructed to chew samples for at least 5 to 10 s to fully obtain all flavor characteristics present within the sample. Panelists were asked to rate lamb flavor intensity on an end-anchored line scale from 0 to 100, with 0 being very mild and 100 being very intense. Off-flavor intensity was rated by consumer panelists on an end-anchored line scale from 0 to 100, with 0 being very mild and 100 being very intense. Specific off-flavors were recorded by panelist when detected, with off-flavors being defined as anything other than lamb/sheep meat flavor. Specific off-flavors options offered to panelists on the sample ballots included sweet, sour, salty, bitter, umami/meaty, browned, metallic, livery, bloody, grassy, fecal/barnyard, urine/ammonia, and an option to write in other off-flavor descriptor(s).

Statistical Analysis

Statistical analysis was performed using the MIXED procedure in SAS (SAS Inst. Inc., Cary, NC) to analyze carcass characteristics, muscle quality characteristics, and SSF of muscle cuts with animal as the experimental unit. The statistical model used was: $Y_{ijk} = \mu + L_i + S_j + LS_{ij} + e_{ijk}$, where L_i = treatment, S_j = sex, LS_{ij} = the interaction of treatment and sex were fixed effects, and e_{ijk} = the random error. The FREQ procedure in SAS was used to summarize quality grade, yield grade, and break joint percentage by treatment (location) and sex. Quality grade (USDA Choice = 0, USDA Prime = 1) and break joint status (break joint = 0, spool joint = 1) were analyzed with the same fixed effects previously mentioned using the GLIMMIX procedure with a binary distribution model and the logit function. Sensory panel data were analyzed using the GLIMMIX procedure in SAS with the statistical model: $Y_{ijk} = \mu + L_i + S_j + LS_{ij} + P_k + e_{ijk}$, where L_i = treatment, S_i = sex, LS_{ij} = the interaction of treatment and sex, all as fixed effects, P_k = panelist listed as a random effect, and e_{ijk} = the random error. For lamb flavor and off-flavor intensity, a data log transformation was conducted (if necessary) when a non-normal distribution residual

of variance was observed and back-transformed to the 0 to 100 end-anchored scale for interpretation consistent with taste panel scoring procedures. The FREQ procedure in SAS was used to detect the frequency of flavor characteristics identified by panelists and analyzed using the GLIMMIX procedure with a binary distribution model and the logit function. At $P \leq 0.05$, differences between treatments were considered significant and tendencies were identified as $0.05 < P \leq 0.10$.

RESULTS AND DISCUSSION

Carcass Characteristics

In contrast with other studies (Field et al., 1990; Jaborek et al., 2017; Jaborek et al., 2018a), hot carcass weight was not different ($P = 0.12$) between wethers and ewes when days on feed were similar (Table 1). Ribeye area ($P \leq 0.02$) and backfat thickness ($P \leq 0.02$) displayed treatment × sex interactions, where HW12 ewes had a greater ribeye area and a lesser backfat thickness when compared with HW12 wethers, while ewes and wethers within other treatments were similar (Figures 1 and 2, respectively). Interestingly, this treatment × sex interaction for ribeye area and backfat thickness has not been reported by others raising lambs to heavy carcass weights (Crouse et al., 1981; Borton et al., 2005; Jaborek et al., 2018a). However, a greater ($P \leq 0.01$) ribeye area, backfat ($P \leq 0.01$), and body wall thickness ($P \leq 0.01$) for HW12 carcasses compared with LW5 and LW12 carcasses (Table 1) are in accordance with the results reported by others (Crouse et al., 1981; Borton et al., 2005; Jaborek et al., 2018a). Yield grade followed a similar pattern to backfat thickness (treatment × sex interaction; $P \leq 0.02$). The percentage of calculated boneless closely trimmed retail cuts had a treatment × sex interaction ($P \leq 0.01$), where HW12 ewe lamb carcasses had a greater retail yield compared with HW12 wether lamb carcasses (39% vs. 36%, respectively), with no differences between ewe and wether carcasses from other treatments. Although, LW5 and LW12 carcasses had a greater retail yield compared with HW12 carcasses (44% vs. 37%, respectively). Jaborek et al. (2017) also reported a greater percentage of calculated boneless closely trimmed retail cuts from typical market weight lambs compared with the heavy weight, long-fed lambs (~45% vs. ~41%, respectively) reported by Jaborek et al. (2018a).

Carcasses from older lambs (LW12 and HW12) had a greater flank streaking score ($P \leq 0.01$) than LW5 carcasses (Modest vs. Slight), indicating age at slaughter may influence the degree of flank streaking regardless of harvest weight endpoint. Similarly, Field et al. (1990) reported that the degree of fat

Table 1. Least squares means of lamb carcass characteristics within treatment and sex

	Treatment[1]				Sex		
Item	LW5 ($n = 16$)	LW12 ($n = 16$)	HW12 ($n = 16$)	SEM[2]	Ewe ($n = 24$)	Wether ($n = 24$)	SEM[2]
Hot carcass weight, kg	31.8[b]	35.1[b]	57.9[a]	0.9	40.7	42.5	0.8
Ribeye area, cm[2] [3]	13.4[b]	14.9[b]	20.1[a]	0.8	16.6	15.6	0.6
Backfat thickness, cm[3]	0.70[b]	0.83[b]	1.04[a]	0.1	1.04	1.19	0.06
Body wall thickness, cm	2.26[b]	2.46[b]	4.43[a]	0.13	3.03	3.08	0.11
Yield grade [3,4]	3.24[b]	3.65[b]	7.46[a]	0.32	4.48	5.09	0.25
BCTRC, %[3,5]	44.68[a]	44.21[a]	37.50[b]	0.41	42.66	41.60	0.33
Carcass conformation[6]	12.6	12.8	13.1	0.2	12.8	12.9	0.2
Flank streaking score[7]	349[b]	490[a]	558[a]	29	466	464	23
Quality grade[8]							
Choice, %	81.3	56.3	30.8		59.1	56.5	
Prime, %	12.5	37.5	69.2		31.8	43.5	
Break joint, %	100.0	93.6	81.3		87.5	95.8	

[a,b]Treatment means within a row without a common superscript letter significantly differ ($P \leq 0.01$)

[1]Treatments: LW5 = 5 mo light weight lambs; LW12 = 12 mo light weight lambs; HW12 = 12 mo heavy weight lambs

[2]The reported standard error of the mean is the greatest between the levels within the treatment and sex

[3]Variables demonstrated a significant treatment × sex interaction

[4]Yield grade = [((BF / 2.54) × 10) + 0.4]

[5]Percent boneless closely trimmed retail cuts = [49.94 − (0.085 × HCW) + (2.46 × LMA) − (4.38 × BF) − (3.53 × BWT)]

[6]Carcass conformation is based on a numeric scale: 11 = Average Choice, 12 = High Choice, and 13 = Low Prime

[7]Flank streaking score is subjective and based on numeric scale: 300–399 = slight, 400–499 = small, 500–599 = modest

[8]Frequency of quality grades and break joint status within treatment and sex

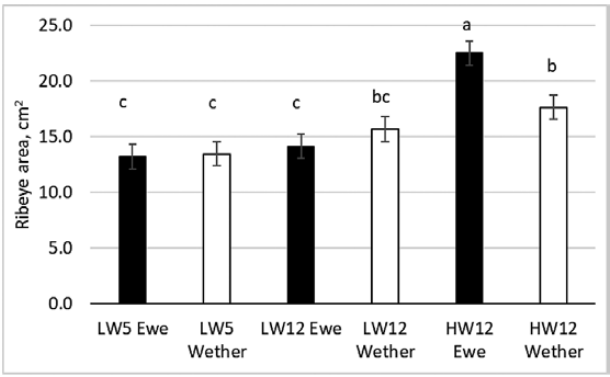

Figure 1. Treatment × sex interaction for ribeye area from lambs. Treatment × sex least squares means without a common letter (a,b,c) are significantly different ($P \leq 0.05$).

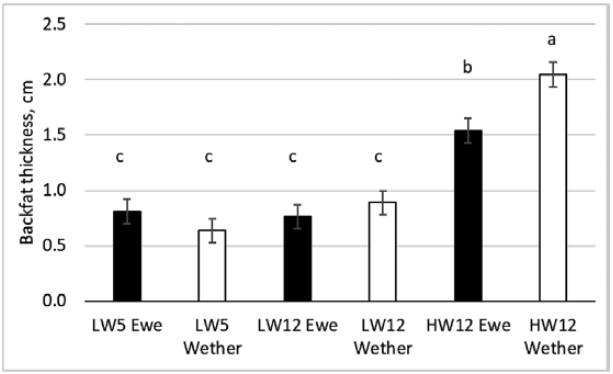

Figure 2. Treatment × sex interaction for backfat thickness from lambs. Treatment × sex least squares means without a common letter (a,b,c) are significantly different ($P \leq 0.05$).

flank streaking increased as lamb age at harvest increased, but there were no differences between the fat flank streaking from ewe and wether carcasses. The diets offered to lambs used in the present study were not controlled and therefore, the influence of diet contributing to the effect of age on flank streaking is not known. While not significantly different ($P = 0.28$), a greater frequency of LW5 carcasses quality graded Choice (13/16), while LW12 carcasses were more balanced between Choice (9/15) and Prime (6/15) quality grades, and the majority (9/13) of HW12 carcasses graded USDA Prime (Table 1).

There were no significant differences ($P = 0.99$) for break joint status, as all carcasses from young lambs (LW5) had break joints, allowing these carcasses to be classified as "lamb maturity." While 1/16 LW12 carcasses had a spool joint and 3/16 HW12 carcasses had spool joints. One wether carcass had a spool joint, while three ewe carcasses had spool joints ($P = 0.99$). As lambs begin to reach puberty, sex hormones ossify the epiphyseal growth plate or "break joint" (Ho et al., 1989; Field et al., 1990). Ho et al. (1989) reported that at 459 days of age, 40% and 0% carcasses from ewes and wether lambs, respectively, had spool joints, while at 557 days of age all (100%) ewe carcasses had spool joints and only 20% wether carcasses had spool joints. The occurrence of spool joints in the present study indicates that lambs in the LW12 and HW12 treatments were beginning to approach "yearling lamb" maturity (USDA, 1992).

Longissimus pH and Color

The ultimate pH (Table 2) of the LT was not different between treatment ($P = 0.22$) or sex ($P = 0.55$). Similarly, Hopkins et al. (2007) reported no difference in pH at 24 h in the *longissimus lumborum* muscle of lambs of 4, 8, 14, and 22 mo of age. In the present study, CIELAB L* values from the LT were greater ($P \leq 0.01$), indicating a lighter appearance, for LW5 and HW12 carcasses when compared with the LT of LW12 carcasses, while no differences were detected due to sex. Furthermore, CIELAB a* values (redness) tended ($P = 0.09$) to be greater for the LT from LW5 and HW12 carcasses compared with the LT from LW12 carcasses and b* values (yellowness) tended ($P = 0.06$) to be greater from the LT of HW12 carcasses compared with the LT from light weight lamb carcasses (LW5 and LW12). However, CIELAB a* values were greater ($P \leq 0.05$) and CIELAB b* values tended ($P = 0.06$) to be greater in the LT from wethers when compared with the LT of ewes.

Lipid Concentration

Lipid concentrations from the LT and GS are presented in Table 3. The extractable lipid percentage from the LT of older lamb carcasses (LW12 and HW12) was greater from wethers compared with ewes, while there was no difference between wether and ewes in the LW5 treatment (treatment × sex; $P \leq 0.01$; Figure 3). In contrast, many studies agree that intramuscular fat deposition in lambs increases with increasing animal age, regardless of sex (Pethick et al., 2005; Hopkins et al., 2006; McPhee et al., 2008; Jaborek et al., 2018b). In the present study, intramuscular fat deposition was influenced predominantly by animal age rather than body weight, even though HW12 carcasses had greater amounts of carcass fat elsewhere (subcutaneous and intermuscular) compared to light weight lambs (LW5 and LW12). For example, in the LT, older lambs (LW12 and HW12) had a greater total lipid concentration ($P \leq 0.01$) compared with LW5 lambs. In general, wether carcasses had a greater ($P \leq$

0.05) total lipid percentage in the LT compared with ewe carcasses. In agreement, McPhee et al. (2008) and Jaborek et al. (2018b) reported that wethers had or tended to have a greater intramuscular fat percentage in the l*ongissimus* muscle compared with ewes.

Lipid concentration of the GS was greater ($P \leq 0.05$) from HW12 carcasses compared with light weight (LW5 and LW12) carcasses, which is indicative of a greater amount of intramuscular fat (marbling), intermuscular (seam fat), and subcutaneous fat cover of the shoulder region. This finding is associated with a greater backfat and body wall thickness measurement for HW12 lamb carcasses as mentioned earlier. Similarly, Jaborek et al. (2018b) reported a greater GS fat percentage from heavy weight, long-fed lambs compared with typical market weight lambs. There was no difference in GS lipid percentage between ewe and wether carcasses, which may be due to a similar backfat and body wall thickness.

Slice Shear Force

SSF measurements for the LT and SM muscles are presented in Table 3. The SSF values were shown to be greater ($P \leq 0.01$) in older 12 mo lambs (LW12 and HW12) when compared with the young, 5 mo lambs in both the LT and SM muscles. Hopkins et al. (2007) reported that young lambs (4 and 8 mo old) had lesser Warner-Bratlzer shear force values in the *longissimus lumborum* muscle compared with 14 mo lambs after 5 d of aging. Similarly, Bouton et al. (1978) evaluated Warner-Bratlzer shear force values of four leg muscles (*biceps femoris*, *semimembranosus*, *semitendinosus*, and *gluteus medius*) from sheep carcasses and determined peak force required to cut through samples increased with animal age from 2 mo to 6 yr old. Shackelford et al. (2012) reported mean SSF values in lamb *longissimus* muscle, aged 7 d postmortem, from lambs with an average age of 7 mo at the time of harvest to range between 19.8 and 26.3 kg.

Table 2. Least squares means of ultimate pH and color characteristics of the *longissimus thoracis* from lamb carcasses

	Treatment[1]				Sex		
Item	LW5 (n = 16)	LW12 (n = 16)	HW12 (n = 16)	SEM[2]	Ewe (n = 24)	Wether (n = 24)	SEM[2]
pH	5.69	5.73	5.67	0.03	5.68	5.70	0.02
Lean color[3]							
L*	41.19[a]	38.16[b]	40.45[a]	0.53	39.64	40.23	0.43
a*	26.38	25.48	26.76	0.41	25.65[e]	26.76[d]	0.33
b*	7.89	7.53	8.74	0.35	7.66	8.45	0.28

[a,b]Treatment means within a row without a common superscript letter significantly differ ($P \leq 0.01$).

[d,e]Sex means within a row without a common superscript letter significantly differ ($P \leq 0.05$).

[1]Treatments: LW5 = 5 mo light weight lambs; LW12 = 12 mo light weight lambs; HW12 = 12 mo heavy weight lambs.

[2]The reported standard error of the mean is the greatest between the levels within the treatment and sex.

[3]Lean color: L* = lightness, a* = redness, and b* = yellowness.

Table 3. Least squares means of lipid concentration of the *longissimus thoracis* and ground shoulder and slice shear force measurement of the *longissimus thoracis* and *semimembranosus* muscles from lamb carcasses

	Treatment[1]				Sex		
Item	LW5 (n = 16)	LW12 (n = 16)	HW12 (n = 16)	SEM[2]	Ewe (n = 24)	Wether (n = 24)	SEM[2]
Total lipid (%)							
L. thoracis	2.92[b]	5.10[a]	4.78[a]	0.37	3.82[h]	4.71[g]	0.31
Ground shoulder	17.70[e]	18.90[e]	23.47[d]	1.42	19.95	20.14	1.16
Slice shear force, kg							
L. thoracis	10.0[b]	13.3[a]	12.8[a]	0.7	11.8	12.3	0.6
Semimembranosus	17.3[b]	20.0[a]	19.4[a]	0.7	19.0	18.9	0.5

[a,b]Treatment means within a row without a common superscript letter significantly differ ($P \leq 0.01$).

[d,e]Treatment means within a row without a common superscript letter significantly differ ($P \leq 0.05$).

[g,h]Sex means within a row without a common superscript letter significantly differ ($P \leq 0.05$).

[1]Treatments: LW5 = 5 mo light weight lambs; LW12 = 12 mo light weight lambs; HW12 = 12 mo heavy weight lambs.

[2]The reported standard error of the mean is the greatest between the levels within the treatment and sex.

Additionally, Jaborek et al. (2018b) reported SSF values of 16.2 and 15.1 kg in typical market weight and heavy weight long-fed lambs, respectively, in the LT muscle (aged for 14 d postmortem). Similar to the present study, Jaborek et al. (2018b) reported no SSF differences between ewes and wethers. In the present study, SSF values were shown to be lesser in comparison with previous studies, which may be due to the combination of a longer aging period (14 d postmortem) of the LT and the use of electrical carcass stimulation during harvest to improve muscle tenderness. Captive-bolt stunning without the use of electrical stimulation methods were reported in both Shackelford et al. (2012) and Jaborek et al. (2018b) studies. Furthermore, SSF values in the present study would be considered "very tender" according to Igo et al. (2015), who reported the beef *longissimus* muscle as "very tender" at a SSF value below 14.5 kg.

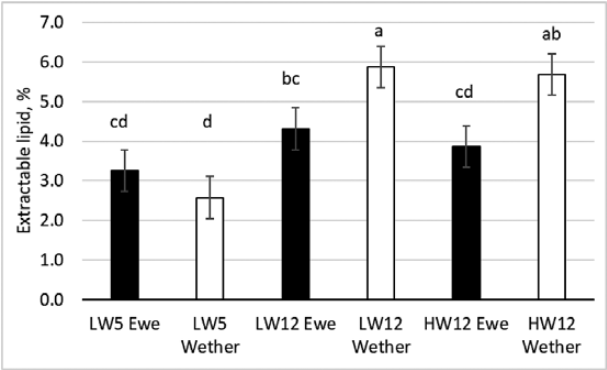

Figure 3. Treatment × sex interaction for the percentage of lipid extracted from the *longissimus thoracis* from lambs. Treatment × sex least squares means without a common letter (a,b,c,d) are significantly different ($P \leq 0.05$).

Taste Panel

Table 4 presents consumer lamb flavor and off-flavor intensity scores for samples from the LT, SM, GM, and GS patty. Lamb flavor intensity scores of the LT were lesser ($P \leq 0.05$) from LW5 lambs when compared with LT samples from both LW12 and HW12 lambs. Furthermore, panelists rated LW5 lambs to have a lesser ($P \leq 0.01$) off-flavor intensity in the LT than LW12 and HW12 lambs. Taste panelists tended ($P = 0.06$) to record browned off-flavor notes more frequently from LT samples from HW12 lambs compared with LW5 and LW12 lambs. In the SM, lamb flavor intensity tended ($P = 0.08$) to be greater for LW12 lambs,

Table 4. Flavor intensity of cooked *longissimus thoracis*, *semimembranosus*, *gluteus medius*, ground shoulder patty samples from lambs

		Treatment[1]				Sex		
Item	Flavor characteristic	LW5 ($n = 16$)	LW12 ($n = 16$)	HW12 ($n = 16$)	SEM [2]	Ewe ($n = 24$)	Wether ($n = 24$)	SEM[2]
Natural log transformation								
Longissimus thoracis	Lamb flavor	3.32^{e}	3.52^{d}	3.46^{de}	0.13	3.42	3.44	0.13
	Off-flavor	−0.61^{b}	0.15^{a}	0.18^{a}	0.42	−0.24	0.05	0.40
Semimembranosus	Lamb flavor							
	Off-flavor[3]	0.16^{b}	1.20^{a}	0.66^{ab}	0.51	0.82	0.53	0.50
Gluteus medius	Lamb flavor							
	Off-flavor	0.72	0.91	0.53	0.44	0.86	0.58	0.42
Ground shoulder	Lamb flavor	3.56	3.48	3.52	0.10	3.52	3.52	0.10
	Off-flavor	0.01	0.50	0.21	0.52	0.39	0.08	0.51
Back transformation[4]								
Longissimus thoracis	Lamb flavor	27.7^{e}	33.7^{d}	31.7^{de}		30.7	31.2	
	Off-flavor	0.5^{b}	1.2^{a}	1.2^{a}		0.8	1.1	
Semimembranosus	Lamb flavor	33.6	39.0	36.4	5.0	35.9	36.7	4.9
	Off-flavor[3]	1.2^{b}	3.3^{a}	1.9^{ab}		2.3	1.7	
Gluteus medius	Lamb flavor	37.8	40.5	38.9	4.5	39.7	38.5	4.4
	Off-flavor	2.1	2.5	1.7		2.4	1.8	
Ground shoulder	Lamb flavor	35.3	32.5	33.6		33.8	33.7	
	Off-flavor	1.0	1.6	1.2		1.5	1.1	

[a,b]Treatment means within a row without a common superscript letter significantly differ ($P \leq 0.01$).

[d,e]Treatment means within a row without a common superscript letter significantly differ ($P \leq 0.05$).

[1]Treatments: LW5 = 5 mo light weight lambs; LW12 = 12 mo light weight lambs; HW12 = 12 mo heavy weight lambs.

[2]The reported standard error of the mean is the greatest between the levels within the treatment and sex.

[3]Variable demonstrated a treatment × sex interaction.

[4]The back transformation is on a 0 to 100 scale, where 0 = very mild and 100 = very intense.

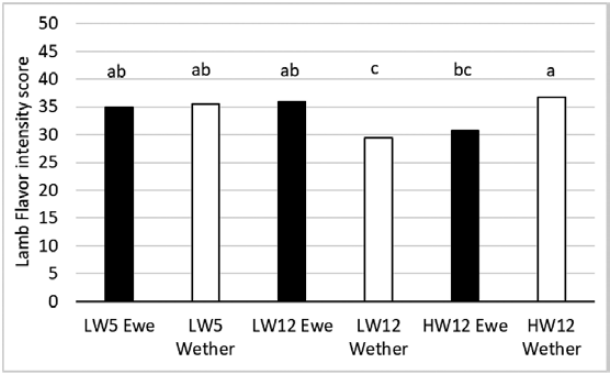

Figure 4. Treatment × sex interaction for the lamb flavor intensity from the ground shoulder patty. Treatment × sex least squares means without a common letter (a,b,c) are significantly different ($P \leq 0.05$).

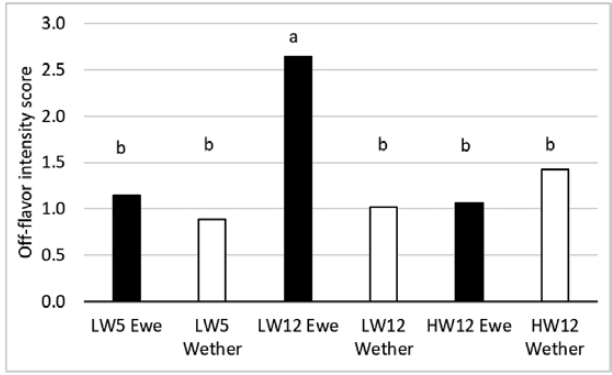

Figure 5. Treatment × sex interaction for off-flavor intensity from the ground shoulder patty. Treatment least squares means without a common letter (a,b) are significantly different ($P \leq 0.05$).

while the off-flavor intensity of LW12 lambs was greater ($P \leq 0.01$) compared with LW5 lambs. The off-flavor intensity of the SM tended ($P = 0.08$) to have a treatment × sex interaction, where LW12 wethers had a much greater off-flavor intensity and LW5 wethers had a lesser off-flavor intensity compared with other treatment × sex combinations. Livery off-flavors in SM samples were recorded more frequently ($P \leq 0.01$) by panelists from LW12 lambs compared with LW5 and HW12 lambs. While bloody off-flavors tended ($P = 0.08$) to be recorded more frequently by panelists from LW12 lambs compared with HW12 lambs. No differences ($P > 0.05$) in lamb flavor and general off-flavor intensity were noted for GM samples between treatment and sex. For GM samples, livery off-flavors were recorded more ($P \leq 0.05$) frequently by panelists from LW12 lambs compared with LW5 lambs. Between ewes and wethers, specific off-flavor notes were only reported for the GM samples, as GM samples from ewes had more sour off-flavors ($P \leq 0.05$), tended to have more livery off-flavors ($P = 0.07$), and less umami off-flavors ($P = 0.07$) compared with wethers. Light weight 12 mo old wethers had a lesser lamb flavor intensity score for the GS patty compared with LW12 ewes, while HW12 wethers had a greater lamb flavor intensity score compared with HW12 ewes (treatment × sex; $P \leq 0.01$; Figure 4). Light weight 12 mo ewes had a greater (treatment × sex; $P \leq 0.05$) off-flavor score compared with all other treatment × sex combinations (Figure 5).

In agreement with the present study, Jeremiah et al. (1998) reported that generally lamb flavor intensity of boneless shoulder roasts increased with advancing age (3 to 15 mo) and harvest weight (31.8 to 76.8 kg) of sheep. Additionally, Jaborek et al. (2020) reported a numerically greater lamb flavor and off-flavor intensity with increasing age between lambs, yearlings, and mature ewes, and a greater lamb flavor and off-flavor intensity for older, heavy weight, long-fed lambs compared with younger, typical market weight lambs. Using subcutaneous fat samples from sheep in the study conducted by Jaborek et al. (2020), Castada et al. (2017) reported that a greater concentration of 3-methylindole (skatole), 4-methyloctanoic acid, 4-methylnonanoic acid, and 4-ethyloctanoic acid corresponded with a greater lamb flavor intensity rating. The concentration of branched-chain fatty acids, 4-methyloctanoic acid, 4-methylnonanoic acid, and 4-ethyloctanoic acid, which are responsible for the species-specific flavor of sheep meat, also increase with advancing animal age (Watkins et al., 2010) and may be the reason for the findings in the present study. Many studies compare the harvest weight of lambs with similar nutritional management, but differing time on feed or animal age. The present study is unique, where the nutritional management was different to allow for a similar age comparison (LW12 vs. HW12) between lambs. Interestingly, across the four muscle cuts studied, HW12 lambs were typically intermediate for lamb flavor and off-flavor intensity scores compared with LW12 and LW5 lambs. Therefore, it may be that the additional fat deposition for HW12 lambs compared with LW12 lambs led to a diluted concentration of branched-chain fatty acids, resulting in a lesser flavor intensity. Overall, in the present study, average lamb intensity scores across muscles were relatively mild (>41), and off-flavor intensity scores were low (>3), considering the scale from 0 to 100.

In conclusion, the present study reports the effects of sheep age, harvest weight, and sex on lamb carcass composition, meat quality attributes, and the flavor profile. We recognize the prior management used to raise these lambs was uncontrolled and could have influenced the results of the present study. Herein, as demonstrated by the HW12 lambs,

allowing lambs to grow to heavier harvest weights shifts carcass conformation toward a greater ratio of fat to lean muscle, resulting in a substantially lesser percentage of boneless closely trimmed retail cuts. The additional weight and fat stored on the carcass did not translate to greater marbling deposition when compared with lambs of a similar age, but older lambs did have a greater LT lipid percentage compared with younger lambs, particularly wethers compared with ewes. Very few differences for muscle pH and lean color were observed in the present study. Tenderness of the LT and SM were lesser at a greater age in lambs. Older lambs had a greater lamb flavor and off-flavor intensity of the LT and SM compared with younger lambs, but had similar lamb flavor and off-flavor intensities in the GM. Overall, animal age demonstrated meat quality differences that could potentially deliver inconsistent eating experiences to lamb consumers. Therefore, sheep meat products should be categorized by age and diet to increase the likelihood of a desirable lamb eating experience by consumers on a consistent basis.

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