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Effects of Marbling and Postmortem Aging on Consumer Assessment of United States Lamb Loin

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Abstract: Consumer sensory analysis was performed to evaluate the effects of three marbling categories [LOW, Intermediate (MED), and HIGH] and 2 postmortem aging categories (21 d and 42 d) on the palatability of lamb loin chops as determined by U.S. consumers and to determine the relationship between marbling, flank streaking, intramuscular fat percentage (IMF), and palatability traits. Marbling and aging did not interact to affect any of the scores for palatability attributes, their acceptances, or the frequency of their overall eating quality classifications ($P < 0.05$). Consumers rated HIGH treatments ($P < 0.05$) as more tender, juicier, and with greater flavor liking and overall liking than MED or LOW, which were similar for all traits ($P > 0.05$). Aging also influenced ($P < 0.05$) all traits, as consumers scored 21 d samples greater for all palatability traits than their 42 d counterparts. A greater ($P < 0.05$) percentage of consumers categorized 42 d samples as 'unsatisfactory' and fewer as 'better than everyday' or 'premium quality' than 21 d samples. A larger proportion of consumers categorized HIGH samples as 'premium quality' than MED or LOW and fewer called HIGH 'good everyday quality' compared to MED ($P < 0.05$). Flank streaking, marbling score, and IMF were all influenced ($P < 0.01$) by marbling category in a linear fashion. Increasing marbling score, more so than flank streaking, was positively linked to increasing eating quality scores. Also, tenderness, juiciness and flavor liking are major drivers for consumer sensory scores for overall liking, with flavor liking having the strongest relationship to overall liking of lamb. Overall, consumers preferred HIGH marbling over LOW and MED marbling loin chops, but had difficulty distinguishing between LOW and MED. Furthermore, extending postmortem aging of lamb loin from 21 to 42 d reduced scores for eating quality traits.

Keywords: consumer, lamb, longissimus, marbling, postmortem aging
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Introduction

Numerous factors influence the overall palatability of meat. While several studies in beef have shown a distinct link between the palatability traits of tenderness, juiciness and flavor and overall liking, some identify tenderness as the most important factor in regards to beef palatability (Miller et al., 1995, 2001; Savell et al., 1987). Other studies have shown that flavor plays an equal role, if not more important, especially when tenderness is acceptable (Killinger et al., 2004; Neely et al., 1998; O'Quinn et al., 2012; Sitz et al., 2005). However, Hunt et al. (2014) declared all 3 traits played major roles in overall liking. These same traits play a major role in lamb palatability as well. Flakemore and Sherifat (2017) observed significant differences between individual consumers for all sensory traits, including tenderness, juiciness, taste, and aroma, indicating clear variability in what consumers consider acceptable quality of cooked lamb product. It has been shown that consumer preference and frequency of consumption/exposure to lamb have played a role in liking of flavor (Cunha De Andrade et al., 2016; Sañudo et al., 1998).

Marbling or intramuscular fat (IMF) level influences consumer acceptance of meat. Several researchers have shown that consumer scores for beef tenderness, juiciness, flavor, and overall liking increased with increased marbling (Lorenzen et al., 1999, 2003; O'Quinn et al., 2012; Savell et al., 1987). Additionally, scores for beef tenderness, juiciness, and flavor increased with increased marbling levels according to trained panelists (Emerson et al., 2013; Garmyn et al., 2011). This trend holds true in lamb, as Pannier et al. (2014) found that increased IMF levels increased consumer scores of lamb loin samples, most notably juiciness, overall liking, and flavor.

Postmortem aging has also been identified as a factor affecting consumer acceptance of meat. Postmortem aging in beef can increase tenderness (Smith et al., 1978; Savell et al., 1981). Likewise, Duckett et al. (1998) reported that shear force values of lamb decreased with increased postmortem aging from d 1 to d 12. Lamb continued to tenderize from d 12 to d 24, but at a much slower rate (Duckett et al., 1998). Lamb aging in the United States typically ranges from 10 to 42 d (USDA, 2011). We chose an extended aging period of 42 d of postmortem aging to be representative of imported lamb that ages for an extended amount of time during chilled sea freight. We realize chilled sea freight temperatures are likely lower than the chilled storage temperatures in the current study; however, we wanted to quantify what, if any, effect extended aging of United States lamb would have on United States consumers' opinion of lamb.

Likely because lamb is the least consumed of the red meats by United States consumers (Duckett et al., 1998), few studies have extensively analyzed consumer preferences of lamb combined with compositional and shear force analyses. Therefore, the objective of this study was to evaluate the effects of marbling category and postmortem aging on the palatability of lamb loin chops as determined by U.S. consumers and to determine the relationship between marbling, flank streaking, intramuscular fat percentage (IMF), and the palatability traits of tenderness, juiciness, flavor liking, and overall liking.

Materials and Methods

Carcass selection

Carcasses were selected at a commercial lamb processing facility in Greeley, CO. After the carcass chilling period (approximately 24 h), trained Texas Tech University personnel examined lamb carcasses prior to fabrication. Due to the time constrictions between ribbing (making a cut at 12th/13th rib interface to begin separation of hindsaddle from foresaddle) and fabrication, selection for marbling occurred very rapidly (within 5 to 10 s) by assessing the longissimus muscle at the posterior surface of the rack. Currently, no marbling reference cards exist for the use of marbling determination in lamb. Pork marbling standards (PMS) correspond to intramuscular fat content, where PMS 1 should have 1% IMF and PMS 5 should have 5% IMF. Due to the rapid selection that had to take place and ease of use of PMS cards, pork marbling standards were used for initial selection at the processing facility. Carcasses were classified as LOW (PMS 1), intermediate (MED; PMS 2), or HIGH (PMS 3+) based on images from the pork quality standards (American Meat Science Association, 2001c). If carcasses were selected for the study, carcass data were collected including: marbling score (1 to 5 as described above) and flank streaking (200 = traces^{00}, 300 = slight^{00}, 400 = small^{00}, 500 = modest^{00}, 600 = moderate^{00}, 700 = slightly abundant^{00}). Flank streaking was evaluated based on the fat streakings within and on the inside flank muscles (American Meat Science Association, 2001b). Carcasses (n = 205; 65 to 70/marbling category) were tagged according to the treatment for which they were selected. Extra loins were selected from each category to ensure 60 loins would ultimately fit into each marbling category.

Loins (Institutional Meat Purchase Specifications #232; 1 × 1, USDA, 2014) were obtained from these carcasses, vacuum packaged, boxed, and shipped under refrigeration to Texas Tech University Gordon W. Davis Meat Laboratory, Lubbock, and stored at 2 to 4°C until 21 d postmortem.

Loin fabrication

Loin trimming and chop cutting was completed on 21 d postmortem in a chilled room maintained at 2 to 4°C. Packages were opened, allowing for oxygenation of the loin eye (exposed longissimus at the anterior end of the loin) for 10 min. Following a 10-min bloom period, marbling was assessed using USDA beef marbling standards (200 = traces^{00}, 300 = slight^{00}, 400 = small^{00}, 500 = modest^{00}, 600 = moderate^{00}, 700 = slightly abundant^{00}) by a single trained evaluator (American Meat Science Association, 2001a). Marbling was reassessed using beef (as opposed to pork) standards so that similar scales were used for flank streaking and marbling, and so that marbling could be assessed using a wider spectrum scale as opposed to discrete marbling categories (1 to 5). Marbling was assessed to ensure loins were classified appropriately on d 1. At this time, any extra loins were removed from the study so that only 60 loins per treatment remained with the following 21 d marbling score ranges: LOW = slight^{00} – slight^{90}, MED = small^{00} – modest^{20}, HIGH = modest^{50} – slightly abundant^{40}.

Both tenderloins were removed, followed by all bone. The longissimus lumborum from each side was excised from the loin, separating it from the flank, all secondary muscles (gluteus medius), and any external fat. Longissimus muscles were trimmed of any visible external fat and connective tissue. Right and left longissimus muscles were assigned randomly to 21 or 42 d postmortem aging within each marbling treatment.

On d 21 postmortem, all longissimus muscles, regardless of aging assignment, were manually cut into 2.54 cm thick chops, resulting in 7 to 9 chops per longissimus muscle. The anterior-most chop was designated for compositional analysis, followed by Warner-Bratzler shear force (WBSF) analysis (chop 2), consumer sensory analysis (chops 3 to 5), flavor analysis (chop 6; not used in this study), and any remaining chops (7+) were labeled as extra. Chops were individually vacuum packaged under 5 millibars using 3.5 mil thermoform vacuum packaging (moisture vapor transmission: 4.8 g/m2/d; Multivac F100; Kansas City, MO) and stored at 2 to 4°C. After the appropriate aging period (either 0 d or an additional 21 d as individually vacuum-packaged chops at 2 to 4°C), chops were frozen at –20°C until further analysis.

Preparation of samples for compositional analysis

Raw lamb longissimus samples were thawed, sliced, frozen in liquid nitrogen, and homogenized into a fine powder. Homogenized samples were individually identified and placed in bags (Whirl-Pak, Nasco, Fort Atkinson, WI) and stored at –80°C until analysis.

Protein analysis

Protein analysis was conducted using an approved Association of Official Analytical Chemists International (AOAC) protocol (AOAC, 2005) for the *LECO TruMacN* (St. Joseph, MI). The machine was calibrated by inserting empty boats to run as blanks, and then ethylenediaminetetraacetic acid (EDTA) standard calibration samples were run. Following EDTA calibration, samples were run by adding 0.3 g of sample into each boat on the carousel, ensuring sample identification and sample weight were properly inputted. Percent nitrogen was converted to percent protein using a conversion factor of 6.25%.

Total fat

Total fat analysis was conducted using a modification of the chloroform: methanol method described by Folch et al. (1957) found in AOAC 983.23 (AOAC, 2012). One gram of the frozen, powdered sample was weighed, and the lipid portion was extracted using chloroform and methanol. The extract was evaporated to dryness on a heating block inside a fume hood for 10 min. The remaining residue was dried in a 101°C drying oven (6905, Thermo Fisher Scientific, Waltham, MA) until a constant weight was obtained. Tubes were cooled and weighed to obtain a final percentage of total lipid.

Moisture analysis

Moisture analysis was conducted following the AOAC protocol (AOAC, 2005) using 5 grams (± 0.05 g) of the frozen, powdered sample that was weighed into the crucibles. After the sample was properly weighed and recorded, crucibles were placed into the drying oven (100°C) for 16 h. Crucibles were then removed from the drying oven and placed into desiccators for at least 30 min to remove any remaining moisture and to cool. Crucibles were then weighed to calculate the percentage of moisture in each sample.

Ash analysis

Following the completion of the moisture analysis, crucibles were then placed into a muffle furnace (F30420C, Thermo Fisher Scientific). Temperature of the muffle furnace was gradually increased (100°C per h) until reaching an endpoint temperature of 550°C. Once the final temperature was achieved, the samples remained in the muffle furnace for at least 24 h. After the 24 h, samples were cooled by placing into desiccators for at least 30 min or until completely cool. Once cool, the crucibles were weighed to calculate the percentage of ash in each sample.

Warner-Bratzler Shear Force (WBSF)

Prior to cooking, chops were thawed for 24 h at 2°C. After thawing, chops were weighed, and temperature was recorded. Temperature was measured in the geometric center of each sample with a Super-Fast Thermapen (Thermoworks; Lindon, UT) digital meat thermometer. Chops were cooked on a Silex clamshell grill with the top plate set at 180°C and the bottom plate set at 205°C (Model S-143L, Silex Grills Australia Pty Ltd., Marricksville, Australia) targeting a medium degree of doneness (71°C). Cooking was conducted using a strict time schedule. Each cooking round consisted of ten chops. Chops were cooked for a total of 3 min. After cooking, chops were unloaded from the grill and allowed to rest for 45 s. After the 45-s rest period, chops were weighed, and temperatures were recorded. The chops were then placed on metal trays, covered with polyvinyl chloride film and chilled at 2°C for 24 h. Warner-Bratzler shear force values were obtained by removing three to five 1.3-cm cores from chops parallel to the longitudinal muscle fiber orientation. According to Shackelford et al. (2004), WBSF of 4 cores (obtained from 2 separate chops) was able to produce highly repeatable estimates of lamb longissimus muscle tenderness. Cores were sheared once, perpendicular to the muscle fibers using a WBSF analyzer (G-R Electric Manufacturing, Manhattan, KS). The Warner-Bratzler head moved at a crosshead speed of 200 mm/min. Shear force values were recorded in kg and the values from the cores from each chop were averaged for statistical analysis.

Consumer sensory analysis

The Texas Tech University Institutional Review Board approved procedures for the use of human subjects for consumer sensory panel evaluations. Consumer panels were conducted in various cities across the United States (Lubbock, TX; Stillwater, OK; Logan, UT; Clemson, SC; and Hicksville, OH). Panels were conducted in large classrooms, sensory rooms or banquet-style rooms with fluorescent lighting. Panelists (n = 360) were recruited from the local communities in the various cities and were compensated for their participation. Consumers were screened for whether and how often they consumed red meat, particularly lamb and beef. Moreover, potential panelists had to eat red meat at least once every 2 wk, be within the ages of 18 and 79, be willing to eat meat cooked to a medium degree of doneness, and could only participate one time. Panel sessions were conducted with 20 consumers per session, with 3 panels per night at most locations, lasting approximately 45 min per session.

Panelists were seated in numbered booths and were provided with an information sheet, ballot, expectorant cup, fork, knife, napkin, and toothpick. Unsalted crackers, diluted apple juice (10% apple juice, 90% water), and water were provided as palate cleansers. Each ballot contained a demographics information portion, 7 sample evaluation ballots, a lamb pricing expectation sheet and a recipient information sheet. Verbal instructions were given to consumers prior to each panel regarding the ballot, the procedure to follow for the panel, and the use of palate cleansers. Panelists were instructed to cut samples into pieces representative of the size consumed per bite during in home steak or chop consumption.

Cooking procedures were identical to those described for WBSF, but samples were not weighed, and temperature was not recorded. Samples were thawed at 2 to 4°C for 24 h prior to consumer evaluation and cooked using a Silex clamshell grill (Model S-143L, Silex Grills Australia Pty Ltd., Marricksville, Australia). The grill was preheated with the top plate set at 180°C and the bottom plate set at 205°C 30 min prior to the start of the panels. Before any test samples were cooked, ten chops (unrelated to the trial) were placed onto the Silex grill to ensure the proper heating of the grill and to begin the cooking cycle. Each cooking round consisted of ten chops. Samples were cooked for 3 min, followed by a 45-s rest period. Following the rest period, chops were cut into 2 equal portions and served to 2 predetermined consumers. Ultimately, each longissimus muscle was tested by 6 different assessors (3 chops, each cut in half).

Consumers evaluated 7 samples, with 6 of the samples being fed in a predetermined and balanced order, representing the different treatments (LOW 21 d, LOW 42 d, MED 21 d, MED 42 d, HIGH 21 d, HIGH 42 d). All consumers received a chop unrelated to the treatment design with mid-level marbling aged 21 d to acquaint consumers to lamb with hypothetical good everyday quality and to provide linkage over all the testing days and locations. The consumers rated the 7 samples for tenderness, juiciness, flavor liking, and overall liking using 100-mm continuous line scales. Zero anchors were labeled as not tender, not juicy, dislike extremely; the 100-mm anchors were labeled as very tender, very juicy, and like extremely. Consumers were also asked to rate each palatability trait as either acceptable or unacceptable for each sample. Finally, consumers were asked to rate the quality of each lamb sample as unsatisfactory, good everyday quality, better than everyday quality, or premium quality.

Statistical analysis

All data were analyzed as a split plot design using the GLIMMIX procedure of SAS (Version 9.4; SAS Inst. Inc., Cary, NC) with fixed effects of aging, marbling, and their interaction. For WBSF, cook loss was also included as a covariate ($P < 0.01$). Location and consumer nested within testing night, as well as loin nested within marbling level, were included as random effects for sensory attributes. Tenderness, juiciness, flavor liking, and overall acceptability, as well as the frequency of each eating quality category were analyzed as binomial proportions using the GLIMMIX procedure of SAS, with the ILINK option of the LSMEANS statement used to calculate least squares means for the proportions. Treatment least squares means were separated with the PDIFF option of

SAS using a significance level of $P < 0.05$. Denominator degrees of freedom were calculated using the Kenward-Roger approximation. Procedure FREQ of SAS (Version 9.4; SAS Inst. Inc.) was used to summarize demographic information. Pearson correlation coefficients were determined using the CORR procedure of SAS ($P < 0.05$).

Results and Discussion

Carcass data

The least squares means for quality characteristics of flank streaking and marbling are displayed in Table 1. Flank streaking and marbling measured at 21 d postmortem were both influenced ($P < 0.01$) by marbling category in a linear fashion. As expected, HIGH had the highest values for flank streaking and 21 d marbling score (modest^{54} and moderate^{09}), MED were intermediate (small^{71} and small ^{56}), and LOW had the lowest values (slight^{53} and slight ^{41}, respectively).

Compositional and WBSF analysis

Table 2 displays the effects of marbling and postmortem aging on proximate components and WBSF values. Marbling and postmortem aging interacted to influence fat, protein, and moisture percentages ($P < 0.05$). For fat percentage, HIGH 42 d samples had greater fat than HIGH 21 d samples, but aging did not influence fat percentage for MED or LOW. HIGH had greater fat percentage than MED or LOW, regardless of aging time. The MED 21 d samples had greater fat than LOW 21 d samples, and MED 42 d samples had greater fat than LOW 42 d samples. For protein, within each marbling level, 42 d samples had greater protein than their 21 d counterparts, resulting in LOW 42 d samples with the highest protein percentage and HIGH 21 d samples with the lowest protein percentage. For moisture, 21 d samples had greater moisture than 42 d samples within each marbling level. Within each aging period, there was a linear decrease in moisture as marbling level (and IMF) increased from LOW to HIGH. There was not an interaction, nor did marbling level or aging have an independent effect on ash percentage ($P > 0.05$).

Table 1. Least squares means for quality characteristics of flank streaking and marbling ($n = 180$)

Trait[1]	High	Medium	Low	SE
Flank streaking	553.90^a	471.44^b	352.67^c	10.23
Marbling	609.49^a	455.51^b	340.67^c	3.38

[a–c]Within a row, least squares means without a common superscript differ ($P < 0.05$).

[1]Flank streaking/marbling scores: 300 to 399 = slight; 400 to 499 = small; 500 to 599 = modest; 600 to 699 = moderate.

The percentage of fat found in the MED and LOW marbling groups in this study was somewhat lower than the value for US Choice lamb loin (5.94%) found in the USDA Nutrient Database (USDA, Agricultural Marketing Service, 2016), but would be comparable to fat percentage in HIGH samples. In addition, Phelps et al. (2018) reported a value of 5.19% fat for US lamb loin. Results from proximate analysis are similar to previous findings in beef that fat percentage increases with increased marbling (Corbin et al., 2015; Emerson et al., 2013; O'Quinn et al., 2012). Similar to findings by Corbin et al. (2015) and O'Quinn et al. (2012), protein and moisture content tended to decrease with higher fat levels. With increased aging times, compositional changes can occur within the muscle. Greater purge loss during postmortem aging can result in lower moisture percentages, thus higher fat and protein percentages.

For WBSF analysis, there was an interaction between marbling category and aging. HIGH samples were the most tender, regardless of aging time ($P < 0.05$), followed by LOW 21 d and 42 d samples; MED 42 d samples were more tender ($P < 0.05$) than MED 21 d samples, which were the toughest ($P < 0.05$). In contrast to a previous study conducted by Duckett et al. (1998), where there was a decrease in WBSF values during post-

Table 2. Proximate and Warner-Bratzler shear force (WBSF) values of lamb loin chops of varying marbling level and postmortem aging ($n = 360$)

	High		Med		Low			*P*-values		
Trait	21 d	42 d	21 d	42 d	21 d	42 d	SE	Marbling	Aging	Marbling × Aging
Fat, %	5.5^b	6.9^a	4.3^{cd}	4.5^c	3.9^e	4.0^{de}	0.13	< 0.01	< 0.01	< 0.01
Protein, %	21.7^e	22.7^d	23.1^c	23.6^b	23.0^c	24.1^a	0.12	< 0.01	< 0.01	0.02
Moisture, %	72.4^d	71.4^e	73.2^c	72.6^d	74.2^a	73.8^b	0.11	< 0.01	< 0.01	0.03
Ash, %	1.0	1.0	1.0	1.0	1.0	1.0	0.02	0.17	0.19	0.82
WBSF, kg	1.3^d	1.3^d	1.8^a	1.7^b	1.6^c	1.6^c	0.04	< 0.01	0.52	0.03

[a–e]Within a row, least squares means without a common superscript differ ($P < 0.05$) due to marbling by aging interaction.

mortem aging from 1 to 12 d, further aging from 21 to 42 d did not improve WBSF values in the current study. Moreover, Kim et al. (2013), did not detect any differences between shear force values of New Zealand lamb loin aged either 2, 3, or 9 wk at –1.5°C. It is well documented in beef that postmortem aging increases tenderness (Savell et al., 1981; Smith et al., 1978); however, it has been reported that in USDA Choice beef carcasses, aging 11 d or more would maximize tenderness (Smith et al., 1978). Lamb responds most rapidly to postmortem aging within the first 7 d of postmortem aging and tenderizes less from 7 to 21 d (Duckett et al., 1998; Koohmaraie et al., 1995), which would explain why no further benefit was observed past 21 d in the current study. In further support of these findings, Gruber et al. (2006) reported that in premium USDA Choice beef, longissimus lumborum did not improve in WBSF past 21 d postmortem; however, USDA Select beef longissimus lumborum had improved WBSF values up to 28 d postmortem (Gruber et al., 2006). Likewise, Colle et al. (2015) found longissimus lumborum WBSF values decreased from d 2 to 14 and 21 to 63 postfabrication, but WBSF values did not change from 21 to 42 d postmortem, which partially aligns with the current findings.

Although a threshold for shear force values in lamb has not been established in the United States, Hopkins et al. (2006) proposed a shear force of about 4.1 kg (40 N) to be classified as 'good every day' quality by Australian consumers. However, to achieve a mean overall liking score of 63 by Australian consumers, a more conservative shear force value of 2.8 kg (27 N) was required (Hopkins et al., 2006). Even though differences were detected between the marbling categories, they would all be considered tender, even using the conservative threshold value of 2.8 kg required to achieve an overall liking score of 63 set forth by Hopkins et al. (2006), based on Australian consumers' appraisal of Australian sheepmeat. Given the low WBSF values in the current study, observed significant differences would not likely result in any meaningful differences in sensory meat tenderness.

Demographic profile and lamb consumption habits of consumers

Consumer demographic data is displayed in Table 3. Overall, the 20 to 29 age bracket had more participants than other age ranges, but this fluctuated from location to location. The primary occupation of participants was a professional. Gender was evenly split overall, but Logan, Utah consumers were predominately male. A majority of households consisted of 2 adults and 0 children. Income level was equally spread between the 4 highest income brackets. A majority of consumers had completed at least some college or technical school and above (84.9%). The participants were predominately Caucasian/White, although Lubbock, Texas had a greater Hispanic population compared to other test sites, while more African-American consumers were represented in Clemson, South Carolina, and Asians and Native Americans collectively accounted for 11.7% of the population in Stillwater, Oklahoma.

Table 4 displays the consumers lamb consumption habits. The majority of consumers never eat lamb (50.6%) with the next largest group only eating lamb 2 to 3 times per year (34%). Many participants enjoy red meat, with it being an important part of their diet (55.9%). Finally, the preferred cooking levels were Medium Rare, Medium, or Medium Well Done.

To ensure the validity of responses given the large proportion of non-lamb eating consumers, we performed a supplementary analysis to determine if lamb eaters vs. non-lamb eaters (those that indicated they rarely/never eat lamb) rated samples any differently. There were no differences in ratings for tenderness or juiciness between these 2 groups ($P = 0.85$ and $P = 0.69$, respectively). Lamb eaters scored flavor liking 4 units greater on average (64.5 vs. 60.5) than those that have never eaten lamb ($P < 0.01$). As a result, lamb eaters also scored overall liking 4.1 units greater on average (66.3 vs. 62.2) than those that have never eaten lamb ($P < 0.01$). For traits such as tenderness, where scores range from not tender to very tender, and juiciness, which ranges from not juicy to very juicy, red meat consumers rated them similarly, whether they had previously eaten lamb or not. However, when traits involve "liking" (i.e., flavor and overall), where scores range from dislike extremely to like extremely, lamb eaters consistently scored flavor and overall liking greater than non-lamb eaters, indicating they might have been less critical on flavor and ultimately overall liking than consumers that had never tried lamb prior to this experiment.

Consumer sensory analysis

Consumer sensory scores were shown in Table 5, displaying the effects of marbling and aging on consumer analysis of tenderness, juiciness, flavor liking, and overall liking. There were no interactions between marbling and aging for any of the palatability attributes ($P > 0.05$). For all traits, marbling influenced consumer scores ($P < 0.05$). Consumers rated the HIGH treatment more tender than LOW ($P < 0.05$), and LOW samples more tender than MED ($P < 0.05$). For all the other traits, consumers rated HIGH treatment samples greater than MED and

Table 3. Demographic characteristics for all consumers and by location (n = 360; 120/Lubbock; 60/all other locations).

Trait	All consumers, %	TX, %[1]	OH, %[1]	OK, %[1]	UT, %[1]	SC, %[1]
Age						
< 20 y	6.1	8.3	0.0	8.3	5.0	6.7
20–29 y	33.1	18.3	10.0	53.3	36.7	61.7
30–39 y	21.7	30.8	26.7	15.0	18.3	8.3
40–49 y	15.3	17.5	16.7	11.7	21.7	6.7
50–59 y	14.2	15.0	21.7	6.7	16.7	10.0
≥ 60 y	9.7	10.0	25.0	5.0	1.7	6.7
Gender						
Male	52.2	46.6	51.7	51.7	68.3	48.3
Female	47.8	53.4	48.3	48.3	31.7	51.7
Occupation						
Tradesperson	7.0	5.8	8.3	8.5	11.9	1.7
Professional	38.0	40.0	30.0	33.9	37.3	46.7
Administration	11.2	11.7	10.0	10.2	11.9	11.7
Sales & Service	10.1	18.3	3.3	5.1	8.5	6.7
Laborer	10.1	8.3	28.3	6.8	8.5	0.0
Homemaker	1.7	0.8	3.3	1.7	3.4	0.0
Student	16.5	10.8	0.0	30.5	17.0	30.0
Currently Not Employed/Retired	5.6	4.2	16.7	3.4	1.7	3.3
Household Size (Adults)						
1	12.8	18.3	15.0	8.3	5.0	11.7
2	56.7	59.2	63.3	60.0	53.3	45.0
3	15.3	12.5	16.7	8.3	20.0	21.7
4	11.1	6.7	1.7	18.3	15.0	18.3
5	2.8	3.3	3.3	3.3	1.7	1.7
6	1.4	0.0	0.0	1.7	5.0	1.7
7	0.0	0.0	0.0	0.0	0.0	0.0
8 or more	0.0	0.0	0.0	0.0	0.0	0.0
Household Size (Children)						
0	55.8	50.8	60.0	61.7	40.0	71.7
1	13.3	13.3	13.3	13.3	15.0	11.7
2	16.9	20.0	16.7	16.7	15.0	13.3
3	8.3	11.7	6.7	6.7	10.0	3.3
4	4.2	3.3	3.3	1.7	13.3	0.0
5	1.1	0.8	0.0	0.0	6.7	0.0
6	0.3	0.0	0.0	0.0	0.0	0.0
8+	0.0	0.0	0.0	0.0	0.0	0.0
Income Level						
< $20,000/year	9.9	6.0	1.7	15.0	17.0	13.8
$20,000–50,000/year	23.0	21.6	31.7	20.0	22.0	20.7
$50,001–75,000/year	21.0	26.7	28.3	15.0	20.3	8.6
$75,001–100,000/year	23.0	19.0	23.3	33.3	15.3	27.6
> $100,000/year	23.2	26.7	15.0	16.7	25.4	29.3
Education Level						
Non-high school graduate	0.9	1.7	1.7	0.0	0.0	0.0
High school graduate	14.4	18.0	37.3	3.3	6.8	3.3
Some college/technical school	34.7	28.2	17.0	46.7	49.2	38.3
College graduate	28.2	26.5	30.5	23.3	32.2	30.0
Post graduate	22.0	25.6	13.6	26.7	11.9	28.3
Cultural Heritage						
African-American	2.5	1.7	0.0	1.7	0.0	10.0
Asian	2.0	1.7	0.0	5.0	0.0	3.3
Caucasian/White	81.5	62.4	97.0	85.0	98.3	83.3
Hispanic	12.1	33.3	1.7	1.7	0.0	3.3
Native American	1.7	0.9	0.0	6.7	1.7	0.0
Other	0.3	0.0	1.7	0.0	0.0	0.0

[1]Locations: Lubbock, Texas; Hicksville, Ohio; Stillwater, Oklahoma; Logan, Utah; Clemson, South Carolina.

Table 4. Lamb consumption habits for all consumers and by location ($n = 360$; 120/Lubbock; 60/all other locations)

Trait	All consumers, %	TX, %[1]	OH, %[1]	OK, %[1]	UT, %[1]	SC, %[1]
How often do you eat lamb?						
Daily	0.0	0.0	0.0	0.0	0.0	0.0
Weekly	1.9	0.8	0.0	0.0	6.7	3.3
Every Other Week	2.5	0.8	0.0	1.7	6.7	5.0
Monthly	4.4	3.3	0.0	5.0	6.7	8.3
Every Other Month	6.7	9.2	0.0	5.0	8.3	8.3
2–3 Times per Year	34.0	40.0	10.0	41.7	33.3	38.3
Never eat	50.6	45.8	90.0	46.7	38.3	36.7
Red Meat In Diet						
I enjoy red meat. It's an important part of my diet.	55.9	55.2	44.1	80.0	47.5	53.3
I like red meat well enough. It's a regular part of my diet	30.5	27.6	44.1	13.3	37.3	33.3
I do eat some red meat although, truthfully it wouldn't worry me if I didn't	10.7	12.9	10.2	6.7	13.6	8.3
I rarely/never eat red meat	2.8	4.3	1.7	0.0	1.7	5.0
Lamb In Diet						
I enjoy lamb. It's an important part of my diet.	4.2	0.9	0.0	3.3	8.5	11.7
I like lamb well enough. It's a regular part of my diet	8.5	9.5	3.3	10.0	11.9	6.7
I do eat some lamb although, truthfully it wouldn't worry me if I didn't	31.0	34.5	13.3	31.7	32.2	40.0
I rarely/never eat lamb	56.3	55.2	83.3	55.0	47.5	41.7
Preferred cooking level						
Blue	0.0	0.0	0.0	0.0	0.0	0.0
Rare	2.1	2.7	2.0	0.0	0.0	5.2
Medium Rare	25.9	16.4	18.4	30.0	33.9	37.9
Medium	30.4	30.9	34.7	36.7	25.4	24.1
Medium Well Done	31.6	35.5	34.7	26.7	35.6	22.4
Well Done	10.1	14.6	10.2	6.7	5.1	10.3

[1]Locations: Lubbock, Texas; Hicksville, Ohio; Stillwater, Oklahoma; Logan, Utah; Clemson, South Carolina.

Table 5. The effects of marbling level and aging on the least squares means for consumer ($n = 360$) sensory scores for palatability traits

	High		Medium		Low			*P*-values		
Trait[1]	21 d	42 d	21 d	42 d	21 d	42 d	SE	Marbling	Aging	Marbling × Aging
Tenderness	$77.8^{a,x}$	$72.7^{a,y}$	$70.6^{c,x}$	$65.5^{c,y}$	$72.3^{b,x}$	$69.4^{b,y}$	2.35	< 0.01	< 0.01	0.43
Juiciness	$77.4^{a,x}$	$70.0^{a,y}$	$69.9^{b,x}$	$64.6^{b,y}$	$69.4^{b,x}$	$64.9^{b,y}$	2.59	< 0.01	< 0.01	0.34
Flavor Liking	$72.4^{a,x}$	$58.8^{a,y}$	$66.7^{b,x}$	$52.7^{b,y}$	$67.3^{b,x}$	$53.5^{b,y}$	2.07	< 0.01	< 0.01	0.98
Overall Liking	$73.5^{a,x}$	$61.0^{a,y}$	$67.3^{b,x}$	$54.7^{b,y}$	$67.9^{b,x}$	$56.0^{b,y}$	2.43	< 0.01	< 0.01	0.94

[1]Sensory scores: 0 = not tender/juicy, dislike flavor/overall extremely; 100 = very tender/juicy, like flavor/overall extremely.

[a–c]Within a row, least squares means without a common superscript differ ($P < 0.05$) due to marbling.

[x,y]Within a row, least squares means without a common superscript differ ($P < 0.05$) due to aging.

LOW treatments ($P < 0.05$), but MED and LOW did not differ ($P > 0.05$). Aging also impacted all traits, as consumers scored 21 d samples as more tender, juicier, and with greater flavor and overall liking ($P < 0.05$) than their 42 d counterparts, regardless of marbling category.

Table 6 displays the percentage of lamb loin chops considered acceptable for tenderness, juiciness, flavor liking, and overall liking as influenced by marbling and aging. There were no interactions between marbling and aging for the acceptability of any palatability traits ($P > 0.05$). Marbling influenced ($P < 0.05$) flavor and overall acceptability, as a greater percentage of consumers considered HIGH treatments more acceptable ($P < 0.05$) than MED, but LOW did not differ from either. Marbling had no effect on consumer acceptance for tenderness and juiciness ($P > 0.05$). Aging impacted ($P < 0.05$) consumer acceptance of tenderness, juiciness, flavor liking and overall liking. A greater proportion of consumers found those traits acceptable for 21 d samples compared to 42 d samples.

The effects of marbling and postmortem aging on the percentage of lamb loin chops categorized into eat-

Table 6. Percentage of lamb loin chops of varying marbling level and aging considered acceptable for tenderness, juiciness, flavor and overall liking by consumers (n = 360)

	High		Medium		Low			*P*-values		
Trait	21 d	42 d	21 d	42 d	21 d	42 d	SE	Marbling	Aging	Marbling × Aging
Tenderness, %	96.1^{x}	93.3^{y}	92.3^{x}	87.2^{y}	95.6^{x}	93.8^{y}	5.47	0.91	< 0.01	0.83
Juiciness, %	96.1^{x}	93.3^{y}	92.3^{x}	87.2^{y}	95.6^{x}	93.8^{y}	5.47	0.91	< 0.01	0.83
Flavor Liking, %	$94.1^{a,x}$	$77.2^{a,y}$	$88.6^{b,x}$	$71.8^{b,y}$	$91.4^{ab,x}$	$74.4^{ab,y}$	4.05	< 0.01	< 0.01	0.39
Overall Liking, %	$94.7^{a,x}$	$81.8^{a,y}$	$90.8^{b,x}$	$75.6^{b,y}$	$92.0^{ab,x}$	$78.1^{ab,y}$	3.13	0.02	< 0.01	0.77

[a,b]Within a row, least squares means without a common superscript differ ($P < 0.05$) due to marbling.

[x,y]Within a row, least squares means without a common superscript differ ($P < 0.05$) due to aging.

ing quality levels by consumers is displayed by Table 7. There were no interactions for any of the eating quality categories ($P > 0.05$). Marbling had an impact on the proportion of samples classified as 'good everyday quality' and 'premium quality' ($P < 0.05$). Aging influenced the percentage of samples categorized as 'unsatisfactory', 'better than everyday quality', and 'premium quality'. A greater percentage of consumers categorized HIGH samples as 'premium quality' than MED or LOW, and fewer called HIGH 'good everyday quality' than MED. A greater proportion of consumers classified 42 d samples as 'unsatisfactory' and fewer as 'better than everyday quality' or 'premium quality' compared to 21 d samples.

Results from the consumer analysis were similar to a previous lamb study conducted in Australia with Australian lamb loin ranging from 2.5 to 7% IMF; Pannier et al. (2014) found that increasing marbling resulted in the higher scores and greater acceptability by consumers for all palatability traits. These results were further supported by O'Reilly et al. (2017), who reported that increasing IMF of Australian lamb loin from 2.5 to 9% positively influenced all eating scores for tenderness, juiciness, flavor liking, and overall liking as assessed by American, Chinese, and Australian consumers. However, in contrast, there were no differences between MED and LOW treatments for juiciness, flavor liking and overall liking in the current study. This result was not surprising given the magnitude of the difference in IMF percentage between MED and LOW was less than the difference between HIGH and MED. The lack of difference between MED and LOW is supported by Young et al. (2009) who investigated the relationship of marbling and eating quality of pasture fed New Zealand lamb. After subjectively assessing loin marbling using a 5-point visual scale (1 = Low and 5 = High), loins from the 50 highest (average marbling score = 2.94) and 50 lowest (average marbling score = 0.94) were subjected to untrained taste panels. Despite differences in objective tenderness, much like our results, the taste panel did not detect differences in texture, juiciness, flavor, or odor between the 2 marbling groups (Young et al., 2009).

With postmortem aging, 21 d aged chops were rated greater and more acceptable than 42 d aged chops for every palatability trait. However, WBSF values were similar between 21 d and 42 d chops with HIGH or LOW marbling. In contrast, Colle et al. (2015) found no difference in consumer tenderness, juiciness, flavor liking, or acceptability scores of beef longissimus lumborum between 21 and 42 d or beyond (63 d). Our findings could suggest the substantial reduction in flavor liking scores associated with extended aging to 42 d elicited a halo effect that reduced tenderness, juiciness, and overall liking scores for 42 d samples compared to their 21 d counterparts. Further investigation is warranted to understand why flavor liking scores were reduced with

Table 7. Percentage of lamb loin chops of varying marbling level and aging categorized into quality levels by consumers (n = 360)

	High		Medium		Low			*P*-values		
Quality level	21 d	42 d	21 d	42 d	21 d	42 d	SE	Marbling	Aging	Marbling × Aging
Unsatisfactory, %	6.3^{y}	18.1^{x}	5.8^{y}	19.3^{x}	5.2^{y}	14.8^{x}	7.17	0.96	< 0.01	0.82
Good Everyday Quality, %	37.3^{b}	39.1^{b}	43.3^{ab}	43.0^{ab}	44.4^{a}	49.8^{a}	3.12	< 0.01	0.29	0.55
Better Than Everyday Quality, %	26.3^{x}	23.7^{y}	30.0^{x}	18.0^{y}	29.4^{x}	18.9^{y}	2.73	0.78	< 0.01	0.07
Premium Quality, %	$27.7^{a,x}$	$16.8^{a,y}$	$16.7^{b,x}$	$12.7^{b,y}$	$16.8^{b,x}$	$9.6^{b,y}$	3.50	< 0.01	< 0.01	0.45

[a,b]Within a row, least squares means without a common superscript differ ($P < 0.05$) due to marbling.

[x,y]Within a row, least squares means without a common superscript differ ($P < 0.05$) due to aging.

additional postmortem aging, but it is possible cutting loins and aging as chops the final 21 d influenced flavor liking. Although samples were always maintained at 2 to 4°C during processing (loin trimming and chop cutting) and postmortem storage, lowering the temperature of chilled storage could also potentially influence flavor liking. Chilled storage temperature varies among researchers who investigate lamb eating quality or tenderness, from –1.5°C (Kim et al., 2013) to 2°C (Duckett et al., 1998; Pannier et al., 2014), or even a range of 0 to 4°C (Hopkins et al., 2006). Chilling temperature and aging form (intact longissimus muscle or individual chop) or perhaps an interaction of factors could most certainly influence flavor liking.

Correlations

The correlation coefficients quantifying the relationships between carcass quality evaluations and consumer palatability ratings are shown in Table 8. With flank streaking being commonly used to evaluate lamb quality in the U.S., a strong positive correlation would be expected with marbling category and fat percentage. Among the eating quality traits, flavor liking was most strongly correlated (r = 0.93; $P < 0.01$) to overall liking, followed by juiciness (r = 0.63; $P < 0.01$) and tenderness (r = 0.62; $P < 0.01$). Tenderness and juiciness scores were also strongly related (r = 0.75; $P < 0.01$) to each other. There were strong relationships ($P < 0.01$) between 21 d marbling score and fat percentage (r = 0.70), as well as between flank streaking with 21 d marbling score and fat percentage (r = 0.60, 0.44, respectively). When examining the relationships between flank streaking with the palatability traits, only juiciness had a correlation (r = 0.07; $P < 0.01$) with flank streaking. Marbling score (21 d) was lowly correlated ($P < 0.05$) with tenderness, juiciness, flavor liking, and overall liking, (r = 0.09, 0.13, 0.09, and 0.09, respectively). However, fat percentage was only related ($P < 0.01$) to tenderness (r = 0.08) and juiciness (r = 0.09).

Increasing marbling score, more so than flank streaking, was positively linked to increasing eating quality scores. Fortunately, flank streaking and marbling score were strongly associated; however, neither flank streaking, marbling score, nor fat percentage had strong linear correlations with lamb eating quality. Also, tenderness, juiciness and flavor liking are major drivers for consumer sensory scores for overall liking, with flavor liking having the biggest impact on overall liking of lamb.

Conclusions

Despite the majority of consumers having never eaten lamb (50.6%) the results clearly show that the lamb product is highly rated by U.S. consumers. Results from the study showed that consumers preferred lamb with the highest level of marbling to elicit greater palatability scores and acceptability than LOW or MED marbling. Also, tenderness, juiciness and flavor liking are major drivers for consumer sensory scores for overall liking, with flavor liking having the biggest impact on overall liking of lamb. Extending aging of domestic lamb from 21 to 42 d appeared to be detrimental to consumer acceptance of lamb loins, regardless of marbling level. Increasing marbling score, more so than flank streaking, was positively linked to increasing eating quality scores. Overall, consumers preferred HIGH marbling over LOW and MED marbling loin chops, but had difficulty distinguishing between LOW and MED. Furthermore, extended postmortem aging of lamb loin is not recommended based on reduced scores for eating quality traits, particularly flavor liking.

Table 8. Pearson correlation coefficients quantifying relationships between carcass quality evaluations, intramuscular fat percentage, and consumer palatability ratings

Trait	Flank streaking	Marbling d 1	Marbling d 21	Fat	Tenderness	Juiciness	Flavor liking
Marbling d 1	0.56**						
Marbling d 21	0.60**	0.91**					
Fat	0.44**	0.68**	0.70**				
Tenderness	0.03	0.09**	0.04*	0.08**			
Juiciness	0.07**	0.13**	0.07**	0.09**	0.75**		
Flavor Liking	0.03	0.09**	0.08**	0.03	0.55**	0.56**	
Overall Liking	0.03	0.09**	0.08**	0.04	0.62**	0.63**	0.93**

**Correlation coefficient differs from 0 ($P < 0.01$).

*Correlation coefficient differs from 0 ($P < 0.05$).

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