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Consumer Assessment of Lamb Loin and Leg from Australia, New Zealand, and United States

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Abstract: Lamb was sourced from 3 countries [Australia (AUS), New Zealand (NZ), and United States (US)] representing 2 muscle types (semimembranosus and longissimus lumborum) to evaluate the palatability of lamb loin and leg chops according to US consumers ($n = 360$). For tenderness, flavor, and overall liking, there was an interaction detected between source country and muscle ($P < 0.05$). Overall, US loin chops had the highest ($P < 0.05$) consumer sensory scores, were rated the most acceptable ($P < 0.05$), and were placed in better than everyday quality or premium quality categories more often than all other treatments. Leg samples sourced from AUS and NZ were rated the lowest ($P < 0.05$) for consumer sensory scores for tenderness, flavor liking and overall liking, as well as being the least acceptable ($P < 0.05$) for flavor liking and overall liking. Both source country and muscle impacted ($P < 0.01$) juiciness scores, as well as tenderness and juiciness acceptability. US chops were juicier and more acceptable for tenderness and juiciness than chops sourced from AUS or NZ, regardless of muscle; consumers rated loin chops juicier and more acceptable for tenderness and juiciness than legs chops, regardless of source country ($P < 0.05$). Overall, consumers detected differences in palatability between muscle type and the source country. Loin chops were preferred over leg chops for all palatability traits. US consumers preferred the domestically sourced lamb over the lamb sourced from AUS and NZ; however, complete animal background (diet, gender, and age) and knowledge of potential differences in slaughter and chilling conditions, as well as control over postmortem aging, is needed to help differentiate if differences in flavor were due to diet, genetics, or other environmental factors.

Keywords: consumer, country-of-origin, lamb, longissimus, semimembranosus
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Introduction

Lamb consumption in the United States (US) has steadily decreased over the years, dropping to less than 1 pound (0.88 lbs. or 0.4 kg) per person annually, which is considerably lower compared to other countries, especially to the higher volumes consumed in countries such as Australia (AUS) at 18.96 lbs. or 8.6 kg or New Zealand (NZ) at 1.98 lbs. or 0.9 kg (OECD, 2017). This difference in consumption can be due to geographic location, consumer background or culture, and consumption habits, as consumers' expectations for flavor can vary (Font i Furnols et al., 2009, Sañudo et al., 1998, 2007).

When evaluating lamb eating quality from multiple countries, various factors can impact sensory attributes of the product, with diet surfacing to the forefront due to different production systems. In the United States, American lamb that is available to consumers is primarily finished on grain (Male, 2012). In Australia, however, there is a combination of grass and grain feeding (Ponnampalam et al., 2014), whereas New Zealand relies more heavily on pasture-based farming systems for both sheep and cattle (Clemens and Babcock, 2004). Pethick et al. (2005) found no significant differences in the consumer acceptance of grilled longissimus muscle samples between lamb finished on pasture or grain-based diets. However, researchers have produced conflicting results on the intensity of lamb flavor. While several find grain fed lamb has a less intense flavor (Fisher et al., 2000; Lupton, 2008; Rousset-Akrim et al., 1997; Sañudo et al., 1998), others report that grass fed lamb produces a less intense flavor (Borton et al., 2005; Priolo et al., 2002) according to consumers. Results from studies have also shown that grass fed lamb has less intramuscular fat or lower fat levels (Borton et al., 2005; Díaz et al., 2002; Priolo et al., 2002), is less tender (Priolo et al., 2002) and can be darker in color (Díaz et al., 2002; Priolo et al., 2002).

Muscle type can affect consumer palatability preferences as well. Muscles are categorized into two types–locomotive and support. The muscles typically included in the support category are from the loin and rack. Locomotive muscles are typically from the shoulder and leg. With tenderness being a major factor for consumer palatability (Miller et al., 1995, 2001; Savell et al., 1987), muscle type can play a role due to the variation in tenderness among muscles (Pethick et al., 2006; Pannier et al., 2014). Pethick et al. (2006) reported significant differences in tenderness according to untrained consumer panelists between several cuts, including the topside and shortloin, with topside being less tender than the shortloin using a roast cooking method. Similarly, consumer sensory scores of Australian lamb topside and loin grill samples varied by 25 units (out of 100) in favor of loin muscle samples (Pannier et al., 2014).

Nearly half of US lamb consumption is derived from Australian (68 to 70% of imports) or New Zealand (30 to 32%) imports (USDA Economic Research Service, 2016), so comparison of lamb sources would provide an understanding of American consumers' preferences for lamb eating quality. Palatability differences in lamb are expected when comparing country origins and muscle types. The objective of this study was to evaluate the effects of country-of-origin and muscle on the palatability of lamb loin and leg chops as determined by US consumers.

Materials and Methods

Product selection and procurement

United States carcasses were selected at a commercial lamb processing facility in Greeley, CO. After the carcass chilling period (approximately 24 h), trained personnel from Texas Tech University examined lamb carcasses prior to fabrication. Due to the time constrictions between ribbing and fabrication, selection occurred very rapidly (5 to 10 s window). Our intention was to minimize the variation in marbling of selected carcasses. Therefore, only carcasses with similar marbling level (pork marbling standard 2) were selected based on images from the pork quality standards. If carcasses were eligible for the study, carcasses were tagged ($n = 60$) and followed through fabrication.

Full loins (Institutional Meat Purchase Specifications #232; 1 × 1; USDA Agricultural Marketing Service, 2014; $n = 30$/treatment) and both legs (Institutional Meat Purchase Specifications #233A; USDA Agricultural Marketing Service, 2014; $n = 60$/treatment; 2/carcass) were obtained from these carcasses, vacuum packaged, boxed, and shipped under refrigeration to Texas Tech University Gordon W. Davis Meat Laboratory (Lubbock, TX). The vacuum packaged lamb was then stored at 2 to 4°C until 21 d postmortem.

Australian and New Zealand loins and legs were exported as frozen product, procured from a wholesale meat distributor, and shipped frozen to Texas Tech University Gordon W. Davis Meat Laboratory (Lubbock, TX). The loins and legs were then stored at –20°C until the subprimals were thawed for fabrication.

Product fabrication

Loin and leg fabrication for US sourced vacuum packaged subprimals was performed at 21 d postmortem. Australian and New Zealand subprimals had been previously frozen on d 1 or d 2 postmortem in their respective country prior to frozen shipment to the United States. Those subprimals were thawed at 2 to 4°C on metal racks for 24 h prior to fabrication. All loins, regardless of country, were fabricated similarly. Both tenderloins were removed, followed by all bone. The longissimus lumborum from each side was excised from the flank, all secondary muscles (gluteus medius), and any external fat. Loins were trimmed of any visible external fat and connective tissue.

All legs, regardless of country, were fabricated similarly, by first removing the semimembranosus and adductor. All other muscles and bone were discarded. The adductor was detached from the semimembranosus, and the semimembranosus was trimmed of any visible external fat and connective tissue. Semimembranosus muscles were manually fabricated into 2.54-cm thick chops, resulting in 7 to 9 chops per muscle. The anterior-most chop was used for proximate and fatty acid analysis, followed by Warner-Bratzler shear force (WBSF) analysis (chop 2), consumer sensory analysis (chops 3 through 5), flavor analysis (chop 6), and any remaining chops (7+) were labeled as extra. Chops were then vacuum packaged individually. The US chops were frozen on d 21 postmortem at –20°C until further analysis. To simulate a similar aging period, Australian and New Zealand chops were stored at 2°C for 10 d following fabrication. Previous work of freezing, thawing, and subsequent aging has shown that 12 d of aging after freezing and thawing will generate slice shear values that are similar to 28 d of fresh, never frozen aging in beef strip loins (Grayson et al., 2014). Hutto (2016) reported that aging beef strip loins until 9 d postmortem after freezing at d 1 postmortem, followed by thawing on d 2 postmortem would generate slice shear values that were similar to 23 d of fresh, never frozen aging. Therefore, we chose an intermediate time of 10 d of additional aging as individually vacuum packaged chops for all New Zealand and Australian products. After the 10-d aging period, chops were frozen at –20°C until further analysis. For external consumer testing sites, samples were transported frozen.

Compositional analysis

Raw lamb chop 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, Ft. Atkinson, WI) and stored at –80°C until analysis.

Protein analysis

Protein analysis was conducted using approved AOAC protocol (AOAC, 2005) for the *LECO TruMacN*. The machine was first calibrated using blanks, followed by ethylenediaminetetraacetic acid (EDTA) samples. Following EDTA, 0.3 g of sample was added into each boat on the carousel, making sure to properly input sample ID and sample weight. To convert percent nitrogen to percent protein, a conversion factor of 6.25% was used.

Total fat

Total fat analysis was conducted using a modification of the chloroform:methanol method described by Folch et al. (1957; AOAC 983.23). 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 five 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. After 16 h in the drying oven, crucibles were removed and placed into desiccators for 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 hour) until reaching an endpoint temperature of 550°C. Once the final temperature was achieved, the samples remained in the muffle furnace for 24 h. After 24 h, samples were cooled and placed into desiccators for 30 min until completely cool. Once cool, the crucibles were weighed to calculate the percentage of ash in each sample.

Warner-Bratzler Shear Force (WBSF)

Chops were thawed prior to cooking for 24 h at 2°C. After thawing, chops were weighed, and temperature was recorded. Temperature was observed with a Super-Fast Thermapen digital meat thermometer (Thermoworks, Lindon, UT). Chops were cooked on a Silex clamshell grill (Model S-143L, Silex Grills Australia Pty Ltd., Marricksville, Australia) with the top plate set at 180°C and the bottom plate set at 205°C targeting a medium degree of doneness (71°C). Cooking was conducted using a detailed time schedule. Each cooking round consisted of 10 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. Chops were then weighed, and temperature was 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 muscle fiber. Cores were sheared once perpendicular to the muscle fibers using a WBSF analyzer (G-R Elec. Mfg., Manhattan, KS) with 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 use of human subjects for consumer sensory panel evaluations (#505630). Consumer panels were conducted in various cities across the United States (Lubbock, TX; Fort Collins, CO; Fresno, CA; Gainesville, FL; and State College, PA). Panels were conducted in large classrooms or banquet-style rooms with fluorescent lighting. Panelists (n = 360) were recruited from the local communities in the various cities and were compensated for participation. Consumers were screened to see if they had consumed red meat and how often, particularly lamb and beef. 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 and a 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 in the home.

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 180ºC and the bottom plate set at 205ºC 30 min prior to the start of the panels. Before any test samples were cooked, 10 chops (unrelated to the trial) were placed onto the Silex grill to ensure the proper heating of the grill and 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, each chop was cut across the midline of each chop into 2 equal portions and served to 2 predetermined consumers.

Consumers evaluated 7 samples, with 6 of the samples being fed in a predetermined and balanced order, representing the different treatments (US loin, US leg, AUS loin, AUS leg, NZ loin, and NZ leg). All consumers received a chop unrelated to the treatment design with low to mid-level marbling aged 21 d to acquaint consumers with lamb 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, and 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. Perceived quality levels were left to the consumers' interpretation.

Statistical analysis

All data were analyzed as a 2 × 3 factorial design using the GLIMMIX procedure of SAS (Version 9.4; SAS Inst. Inc., Cary, NC) with fixed effects of muscle, country, and their interaction. For WBSF, cook loss was included as a covariate ($P < 0.01$). Location and consumer nested within testing night were included as random effects for sensory attributes. Tenderness, juiciness, flavor liking, and overall acceptability 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 with a significance level of $P < 0.05$. Denominator degrees of freedom were calculated using Kenward-Roger approximation. The PROC 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

Proximate and WBSF analysis

Table 1 displays the effects of country and muscle on proximate components and WBSF values. Country and muscle interacted ($P < 0.01$) to influence fat, protein, moisture, and ash. The US and AUS loins had greater fat percentage than all other treatments. The

Table 1. Proximate and WBSF values of lamb leg and loin chops from Australia, New Zealand, and the United, States (n = 360; 60/treatment)

	Australia		New Zealand		United States			*P*-values		
Trait	Leg	Loin	Leg	Loin	Leg	Loin	SE	Muscle	Country	Muscle × Country
Fat, %	4.06^{b}	5.13^{a}	3.34^{c}	3.45^{c}	4.22^{b}	5.19^{a}	0.10	< 0.01	< 0.01	< 0.01
Protein, %	24.74^{a}	23.44^{c}	24.03^{b}	23.59^{c}	22.76^{d}	22.96^{d}	0.15	< 0.01	< 0.01	< 0.01
Moisture, %	72.32^{d}	72.11^{d}	73.28^{b}	74.16^{a}	73.32^{b}	72.83^{c}	0.15	< 0.01	0.60	< 0.01
Ash, %	1.07^{b}	1.16^{a}	1.19^{a}	1.06^{b}	1.07^{b}	1.01^{c}	0.01	< 0.01	< 0.01	< 0.01
WBSF, kg	2.11^{b}	1.46^{d}	2.31^{a}	1.61^{c}	1.63^{c}	1.54^{cd}	0.51	< 0.01	< 0.01	< 0.01

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

US and AUS leg were intermediate, and NZ loin and leg had the lowest fat percentage and did not differ. The AUS leg had a greater ($P < 0.05$) percentage of protein than any other treatment ($P < 0.05$), with US loin and leg being the lowest. The NZ loin had a greater percentage of moisture than all other treatments ($P < 0.05$), with AUS loin and leg being the lowest. For ash, AUS loin and NZ leg had the highest percentage of ash ($P < 0.05$), with US loin being the lowest.

The percentage of fat found in various muscles in this study are somewhat consistent with values found in the USDA Nutrient Database (USDA Agricultural Marketing Service, 2016), as well as those specifically published for Australian lamb leg and loin (Williams et al., 2007). In comparison to those found in the nutrient database, fat was lower for Australian cuts in our study, but published values encompass the whole leg (without sirloin) and so a direct comparison should be made with caution. Conversely, Williams et al. (2007) reported whole leg roast with 3.2% total fat, which is somewhat lower than the current findings, but again this encompasses the whole leg and not the specific muscle that was evaluated. According to Williams et al. (2007), the fat percentage for a raw loin chop was quite consistent with our findings (5.0 vs. 5.1%, respectively). In a study conducted by Xu et al. (2017), comparing the composition and eating quality of semimembranosus and longissimus muscles of Dorper sheep in China, total fat percentage was lower in semimembranosus than longissimus, with no differences in crude protein or ash.

Much like proximate components, an interaction was observed ($P < 0.01$) between muscle and country for WBSF values. The NZ leg required the most force to shear, while AUS loin had a lower WBSF value than all treatments except US loin. The AUS and NZ legs had greater ($P < 0.05$) WBSF values than the loins from their respective country, but the WBSF of US leg and loin did not differ ($P > 0.05$).

Loin samples had lower shear force values than leg samples, similar to findings by Pannier et al. (2014); however, those shear force values were measured at 5 d postmortem (loin: 25.4 N; topside: 39.9 N). Although no threshold for shear force values in lamb has 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 muscles, all WBSF values in the current study, regardless of muscle or country, were below both proposed threshold values.

Demographic profile and lamb consumption habits of consumers

Consumer demographic data is shown in Table 2. A majority of the consumers were between the ages of 20 to 29 yr old, due to higher than average frequencies of this group in CO, FL, and CA. Overall gender was equally represented with a slight edge toward more females. This trend was driven by higher female test subject populations in CO and CA. The most common occupation was student, followed by professionals, and individuals in administration. A clear majority of the consumers reside in households with 2 adults and 0 children. Income level was distributed among all levels, but over half of all consumers in the current study earned $50,000 or less annually. Nearly three-quarters of participants were Caucasian/White, followed by a strong representation in the Hispanic population. Texas and California had greater proportions of Hispanic consumers than other test locations, while more African-American consumers were represented in Texas. More Asian consumers were represented in Colorado.

Consumer lamb consumption habits are displayed in Table 3. Most consumers stated that they ate lamb 2 to 3 times per year (45.6%), but many had never eaten lamb (27.2%). When asked if they enjoyed red meat in the diet, 60.3% of participants

Table 2. Demographic characteristics for all consumers and by location ($n = 360$; 120/Lubbock; 60/all other locations)

Trait	All consumers, %	TX, %[1]	PA, %[1]	CO, %[1]	FL, %[1]	CA, %[1]
Age						
< 20 y	10.3	8.3	0.0	3.3	15.0	26.7
20–29 y	52.2	30.0	36.7	90.0	60.0	66.7
30–39 y	12.5	20.0	18.3	1.7	15.0	0.0
40–49 y	12.5	23.3	16.7	3.3	3.3	5.0
50–59 y	8.1	12.5	13.3	1.7	6.7	1.7
≥ 60 y	4.4	5.8	15.0	0.0	0.0	0.0
Gender						
Male	44.6	50.4	53.3	36.7	48.3	28.3
Female	55.4	49.6	46.7	63.3	51.7	71.7
Occupation						
Tradesperson	5.6	6.7	5.0	1.7	8.3	5.1
Professional	25.1	28.3	36.7	16.7	33.3	6.8
Administration	13.1	15.8	16.7	3.3	16.7	10.2
Sales & Service	7.2	10.8	6.7	0.0	0.0	10.2
Laborer	4.7	8.3	1.7	0.0	3.3	6.8
Homemaker	0.8	1.7	0.0	0.0	1.7	0.0
Student	41.2	24.2	30.0	73.3	36.7	59.3
Currently Not Employed/Retired	2.2	4.2	3.3	0.0	0.0	1.7
Household Size (Adults)						
1	12.5	15.8	18.3	10.0	11.7	3.3
2	47.8	51.7	53.3	45.0	50.0	35.0
3	21.9	17.5	18.3	36.7	13.3	28.3
4	12.2	10.8	6.7	5.0	20.0	20.0
5	3.6	2.5	0.0	3.3	3.3	10.0
6	1.3	0.8	3.3	0.0	1.7	3.3
7	0.0	0.0	0.0	0.0	0.0	0.0
8 or more	0.3	0.8	0.0	0.0	0.0	0.0
Household Size (Children)						
0	67.5	50.8	70.0	88.3	66.7	78.3
1	12.2	11.7	20.0	8.3	13.3	8.3
2	11.4	20.0	8.3	3.3	10.0	6.7
3	7.3	8.3	1.7	0.0	5.0	5.0
4	4.7	7.5	0.0	0.0	1.7	0.0
5	1.11	1.7	0.0	0.0	3.3	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0
8+	0.3	0.0	0.0	0.0	0.0	1.7
Income Level						
< \$20,000/year	26.3	21.9	8.5	51.7	18.6	35.0
\$20,000 – 50,000/year	27.2	29.4	30.5	28.3	20.3	25.0
\$50,001 – 75,000/year	14.0	14.3	22.0	8.3	11.9	13.3
\$75,001 – 100,000/year	14.6	15.1	18.6	3.3	22.0	13.3
> \$100,000/year	17.9	19.3	20.3	8.3	27.1	13.3
Education Level						
Non-high school graduate	1.7	4.2	0.0	0.0	0.0	1.7
High school graduate	8.9	13.3	1.7	1.7	10.2	13.3
Some college/technical school	39.4	43.3	18.6	30.0	37.3	63.3
College graduate	29.6	25.8	37.3	40.0	33.9	15.0
Post graduate	20.4	13.3	42.4	28.3	18.6	6.7
Cultural Heritage						
African-American	4.5	11.8	1.7	0.0	1.7	0.0
Asian	4.8	1.7	5.1	11.7	1.7	6.7
Caucasian/White	71.2	57.1	88.1	81.7	81.4	61.7
Hispanic	17.4	27.7	5.1	3.3	15.3	25.0
Native American	0.8	0.0	0.0	1.7	0.0	3.3
Other	1.4	1.7	0.0	1.7	0.0	3.3

[1]Locations: Lubbock, TX; State College, PA; Fort Collins, CO; Gainesville, FL; Fresno, CA.

Table 3. Lamb consumption habits for all consumers and by location ($n = 360$; 120/Lubbock; 60/all other locations)

Trait	All consumers, %	TX, %[1]	PA, %[1]	CO, %[1]	FL, %[1]	CA, %[1]
How often do you eat lamb?						
Daily	0.0	0.0	0.0	0.0	0.0	0.0
Weekly	2.2	1.7	1.7	6.7	1.7	0.0
Every Other Week	3.9	2.5	6.7	8.3	1.7	1.7
Monthly	11.9	6.7	23.3	13.3	13.3	8.3
Every Other Month	9.2	4.2	16.7	6.7	13.3	10.0
2–3 Times per Year	45.6	40.0	45.0	51.7	48.3	48.3
Never eat	27.2	45.0	6.7	13.3	21.7	31.7
Red Meat in Diet						
I enjoy red meat. It's an important part of my diet.	60.3	47.5	57.6	70.0	78.0	61.7
I like red meat well enough. It's a regular part of my diet	26.8	35.8	33.9	13.3	17.0	25.0
I do eat some red meat although, truthfully it wouldn't worry me if I didn't	10.6	12.5	8.5	13.3	5.01	11.7
I rarely/never eat red meat	2.2	4.2	0.0	3.3	0.0	1.7
Lamb in Diet						
I enjoy lamb. It's an important part of my diet.	8.7	3.3	18.6	13.3	8.5	5.1
I like lamb well enough. It's a regular part of my diet	16.5	10.8	28.8	10.0	22.0	17.0
I do eat some lamb although, truthfully it wouldn't worry me if I didn't	40.1	34.2	45.8	48.3	37.3	40.7
I rarely/never eat lamb	34.7	51.7	6.8	28.3	32.2	37.3
Preferred cooking level						
Blue	0.0	0.0	0.0	0.0	0.0	0.0
Rare	2.6	0.0	6.9	3.33	1.7	3.4
Medium Rare	32.1	24.6	41.4	45.0	31.0	25.4
Medium	30.1	29.8	29.3	25.0	40.0	27.1
Medium Well Done	26.7	31.6	19.0	21.7	20.7	35.6
Well Done	8.6	14.0	3.5	5.0	6.9	8.47

[1]Locations: Lubbock, TX; State College, PA; Fort Collins, CO; Gainesville, FL; Fresno, CA.

stated that they enjoyed consuming red meat, and that it was an important part of their diet. However, when asked how participants felt about lamb in their diet, many consumers stated that either they do eat lamb, but it truthfully wouldn't worry them if they didn't (40.1%) or they stated that they never/rarely ate lamb (34.7%). When asked about their preferred cooking level, consumers indicated they most often preferred medium rare (32.1%), followed by medium (30.1%), and medium well done (26.7%).

Consumer sensory analysis

Table 4 displays the effects of muscle and country-of-origin on consumer sensory scores for tenderness, juiciness, flavor liking, and overall liking. An interaction was detected ($P \leq 0.02$) between muscle and country for tenderness, flavor liking, and overall liking, but not for juiciness ($P = 0.29$). Consumers rated US loin samples most tender ($P < 0.05$), followed by NZ and AUS loin samples, which were similar; NZ leg and AUS leg samples were

Table 4. The effects of muscle type and country-of-origin on the least squares means for consumer ($n = 360$) sensory scores for palatability traits

	Australia		New Zealand		United States		SE	*P*-values		
Trait[1]	Leg	Loin	Leg	Loin	Leg	Loin		Muscle	Country	Muscle × Country
Tenderness	47.7^{d}	72.7^{b}	46.1^{d}	72.7^{b}	61.9^{c}	79.1^{a}	1.42	< 0.01	< 0.01	< 0.01
Juiciness	59.0^{n,y}	65.3^{m,y}	57.5^{n,y}	62.9^{m,y}	71.2^{n,x}	74.4^{m,x}	1.28	< 0.01	< 0.01	0.29
Flavor Liking	51.8^{d}	63.4^{b}	52.5^{d}	58.2^{c}	64.9^{b}	70.6^{a}	1.97	< 0.01	< 0.01	< 0.01
Overall Liking	50.8^{d}	65.3^{b}	50.6^{d}	60.4^{c}	53.7^{b}	72.8^{a}	1.72	< 0.01	< 0.01	0.02

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

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

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

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

rated the lowest ($P < 0.05$) for tenderness. Within each country, consumers found the loins more tender ($P < 0.05$) than legs. For juiciness, muscle and country both influenced consumer scores ($P < 0.01$). Consumers rated US samples juicier ($P < 0.05$) than AUS and NZ samples, which were similar ($P > 0.05$). Also, consumers scored loin samples juicier ($P < 0.05$) than leg samples, regardless of country. For flavor and overall liking, US loin samples were more liked ($P < 0.05$) than any other treatment, followed by AUS loin and US leg samples, which were similar ($P > 0.05$); AUS and NZ leg samples were least liked ($P < 0.05$) of all samples. Much like tenderness, loins were more liked for flavor and overall ($P < 0.05$) than leg samples, regardless of country.

Table 5 displays the effects of muscle and country on the percentage of lamb loin and leg chops considered acceptable for tenderness, juiciness, flavor liking, and overall liking. Muscle and country both independently influenced ($P < 0.01$) tenderness and juiciness acceptability, but no interactions were detected for either trait ($P = 0.10$). An interaction between muscle and country was observed ($P \leq 0.02$) for flavor liking and overall liking. Consumers considered loin samples more acceptable for tenderness and juiciness ($P < 0.05$) than leg samples, regardless of country. A greater percentage of consumers also considered US samples acceptable ($P < 0.05$) for tenderness and juiciness when compared to AUS and NZ samples ($P > 0.05$). The US loins were more acceptable ($P < 0.05$) for flavor than all other treatments, apart from US legs. For overall acceptability, consumers found US legs and loins, as well as AUS loins more acceptable than the remaining treatments, while AUS and NZ leg samples were least acceptable overall ($P < 0.05$).

Correlation coefficients were generated to determine the relationships between eating quality traits (data not shown in tabular form). Flavor was most strongly associated to overall liking ($r = 0.90$; $P < 0.01$), followed by tenderness and juiciness ($r = 0.65$ and 0.62, respectively; $P < 0.01$). Tenderness and juiciness scores were also strongly related ($r = 0.60$; $P < 0.01$) to each other, more so than flavor to either trait. However, there was still an association ($P < 0.01$) of flavor to both tenderness ($r = 0.52$) and juiciness ($r = 0.51$).

Table 6 displays the effects of muscle and country on the percentage of lamb leg and loin chops categorized into quality levels by consumers. An interaction was detected between muscle and country for the percentage of unsatisfactory, better than everyday quality, and premium quality ($P \leq 0.05$) samples, but muscle and country independently affected ($P < 0.01$) the percentage of good everyday quality samples. The

Table 5. Percentage of lamb leg and loin chops from Australia, New Zealand, and the United States considered acceptable for tenderness, juiciness, flavor and overall liking by consumers ($n = 360$)

	Australia		New Zealand		United States			*P*-values		
Trait	Leg	Loin	Leg	Loin	Leg	Loin	SE	Muscle	Country	Muscle × Country
Tenderness	$81.8^{n,y}$	$92.0^{m,y}$	$82.2^{n,y}$	$87.9^{m,y}$	$93.9^{n,x}$	$94.7^{m,x}$	2.34	< 0.01	< 0.01	0.10
Juiciness	$81.8^{n,y}$	$92.0^{m,y}$	$82.2^{n,y}$	$87.9^{m,y}$	$93.9^{n,x}$	$94.7^{m,x}$	2.34	< 0.01	< 0.01	0.10
Flavor Liking	73.5^{c}	87.5^{b}	73.7^{c}	78.2^{c}	91.0^{ab}	92.4^{a}	5.03	< 0.01	< 0.01	0.02
Overall Liking	71.0^{c}	91.0^{a}	73.5^{c}	81.7^{b}	89.2^{a}	92.7^{a}	4.12	< 0.01	< 0.01	< 0.01

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

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

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

Table 6. Percentage of lamb leg and loin chops from Australia, New Zealand, and the United States categorized into overall quality levels by consumers ($n = 360$)

	Australia		New Zealand		United States			*P*-values		
Quality Level	Leg	Loin	Leg	Loin	Leg	Loin	SE	Muscle	Country	Muscle × Country
Unsatisfactory	28.1^{a}	$9.7^{c,d}$	30.9^{a}	18.4^{b}	11.4^{c}	6.4^{d}	3.99	< 0.01	< 0.01	0.05
Good Everyday Quality	$53.7^{m,x}$	$38.9^{n,x}$	$48.1^{m,x}$	$38.3^{n,x}$	$40.9^{m,y}$	$29.3^{n,y}$	2.84	< 0.01	< 0.01	0.66
Better Than Everyday Quality	12.1^{c}	36.0^{a}	16.5^{c}	24.1^{b}	32.3^{a}	33.8^{a}	3.73	< 0.01	< 0.01	< 0.01
Premium Quality	4.3^{c}	13.3^{b}	2.8^{c}	16.7^{b}	13.3^{b}	28.8^{a}	2.57	< 0.01	< 0.01	0.04

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

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

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

AUS and NZ legs were most commonly classified as unsatisfactory when compared to all other treatments, while US and AUS loins were rarely classified as unsatisfactory, with US legs being similar to AUS loins ($P < 0.05$). Leg samples were classified as good everyday quality more often ($P < 0.01$) than loin samples, regardless of country. The AUS and NZ samples were placed into this category more often than US samples, regardless of muscle ($P < 0.05$). For better than everyday quality, US loin, US leg, and AUS loin were placed in this category more often than other treatments, while AUS and NZ leg were classified as better than everyday quality less than other treatments ($P < 0.05$). The US loins were classified as premium quality more often ($P < 0.05$) than any other treatment, while AUS and NZ leg were classified as premium quality less than other treatment ($P < 0.05$).

Results for consumer sensory scores and acceptability's for tenderness align with results from WBSF. The AUS and NZ leg had the highest WBSF values and corresponding lowest scores for tenderness as rated by consumers. Loin samples received higher consumer tenderness scores than legs, with WBSF results following a similar trend. The US treatments were also preferred and required less force to shear than their AUS and NZ counterparts. Overall, WBSF values were low, with all treatments being considered tender. This can be further confirmed with consumer tenderness acceptability percentages all being quite high (81.8% acceptable or higher).

Results for consumer sensory scores from this study show that consumers rated domestic loins more favorably than all other treatments for sensory scores, acceptability, and when classifying into overall quality categories. There was a trend for consumers to prefer US over AUS or NZ and loin over leg samples. The AUS leg and NZ leg were the least desirable to consumers in all palatability traits and acceptability. Several research studies using various sheep and diet types have shown that grain fed lamb has higher palatability ratings compared to grass fed lamb (Fisher et al., 2000; Lupton, 2008; Rousset-Akrim et al., 1997; Sañudo et al., 1998); however, Pethick et al. (2005) found no significant differences in the consumer acceptance of grilled longissimus muscle samples between lamb finished on pasture or grain-based diets. Since the US relies more heavily on grain finishing of lambs than NZ or AUS, our results could support these findings. However, it should be noted the exact diets are not known for any treatments as either the carcasses were selected or subprimals were procured without this knowledge. Moreover, numerous unknown factors could also influence lamb derived from the 3 countries, including age of lambs preslaughter, as well as slaughter conditions (pH and temperature decline), and chilling conditions. Our results also align with findings that lamb longissimus muscles are rated higher or more desirable by consumers in regards to palatability than semimembranosus (Pannier et al., 2014).

According to Hoffman et al. (2015), flavor or taste is a defining component of lamb quality to consumers. Our strong correlation between flavor and overall liking supports this finding. Research has shown that a consumer's past eating experience highly affects his or her acceptance or aversion to sheep-specific flavors, suggesting that US consumers are more likely to prefer domestic lamb, especially loins (Prescott et al., 2001; Sañudo et al., 2000). Hoffman et al. (2015) also indicated consumers consider origin (local or American) as their second preference for eating satisfaction, which supports US samples performing better than imported samples in the current study. Lastly, consumers acknowledged sheep raising practices (defined as grass fed) was their third preference for eating satisfaction, countering research showing grain fed treatments being more desirable to consumers (Hoffman et al., 2015). Lamb purchasers in the study conducted by Hoffman et al. (2015) rated origin and sheep raising practices as non-negotiable requirements for purchase. Those US consumers stated that they preferred US grass fed lamb, while foodservice and retail distributors claim US grain fed lamb has preferable, milder flavor and is more desirable to US consumers (Hoffman et al., 2015)

Conclusions

Despite most consumers having never eaten lamb or only eating lamb on an annual basis, the results clearly show that the lamb product, and particularly loin, is highly rated by US consumers. Loin chops were preferred over leg chops for all palatability traits. The US consumers preferred the domestically sourced lamb over the imported lamb from AUS and NZ when comparing tenderness, juiciness, flavor, and overall liking; however, further research is warranted with controlled aging of imported lamb product from AUS and NZ to ensure consistency of selected product. Moreover, a complete animal background, including but not limited to diet, gender, and age, as well as knowledge on potential differences in slaughter and chilling conditions, would be useful for future studies to help differentiate if differences in flavor were due to diet, genetics, or other environmental factors.

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