Meat and Muscle Biology™

Consumer Palatability of Beef Muscles from Australian and US Production Systems With or Without Enhancement

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Abstract: The objective was to assess the consumer (n = 360) palatability and satisfaction of enhanced (7%) and nonenhanced Australian grain-fed, Australian grass-fed, and US grain-fed beef from 2 beef muscles. Strip loin (*longissimus lumborum* [LL]) and top sirloin butt (*gluteus medius* [GM]) subprimals were collected from 12 Australian grass-fed, 12 Australian grain-fed, and 12 US grain-fed (USDA Choice) carcasses. In addition, tenderloin (*psoas major*) and eye of round (*semitendinosus*) subprimals were collected from the same US carcasses to serve as anchors for high and low palatability. All subprimals were aged until 29 to 32 d postmortem. All fabrication and enhancement occurred in Lubbock, Texas. Data were analyzed initially as a randomized complete design and subsequently as a split-split plot design, with the main effects of country of origin/diet (Australian grain-fed, Australian grass-fed, and US grain-fed), muscle (LL and GM), and enhancement (0% or 7%) and all potential interactions as fixed effects. Enhancement significantly improved palatability in both LL and GM steaks as evidenced by greater ($P < 0.05$) consumer ratings for tenderness, juiciness, flavor liking, overall liking, and satisfaction. Enhancing LL steaks resulted in consumer responses that were comparable or superior to consumer responses for *psoas major* samples. Similarly, enhancing GM steaks resulted in consumer responses that were comparable or superior to nonenhanced LL samples. Consumers reacted least favorably to nonenhanced Australian grass-fed beef as they rated all palatability traits lowest ($P < 0.05$) for both LL and GM samples. However, enhancing grass-fed beef resulted in consumer responses that were similar ($P > 0.05$) to nonenhanced grain-fed beef. This response to enhancement was observed in consumer scores for both LL and GM samples. Consumers could not detect differences ($P > 0.05$) in tenderness, juiciness, flavor, overall liking, or satisfaction between grain-fed beef from Australia and the US.

Keywords: Australia, beef, consumer, enhancement, palatability
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Introduction

The global beef industry strives to produce and deliver consistent, high-quality beef products that meet expectations for consumer eating quality. In Australia, beef eating quality is underpinned by the Meat Standards Australia (MSA) grading system (Polkinghorne et al., 2008), whereas the United States relies on the US Department of Agriculture (USDA) quality grading system to sort carcasses based on marbling and maturity to predict beef palatability of US beef (USDA, 1997). Eating quality can be influenced by a number of antemortem and postmortem factors, including, but not limited, to animal breed type and diet, muscle, postmortem aging, and cooking method. *Bos indicus* cattle are well suited for certain regions in Australia, yet the beef from these cattle can suffer from tenderness issues (Wheeler et al., 1994; Shackelford et al., 1995). The Australian beef industry is largely pastoral or rangeland based; however, feedlot finishing represents approximately one-third of the annual adult cattle population slaughtered in Australia (Greenwood et al., 2018). Feedlot finishing has increased over the years to ensure the eating quality of beef entering the domestic supply chain and beef destined for high-value export markets (Greenwood et al., 2018). Previous research has shown that US consumers prefer the flavor of domestic beef over that of Australian grass-fed beef or Canadian grain-fed beef, which uses similar grains as Australia (Sitz et al., 2005). However, to our knowledge, there has not been an extensive study comparing the eating quality of Australian grain-fed and grass-fed beef to US grain-fed beef with enhancement.

Value adding or enhancement is still required of some lower-quality cuts or cuts that would otherwise be considered unsatisfactory in the MSA grading system. Numerous researchers have shown the positive influence of enhancement on beef eating quality, typically through improvement to tenderness, juiciness, and flavor (Robbins et al., 2003; Baublits et al., 2006; Hardcastle et al., 2018). Therefore, our objective was to determine the consumer eating quality and satisfaction of enhanced (7%) and nonenhanced Australian grain-fed, Australian grass-fed, and US grain-fed beef from 2 beef muscles (*longissimus lumborum* [LL] and *gluteus medius* [GM]). We hypothesized that differences between Australian and US beef eating quality will exist due to differences in finishing systems between the 2 countries but that enhancement will improve eating quality scores regardless of country of origin (COO) or muscle.

Materials and Methods

Product sourcing

A representative selection of Australian grass- and grain-finished cattle was made by selecting carcasses from a number of supplier beef brands. Institutional Animal Care and Use Committee approval was not needed as no live cattle were used in this experiment. Live animal information was made available through the animal identification system in Australia, but no data were collected on farm. According to MSA, grain-fed cattle are supplied through a National Feedlot Accreditation Scheme feedlot and meet the Australian grain-fed beef minimum standard specifications (MLA, 2017). Cattle were fed a minimum ration consisting of average metabolizable energy content greater than 10 MJ/kg on a dry matter basis. Grain was the single highest component of the ration. Cattle must be on high-energy rations at least 80 d and on feed a minimum of 100 d (AUS-MEAT, 2018). Animals that do not meet grain specifications are categorized as grass-fed cattle (MLA, 2017). Although grass-fed cattle were not "Certified Pasturefed," these diets could include annual and/or perennial grass, cereal grain crops in a pre-grain state, legumes (alfalfa, clover, peas), and brassica (beets, kale, turnips), as well as hay, haylage, balage, silage, forage products (grass cubes or pellets), cereal crop residue without grain, and roughage products (hulls, hull pellets, or cubes from cottonseed, rice, or soybean) while on pasture (CCA, 2016). Grass-fed cattle were selected from 3 suppliers and harvested at 4 different commercial abattoirs. The Australian grain-fed product was also sourced from 3 commercial abattoirs and suppliers, one being common to the grass-fed supplier and abattoir. The cattle were representative of the general cattle population in southern Queensland with grass-fed cattle ranging from 0% to 50% *B. indicus* and the grain-fed from 0% to 37.5% *B. indicus*. All grain-fed cattle had received a hormonal growth promotant implant, whereas some of the grass-fed cattle were not implanted. Tropical breed content and implant usage was monitored and reported for Australian cattle according to their accompanying MSA vendor declaration when they were transferred to an MSA-licensed abattoir (MSA, 2019).

Australian cattle were harvested over a 3-d period. MSA grade data were recorded for carcasses selected for cut collection. MSA marbling was scored from 100 to 1,190 in increments of 10 based on amount and distribution of marbling in the *longissimus dorsi* (AUS-MEAT, 2019). Ossification was scored from 100 to 590 in increments of 10 using the AUS-MEAT Carcase Maturity Chart (AUS-MEAT, 2019). In addition, hot carcass weight (kg), 12th rib fat thickness, ribeye area (cm^2), and hump height (mm) were collected and recorded for each carcass. In the MSA grading system, hump height serves as an indicator of tropical breed content. Strip loin (Institutional Meat Purchase Specifications [IMPS] 180) and top sirloin butt/rump (IMPS 184B) subprimals were collected from 12 grass-fed and 12 grain-fed carcasses during fabrication and identified with laminated tags that were placed in bags with associated subprimals. Subprimals were vacuum packaged individually. All subprimals were combined into a single airfreight consignment from Brisbane, Australia, to Texas Tech University, Lubbock, Texas. Subprimals were held at 0°C to 3°C during storage and shipment.

US-sourced subprimals were selected from 12 USDA Choice (USDA, 1997) carcasses at a commercial West Texas packing plant by trained personnel from Texas Tech University. MSA data were recorded by an Australian MSA grader. Tenderloin (IMPS 190A), strip loin (IMPS 180), top sirloin butt (IMPS 184B), and eye of round (IMPS 171C) subprimals were collected during fabrication, identified by individually numbered laminated tags, vacuum packaged, and shipped to the Texas Tech University Gordon W. Davis Meat Science Laboratory, Lubbock for storage at 0°C to 1°C until fabrication.

Sample fabrication

Products were fabricated into steaks in accordance with MSA protocols (Watson et al., 2008). Subprimals were rendered into single muscles, and all external fat and connective tissue were removed. Subprimals were fabricated into 2.5-cm steaks. Whole steaks were further processed into smaller pieces measuring approximately 5 cm × 5 cm × 2.5 cm. Steak pieces were wrapped individually and vacuum packaged as sets of 5 based on position within the subprimal. Two or three sets of five steak pieces were prepared from the eye of round and tenderloin subprimals. The LL from strip loin subprimals was divided into halves, and one half was retained as a block for enhancement. The other half was fabricated into 2.5-cm steaks, which were further processed into smaller pieces measuring approximately 5 cm × 5 cm × 2.5 cm. The portions allocated for enhancement versus untreated control were rotated between anterior and posterior positions. The GM was removed from the top sirloin butt subprimal and further separated along the seam into 2 portions. The smaller "eye" portions of the GM were also fabricated into 2.5-cm steaks, which were further processed into smaller pieces measuring approximately 5 cm × 5 cm × 2.5 cm. Those steaks were utilized as link or warm-up samples but were not included in the test design. A controlled balance of the larger "D" or "heart" section from either the left or right sides of each carcass was retained as a block for enhancement with the alternate side prepared into 2.5-cm steaks, which were further processed into smaller pieces measuring approximately 5 cm × 5 cm × 2.5 cm.

The blocks allocated to enhancement were weighed and then enhanced with a solution (BAFOS, Bavaria Corporation, Apopka, FL) beef steak blend consisting of sodium phosphates, hydrolyzed beef protein, salt, sodium bicarbonate, and beef flavor [autolyzed yeast extract, beef flavor, beef extract, salt, and beef stock]) to achieve a 7% pump (GM 6.9% ± 1.4%; LL 6.9% ± 1.6%) using a multineedle pickle injector (Wolf-Tec, Model Schroder/Imax 350, Kingston, NY). After 5 min, samples were reweighed to calculate the weight added. After resting, they were taken to a separate table and cutting board for fabrication into 2.5-cm steaks, which were further processed into smaller pieces measuring approximately 5 cm × 5 cm × 2.5 cm.

All sets of 5 steak pieces were vacuum packaged and labeled with unique ID codes produced from MSA software prior to freezing at −20°C. Steaks were stored frozen until sensory testing. This resulted in an aging time of 29 d postmortem for the US product and a range of 29 to 32 d for the Australian product. Frozen samples were sorted into a predetermined cook order. After sorting, steaks remained frozen until sensory analysis was conducted.

Consumer testing

The Texas Tech University Institutional Review Board approved procedures for use of human subjects for consumer panel evaluation of sensory attributes (#502185).

Steak samples were thawed at 2°C to 4°C for 24 h prior to consumer evaluation. All steaks were cooked on a Silex clamshell grill (Model S-143K, Silex Grills Australia Pty Ltd., Marrickville, Australia) with the temperature set at 225°C. The Silex grill was preheated 45 min prior to the start of the panels. Ten steak pieces (unrelated to trial) were prepared on the grill before consumer samples to initiate the cooking cycle and stabilize temperatures throughout the heating elements. A strict and detailed time schedule was followed to ensure that all steaks were prepared identically (Gee, 2006). Each cooking round consisted of 10 samples that were cooked at the same time on one grill. All steaks were cooked for 5 min and 45 s, followed by a 3-min rest period. After the rest period, each steak was cut into 2 equal-size pieces and served to 2 separate predetermined consumer panelists.

Consumer panels were conducted in the Texas Tech University Animal and Food Sciences Building. Consumer panelists ($n = 360$) were recruited from Lubbock, Texas, and the surrounding local communities. Each consumer was monetarily compensated and was only allowed to participate one time. Each session consisted of 20 people, with 3 sessions conducted on a given night. Each session lasted approximately 60 min.

Consumer testing was conducted according to MSA grill protocols (Watson et al., 2008). Each consumer evaluated 7 samples. One steak sample was included in the cooking order, drawn from the smaller "eye" portion of the GM, as a warm-up sample for consumers and to provide linkage across all testing nights. The link samples were always served in the first position, followed by 6 test samples served in a predetermined, balanced order. Consumers received one from each of the 6 products, with serving order controlled by a 6 × 6 Latin square design ensuring that all products were presented an equal number of times in each serving-order position and before and after each other product. The 6 products were *semitendinosus* (ST; used as a low-quality anchor), *psoas major* (PM; used as a high-quality anchor), nonenhanced GM, enhanced GM, nonenhanced LL, and enhanced LL. All PM and ST were US sourced and nonenhanced. Within each group of 60 consumers, both enhanced and nonenhanced GM and LL samples consisted of 2 US-sourced samples, 2 Australian grass-fed samples, and 2 Australian grain-fed samples. Those products were equally represented and evenly distributed among the 60 consumers each night. Software-controlled routines ensured that the 5 individual steak pieces from each individual sample set were served in 5 different serving-order positions and within different subsets of 12 consumers within each group of 60.

Each panelist was seated at a numbered booth and was provided with a ballot, plastic utensils, a toothpick, unsalted crackers, a napkin, an empty cup, a water cup, and a cup with diluted apple juice (10% apple juice and 90% water). Each ballot consisted of a demographic questionnaire, 7 sample ballots, and a post-panel survey regarding beef purchasing habits. Before beginning each panel, consumers were given verbal instructions by Texas Tech personnel about the ballot and the process of testing samples. Panels were conducted in a large classroom under fluorescent lighting with tables that were divided into individual consumer booths.

Each sample had 10 consumer observations (i.e., 5 consumer steaks all being cut in half and served to 2 individuals each). Consumers scored palatability traits of tenderness, juiciness, flavor liking, and overall liking on 100-mm line scales verbally anchored at 0 (not tender, not juicy, dislike extremely) and 100 (very tender, very juicy, like extremely). The 10 individual scores for tenderness, juiciness, flavor liking, and overall liking were averaged to generate mean sensory scores for each palatability trait prior to analysis.

Statistical analysis

All data were analyzed using the GLIMMIX procedure of SAS (version 9.4, SAS Institute Inc., Cary, NC). Carcass data were analyzed as a randomized complete design with COO/diet as the fixed effect. Initially, all consumer data were analyzed as a completely randomized design with 14 treatment options. PM and ST were not enhanced and were sourced only from the US. The intention of including PM and ST as samples was to provide low and high eating quality anchors for consumers. In addition to those 2 muscles, 12 additional treatment combinations were generated from COO/diet, muscle (LL and GM), and enhancement combinations. Following the initial analyses, PM and ST were omitted so that data could be analyzed as a split-split plot arrangement of treatments. COO/diet was considered the whole plot factor, whereas muscle was the subplot factor and enhancement the sub-subplot factor. The main effects of COO/diet (Australian grain-fed, Australian grass-fed, or US grain-fed), muscle (LL or GM), and enhancement (Control or 7% Enhancement) were included as fixed effects as well as in all two-way and three-way interactions. Random effects included testing day, carcass ID as the whole plot unit nested within the whole plot factor (COO/diet), and carcass ID × muscle nested within the whole plot factor (COO/diet). The three-way interaction was not significant. Enhancement × muscle was the only significant two-way interaction. Treatment least square means were separated with the PDIFF option at a significance level of $P < 0.05$. Pearson correlations were calculated using PROC CORR in SAS ($P < 0.05$). Demographic data were summarized using PROC FREQ.

Results and Discussion

Carcass data

As seen in Table 1, COO/diet influenced ($P \leq 0.02$) all carcass traits except *longissimus* muscle ultimate pH (P = 0.42). US grain-fed carcasses had greater ($P < 0.05$) marbling than Australian carcasses, which did not differ ($P > 0.05$) due to classification as grass or grain-fed. Australian grain-fed carcasses were heavier ($P < 0.05$) than Australian grass-fed or US grain-fed, which were similar ($P > 0.05$). Australian grass-fed carcasses had smaller ribeye area, less 12th rib fat, and lower average ossification score ($P > 0.05$) compared to Australian or US grain-fed carcasses, which did not differ ($P > 0.05$). Australian grain-fed carcasses had greater ($P < 0.05$) hump height than US grain-fed carcasses, but Australian grass-fed carcasses did not differ from either ($P > 0.05$). In the

Table 1. Least square means for carcass data of selected cattle according to treatment (n = 12/treatment)

Treatment	Hot carcass weight, kg	Ribeye area, cm^2	12th rib fat thickness, mm	MSA marbling[1]	Ossification[2]	Hump height, cm	pH
Australia grain[3]	374.3^a	83.5^a	11.2^a	371^b	187^a	84^a	5.57
Australia grass[4]	302.6^b	74.3^b	5.5^b	366^b	161^b	76^{ab}	5.53
US grain[5]	321.7^b	90.7^a	12.3^a	537^a	181^a	63^b	5.54
SEM[6]	14.03	2.86	1.01	15.5	5.88	5.3	0.0205
P value	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.42

[a–g]Within a column, least square means without a common superscript differ ($P < 0.05$).

[1]Meat Standards Australia (MSA) marbling is scored from 100 to 1,190 in increments of 10 based on amount and distribution of marbling in the *longissimus dorsi* (AUS-MEAT, 2019).

[2]Ossification is scored from 100 to 590 in increments of 10 using the AUS-MEAT Carcase Maturity Chart (AUS-MEAT, 2019).

[3]Cattle were fed minimum ration consisting of average metabolizable energy content greater than 10 MJ/kg on a dry matter basis. Grain was the single highest component of the ration. Cattle must be on high-energy rations at least 80 d and on feed a minimum of 100 d (AUS-MEAT, 2018).

[4]Animals that do not meet grain-fed specifications are categorized as grass-fed cattle (MLA, 2017). These diets could include annual and/or perennial grass, cereal grain crops in a pre-grain state, legumes (alfalfa, clover, peas), and brassica (beets, kale, turnips), as well as hay, haylage, balage, silage, forage products, cereal crop residue without grain, and roughage products while on pasture (CCA, 2016).

[5]Carcasses were selected to represent USDA Choice beef (USDA, 1997).

[6]SEM (largest) of the least square means.

MSA grading system, hump height serves as an indicator of tropical breed content. Australian grass-fed cattle ranged from 0% to 50% *B. indicus*, and the Australian grain-fed cattle ranged from 0% to 37.5% *B. indicus* according to their MSA vendor declarations that accompanied those cattle. The percentage of *B. indicus* influence was not available for carcasses in the US. It is possible, given the regionality, that *B. indicus*–influenced cattle were selected from to obtain the US subprimals. Given the lesser hump height of US carcasses compared to Australian grain-fed carcasses, there could have been less *B. indicus* influence in those animals, but other factors (such as gender) can also contribute to hump-height differences.

Demographic data and consumption trends

Demographic characteristics of participating consumers can be found in Table 2. Consumer age was evenly distributed between 3 age brackets (18 to 34, 35 to 50, and over 50 y old). Participants were evenly split between male and female. The most common household size was 2 to 4 people, representing over three-fourths of participants, and approximately two-thirds of consumers lived in dual-income households. This likely led to annual household income levels over $70,000 for half of the participants. Most participants identified as being "Caucasian/White," whereas "Hispanic," "Asian," and "African American" conjointly accounted for less than 10% of participants.

Table 3 highlights the beef consumption and purchasing trends of consumer participants. Nearly 90% of consumers eat beef 1 to 6 times per week, while nearly 10% of those participants eat beef at least daily. Over 90% of participants like or enjoy red meat and consider it a regular or even an important part of their diet. When consumers were asked which palatability trait was most important while eating beef steaks, most consumers responded that they equally rely on flavor or tenderness as their most important palatability trait, which is similar to previous results (Hunt et al., 2014; Lucherk et al., 2016; Ron et al., 2019). Like Ron et al. (2019), tenderness and flavor were equally selected as most important in the current study, but tenderness was more common in the results of Hunt et al. (2014).

Consumer eating quality

For the initial analysis with 14 treatment options, results can be found in Table 4. All palatability traits, overall liking, and satisfaction were influenced ($P < 0.01$) by treatment. For all traits except juiciness, the PM received the highest scores; however, the PM was similar to multiple enhanced samples for each trait. For tenderness, Enhanced-LL from US grain-fed carcasses was similar ($P > 0.05$) to PM. For flavor liking, PM samples did not differ ($P > 0.05$) from any enhanced LL, regardless of COO/diet, or from Enhanced-GM from US grain-fed carcasses. For overall liking, Enhanced-LL from grain-fed carcasses (from both the US and Australia) had similar ($P > 0.05$) overall liking to PM. Consumers scored all Enhanced-LL samples, regardless of COO/diet, juicier ($P < 0.05$) than PM samples. ST samples were scored lower ($P < 0.05$) than any other treatment option for tenderness, juiciness, flavor liking, and satisfaction.

Table 2. Demographic characteristics for consumers who participated in sensory panels in Lubbock, TX ($n = 360$)

Trait	Percentage, %
Age	
18–34 y	31.5
35–50 y	32.9
>50y	35.7
Gender	
Male	50.4
Female	49.6
Household size	
1	14.8
2	33.0
3	21.2
4	19.8
5	7.5
6	2.2
7+	1.4
Household type	
Single Income	38.0
Dual Income	62.0
Annual household income level	
<$20,000/y	7.5
$20,000–29,000/y	6.9
$30,000–49,000/y	16.7
$50,000–69,000/y	17.9
$70,000–100,000/y	28.5
>$100,000/y	22.5
Education level	
Non-high school graduate	1.1
High school graduate	13.2
Some college/technical school	33.4
College graduate	35.7
Post-graduate	16.6
Cultural heritage	
African American	1.4
Caucasian/White	89.8
Native American	0.3
Hispanic	6.2
Asian	2.0
Other	0.3

However, ST and Control-GM from Australian grass-fed carcasses were scored similarly ($P > 0.05$) and lower ($P < 0.05$) for overall liking than any other treatment option.

Enhancement resulted in increased ($P < 0.05$) scores for tenderness, juiciness, flavor liking, and overall liking for all LL, regardless of COO/diet. Consumers scored LL more tender ($P < 0.05$) by 10.4 to 15.0 units compared to the control counterparts. Juiciness scores for LL were elevated ($P < 0.05$) by 11.1 to 16.5 units due to enhancement. A boost ($P < 0.05$) of 11.8 to 15.5 units was observed in flavor liking scores when comparing control to enhanced samples. Finally, overall liking increased ($P < 0.05$) by 11.3 to 16.5 units as a result of enhancement. For each trait, LL from Australian grass-fed carcasses received the largest lift in consumer scores for all traits. Although satisfaction of LL samples increased ($P < 0.05$) for all COO/diet treatments, enhancement of Australian and US grain-fed LL samples resulted in a shift into the next quality category for satisfaction. So rather than being considered "good everyday quality," those samples were perceived as "better than everyday quality."

Table 3. Beef consumption trends of consumers who participated in sensory panels in Lubbock, TX ($n = 360$)

Question	Percentage, %
How often do you eat beef?	
<1 time/wk	0.8
1–3 times/wk	48.5
4–6 times/wk	39.6
7+ times/wk	11.1
Red meat in diet	
I enjoy red meat. It's an important part of my diet.	62.8
I like red meat well enough. It's a regular part of my diet.	31.4
I do eat some red meat although, truthfully, it wouldn't worry me if I didn't.	5.6
I rarely eat red meat.	0.3
Are you the regular purchaser of meat for your household?	
Yes	73.9
No	26.1
What is the most important palatability trait when you consume beef steaks?	
Flavor	41.2
Tenderness	46.1
Juiciness	12.7
How often do you eat steaks in a restaurant and have an excellent eating experience?	
Always	1.4
Almost always	44.4
Some of the time	45.8
Almost never	7.8
Never	0.6

For GM samples, enhancement improved ($P < 0.05$) nearly all scores for tenderness, juiciness, flavor liking, and overall liking, regardless of COO/diet. The one exception was that tenderness did not differ ($P > 0.05$) between control and enhanced GM samples from Australian grain-fed carcasses. Consumers scored enhanced GM as more tender ($P < 0.05$) by 10.1 and 10.4 units compared to the control counterparts, for GM samples from Australian grass-fed carcasses and

Table 4. The effects of treatment (muscle, country of origin/diet, enhancement) on eating quality scores as rated by consumers ($n = 360$)

Muscle	COO/diet[1]	Enhancement[2]	Tenderness[3]	Juiciness[3]	Flavor liking[3]	Overall liking[3]	Satisfaction[4]
Semitendinosus	US grain	Control	38.2[i]	45.9[g]	48.7[g]	45.7[h]	2.8[i]
Gluteus medius	Australia grain	Control	61.3[efg]	57.7[ef]	59.8[de]	58.3[efg]	3.4[fgh]
Gluteus medius	Australia grain	Enhancement	66.7[def]	65.8[cd]	69.1[bc]	65.3[cd]	3.6[def]
Gluteus medius	Australia grass	Control	50.3[h]	54.8[f]	52.9[fg]	48.8[h]	3.1[h]
Gluteus medius	Australia grass	Enhancement	60.4[fg]	62.7[cde]	60.3[de]	56.0[fg]	3.3[gh]
Gluteus medius	US grain	Control	57.7[g]	59.8[def]	62.5[de]	63.1[def]	3.5[efg]
Gluteus medius	US grain	Enhancement	68.1[de]	66.1[bcd]	71.4[ab]	71.4[bc]	3.7[cd]
Longissimus lumborum	Australia grain	Control	68.9[d]	66.9[bc]	63.2[d]	63.4[de]	3.6[de]
Longissimus lumborum	Australia grain	Enhancement	79.3[b]	78.3[a]	75.0[a]	74.7[ab]	4.1[ab]
Longissimus lumborum	Australia grass	Control	61.2[efg]	62.6[cde]	57.0[ef]	54.9[g]	3.3[gh]
Longissimus lumborum	Australia grass	Enhancement	76.2[bc]	79.1[a]	72.5[a]	71.2[bc]	3.9[bc]
Longissimus lumborum	US grain	Control	69.3[cd]	68.6[bc]	63.7[cd]	66.7[cd]	3.6[de]
Longissimus lumborum	US grain	Enhancement	82.9[ab]	79.7[a]	75.9[a]	79.5[a]	4.0[ab]
Psoas major	US grain	Control	85.9[a]	71.7[b]	74.9[a]	79.4[a]	4.1[a]
SEM[5]			2.65	2.65	2.06	2.53	0.10
P value[6]			<0.01	<0.01	<0.01	<0.01	<0.01

[1]Country of origin (COO)/diet: Australia grass = Animals that do not meet grain-fed specifications are categorized as grass-fed cattle (MLA, 2017). These diets could include annual and/or perennial grass, cereal grain crops in a pre-grain state, legumes (alfalfa, clover, peas), or brassica (beets, kale, turnips), as well as hay, haylage, balage, silage, forage products, cereal crop residue without grain, and roughage products while on pasture (CCA, 2016). Australia grain = Cattle were fed minimum ration consisting of average metabolizable energy content greater than 10 MJ/kg on a dry matter basis. Grain was the single highest component of the ration. Cattle must be on high-energy rations at least 80 d and on feed a minimum of 100 d. US grain = carcasses were selected to represent USDA Choice beef.

[2]Control = No enhancement; Enhancement = Enhanced with 7% (± 1.5%) BAFOS (BAFOS, Bavaria Corporation, Apopka, FL) beef steak blend solution (sodium phosphates, hydrolyzed beef protein, salt, sodium bicarbonate, beef flavor [autolyzed yeast extract, beef flavor, beef extract, salt, beef stock]).

[3]0 = not tender, not juicy, dislike flavor extremely, dislike overall extremely; 100 = very tender, very juicy, like flavor extremely, like overall extremely.

[4]Satisfaction score: 2 = unsatisfactory; 3 = good everyday quality; 4 = better than everyday quality; 5 = premium quality.

[5]Pooled (largest) SEM reported of least square means.

[6]Observed significance levels for treatment (muscle, COO/diet, enhancement).

[a–i]Within a column, least square means without a common superscript differ ($P < 0.05$).

US grain-fed carcasses, respectively. Juiciness scores for GM increased ($P < 0.05$) by 6.3 to 8.1 units due to enhancement. A lift ($P < 0.05$) of 7.4 to 9.3 units was observed in flavor liking scores of GM samples when comparing control to enhanced samples. Finally, overall liking of GM samples improved ($P < 0.05$) by 7.0 to 8.3 units as a result of enhancement. Unlike the LL samples, there was no consistent benefit to one particular COO/diet in the palatability scores for GM samples. Satisfaction of GM samples increased ($P < 0.05$) only for Australian and US grain-fed samples, but the magnitude of difference was not sufficient to move those samples into the next quality category for satisfaction. All GM samples, regardless of COO/diet and enhancement, were categorized as "good everyday quality."

Subsequent analysis focusing on the intended split plot design was performed. As seen in Table 5, COO/diet affected ($P < 0.01$) tenderness, flavor liking, overall liking, and satisfaction but did not influence juiciness ($P = 0.09$). Australian and US grain-fed samples were similar for tenderness, flavor liking, and satisfaction; however, US grain-fed beef was more liked overall than Australian grain-fed beef, and both were superior to Australian grass-fed beef. Consumers rated Australian grass-fed beef as less tender and lower for flavor liking, overall liking, and satisfaction compared to Australian or US grain-fed beef.

According to cattle feeding surveys, feedyard rations in Texas, Oklahoma, and Kansas consist predominately of corn (high moisture, steam flaked, and/or dry rolled), wet or modified distillers grains, haw, silage, and mineral (Asem-Hiablie et al., 2015). These cattle are typically on finishing rations an average of 149 d, with a range of 100 to 200 d (Asem-Hiablie et al., 2015). About 97% of finished cattle in Kansas, Oklahoma, and Texas receive at least one growth promotant implant (Asem-Hiablie et al., 2015). As previously mentioned, Australian grain-fed cattle

Table 5. Effects of country of origin/diet on consumer responses for tenderness, juiciness, flavor liking, overall liking, and satisfaction of *longissimus lumborum* and *gluteus medius* samples

	Country of origin/diet[1]				
Trait	AUS grain	AUS grass	US grain	SEM[2]	*P* value
Tenderness[3]	69.0[a]	62.0[b]	69.5[a]	1.38	<0.01
Juiciness[3]	67.2	64.8	68.6	1.33	0.09
Flavor liking[3]	66.8[a]	60.7[b]	68.4[a]	1.02	<0.01
Overall liking[3]	66.3[b]	58.5[c]	71.0[a]	1.59	<0.01
Satisfaction[4]	3.7[a]	3.4[b]	3.7[a]	0.057	<0.01

[1]Australia (AUS) grass = Animals that do not meet grain-fed specifications are categorized as grass-fed cattle (MLA, 2017). These diets could include annual and/or perennial grass, cereal grain crops in a pre-grain state, legumes (alfalfa, clover, peas), or brassica (beets, kale, turnips), as well as hay, haylage, balage, silage, forage products, cereal crop residue without grain, and roughage products while on pasture (CCA, 2016). AUS grain = Cattle were fed minimum ration consisting of average metabolizable energy content greater than 10 MJ/kg on a dry matter basis. Grain was the single highest component of the ration. Cattle must be on high-energy rations at least 80 d and on feed a minimum of 100 d. US grain = carcasses were selected to represent USDA Choice beef.

[2]Pooled (largest) SEM reported of LS means.

[3]0 = not tender, not juicy, dislike flavor extremely, dislike overall extremely; 100 = very tender, very juicy, like flavor extremely, like overall extremely.

[4]Satisfaction score: 2 = unsatisfactory; 3 = good everyday quality; 4 = better than everyday quality; 5 = premium quality.

[abc]Within a row, least square means without a common superscript differ ($P < 0.05$).

must be on high-energy rations at least 80 d and on feed a minimum of 100 d, so the feeding period could be considerably shorter in Australia than the US. Another notable difference between grain feeding in Australia and the US is the composition of the diet. Whereas corn is the predominant grain in the US, Australian feedlot diets are formulated to provide high energy to cattle by way of wheat, barley, and sorghum (Greenwood et al., 2018; ALFA, 2019). Hay or silage is used for fiber, and sunflower or lupins are fed as a protein source (Greenwood et al., 2018; ALFA, 2019).

Despite a difference in marbling score between Australian and US grain-fed beef and apparent differences in commercial grain finishing systems between the 2 countries, tenderness, flavor liking, and satisfaction did not differ ($P > 0.05$) between Australian and US grain-fed samples. When Sitz et al. (2005) matched US strip loin steaks to Canadian strip loin steaks according to similar Warner-Bratzler shear force values and marbling, US consumers were accustomed to US domestic beef flavor and preferred that over Canadian beef. In Canada, much like Australia, the majority of cattle finishing diets are barley based, with either silage or grain (Mir et al., 1997; Beauchemin and Koenig, 2005; Markus et al., 2011). When Tedford et al. (2014) matched US and Canadian strip loin steaks for marbling, consumers could not differentiate between equivalent grades from both countries for any palatability traits. However, when comparing USDA Choice to Canadian AA (equivalent to USDA Select), which would be a similar comparison to the grain-fed samples in the current study, consumers found the USDA Choice samples more tender but did not find differences in juiciness or flavor. Sitz et al. (2005) believed that US consumers were more accustomed to domestic beef flavor and therefore preferred that over Canadian grain-fed or Australian grass-fed beef. However, after feeding corn, corn/barley, or barley-based diets to cattle for approximately 100 d, trained panelists could not differentiate between dietary grain source when assessing descriptive sensory flavor attributes (Miller et al., 1996). This could explain why consumers in the current study rated grain-fed beef from Australia and the US similarly for most palatability traits.

US consumers sometimes prefer the flavor of grain-finished beef compared to grass-fed beef, although grass-fed beef flavor can undoubtedly vary from country to country depending on the type, quality, and maturity of the forage the cattle consume. Sitz et al. (2005) reported that steaks from Australian grass-fed beef had lower scores for tenderness, juiciness, flavor, and overall acceptability than steaks from US grain-finished beef. Garmyn et al. (2019), however, found that US consumers could not distinguish between grass-finished beef from New Zealand, which had marbling scores representative of the USDA Select grade, and USDA Select LL when samples were aged for 21 d postmortem. When samples were aged 35 d postmortem, consumers actually scored New Zealand grass-fed beef greater for all palatability traits compared to USDA Select (Garmyn et al., 2019). However, when comparing Top Choice LL samples to those same New Zealand grass-fed samples, Top Choice samples were scored greater for all palatability traits regardless of postmortem aging period (Garmyn et al., 2019). This would be a more comparable comparison to the current study because there was a sizable (171-degree) difference, albeit in MSA marbling score units, in average marbling score between US grain-fed and Australian grass-fed carcasses. In this study, marbling score is not the sole driver of consumer liking as Australian grass-fed and grain-fed carcasses had similar marbling scores, yet Australian grain-fed was scored similarly to US grain-fed while Australian grass-fed was less liked overall. Maughan et al. (2012) developed a beef flavor lexicon to compare the flavor profile of beef from cattle finished on grass or grain. Barny, bitter, gamey, and grassy flavors were more dominant in beef from grass-fed cattle, whereas umami was more prevalent in grain-finished beef (Maughan et al., 2012). Degree of liking was negatively related to gamey, barny, bitter, and grassy flavors and positively associated with brothy, umami, roast beef, browned, fatty, and salty flavors (Maughan et al., 2012). In this study, grass-fed cattle were supplemented with alfalfa during the winter and finished on grass for 120 d, but no further description of the finishing grass was provided (Maughan et al., 2012). We believe this is relevant because Larick and Turner (1990) demonstrated that different forages elicit different flavor notes, suggesting that not all beef from grass-fed cattle will taste the same. This could help explain conflicting results of consumer preference for grass-fed or grain-fed beef, depending on the country where the beef originated. According to Sitz et al. (2005), consumers pointed out more off-flavors and off-odors in the Australian grass-fed samples than domestic US beef, which could have been attributed to the cattle diets or the extended aging period of the Australian beef. Postmortem aging period was comparable between US and Australian samples in the current study, so cattle diet is the likely driving force in the palatability differences.

Although no interaction was detected for tenderness, both muscle and enhancement influenced ($P < 0.01$) consumer tenderness scores. Consumers rated LL more tender than GM (73.0 vs. 60.8; $P < 0.01$) regardless of enhancement, and enhancement improved tenderness scores (72.3 vs. 61.4; $P < 0.01$) regardless of muscle. A two-way interaction between muscle and enhancement was observed for juiciness, flavor liking, overall liking, and satisfaction ($P \leq 0.05$; Table 6). Enhanced-LL was juicier ($P < 0.05$) than all other treatment combinations. Enhanced-GM and Control-LL were intermediate, and Control-GM was least juicy ($P < 0.05$). Consumers liked the flavor of Enhanced-LL more ($P < 0.05$) than any other treatment combination, Enhanced-GM was intermediate, and Control from both LL and GM had the least liked flavor. Overall liking and satisfaction followed a similar trend to juiciness, in which Enhanced-LL were liked most ($P < 0.05$) overall, followed by Enhanced-GM and Control-LL, which were similar ($P > 0.05$), and Control-GM was least liked ($P < 0.05$) overall by consumers. Satisfaction of LL samples increased ($P < 0.05$) due to enhancement, resulting in a shift into the next quality category for satisfaction; so rather than being considered “good everyday quality,” these samples were perceived as “better than everyday quality.” Satisfaction of GM samples also increased with

Table 6. Effects of enhancement[1] and muscle on consumer responses for tenderness, juiciness, flavor liking, overall liking, and satisfaction

	Longissimus lumborum		*Gluteus medius*			*P* value[2]		
Trait	CON	ENH	CON	ENH	SEM[3]	TRT	Muscle	TRT × muscle
Tenderness[4]	66.5	79.5	56.4	65.1	1.55	<0.01	<0.01	0.14
Juiciness[4]	66.1[b]	79.0[a]	57.4[c]	64.9[b]	1.48	<0.01	<0.01	0.05
Flavor liking[4]	61.3[c]	74.5[a]	58.4[c]	66.9[b]	1.15	<0.01	<0.01	0.04
Overall liking[4]	62.5[b]	76.0[a]	57.6[c]	65.1[b]	1.20	<0.01	<0.01	0.01
Satisfaction[5]	3.5[b]	4.0[a]	3.3[c]	3.5[b]	0.061	<0.01	<0.01	<0.01

[1]CON = Control (no enhancement); ENH = Enhanced with 7% (± 1.5%) BAFOS (Bavaria Corporation, Apopka, FL) beef steak blend solution (sodium phosphates, hydrolyzed beef protein, salt, sodium bicarbonate, beef flavor [autolyzed yeast extract, beef flavor, beef extract, salt, beef stock]).

[2]Observed significance levels for main effects of treatment (enhancement), cut, and the treatment × cut interaction.

[3]Pooled (largest) SEM reported of least square means.

[4]Score: 0 = not tender, not juicy, dislike flavor extremely, dislike overall extremely; 100 = very tender, very juicy, like flavor extremely, like overall extremely.

[5]Score: 2 = unsatisfactory; 3 = good everyday quality; 4 = better than everyday quality; 5 = premium quality.

[abc]Within a row, least square means without a common superscript differ ($P < 0.05$) due to treatment × muscle.

enhancement, but the difference was not substantial enough to move into the next quality level. All GM samples, regardless of enhancement, were categorized as "good everyday quality."

Previous results have failed to find differences in tenderness between the LL and GM (Neely et al., 1998; Hunt et al., 2014), and ranking of overall tenderness of LL and GM by trained sensory assessors also contradicts the present findings (McKeith et al., 1985; Rhee et al., 2004). According to Neely et al. (1998), consumers scored LL juicier than GM, and McKeith et al. (1985) had similar findings with trained panelists. However, Hunt et al. (2014) did not observe differences in consumer juiciness scores between LL and GM within a particular quality grade, and similar findings were reported with trained panelists (Rhee et al., 2004). Hunt et al. (2014) found that consumers scored flavor and overall liking similarly for LL and GM samples. However, Neely et al. (1998) reported that consumers preferred LL over GM regardless of quality grade, which supports the current findings. Results comparing muscle are very inconsistent, as postmortem aging and study design may vary. Previous reports have often contained more muscles than just the GM and LL, as well as other factors such as quality grade and cooking method, which presents challenges for comparing results and making inferences about differences and similarities in the results.

Enhancement improved all palatability traits within each muscle. These results align with previous findings in which the incorporation of various nonmeat ingredients augmented tenderness, juiciness, and flavor (Robbins et al., 2003; Baublits et al., 2006; Hardcastle et al., 2018). Hardcastle et al. (2018) found enhancement particularly beneficial in Honduras to minimize differences in tenderness in cattle produced in traditional (grazing) and nontraditional production systems (using higher-energy experimental finishing diets). Although grazing systems and native grasses will vary between these 2 countries, Honduras also relies heavily on *B. indicus* cattle. Enhanced beef is typically juicier than nonenhanced beef (Robbins et al., 2003; Baublits et al., 2006; Hardcastle et al., 2018), which aligns with the current findings. Enhancement can increase muscle pH and decrease free water, increasing moisture retention (Robbins et al., 2003; Baublits et al., 2006). Flavor liking and overall liking of LL and GM both increased in the current study due to enhancement, again aligning with previous results (Robbins et al., 2003; Baublits et al., 2006; Hardcastle et al., 2018). Stetzer et al. (2008) showed that sodium chloride can increase saltiness and enhance beef flavor intensity; however, Wicklund et al. (2005) speculated that enhancement ingredients, particularly salt, could mask other flavors. In some cases, salt intensity can mask beef flavor intensity (Rose et al., 2010). Nonetheless, saltiness did not appear to be detrimental or overwhelming in the current results as flavor liking improved with enhancement.

Table 7. Pearson's correlation coefficients for the relationships between consumer sensory scores of *longissimus lumborum*, *gluteus medius*, *semitendinosus*, and *psoas major* muscle samples representing Australian grass-fed, Australian grain-fed, and US grain-fed beef

Trait	Juiciness	Flavor liking	Overall liking	Satisfaction
Tenderness	0.85*	0.85*	0.93*	0.89*
Juiciness		0.82*	0.89*	0.82*
Flavor liking			0.95*	0.87*
Overall liking				0.92*

*Correlation coefficients were significant ($P < 0.01$).

Correlations

To estimate the extent to which eating quality scores are linked to overall liking, correlation coefficients between palatability traits were determined (Table 7). Consumer overall liking was associated ($P < 0.01$) with consumer tenderness (r = 0.93) and juiciness ratings (r = 0.89) but was most highly related with flavor liking (r = 0.95). Individual palatability traits were strongly correlated to each other ($r \geq 0.82$), indicating that individual improvements of these traits could influence the perception of another trait.

The current results were not unexpected because the previous reports of beef eating quality for US consumers align with these coefficients for grain-fed beef (Hunt et al., 2014; Corbin et al., 2015) and grass-fed beef (Crownover et al., 2017; Garmyn et al., 2019). These data also support the relationship of tenderness, flavor, and juiciness conjointly contributing to the consumer perception of overall liking, as reported previously (Hunt et al., 2014; Corbin et al., 2015; Crownover et al., 2017; Hardcastle et al., 2018; Garmyn et al., 2019).

Conclusions

Enhancement significantly improved palatability in both LL and GM steaks as evidenced by higher consumer ratings for tenderness, juiciness, flavor liking, overall liking, and satisfaction. Enhancing LL steaks resulted in consumer responses that were comparable or superior to consumer responses for PM samples. Similarly, enhancing GM steaks resulted in consumer responses that were comparable or superior to nonenhanced LL samples. Consumers reacted least favorably to nonenhanced Australian grass-fed beef as they rated all palatability traits lowest for both LL and GM samples. In addition, satisfaction was lowest for Australian grass-fed beef. However, enhancing grass-fed beef resulted in consumer responses that were similar to nonenhanced grain-fed beef. This response to enhancement was observed in consumer scores for both LL and GM samples. Consumers could not detect differences in tenderness, juiciness, flavor, overall liking, or satisfaction in enhanced grain-fed beef from Australia and the US or between nonenhanced grain-fed beef from Australia and the US.

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