Meat and Muscle Biology™

# Consumer Eating Quality, Cooking Traits, and Compositional Assessment of Smoked Briskets From MSA and USDA Graded Beef Carcasses

Justin E. Johnston[1], Andrea J. Garmyn[2,3]*, Nicholas C. Hardcastle[1], Jerrad F. Legako[1], J Chance Brooks[1], Rod J. Polkinghorne[4], and Markus F. Miller[1]

[1]Animal and Food Sciences, Texas Tech University, Lubbock, TX, 79409, USA
[2]Food Science and Human Nutrition, Michigan State University, East Lansing, MI, 48824, USA
[3]Animal Science, Michigan State University, East Lansing, MI, 48824, USA
[4]Birkenwood Pty. Ltd., 46 Church St., Hawthorn, VIC 3122, Australia
*Corresponding author. Email: garmynan@msu.edu (Andrea J. Garmyn)

**Abstract:** The objective of this study was to determine consumer eating quality of smoked briskets based on the following factors: combined treatment (carcass grade, diet, country origin), muscle portion (*pectoralis profundus* = flat vs. *pectoralis superficialis* = point), serving form (chopped, sliced, pulled), and serving time (hot/fresh or reheated). Subprimals were collected from the combined treatments based on country of origin, diet, and grade of Australian grass-fed (Company grades 2, 3, 4, 5, and cull cow derived from Meat Standards Australia [MSA] predicted muscle composite eating quality [MQ4] scores), Australian grain-fed (Company Graded 2, 3, 4, or 5), or US (USDA Prime, Choice, and Select) carcasses. All briskets were trimmed, seasoned, and smoked whole to a common endpoint temperature (93°C). There was an interaction between combined treatment and muscle portion that influenced consumer scores ($P < 0.05$) for juiciness, tenderness, flavor liking, overall liking, and the MQ4 score. Consumers had difficulty distinguishing between US and Australian grain-fed or between grain-fed and grass-fed samples for tenderness and juiciness, regardless of muscle portion; however, consumers could differentiate grain-fed from grass-fed for flavor and overall liking within certain quality grade tiers. The samples that were served hot on their original cooking day were scored greater for all traits ($P < 0.05$) compared to reheated brisket samples. Serving form influenced ($P < 0.05$) all palatability traits, in which sliced and chopped brisket generally scored greater than pulled brisket samples. These results suggest that consumers have distinct preferences for hot/fresh products and can differentiate different serving forms. Moreover, carcass-combined treatment and muscle interacted, suggesting carcass quality grade may not be a straightforward predictor of smoked brisket eating quality.

**Key words:** brisket, carcass quality, consumer sensory, diet, reheat, smoked beef
*Meat and Muscle Biology* 8(1): 18281, 1–15 (2024) **doi:10.22175/mmb.18281**
Submitted 26 July 2024 Accepted 10 October 2024

## Introduction

Increased marbling level in the longissimus muscle is linked with increased beef tenderness, juiciness, flavor, and overall palatability rankings in both trained and untrained consumer sensory panels (Corbin et al., 2015; Garmyn et al., 2011; O'Quinn et al., 2012; Smith et al., 1985); however, the effect of marbling on tenderness is more apparent in cuts of meat in the rib and loin than certain end cuts (Hunt et al., 2014; Nelson et al., 2004). The longissimus muscle has traditionally been the point of interest in beef palatability research, leaving a knowledge gap for other muscles, especially when cooked and/or served in alternative forms.

Little research has been conducted on beef palatability in the "low and slow" cooking method for items like brisket or short ribs that benefit from cooking at low temperatures for extended periods of time. Several researchers have shown the brisket can be quite tough in comparison to other muscles, both in terms of sensory evaluation or shear force testing, indicating that when prepared as a steak (dry high heat, short cooking duration), brisket is unacceptable (Carmack et al., 1995; Kukowski et al., 2004; McKeith et al., 1985; Patterson and Parrish, 1986). Sullivan and Calkins (2011) categorized the *pectoralis profundus* as one of the toughest muscles in the carcass, along with the semitendinosus, gluteus medius, supraspinatus. Smith et al. (1978) corroborated these findings of "tough" Warner-Bratzler shear force (WBSF) values for the brisket muscles, reporting average WBSF values (from pooling postmortem aging periods from 5 to 28 d) for the *pectoralis profundi* at 4.73 kg and *pectoralis superficialis* at 5.18 kg; however, researchers have begun to examine palatability traits of beef brisket prepared using alternative cooking techniques, such as Texas-style barbeque. Harris et al. (2017) found postmortem aging did not improve beef brisket palatability, but eating quality can be differentiated between the pectoralis muscle portion (point vs. flat). Fletcher et al. (2021) examined the quality grade and muscle portion (point vs. flat) differences of Texas-style barbeque brisket and showed consumers perceived similar eating quality between Prime, Choice, and Select point portions (superficial pectoral); however, the flat portion (deep pectoral) of Prime briskets had superior eating quality to the same portions of Choice and Select briskets, and consumers were willing to pay more for samples they deemed to have superior eating quality (Fletcher et al., 2021). The aforementioned studies utilizing Texas-style barbeque cooking techniques focused on US-sourced briskets in the US market, but beef brisket demand continues to surge around the globe due to rising numbers of barbeque enthusiasts. This is especially true in countries such as Australia, which produce high volumes of beef each year. The beef industry is consistently identifying ways to add value to its products. Utilizing the "low and slow" cook method for briskets in areas outside the US is one possibility; however, the evaluation of eating quality of smoked briskets sourced outside the US is limited. Lees et al. (2024) focused on comparing Australian and US consumer perceptions of Australian briskets and not the quality differences of the carcasses from which the briskets were sourced.

Our main objective was to determine the effects of carcass quality grade and origin on the eating quality of smoked brisket. To achieve this, briskets were selected in the US and Australia to represent a range of carcass quality grades and finishing designations. Moreover, we were interested in determining if the serving form of brisket impacted the consumer eating quality, so briskets were served as either sliced, chopped, or pulled brisket samples. Lastly, we aimed to determine if and how smoked brisket eating quality differs if samples were served fresh on the day they were prepared or were reheated following 7 d of chilled vacuum-packaged storage. We believe the differences in carcass quality will be detectable by consumers, but differences in finishing diet may be overcome due to the light seasoning and cooking process for the briskets. Yang et al. (2002) found that consumers preferred freshly prepared samples over samples that were reheated after 3 d, so our final hypothesis is that consumers will also prefer the eating quality of freshly cooked and served brisket over samples that were reheated.

# Materials and Methods

## *Product procurement and preparation*

A total of 81 carcasses were utilized in the current study, including Australian grass-fed, Australian grain-fed, or United States Department of Agriculture (USDA) graded (Table 1). Institutional Animal Care and Use Committee approval was not needed as no live cattle were used in this experiment. Live animal information pertaining to diet (grass vs. grain) was made available through the animal identification system in Australia, but no data were collected on the farm.

Grass-fed cattle were selected at 2 different commercial abattoirs. The Australian grain-fed product was sourced from a single commercial abattoir, which

**Table 1.** Sampling numbers.

| Combined Treatment | *n* |
|---|---|
| **Australian** | |
| 5 Grain | 6 |
| 5 Grass | 6 |
| 4 Grain | 6 |
| 4 Grass | 6 |
| 3 Grain | 6 |
| 3 Grass | 6 |
| 2 Grain | 6 |
| 2 Grass | 4 |
| Manufacture Cow | 17 |
| **US** | |
| USDA Prime | 6 |
| USDA Choice | 6 |
| USDA Select | 6 |
| **TOTAL** | 81 |

was common to the grass-fed abattoir. Information pertaining to live animal management, such as diet, was monitored and reported for Australian cattle according to their accompanying Meat Standards Australia (MSA) vendor declaration when they were transferred to an MSA-licensed abattoir (Meat Standards Australia, 2019).

Australian cattle were harvested on one of 2 d. Meat Standards Australia grade data were recorded for carcasses selected for subprimal collection. Meat Standards Australia marbling was scored from 100 to 1190 in increments of 10 using marbling reference standard pictures (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 (HCW; kg) was recorded for each carcass; 12th rib fat thickness (RF; mm) and hump height (mm) were measured via rulers, and ribeye (longissimus muscle) area (REA; cm$^2$) was measured with a grid. AUS-MEAT fat and meat color scores were also recorded (AUS-MEAT, 2019). Finally, ultimate pH of the longissimus thoracis was collected at the time of carcass grading using a handheld temperature–pH meter equipped with an intermediate junction pH sensor (TPS Model WP-90 with pH sensor part #111227, TPS Pty Ltd., Brendale, QLD, Australia).

The MSA grading system predicts consumer eating quality outcomes for several muscles by utilizing carcass grading inputs (Stewart et al., 2024). Carcasses were classified into company grades derived from MSA muscle MQ4 score bands: 2 (fail/unsatisfactory), 4 ,3, or 5, based on carcass data, including MSA marbling, ossification, pH, hump height, hot carcass weight, and 12$^{th}$ rib fat, coupled with other inputs, such as sex (steer or heifer), tropical breed content, hormone growth promotant status, and predetermined postmortem aging period. Grass- and grain-fed carcasses were selected to fill all 4 company grades, resulting in 8 combined treatments that incorporate diet and carcass quality. In addition, grass-fed manufacture (cull) cow carcasses were included as a ninth combined treatment, but a corresponding grain-fed treatment did not exist for manufacture cow. Australian-combined treatments will be referred to as follows: A5grain, A4grain, A3grain, A2grain, A5grass, A4grass, A3grass, A2grass, and ACow. Paired brisket subprimals including the navel end with deckle removed (AUS-MEAT #2323) were collected from 39 grass-fed and 24 grain-fed carcasses during fabrication. More grass-fed carcasses were utilized due to the collection of subprimals from manufacture cows, which were all grass-fed. A greater number of briskets was required from the manufacture cows due to the lower weight of the carcasses and subsequent smaller size of the brisket subprimals. Subprimals were vacuum packaged individually and frozen at −20°C at 3 d postmortem. All subprimals were shipped via cargo ship from Brisbane, Australia, to the US, and shipped via road transport to Texas Tech University, Lubbock, Texas, upon clearance through customs. Subprimals were held at −20°C during storage and shipment.

US-sourced subprimals were selected from 18 USDA-graded carcasses at a commercial abattoir in Omaha, Nebraska to represent USDA Prime, average Choice, and Select carcasses (USDA, 2017). US-combined treatments will be referred to by the following terms: USDA Prime (UPR), USDA average Choice (UCH), and USDA Select (USEL). Carcasses were selected from cattle that would be considered commercially grain-fed. Cattle in the Northern Plains (Nebraska, South Dakota, North Dakota) are on finishing rations for an average of 137 d (Asem-Hiablie et al., 2016); however, the exact composition and duration of the finishing ration was not known in the current study due to their selection from a commercial abattoir. Carcass data were recorded by personnel trained for both USDA and MSA grading standards. The addition of the US-sourced product added 3 more combined treatments, for a total of 12 combined treatments (9 Australian, 3 US). Paired brisket subprimals (Institutional Meat Purchase Specifications #120) were collected during fabrication, identified individually by numbered laminated tags, vacuum packaged, and shipped to the Texas Tech University and frozen (−20°C) immediately upon receipt at 5 d postmortem. The number of carcasses per combined treatment utilized for consumer testing is summarized in Table 1.

### Brisket preparation and cooking procedures

Briskets were thawed at the Gordon W. Davis Meat Science Laboratory for 72 h at 2 to 4°C. The briskets were prepared approximately 12 h prior to the start of the cooking process. Preparation and cooking followed the procedures of Fletcher et al. (2021) with some modifications. After briskets were removed from vacuum packaging, trimming and seasoning was performed. The surface fat was trimmed to 6 mm. The brisket was placed fat side down, and the surface membrane was removed from the exposed *pectoralis profundus.* The muscle was squared off at the caudal end to ensure a minimum thickness of 25 mm. A standard rub consisting of 50% coarse iodized salt (Morton Salt Inc., Chicago, IL, USA) and 50% coarse black pepper (McCormick & Co. Inc; Hunt Valley, MD, USA) was applied to all surfaces of the prepared brisket. The weight of the trimmed, fully prepared brisket was obtained and recorded.

The smokers (Jim Bowie model, Green Mountain Grills, Reno, NV, USA) were powered on and preheated to 121°C 11 h before a consumer session. Before briskets were placed in a smoker, a numbered metal tag was securely pinned to each brisket with a linked reference to the subprimal identification. When the smokers reached 121°C the briskets were placed on the cooker rack fat side down. A temperature probe was placed in the thickest portion of the smallest brisket being cooked in each smoker. When the temperature reached 66°C, a calibrated digital thermometer (Classic Thermapen, Thermoworks, American Fork, UT, USA) was used to confirm the temperature. The brisket was removed from the smoker to wrap in heavy-duty aluminum foil. Each brisket was returned to the cooker in the same position with the fat side down. As briskets were removed from the smoker for wrapping, the temperature probe was transferred to the next smallest brisket until all briskets were removed for wrapping and returned to the smoker. After all briskets were wrapped, the probe was reinserted into the smallest brisket. When a probe temperature reached 93°C, the brisket temperature was confirmed using a calibrated digital thermometer, and the brisket was removed from the smoker. These briskets were placed in a 142 liter insulated container and the time was recorded. The temperature probe was transferred to the next smallest brisket until all were fully cooked. Cooked briskets were held a minimum of 30 min before sample preparation began.

## Sample processing

Each brisket was removed from the insulated container, unwrapped, and weighed whole. The *pectoralis profundus* and *pectoralis superficialis* were separated and weighed individually. Once weights were recorded, external fat was trimmed. Each muscle was further divided into 2 sections. Those sections were allocated and processed into one of 3 serving forms (chopped, pulled, and sliced), which were predetermined and balanced among combined treatments. Meat Standards Australia software was used to generate alpha-numeric identification codes and assign serving forms. As muscles were portioned and processed into serving form, "hot" samples (those being served on the cooking day) were transferred to individual pans held within preheated water bath warming units (Model W-3Vi; American Permanent Ware Company; Dallas, TX, USA) maintained at approximately 60°C until serving and reheat samples (those being stored and served at a later date) were vacuum packaged with their respective identification code and stored in refrigeration (1 to 3°C) for 7 d.

## Serving form and time

For the sliced samples, a cutting guide was adjusted to produce 6-mm slices. For positions within a muscle that were designated as sliced, an initial cut was made at a 90° angle to the fiber direction to square off the leading edge prior to slicing. The slices were cut one at a time and fiber direction was monitored. The leading edge was resurfaced if the fiber direction changed. A minimum of 10 slices was required, which were fed to 10 predetermined consumers. The ideal slice dimension was about 6-mm thick × 70-mm long × 40-mm wide. For chopped samples, the muscle portion was chopped manually into cubes using a cleaver. Cubes measured approximately 10 mm on any given side. For pulled samples, samples were pulled in the direction of the muscle fibers, starting from the edge of the portion. Samples were approximately 20-mm thick × 70-mm long. If the pulled samples were too long, samples were sized down in length. A minimum of 10 samples was required to accommodate consumer testing.

Samples that were allocated to reheat were cooked 7 d in advance, vacuum packaged with identification, and refrigerated as previously described. On the designated consumer testing day, vacuum-packaged samples were removed from refrigeration no less than 5 h prior to serving. Samples were rested at room temperature for approximately 1 h before being placed in a water bath maintained at 60°C using a sous vide immersion water circulator (SmartVide6; Sammic; Evanston, IL, USA) for a minimum of 3 h. Samples were then removed from vacuum packaging and transferred to individual pre-identified pans held within preheated water bath warming units (Model W-3Vi; American Permanent Ware Company; Dallas, TX, USA) maintained at 60°C until serving.

## Consumer sensory evaluation

The Texas Tech University Institutional Review Board approved procedures for the use of human subjects for consumer sensory panel evaluations (IRB2017-598). Sessions were conducted in accordance with MSA consumer eating quality protocols (Watson et al., 2008) and followed previous MSA testing conducted at this test location (O'Quinn et al., 2012; Crownover et al., 2017; Garmyn et al., 2019; Garmyn et al., 2020). Panels were conducted on the Texas Tech University campus in a large classroom equipped with standard overhead fluorescent lighting. Panelists ($n = 960$) were recruited from the local communities and were compensated for participation. Each session included 60 participants and lasted approximately 45 min. Panelists were seated in numbered booths stocked with an information sheet, demographic questionnaire, ballots, expectorant cup, fork, knife, napkin, and toothpick. Unsalted crackers, diluted apple juice (10% apple juice, 90% water), and water were provided as palate cleansers. A summary of the participants' demographic information can be found in Table 2. Verbal instructions were given to consumers prior to each panel regarding the ballot, the testing procedures for the samples, and the use of palate cleansers. All consumers received a slice unrelated to the treatment design with low to mid-level marbling aged 7 d as their first sample to acquaint consumers with brisket samples and to provide linkage over all the testing days. The following 6 samples were fed in a predetermined and balanced order created by a $6 \times 6$ Latin square, representing the different treatments (combined treatment, muscle, serving form, and serving time). 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. Finally, consumers were asked to rate the quality of each brisket sample as "unsatisfactory," "good everyday quality," "better than everyday quality," or "premium quality."

A weighted eating MQ4 as used by MSA to determine consumer satisfaction was later calculated as follows: (tenderness × 0.3) + (juiciness × 0.1) + (flavor liking × 0.3) + (overall liking × 0.3).

**Table 2.** Demographic summary of participants ($n = 960$) evaluating smoked beef brisket samples.

| Characteristic | Category | Percentage |
|---|---|---|
| Age | <20 years old | 5.5 |
| | 20–29 years old | 21.8 |
| | 30–39 years old | 25.6 |
| | 40–49 years old | 22.2 |
| | 50–59 years old | 13.5 |
| | 60 years old or older | 11.6 |
| Gender | Male | 43.6 |
| | Female | 56.4 |
| Frequency of Beef Consumption | Daily | 12.1 |
| | 4–5 times per week | 28.4 |
| | 2–3 times per week | 40.1 |
| | Weekly | 12.3 |
| | Bi-weekly | 4.2 |
| | Monthly | 2.7 |
| | Rarely | 0.2 |
| Annual Household Income | <$20,000 | 14.2 |
| | $20,000–50,000 | 24.7 |
| | $50,001–$75,000 | 22.1 |
| | $75,001–$100,000 | 17.1 |
| | >$100,000 | 21.9 |
| Level of Education | Non-high school graduate | 3.9 |
| | High school graduate | 23.2 |
| | Some college/technical school | 34.7 |
| | College graduate | 26.2 |
| | Postgraduate | 12.0 |
| Cultural Heritage | African American | 11.1 |
| | Asian | 0.3 |
| | Caucasian/White | 45.8 |
| | Hispanic | 40.9 |
| | Native American | 0.3 |
| | Other | 1.5 |

## Compositional analysis

A minimum of 100 g of cooked sample representing both muscles from every brisket was collected immediately following the consumer panel and was frozen at −28°C under vacuum and retained for further analysis. Frozen cubed samples were then homogenized in a precooled food processor (NutriBullet, Capital Brands LLC, Los Angeles, CA, USA), blended into a fine powder, placed in a labeled Whirl-Pak bag, and transferred into a freezer for storage at −80°C. Compositional analysis was performed in accordance with approved Association of Official Agricultural Chemists (AOAC) protocols to determine the percentages of moisture, ash, protein, and fat for each sample. Compositional analysis of cooked samples followed the procedures of Hardcastle et al. (2018).

Protein analysis was conducted using a LECO TruMac N (St. Joseph, MI, USA) in accordance with an approved AOAC official method 992.15 (AOAC, 2012a). Specifically, the machine was calibrated with blanks, and ethylenediaminetetraacetic acid (EDTA) samples were run. Following EDTA, samples were analyzed by adding 0.3 g of sample into each boat on the carousel, making sure to properly input sample identification and sample weight. Percent protein was obtained by applying a conversion factor of 6.25% to percent nitrogen.

Moisture analysis was conducted in accordance with an AOAC official method 950.46 (AOAC, 2012b). Five grams (± 0.05 g) of powdered sample was weighed into crucibles, which were then placed into a drying oven for 16 h at 100°C. After drying, crucibles were removed from the oven and placed into desiccators for 30 min to cool and remove any remaining moisture. A final crucible weight was obtained to calculate the percentage of moisture in each sample. Following moisture determination, crucibles were placed into a muffle furnace (Model F30420C, Thermo Fisher Scientific, Waltham, MA, USA). Furnace temperature was gradually increased to 550°C in increments 100°C per h. After at least 24 h, samples were cooled in desiccators for 30 min and then weighed to calculate the percentage of ash in each sample (official method 920.153; AOAC, 2012c).

Analysis of fat was conducted via a modification (official method 983.23; AOAC, 2012d) to the chloroform:methanol method described by Folch et al. (1957). Specifically, the lipid portion was extracted from 1 g of frozen powder using chloroform and methanol. The extract was evaporated on a heating block inside a fume hood for 10 min. All remaining residue was placed in a drying oven (Model 6905, Thermo Fisher Scientific, Waltham, MA, USA) at 101°C. Upon reaching a constant weight, each tube was cooled and weighed to obtain a final percentage of total lipid.

### *Statistical analysis*

Data were analyzed using PROC GLIMMIX (version 9.4, SAS Inst. Inc., Cary, NC). For carcass data and cooked yield data, combined treatment (which accounted for carcass grade and origin) was used as the fixed effect. Initially, consumer sensory data were analyzed using combined treatment, cut (point vs flat), serve form (sliced, chopped, or pulled), and serve time (hot or reheat) as fixed effects, testing all potential interactions. Ultimately, the 2-way interaction between combined treatment and muscle was observed ($P < 0.05$) for all eating quality traits, along with the main effects of serve time and serve form. No other interactions were detected ($P > 0.05$) and were consequently removed from the model. To achieve our main objective of determining the effects of carcass quality grade and origin on the eating quality of smoked brisket, the combined treatment's main effect on eating quality traits will be reported in addition to the significant interaction. Compositional data were analyzed with fixed effects of combined treatment, muscle, and their interaction. Carcass was included in all models as a random effect to account for animal variation. Treatment least-squares means were separated with the PDIFF option at a significance level of $P < 0.05$. Mean separation tests for all pairwise comparisons were performed using the PDIFF function, which requests that $P$ values for differences of all least-squares means be produced ($\alpha = 0.05$). Pearson correlation coefficients were calculated between carcass and eating traits using PROC CORR in SAS ($P < 0.05$).

## Results and Discussion

### *Carcass traits*

As seen in Table 3, combined treatment affected ($P < 0.05$) all carcass traits. Although differences were observed in traits related to carcass yield (i.e., HCW, REA, RF), only differences related to carcass quality traits (i.e., ossification, marbling, meat color, fat color, and pH) will be discussed further. Ossification (skeletal maturity) and marbling are 2 traits that are critical to predicting eating quality. These traits are highly emphasized in both the MSA and USDA beef quality grading systems. ACow and A2grass were similar ($P > 0.05$) and had greater ($P < 0.05$) ossification scores than all other combined treatments. These elevated ossification scores likely explain why these carcasses failed MSA grading and were downgraded into the 2 category. UPR carcasses had the greatest ($P < 0.05$) marbling score, followed by A5grass, UCH, and A5grain, with a significant difference between each of the aforementioned combined treatments ($P < 0.05$). The MSA grading system utilizes several carcass inputs and does not solely focus on one or 2 traits, such as marbling and ossification. Therefore, it is not surprising when there are marbling score differences within an Australian grade. For example, A5grass had a greater average marbling score than A5grain. Within the remaining Australian carcasses, no difference ($P > 0.05$) in marbling score was detected from A2 to A4, regardless of diet. A2grass and ACow had greater ($P < 0.05$) meat color scores than all other treatments, suggesting the exposed longissimus at the 12$^{th}$ rib was darker. ACow and A2grass had the yellowest ($P < 0.05$) fat color compared to all other treatments. Fat color scores were not different ($P > 0.05$) in the US treatments, the Australian grain treatments, and A4grass. Although minor differences were detected in pH, all mean pH values were below 5.8, which should have minimal biological significance. This is supported by Holdstock et al. (2014) who found decreased tenderness at a pH 5.8–6.1.

**Table 3.** The main effects of combined treatment on carcass data.

| Combined Treatment | Hot Carcass Weight, kg | Hump Height, mm | Ribeye Area, cm$^2$ | 12$^{th}$ Rib Fat, mm | OSS[1] | MB[2] | MC[3] | FC[4] | pH |
|---|---|---|---|---|---|---|---|---|---|
| **Australian** | | | | | | | | | |
| 5 Grain | 363.8$^{cd}$ | 70.0$^{de}$ | 90.8$^{bc}$ | 10.3$^{cde}$ | 143$^{b}$ | 467$^{d}$ | 2.7$^{b}$ | 0.8$^{e}$ | 5.51$^{bcd}$ |
| 5 Grass | 451.2$^{a}$ | 83.3$^{cd}$ | 89.8$^{bc}$ | 11.2$^{c}$ | 190$^{b}$ | 737$^{b}$ | 2.7$^{b}$ | 2.5$^{bc}$ | 5.55$^{bcd}$ |
| 4 Grain | 421.7$^{ab}$ | 85.0$^{cd}$ | 91.3$^{bc}$ | 9.2$^{cde}$ | 187$^{b}$ | 357$^{e}$ | 2.6$^{b}$ | 0.3$^{e}$ | 5.56$^{bcd}$ |
| 4 Grass | 300.0$^{f}$ | 64.2$^{ef}$ | 82.3$^{cd}$ | 5.5$^{fg}$ | 175$^{b}$ | 342$^{ef}$ | 2.2$^{b}$ | 1.5$^{cde}$ | 5.52$^{bcd}$ |
| 3 Grain | 387.5$^{bcd}$ | 81.7$^{cd}$ | 93.7$^{ab}$ | 7.8$^{def}$ | 185$^{b}$ | 340$^{ef}$ | 2.6$^{b}$ | 0.5$^{e}$ | 5.45$^{d}$ |
| 3 Grass | 311.5$^{ef}$ | 74.2$^{cde}$ | 86.0$^{bc}$ | 5.0$^{fg}$ | 178$^{b}$ | 293$^{ef}$ | 2.0$^{b}$ | 2.3$^{bcd}$ | 5.52$^{bcd}$ |
| 2 Grain | 352.5$^{de}$ | 89.2$^{bc}$ | 89.8$^{bc}$ | 7.7$^{ef}$ | 178$^{b}$ | 305$^{ef}$ | 2.7$^{b}$ | 0.7$^{e}$ | 5.48$^{cd}$ |
| 2 Grass | 311.8$^{ef}$ | 105.0$^{ab}$ | 72.8$^{cd}$ | 10.8$^{cde}$ | 498$^{a}$ | 353$^{ef}$ | 4.3$^{a}$ | 3.3$^{ab}$ | 5.62$^{b}$ |
| Manufacture Cow | 215.7$^{g}$ | 113.2$^{a}$ | 55.0$^{e}$ | 3.7$^{g}$ | 544$^{a}$ | 289$^{f}$ | 3.8$^{a}$ | 4.5$^{a}$ | 5.76$^{a}$ |
| **US** | | | | | | | | | |
| USDA Prime | 421.3$^{ab}$ | 50.0$^{f}$ | 90.8$^{bc}$ | 16.3$^{b}$ | 160$^{b}$ | 892$^{a}$ | 2.3$^{b}$ | 1.0$^{de}$ | 5.59$^{bc}$ |
| USDA Choice | 418.4$^{ab}$ | 50.0$^{f}$ | 90.2$^{bc}$ | 19.7$^{a}$ | 157$^{b}$ | 658$^{c}$ | 2.5$^{b}$ | 1.0$^{de}$ | 5.60$^{c}$ |
| USDA Select | 398.9$^{bc}$ | 50.0$^{f}$ | 103.7$^{a}$ | 11.0$^{cd}$ | 177$^{b}$ | 343$^{ef}$ | 2.3$^{b}$ | 1.2$^{cde}$ | 5.58$^{bc}$ |
| SEM (largest) | 18.0 | 7.3 | 4.8 | 1.4 | 21 | 32 | 0.4 | 0.6 | 0.53 |
| *P* value | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |

[a–f]Within a column and treatment, means sharing a common superscript, do not differ ($P < 0.05$).

[1]OSS = Ossification: 100 to 590.

[2]MB = MSA Marbling: 100 to 1100.

[3]MC = Meat Color: AUS-MEAT color chips 1A (very pale) to 7 (very dark purple).

[4]FC = Fat Color: AUS-MEAT color chips 0 (white) to 9 (yellow).

## *Cooking traits*

As seen in Table 4, raw weight, cooked weight, and cooking loss were impacted by combined treatment ($P < 0.01$). ACow possessed the lowest ($P < 0.05$) raw and cooked weights of all treatments. These weights were likely impacted by carcass weight. Although differences occurred in the remaining combined treatments, brisket weights were not in line with carcass weights. Namely, US briskets were much lighter than Australian briskets from similar-weight carcasses. This

**Table 4.** The main effect of combined treatment on smoked brisket weights and cooking loss.

| Combined Treatment | Raw Weight, kg | Cooked Weight, kg | Flat Cooked Weight, kg | Point Cooked Weight, kg | Cooking loss, % |
|---|---|---|---|---|---|
| **Australian** | | | | | |
| 5 Grain | 5.89$^{c}$ | 3.59$^{cd}$ | 2.11$^{bc}$ | 1.41$^{bc}$ | 39.14$^{bc}$ |
| 5 Grass | 6.78$^{ab}$ | 4.00$^{ab}$ | 2.31$^{ab}$ | 1.61$^{ab}$ | 40.75$^{b}$ |
| 4 Grain | 7.16$^{a}$ | 4.30$^{a}$ | 2.50$^{a}$ | 1.76$^{a}$ | 39.56$^{bc}$ |
| 4 Grass | 4.55$^{e}$ | 2.86$^{f}$ | 1.64$^{d}$ | 1.29$^{cde}$ | 37.50$^{c}$ |
| 3 Grain | 6.39$^{bc}$ | 3.88$^{bc}$ | 2.28$^{b}$ | 1.58$^{ab}$ | 39.26$^{bc}$ |
| 3 Grass | 5.05$^{de}$ | 3.15$^{ef}$ | 1.98$^{c}$ | 1.17$^{e}$ | 37.57$^{c}$ |
| 2 Grain | 5.91$^{c}$ | 3.46$^{de}$ | 2.06$^{c}$ | 1.41$^{bcd}$ | 40.55$^{b}$ |
| 2 Grass | 3.38$^{f}$ | 2.00$^{g}$ | 1.20$^{e}$ | 0.81$^{f}$ | 40.44$^{bc}$ |
| Manufacture Cow | 2.07$^{g}$ | 1.13$^{h}$ | 0.76$^{f}$ | 0.39$^{g}$ | 45.10$^{a}$ |
| **US** | | | | | |
| USDA Prime | 4.76$^{de}$ | 2.90$^{f}$ | 1.69$^{d}$ | 1.18$^{de}$ | 39.44$^{bc}$ |
| USDA Choice | 4.99$^{de}$ | 2.96$^{f}$ | 1.62$^{d}$ | 1.30$^{cde}$ | 40.72$^{b}$ |
| USDA Select | 5.19$^{d}$ | 3.09$^{ef}$ | 1.72$^{d}$ | 1.34$^{cde}$ | 40.32$^{bc}$ |
| SEM (largest)[1] | 0.31 | 0.19 | 0.10 | 0.11 | 1.25 |
| *P* value | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |

[a,f]Within a column means sharing a common superscript, do not differ ($P < 0.05$).

[1]Pooled (largest) standard error of least squares means.

was likely a function of greater fat trimming of the US briskets, as the surface fat of all briskets was trimmed to 6 mm of fat before cooking. Briskets from ACow had greater ($P < 0.05$) cooking loss than all other combined treatments. Differences occurred in cooking loss between our remaining combined treatments; however, the measurable percentage difference was minimal compared to the difference between ACow and the remaining combined treatments.

The effect of combined treatment on cooking times can be found in Table 5. The time required to reach the temperature when briskets were wrapped (time-to-wrap) was influenced ($P < 0.05$) by combined treatment. No differences occurred ($P > 0.05$) in time-to-wrap, total cook time, or cook time per kg in the 3 US combined treatments. ACow required the least ($P < 0.05$) amount of time compared to all other treatments, except A2grass ($P > 0.05$). The weight of ACow samples coupled with a reduced cook time resulted in the greatest ($P < 0.05$) cook time per kg of all treatments, excluding A2grass and A2grain. When focusing on cook time per kg, briskets from A2 and A4 grass-fed carcasses took longer than ($P < 0.05$) the grain-fed counterparts. No other differences ($P > 0.05$) in cook time per kg were noted between diets for A3 and A5 carcasses. No apparent explanations exist for these differences in cook time per kg of grass vs. grain-fed briskets. Location placement was randomized in the grill. Compositional differences do not relate to differences in cook time per kg.

### Composition of cooked samples

Combined treatment and muscle did not interact ($P > 0.05$) to affect the composition of cooked brisket samples. As seen in Table 6, cooked composition of brisket samples was influenced ($P < 0.01$) by combined treatment. A5grass and UPR had similar ($P > 0.05$) and greater ($P < 0.05$) fat percentages than all other combined treatments. There was a distinct difference in fat percentage between the 3 US grades, in which UPR > UCH > USEL for fat percentage. A5grain had greater ($P < 0.05$) fat percentage than A4grain, A3grain, and A2grain, which did not differ ($P > 0.05$). A5grass had greater ($P < 0.05$) fat percentage than A4grass, which in turn had a greater fat percentage than A3grass, A2grass, and ACow, the latter two of which were similar ($P > 0.05$). Moisture typically has an inverse relationship to fat percentage; however, that trend was not observed in the cooked moisture percentage of the current samples. Moisture generally decreased as fat decreased, suggesting a positive, rather than inverse, relationship to fat percentage. Protein and ash also varied by combined treatment. In fact, protein appears to have more of an inverse

**Table 5.** The main effect of combined treatment on cooking times of Australian and US smoked briskets.

| Combined Treatment | Time-to-Wrap, h | Cook Time, h | Cook Time per kg, h |
|---|---|---|---|
| **Australian** | | | |
| 5 Grain | 4.10$^{ab}$ | 6.61$^{cd}$ | 1.14$^{de}$ |
| 5 Grass | 4.74$^{a}$ | 6.74$^{bcd}$ | 1.03$^{e}$ |
| 4 Grain | 4.82$^{a}$ | 5.97$^{d}$ | 1.00$^{e}$ |
| 4 Grass | 4.04$^{ab}$ | 6.22$^{cd}$ | 1.43$^{bcd}$ |
| 3 Grain | 4.36$^{ab}$ | 6.84$^{abcd}$ | 1.12$^{de}$ |
| 3 Grass | 4.40$^{a}$ | 6.90$^{abcd}$ | 1.33$^{cde}$ |
| 2 Grain | 4.70$^{a}$ | 7.89$^{ab}$ | 1.30$^{cde}$ |
| 2 Grass | 3.41$^{bc}$ | 7.91$^{a}$ | 1.90$^{b}$ |
| Manufacture Cow | 3.27$^{c}$ | 6.54$^{cd}$ | 2.94$^{a}$ |
| **US** | | | |
| USDA Prime | 4.04$^{ab}$ | 7.04$^{abc}$ | 1.43$^{bcde}$ |
| USDA Choice | 4.76$^{a}$ | 7.02$^{abc}$ | 1.59$^{bc}$ |
| USDA Select | 4.25$^{ab}$ | 7.35$^{abc}$ | 1.40$^{cde}$ |
| SEM (largest)[1] | 0.39 | 0.6 | 0.2 |
| *P* value | <0.01 | 0.0081 | <0.01 |

[a–e]Within a column, means sharing a common superscript, do not differ ($P < 0.05$).

[1]Pooled (largest) standard error of least squares means.

**Table 6.** The main effect of combined treatment on the cooked composition for total fat, moisture, protein, and ash of Australian and US smoked briskets.

| Combined Treatment | Fat | Moisture | Protein | Ash |
|---|---|---|---|---|
| **Australian** | | | | |
| 5 Grain | 10.2$^{b}$ | 54.3$^{ab}$ | 34.4$^{ef}$ | 1.05$^{def}$ |
| 5 Grass | 13.0$^{a}$ | 54.0$^{abc}$ | 31.9$^{g}$ | 1.02$^{f}$ |
| 4 Grain | 8.5$^{cd}$ | 53.9$^{abc}$ | 36.5$^{cd}$ | 1.06$^{cde}$ |
| 4 Grass | 9.4$^{bc}$ | 54.2$^{ab}$ | 35.4$^{de}$ | 1.09$^{bc}$ |
| 3 Grain | 8.7$^{cd}$ | 53.3$^{bcd}$ | 36.9$^{bcd}$ | 1.08$^{bcd}$ |
| 3 Grass | 6.9$^{e}$ | 51.8$^{e}$ | 40.1$^{a}$ | 1.15$^{a}$ |
| 2 Grain | 7.4$^{de}$ | 51.9$^{e}$ | 39.5$^{a}$ | 1.10$^{b}$ |
| 2 Grass | 7.7$^{de}$ | 52.4$^{de}$ | 38.8$^{abc}$ | 1.09$^{bc}$ |
| Manufacture Cow | 6.7$^{e}$ | 52.3$^{de}$ | 39.9$^{a}$ | 1.08$^{bc}$ |
| **US** | | | | |
| USDA Prime | 11.7$^{a}$ | 54.8$^{a}$ | 32.5$^{fg}$ | 1.04$^{ef}$ |
| USDA Choice | 9.7$^{bc}$ | 54.0$^{abc}$ | 35.2$^{de}$ | 1.06$^{cde}$ |
| USDA Select | 6.9$^{e}$ | 52.8$^{cde}$ | 39.2$^{ab}$ | 1.09$^{bc}$ |
| SEM (Largest)[1] | 0.67 | 0.56 | 0.95 | 0.005 |
| *P* Value | <0.01 | <0.01 | <0.01 | 0.01 |

[a–f]Within a column, means sharing a common superscript, do not differ ($P < 0.05$).

[1]Pooled (largest) standard error of least squares means.

**Table 7.** The main effect of muscle on cooked composition for total fat, moisture, protein, and ash of Australian and US smoked briskets.

| Muscle | Fat | Moisture | Protein | Ash |
|---|---|---|---|---|
| Point | 10.9[a] | 54.4[a] | 33.6[b] | 1.05[b] |
| Flat | 6.9[b] | 52.2[b] | 39.8[a] | 1.10[a] |
| SEM[1] | 0.22 | 0.19 | 0.32 | 0.005 |
| $P$ value | <0.01 | <0.01 | <0.01 | <0.01 |

[a,b]Within a column, means sharing a common superscript, do not differ ($P < 0.05$).

[1]Pooled (largest) standard error of least squares means.

relationship with fat in the current results, in which protein increased as fat percentage decreased. Although differences were detected for ash, the biological significance of those differences should be relatively minor due to the extremely small variation between samples.

As seen in Table 7, cooked composition of brisket samples was influenced ($P < 0.01$) by muscle. Overall, the point and flat portions differed ($P < 0.05$) for all components. The point had greater ($P < 0.05$) fat and moisture, whereas the flat had greater ($P < 0.05$) protein and ash. Mason et al. (2009) reported that retail brisket point halves had greater extractable fat and less moisture than retail flat halves. Our fat percentages follow a similar trend as Mason et al. (2009), but our moisture results are conflicting. This could be due simply to the fact that the samples in the current study were cooked, while the samples analyzed by Mason et al. (2009) were raw. When comparing values published for cooked point and flat half briskets of all grades completely trimmed in the US Nutrient Database, the fat percentage was much greater, and protein and ash were less for point halves compared to flat halves, which supports our findings; however, moisture was lower in point halves (USDA, 2019), which conflicts with the current findings.

## Combined treatment by muscle

As seen in Table 8, an interaction between combined treatment and muscle was observed ($P < 0.05$) for all palatability traits, MQ4, and satisfaction, resulting in a wide range of consumer scores for those traits. Ultimately, 12 combined treatments were tested between the 9 Australian categories and the 3 USDA grades. For the most part, point portions received greater scores than flat portions within each combined treatment; however, that was not always the case, which was the driving force for the significant interaction between combined treatment and muscle. The point portion was more tender ($P < 0.05$) than the flat portion from all combined treatments except A5grass, A4grass, A2grass, and ACow. In fact, ACow flat portion was more tender ($P < 0.05$) than the point portion, the only combined treatment where this was observed. Overall, there was an 8.7-unit difference (69.8 vs. 61.1) between point and flat portions, respectively, regardless of combined treatment ($P < 0.05$). The most variation between point and flat portions was observed for juiciness, as the samples from ACow carcasses were the only combined treatment where the point and flat portions did not differ ($P > 0.05$) for juiciness. For all other combined treatments, the point portion was juicier ($P < 0.05$) than the flat portion. These differences resulted in a 23-unit advantage for the point vs. the flat (66.9 vs. 46.3; $P < 0.05$), respectively, regardless of combined treatment. Minimal muscle differences in flavor liking were noticed, as A3grain and A2grain were the only combined treatments where the point portion was preferred ($P < 0.05$). Regardless of combined treatment, point portions were only scored 4 units (63.1 vs. 58.8) greater than flat portions ($P < 0.05$). Overall, point portions were liked more ($P < 0.05$) than flat portions for A5grain, A4grain A3grain, A3grass, A2grain, and USEL. Of those groups, most were from grain-fed beef cattle. Ultimately, this resulted in a 7.5-unit advantage (65.5 vs. 58.0) in overall liking scores for point portions compared to flat portions ($P < 0.05$), regardless of combined treatment. An identical trend to overall liking was observed for MQ4, in which the composite eating quality score was greater ($P < 0.05$) for point compared to flat portions for half of the combined treatments, including A5grain, A4grain, A3grain, A3grass, A2grain, and USEL. A lack of difference between point and flat portions was noted in nearly all grass-fed briskets, as the scores for point and flat portions from A5grass, A4grass, and A2grass were similar ($P > 0.05$) for 3 of the 4 consumer scores (tenderness, flavor liking, and overall liking), as well as MQ4 ($P > 0.05$). Flavor liking and overall liking were similar ($P > 0.05$) between point and flat portions of UPR and UCH. Satisfaction did not differ ($P > 0.05$) between point and flat portions on either end of the carcass quality spectrum. The higher quality carcasses (UPR, A5grain, A5grass, and UCH) and the lower quality carcasses (A2grass and ACow) did not differ ($P > 0.05$) in satisfaction between their respective point and flat portions.

Consumers did not differentiate ($P > 0.05$) between grain and grass within A5, A4, and A3 grades for tenderness or juiciness, regardless of muscle portion. Few differences were noted between grass and grain for flavor and overall liking. No differences ($P > 0.05$) between grass and grain were observed in

**Table 8.** The interactive effects of muscle and combined treatment on consumer scores[1] ($n = 960$) for tenderness, juiciness, flavor liking, and overall liking of Australian (AUS) and US smoked briskets.

| Combined Treatment | Tenderness | Juiciness | Flavor Liking | Overall Liking | MQ4[2] | Satisfaction[3] |
|---|---|---|---|---|---|---|
| AUS 5 grain – Flat | $70.6^{efg}$ | $54.6^{e}$ | $65.5^{abcde}$ | $66.8^{bcd}$ | $66.6^{bcde}$ | $3.39^{bcdefgh}$ |
| AUS 5 grain – Point | $79.0^{abc}$ | $78.4^{ab}$ | $69.0^{ab}$ | $76.8^{a}$ | $77.0^{a}$ | $3.72^{ab}$ |
| AUS 5 grass – Flat | $73.9^{cdef}$ | $54.5^{ef}$ | $56.6^{efg}$ | $59.3^{def}$ | $62.5^{def}$ | $3.26^{fghij}$ |
| AUS 5 grass – Point | $76.3^{abcde}$ | $71.3^{abcd}$ | $61.1^{bcdef}$ | $65.0^{bcd}$ | $67.9^{abcd}$ | $3.36^{defgh}$ |
| AUS 4 grain – Flat | $64.0^{hij}$ | $48.4^{efg}$ | $60.8^{bcdef}$ | $60.6^{cde}$ | $60.9^{def}$ | $3.28^{efghi}$ |
| AUS 4 grain – Point | $77.0^{abcd}$ | $74.1^{abcd}$ | $68.6^{abc}$ | $72.2^{ab}$ | $73.2^{abc}$ | $3.66^{ab}$ |
| AUS 4 grass – Flat | $66.8^{ghi}$ | $51.0^{ef}$ | $63.0^{bcdef}$ | $62.6^{cd}$ | $62.9^{de}$ | $3.27^{fghij}$ |
| AUS 4 grass – Point | $71.7^{defg}$ | $65.2^{d}$ | $64.5^{abcde}$ | $66.6^{bcd}$ | $67.4^{bcd}$ | $3.48^{abcde}$ |
| AUS 3 grain – Flat | $62.6^{ijk}$ | $46.2^{fg}$ | $60.2^{def}$ | $59.7^{def}$ | $59.7^{efg}$ | $3.19^{ghij}$ |
| AUS 3 grain – Point | $74.4^{bcdef}$ | $68.5^{cd}$ | $68.0^{abc}$ | $70.3^{ab}$ | $71.0^{abc}$ | $3.60^{abcd}$ |
| AUS 3 grass – Flat | $61.8^{ijk}$ | $43.1^{gh}$ | $55.7^{fg}$ | $55.3^{efg}$ | $56.3^{fg}$ | $3.07^{ijk}$ |
| AUS 3 grass – Point | $74.8^{bcdef}$ | $68.0^{d}$ | $57.6^{efg}$ | $63.7^{cd}$ | $65.7^{cde}$ | $3.37^{cdefgh}$ |
| AUS 2 grain – Flat | $57.0^{kl}$ | $38.6^{hi}$ | $54.9^{fgh}$ | $53.5^{fg}$ | $53.9^{gh}$ | $3.06^{jkl}$ |
| AUS 2 grain – Point | $72.5^{defg}$ | $70.3^{abcd}$ | $68.7^{abc}$ | $71.5^{ab}$ | $71.2^{abc}$ | $3.59^{abcd}$ |
| AUS 2 grass – Flat | $43.0^{m}$ | $34.3^{ij}$ | $47.5^{hi}$ | $43.9^{hi}$ | $44.1^{ij}$ | $2.75^{lm}$ |
| AUS 2 grass – Point | $50.7^{lm}$ | $49.3^{efg}$ | $45.9^{i}$ | $49.0^{gh}$ | $49.0^{hi}$ | $2.93^{klm}$ |
| AUS Manufacture Cow – Flat | $32.3^{n}$ | $29.8^{j}$ | $50.7^{ghi}$ | $42.6^{hi}$ | $41.0^{jk}$ | $2.68^{mn}$ |
| AUS Manufacture Cow – Point | $25.9^{o}$ | $34.7^{ij}$ | $46.4^{i}$ | $37.3^{i}$ | $36.8^{k}$ | $2.52^{n}$ |
| USDA Prime – Flat | $72.1^{defg}$ | $56.6^{e}$ | $66.8^{abcd}$ | $68.1^{abc}$ | $67.7^{abcd}$ | $3.46^{abcdef}$ |
| USDA Prime – Point | $81.1^{a}$ | $78.5^{a}$ | $73.1^{a}$ | $72.2^{ab}$ | $74.5^{ab}$ | $3.70^{a}$ |
| USDA Choice – Flat | $69.7^{fgh}$ | $55.8^{e}$ | $63.7^{abcdef}$ | $65.5^{bcd}$ | $65.3^{cde}$ | $3.39^{abcdefg}$ |
| USDA Choice – Point | $80.3^{ab}$ | $75.5^{abc}$ | $66.9^{abcd}$ | $69.3^{abc}$ | $72.5^{abc}$ | $3.57^{abcde}$ |
| USDA Select – Flat | $59.1^{jk}$ | $42.8^{ghi}$ | $60.8^{cdef}$ | $58.2^{def}$ | $57.8^{efg}$ | $3.13^{hijk}$ |
| USDA Select – Point | $73.3^{cdef}$ | $69.3^{bcd}$ | $67.7^{abcd}$ | $71.6^{ab}$ | $70.8^{abc}$ | $3.60^{abc}$ |
| SEM (largest)[4] | 3.2 | 5.7 | 5.2 | 5.0 | 4.8 | 0.18 |
| *P* value | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 | <0.01 |

[a–m]Within a column, means sharing a common superscript, do not differ ($P < 0.05$).

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

[2]MQ4 = tenderness × 0.3 + juiciness × 0.1 + flavor liking × 0.3 + overall liking × 0.3.

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

[4]Pooled (largest) standard error of least squares means.

the composite MQ4 score from the A5, A4, and A3 combined treatments, regardless of muscle portion. There was a distinct difference ($P < 0.05$) between grain and grass for all traits within the A2 briskets, which was more apparent in the point portions than the flat portions. Within the US samples, UPR and UCH did not differ ($P > 0.05$) for tenderness, juiciness, flavor liking, overall liking, MQ4 score, or satisfaction, regardless of muscle portion. Briskets from UPR and UCH were more ($P < 0.05$) tender than USEL, regardless of muscle portion. No differences ($P > 0.05$) in flavor liking for either muscle portion were observed between US briskets. UPR flat muscle samples were liked more ($P < 0.05$) overall than USEL flat muscle samples; however, point portions from the US-graded carcasses had similar ($P > 0.05$) overall liking scores. A similar trend was observed for MQ4 composite scores.

Harris et al. (2017) found the juiciness of the point to be preferred over the flat. The current study found point and flat differences in juiciness to be treatment dependent. For instance, there was no difference ($P > 0.05$) between A5grass muscles for juiciness in this study. The US points and flats were not different aside from USEL, which was significantly ($P < 0.05$) lower for overall liking and flavor liking. Harris et al. (2017) also found no differences between muscles for tenderness, which differs from the current study. This could be explained in the difference in preparation technique, where the current study cooked briskets to an endpoint temp of 93°C while Harris et al. finished at 85°C. Palka (1999) suggests that at 70°C soluble collagen doubles and then drastically decreases from 80°C to 121°C. Palka (1999) also suggests that after 70°C the collagen begins to gelatinize, which could lead to increased tenderness, and could be enhanced by a greater endpoint temperature. Fletcher et al. (2021) reported similar results to the current study with a grade by muscle interaction. They found consumers were unable to discern differences in tenderness, juiciness, flavor liking, and overall liking amongst point samples from USDA Prime, Choice, and Select samples, and consistently scored point samples greater than flat samples. The current study showed no difference ($P > 0.05$) in UPR and UCH flat samples for all 4 consumer scores but the USEL samples were significantly lower ($P < 0.05$) for tenderness and juiciness. Lees et al. (2024) reported lower scores for flat vs. point portions for all consumer sensory traits as rated by US and Australian consumers, where samples were cooked similarly to the current trial.

It should be noted that numerical, but not statistical differences were observed between some grass-fed and grain-fed samples when analyzing the interaction between combined treatment and muscle; however, isolation and analysis of combined treatment without considering muscle yielded alternative results (Table 9). USDA Prime, A5grain, and A5grass were similar ($P > 0.05$) and scored among the highest combination treatments for tenderness. USDA average Choice was scored more tender than A4grain and A4grass, which were similar ($P > 0.05$). USDA Select, A3grain, and A4grass were similar ($P > 0.05$). Within each quality grade tier, the US sample and both Australian samples were scored similarly for juiciness. As such, UPR, A5grain, and A5grass were similar ($P > 0.05$); UCH, A4grain, and A4grass were similar ($P > 0.05$), and USEL, A3grain, and A3grass were perceived to have similar juiciness scores ($P > 0.05$). Although juiciness scores generally decreased as quality grades decreased, there was an overlap between quality grade tiers. Despite seasoning with salt and pepper, along with the smoke flavor imparted from the cooking process, flavor liking varied ($P < 0.05$) due to combined treatment. In the highest (5) and lowest (3) quality grade tier, the grain-fed samples were similar ($P > 0.05$) and liked more ($P < 0.05$) than the grass-fed samples, so UPR and A5grain were more liked than A5grass, and USEL and A3grain were more liked than A3grass. There were no differences ($P > 0.05$) in flavor liking among UCH, A4grain, and A4grass. Overall liking followed an identical trend as flavor liking.

It is well documented that beef fat level and composition contribute to consumer flavor variation. Fat provides the necessary molecules to produce volatile compounds that are essential in flavor development (Hwang and Joo, 2017). Grass-fed and grain-fed consumer sensory differences have been widely discussed in the literature. Hwang and Joo (2017) found grain-fed Hanwoo beef was preferred to grass-fed Hanwoo, but there was no difference between US grain-fed and

**Table 9.** The main effect of combined treatment on consumer scores[1] (n = 960) for tenderness, juiciness, flavor liking, and overall liking of Australian (AUS) and US smoked briskets.

| Combined Treatment | Tenderness | Juiciness | Flavor Liking | Overall Liking | MQ4[2] | Satisfaction[3] |
|---|---|---|---|---|---|---|
| USDA Prime | 78.6[a] | 67.6[a] | 67.9[ab] | 70.1[a] | 71.1[a] | 3.58[a] |
| AUS 5 grain | 74.8[ab] | 66.5[ab] | 69.3[a] | 71.8[a] | 71.8[a] | 3.55[ab] |
| AUS 5 grass | 75.1[a] | 62.9[abc] | 58.9[cd] | 62.2[cd] | 65.2[abc] | 3.31[bcd] |
| USDA Choice | 75.0[a] | 65.7[ab] | 65.3[ab] | 67.4[ab] | 69.8[ab] | 3.48[abc] |
| AUS 4 grain | 70.5[bc] | 61.2[abc] | 64.7[abc] | 66.4[abc] | 67.1[ab] | 3.47[abc] |
| AUS 4 grass | 69.3[c] | 58.1[bc] | 63.7[abc] | 64.6[abc] | 65.2[abc] | 3.38[bcd] |
| USDA Select | 66.2[cd] | 56.1[bc] | 64.2[abc] | 64.9[abc] | 64.3[abc] | 3.37[bcd] |
| AUS 3 grain | 68.5[cd] | 57.3[bc] | 64.1[abc] | 65.0[abc] | 65.3[abc] | 3.39[abc] |
| AUS 3 grass | 66.3[cd] | 55.5[c] | 56.6[d] | 59.5[d] | 60.9[c] | 3.22[d] |
| AUS 2 grain | 64.7[d] | 54.4[c] | 61.8[bcd] | 62.5[bcd] | 62.5[bc] | 3.30[cd] |
| AUS 2 grass | 48.9[e] | 41.8[d] | 46.7[e] | 46.5[e] | 46.6[d] | 2.84[e] |
| AUS Manufacture Cow | 29.1[f] | 32.3[e] | 48.5[e] | 39.9[f] | 38.9[e] | 2.60[f] |
| SEM (largest)[4] | 2.2 | 4.8 | 5.0 | 4.7 | 4.6 | 0.17 |
| *P* value | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 | <0.01 |

[a–f]Within a column, means sharing a common superscript, do not differ ($P < 0.05$).

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

[2]MQ4 = tenderness × 0.3 + juiciness × 0.1 + flavor liking × 0.3 + overall liking × 0.3.

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

[4]Pooled (largest) standard error of least squares means.

Australian grass-fed beef for flavor liking. The same study reported that grain-fed samples were preferred overall to the grass-fed samples. Seideman et al. (1982) saw little difference between grass-fed and grain-fed samples (longissimus, semitendinosus, and semimembranosus) for juiciness, tenderness, and flavor intensity. Heating meat creates a melting/rendering effect on the intramuscular fat explained by Coleman et al. (1988). This effect produces a liquid that could increase juiciness scores. According to Seideman et al. (1982), the point (*pectoralis superficialis*) contains more intramuscular fat than the flat (*pectoralis profundi*), which could explain the consistently greater scoring of the point compared to the flat samples for juiciness. This is supported by O'Quinn et al. (2012) looking at consumer evaluation of beef strip steaks of varying fat levels. Corbin et al. (2015) evaluated the link between intramuscular fat and consumer sensory preferences, noting that increased marbling scores increased consumer sensory scores for juiciness and overall liking.

Tenderness is also affected by cooking method. The low and slow Texas-style barbeque cooking technique is beneficial for cuts like the brisket (Fletcher et al., 2021; Harris et al., 2017; Lees et al., 2024), which has high WBSF values (Belew et al., 2003; McKeith et al., 1985), high perceptible connective tissue and low tenderness scores (Jeremiah et al., 2003b; McKeith et al., 1985). McKeith et al. (1985) also reported low correlations between total collagen and tenderness, suggesting the solubility of collagen rather than the total amount could be more relevant to beef tenderness. Jeremiah et al. (2003a) reported the flat and point portions had collagen solubility of less than 10% and 15%, respectively, when roasted at 72°C, perhaps suggesting full gelatinization of collagen was limited. ACow samples consistently scored lower for all palatability traits compared to the other combined treatments. The breakdown of collagen was not apparent in the cooked brisket from ACow, which was supported by the low tenderness scoring of those samples. This was likely due to increased collagen crosslinking, as it is known that collagen solubility decreases as animals age (Herring et al., 1967). Herring et al. (1967) reported similar collagen content in the longissimus muscle when comparing samples from A-, B-, and E-maturity animals. Collagen content was not related to sensory panel tenderness scores, but rather collagen solubility, which decreased with each advancing maturity group from A to B to E in both the longissimus dorsi and semimembranosus muscles (Herring et al., 1967). Likewise, Gredell et al. (2018) reported slight differences in total collagen content of longissimus muscle from young and mature beef, but considerably lower collagen solubility in mature compared to young beef.

## Relationship of eating quality to carcass traits

Pearson correlation coefficients seen in Table 10 indicated linear relationships existed between carcass traits and brisket eating quality. Carcass weight, ribeye area, rib fat, and marbling were all positively correlated with eating quality ($P < 0.01$). Increased carcass weight and ribeye area were linked to greater eating quality scores. Carcasses originating from grain-fed animals were generally heavier and had larger ribeye areas than those from grass-fed animals. Rib fat and marbling were also positively related to eating quality. These traits tended to decrease as quality grade decreased. This was observed in both Australian and US grades, with the exception of A2grass. Hump height, ossification, and pH negatively affected eating quality ($P < 0.01$). Hump height, which is tied to tropical breed content, and ossification, which increases from advanced physiological maturity, were both negatively related to eating quality. Ultimate pH had a negative relationship to eating quality.

## Serve time and serve form

As seen in Table 11, serve time (hot vs. reheat) affected ($P < 0.05$) all eating quality traits. The hot

**Table 10.** Pearson correlation coefficients for the relationship between carcass traits and consumer sensory scores of Australian and US smoked brisket*.

| Trait | Tenderness | Juiciness | Flavor Liking | Overall Liking | MQ4 | Satisfaction |
|---|---|---|---|---|---|---|
| Carcass Weight | 0.53 | 0.40 | 0.31 | 0.43 | 0.46 | 0.40 |
| Hump Height | −0.48 | −0.38 | −0.40 | −0.48 | −0.48 | −0.44 |
| Ribeye Area | 0.46 | 0.31 | 0.30 | 0.39 | 0.41 | 0.35 |
| Rib Fat | 0.37 | 0.33 | 0.32 | 0.37 | 0.37 | 0.36 |
| Ossification | −0.70 | −0.50 | −0.45 | −0.59 | −0.62 | −0.54 |
| Marbling | 0.38 | 0.36 | 0.26 | 0.33 | 0.35 | 0.31 |
| pH | −0.34 | −0.22 | −0.21 | −0.28 | −0.30 | −0.25 |

*All coefficients differed from 0 ($P < 0.01$).

**Table 11.** The main effects of serve time and serve form on consumer scores ($n = 960$) for tenderness, juiciness, flavor liking, and overall liking of Australian and US smoked briskets.

| Treatment | Tenderness[1] | Juiciness[1] | Flavor Liking[1] | Overall Liking[1] | MQ4[2] | Satisfaction[2] |
|---|---|---|---|---|---|---|
| **Serve Time** | | | | | | |
| Hot | 67.4[a] | 59.4[a] | 62.9[a] | 63.7[a] | 64.3[a] | 3.36[a] |
| Reheat | 63.4[b] | 53.8[b] | 59.1[b] | 59.8[b] | 60.3[b] | 3.22[b] |
| SEM (largest)[4] | 0.7 | 2.8 | 2.6 | 2.4 | 2.4 | 0.09 |
| *P* value | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| **Serve Form** | | | | | | |
| Chop | 65.8[b] | 57.2[a] | 62.0[a] | 62.4[a] | 63.0[a] | 3.31[a] |
| Pull | 61.6[c] | 54.1[b] | 58.9[b] | 59.4[b] | 59.6[b] | 3.19[b] |
| Slice | 68.9[a] | 58.5[a] | 62.0[a] | 63.4[a] | 64.4[a] | 3.37[a] |
| SEM (largest)[4] | 0.8 | 2.9 | 2.6 | 2.5 | 2.4 | 0.09 |
| *P* value | <0.01 | <0.01 | 0.01 | <0.01 | <0.01 | <0.01 |

[a–c]Within a column and treatment, means sharing a common superscript, do not differ ($P < 0.05$).

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

[2]MQ4 = tenderness × 0.3 + juiciness × 0.1 + flavor liking × 0.3 + overall liking × 0.3.

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

[4]Pooled (largest) standard error of least squares means.

samples were consistently scored 4 units greater ($P < 0.05$) compared to their reheated counterparts. Samples differed in satisfaction ($P < 0.05$), but hot and reheated samples would both be classified into the "good everyday quality" designation. These findings are consistent with a study conducted by Yang et al. (2002), who found meat flavor and aroma were lower in roast beef samples that had been reheated after 3 d of chilled storage compared to samples that were freshly cooked.

The hot brisket was held in higher (3.8 units) regard in terms of overall liking. Again, these findings are consistent with Yang et al., (2002), who found the meat flavor and aroma, and consequently overall quality, were lower in roast beef samples that had been reheated after 3 d of chilled storage compared to samples that were freshly cooked. In the current study, the largest spread between hot and reheated samples was noted for juiciness. This could be attributed to additional moisture loss during the reheating cycle.

Serve form influenced ($P < 0.05$) all palatability traits as seen in Table 10. Sliced samples were considered the most tender, chopped samples were intermediate, and pulled samples were scored as least tender ($P < 0.05$). Chopped and sliced samples were not different ($P > 0.05$) for juiciness, flavor liking, and overall liking scores, and both were scored greater than pulled samples ($P < 0.05$). All forms were considered "good everyday quality;" however, pulled samples had lower ($P < 0.05$) satisfaction scores compared to sliced and chopped, which were similar ($P > 0.05$).

Differences were observed in consumer eating quality due to serving form. This bias in serving form likely was the result of consumers biting across the muscle fibers of pulled samples, as opposed to biting between the muscle fibers in the sliced and chopped samples. Marks et al. (1998) found a significant shear force (Kramer shear cell) difference ($P < 0.05$) between longitudinal compared to transverse fiber orientation in 7 ostrich muscles. The sample dimensions in the current study could also influence the tenderness scores, as the thickness varied from 3 mm to 20 mm, depending on the serving form.

## Conclusions

Eating quality of smoked brisket was influenced by the interaction between combined treatment and muscle. For the most part, point portions received greater scores than flat portions, at least partially due to their greater fat percentages, within each combined treatment; however, that was not always the case, which was the driving force for the interaction between combined treatment and muscle. Consumers had difficulty distinguishing between US and Australian grain-fed or between grain-fed and grass-fed samples for tenderness and juiciness, as well as the calculated composite eating quality score within the quality grade tiers, regardless of muscle portion; however, consumers could differentiate grain-fed from grass-fed for flavor and overall liking, suggesting they preferred grain-fed flavor more than grass-fed flavor. This trend was observed in the highest quality grade tier (UPR, A5grain, and A5grass) and the lowest quality grade tier (USEL, A3grain, and A3grass). The hot samples were scored greater for all traits compared to reheated brisket samples. Serve form also influenced all palatability traits, where sliced and chopped brisket generally scored greater than pulled brisket samples. These results suggest that consumers have distinct preferences for hot/fresh products and can differentiate between serving forms, regardless of combined treatments or grades.

Carcass quality grade may not be a straightforward predictor of smoked brisket eating quality; however, when isolating carcass traits, many had a strong relationship with eating quality. Marbling and rib fat were positively linked to eating quality while pH, ossification, and hump height were negatively related. These results suggest the components relevant to carcass quality grading and fat content should help predict brisket eating quality and are critical in determining consumer acceptance, but other factors, such as preparation method and serving form, will also influence consumer eating quality.

## Literature Cited

AOAC. 2012a. Official Methods of Analysis Official Method 992.15. 19th ed. AOAC International, Gaithersburg, MD, USA.

AOAC. 2012b. Official Methods of Analysis Official Method 950.46. 19th ed. AOAC International, Gaithersburg, MD, USA.

AOAC. 2012c. Official Methods of Analysis Official Method 920.153. 19th ed. AOAC International, Gaithersburg, MD, USA.

AOAC. 2012d. Official Methods of Analysis Official Method 983.23. 19th ed. AOAC International, Gaithersburg, MD, USA.

Asem-Hiablie, S., C. A. Rotz, R. Stout, and K. Stackhouse-Lawson. 2016. Management characteristics of beef cattle production in the Northern Plains and Midwest regions of the United States. Applied Animal Science 32:736–749. https://dx.doi.org/10.15232/pas.2016-01539

Authority for the Uniform Specification of Meat and Livestock (AUS-MEAT). Australian beef carcase evaluation. Beef and veal chiller assessment language. https://www.ausmeat.com.au/WebDocuments/Chiller_Assessment_Language.pdf. (Accessed November 1, 2019).

Belew, J. B., J. C. Brooks, D. R. McKenna, and J. W. Savell. 2003. Warner-Bratzler shear evaluations of 40 bovine muscles. Meat Sci. 64:507–512. https://doi.org/10.1016/S0309-1740(02)00242-5

Carmack, C. F., C. T. Kastner, M. E. Dikeman, J. R. Schwerke, C. M. Garcia-Zepeda. 1995. Sensory evaluation of beef flavor intensity, tenderness, and juiciness among major muscles. Meat Sci. 39:143–147. https://doi.org/10.1016/0309-1740(95)80016-6

Coleman, M. E., K. S. Rhee, and H. R. Cross. 1988. Sensory and cooking properties of beef steaks and roasts cooked with and without external fat. J. Food Sci. 53:34–36. https://doi.org/10.1111/j.1365-2621.1988.tb10171.x

Corbin, C. H., T. G. O'Quinn, A. J. Garmyn, J. F. Legako, M. R. Hunt, T. T. N. Dinh, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2015. Sensory evaluation of tender beef strip loin steaks of varying marbling levels and quality treatments. Meat Sci. 100:24–31. https://doi.org/10.1016/j.meatsci.2014.09.009

Crownover, R. D., A. J. Garmyn, R. J. Polkinghorne, R. J. Rathmann, B. C. Bernhard, and M. F. Miller. 2017. The effects of hot- vs. cold-boning on eating quality of New Zealand grass fed beef. Meat Muscle Biol. 1:207–217. https://doi.org/10.22175/mmb2017.06.0030

Fletcher, W. T., A. J. Garmyn, J. F. Legako, D. R. Woerner, and M. F. Miller. 2021. Investigation of smoked beef brisket palatability from three USDA quality grades. Meat Muscle Biol. 5:1, 1–12. https://doi.org/10.22175/mmb.10963

Folch, J., M. Lees, and G. H. S. Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226:497–509.

Garmyn, A. J., G. G. Hilton, R. G. Mateescu, J. B. Morgan, J. M. Reecy, R. G. Tait, Jr., D. C. Beitz, Q. Duan, J. P. Schoonmaker, M. S. Mayes, M. E. Drewnoski, Q. Liu, and D. L. VanOverbeke. 2011. Estimation of relationships between mineral concentration and fatty acid composition of longissimus muscle and beef palatability traits. J. Anim. Sci. 89:2849–2858. https://doi.org/10.2527/jas.2010-3497

Garmyn, A. J., R. J. Polkinghorne, J. C. Brooks, and M. F. Miller. 2019. Consumer assessment of New Zealand forage finished beef compared to US grain fed beef. Meat Muscle Biol. 3:22–32. https://doi.org/10.22175/mmb2018.10.0029

Garmyn, A. J., L. G. Garcia, K. S. Spivey, R. J. Polkinghorne, and M. F. Miller. 2020. Consumer palatability of beef muscles from Australian and US production systems with or without enhancement. Meat Muscle Biol. 4:1–12. https://doi.org/10.22175/mmb.9478

Gredell, D. A., T. G. O'Quinn, J. F. Legako, J. C. Brooks, and M. F. Miller. 2018. Palatability and biochemical factors of beef from mature cattle finished on a concentrate diet prior to harvest. Meat Muscle Biol. 2:111–126. https://doi.org/10.22175/mmb2017.09.0046

Hardcastle, N. C, A. J. Garmyn, J. F. Legako, M. M. Brashears, and M. F. Miller. 2018. Honduran consumer perception of palatability of enhanced and non-enhanced beef from various finishing diets. Meat Muscle Biol. 2:277–295. https://doi.org/10.22175/mmb2018.05.0012

Harris, M. K., R. R. Riley, A. N. Arnold, R. K. Miller, D. B. Griffin, K. B. Gehring, and J. W. Savell. 2017. Assessment of postmortem aging effects on Texas-style barbecue beef briskets. Meat and Muscle Biol. 1:46–52. https://doi.org/10.22175/mmb2017.01.0003

Herring, H. K., R. G. Cassens, and E. J. Briskey. 1967. Factors affecting collagen solubility in bovine muscles. J. Food Sci. 32:534–538. https://doi.org/10.1111/j.1365-2621.1967.tb00826.x

Holdstock, J., J. L. Aalhus, B. A. Uttaro, Ó. López-Campos, I. L. Larsen, and H. L. Bruce. 2014. The impact of ultimate pH on muscle characteristics and sensory attributes of the longissimus thoracis within the dark cutting (Canada B4) beef carcass grade. Meat Sci. 98:842–849. https://doi.org/10.1016/j.meatsci.2014.07.029

Hunt, M. R., A. J. Garmyn, T. G. O'Quinn, C. H. Corbin, J. F. Legako, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2014. Consumer assessment of beef palatability from four beef muscles from USDA Choice and Select graded carcasses. Meat Sci. 98:1–8. https://doi.org/10.1016/j.meatsci.2014.04.004

Hwang, Y.-H., and S.-T. Joo. 2017. Fatty acid profiles, meat quality, and sensory palatability of grain-fed and grass-fed beef from Hanwoo, American, and Australian crossbred cattle. Food Science of Animal Resources 37:153–161. https://doi.org/10.5851/kosfa.2017.37.2.153

Jeremiah, L. E., M. E. R. Dugan, J. L. Aalhus, and L. L. Gibson. 2003a. Assessment of the chemical and cooking properties of the major beef muscles and muscle groups. Meat Sci. 65:985–992. https://doi.org/10.1016/S0309-1740(02)00308-X

Jeremiah, L. E., L. L. Gibson, J. L. Aalhus, and M. E. R. Dugan. 2003b. Assessment of palatability attributes of the major beef muscles. Meat Sci. 65:949–958. https://doi.org/10.1016/S0309-1740(02)00307-8

Kukowski, A. C., R. J. Maddock, and D. M. Wulf. 2004. Evaluating consumer acceptability of various muscles from the beef chuck and rib. J. Anim. Sci. 82:521–525. https://doi.org/10.1093/ansci/82.2.521

Lees, J., N. Hardcastle, J. Johnston, R. Wong, H. Cuthbertson, G. Tarr, A. Garmyn, M. Miller, R. Polkinghorne, and P. McGilchrist. 2024. Australian and United States consumer acceptance of beef brisket cooked using the low and slow barbeque method. Foods 13:3049. https://doi.org/10.3390/foods13193049

Marks, J., W. Stadelman, R. Linton, H. Schmieder, and R. Adams. 1998. Tenderness analysis and consumer sensory evaluation of ostrich meat from different muscles and different aging times. J. Food Quality 21:369–381. https://doi.org/10.1111/j.1745-4557.1998.tb00529.x

Mason, C. L., K. L. Nicholson, J. C. Brooks, R. J. Delmore, W. R. Henning, D. D. Johnson, C. L. Lorenzen, R. J. Maddock, R. K. Miller, J. B. Morgan, B. E. Wasser, B. L. Gwartney, K. B. Harris, D. B. Griffin, D. S. Hale, and J. W. Savell. 2009. National beef market basket survey – 2006: External fat thickness measurements and separable component determinations for beef from US retail establishments. Meat Sci. 81:335–343. https://doi.org/10.1016/j.meatsci.2008.08.010

McKeith, F. K., D. L. De Vol, R. S. Miles, P. J. Bechtel, and T. R. Carr. 1985. Chemical and sensory properties of thirteen major beef muscles. J. Food Sci. 50:869–872. https://doi.org/10.1111/j.1365-2621.1985.tb12968.x

Meat Standards Australia (MSA). 2019. Completing your MSA beef vendor declaration. https://producer.msagrading.com.au/Learning. (Accessed November 1, 2019).

Nelson, J. L., H. G. Dolezal, F. K. Ray, and J. B. Morgan. 2004. Characterization of certified angus beef steaks from the round, loin, and chuck. J. Anim. Sci. 82:1437–1444. https://doi.org/10.2527/2004.8251437x

O'Quinn, T. G., J. C. Brooks, R. J. Polkinghorne, A. J. Garmyn, B. J. Johnson, J. D. Starkey, R. J. Rathmann, and M. F. Miller. 2012. Consumer assessment of beef strip loin steaks of varying fat levels. J. Anim. Sci. 90:626–634. https://doi.org/10.2527/jas.2011-4282

Palka, K. 1999. Changes in intramuscular connective tissue and collagen solubility of bovine *m.semitendinosus* during retorting. Meat Sci. 53:189–194. https://doi.org/10.1016/S0309-1740(99)00047-9

Patterson, B. C., and F. C. Parrish. 1986. A sensory panel and chemical analysis of certain beef chuck muscles. J. Food Sci. 514: 876–879. https://doi.org/10.1111/j.1365-2621.1986.tb11189.x

Seideman, S. C., J. D. Crouse, and H. R. Cross. 1982. Effect of feeding regimen and vacuum-packaged storage on sensory and physical properties of beef steaks. J. Food Protect. 45:1227–1231. https://doi.org/10.4315/0362-028x-45.13.1227

Smith, G. C., G. R. Culp, and Z. L. Carpenter. 1978. Postmortem aging of beef carcasses. J. Food Sci. 43:823–826. https://doi.org/10.1111/j.1365-2621.1978.tb02430.x

Smith, G. C., Z. L. Carpenter, H. R. Cross, C. E. Murphey, H. C. Abraham, J. W. Savell, G. W. Davis, B. W. Berry, and F. C. Parrish. 1985. Relationship of USDA marbling groups to palatability of cooked beef. J. Food Quality 7:289–308. https://doi.org/10.1111/j.1745-4557.1985.tb01061.x

Stewart, S. M., R. Polkinghorne, D. W. Pethick, and L. Pannier. 2024. Carcass assessment and value in the Australian beef and sheepmeat industry. Animal Frontiers 14:5–14. https://doi.org/10.1093/af/vfae005

Sullivan, G. A., and C. R. Calkins. 2011. Ranking beef muscles for Warner-Bratzler shear force and trained sensory panel ratings from published literature. J. Food Quality. 34:195–203. https://doi.org/10.1111/j.1745-4557.2011.00386.x

United States Department of Agriculture (USDA). 2017. United States standards for grades of carcass beef. Livest. Seed Program, Agric. Market. Serv, Washington, DC.

United States Department of Agriculture (USDA). 2019. Agricultural Research Service. FoodData Central. fdc.nal.usda.gov. (Accessed February 14, 2020).

Watson, R., A. Gee, R. Polkinghorne, and M. Porter. 2008. Consumer assessment of eating quality development of protocols for Meat Standards Australia (MSA) testing. Aust. J. Exp. Agr. 48:1360–1367. https://doi.org/10.1071/EA07176

Yang, A., M. J. Brewster, S. L. Beilken, M. C. Lanari, D. G. Taylor, and R. K. Tume. 2002. Warmed-over flavor and lipid stability of beef: Effects of prior nutrition. J. Food Sci. 67:3309–3313. https://doi.org/10.1111/j.1365-2621.2002.tb09584.x