Published June 7, 2017

Meat and Muscle Biology™

Assessment of Postmortem Aging Effects on Texas-style Barbecue Beef Briskets

McKensie K. Harris, Ray R. Riley, Ashley N. Arnold, Rhonda K. Miller, Davey B. Griffin, Kerri B. Gehring, and Jeffrey W. Savell*

Department of Animal Science, Texas A&M University, Texas A&M AgriLife Research, College Station, TX 77843, USA
*Corresponding author. Email: j-savell@tamu.edu (J. Savell)

Abstract: Palatability traits (tenderness, juiciness, flavor, and overall liking) of beef briskets ($n = 48$) were evaluated for 3 different postmortem aging period comparisons: 7 d vs. 21 d (Set 1), 21 d vs. 35 d (Set 2), and 7 d vs. 35 d (Set 3). Briskets were prepared as Texas-style barbecue by seasoning with salt and pepper and smoking with oak wood over a long period (approx. 11 h) using a commercial oven designed for such purposes until deemed tender (approx. 85°C internal temperature). Within each treatment set, Warner-Bratzler shear (WBS) force measurements did not differ ($P > 0.05$) between aging days; however, WBS force measurements for point (*Mm. pectorales superficiales* composed of the *M. pectoralis transversus and M. pectoralis descendens*) were lower ($P < 0.05$) compared to the flat portions (*M. pectorals profundus*) within each aging set. Consumer panelists did not ($P > 0.05$) detect differences between aging days within each set for overall liking, flavor liking, tenderness liking, and juiciness liking. Conversely, differences were found between brisket point and flat portions; Set 1 differed for flavor liking (flat > point; $P = 0.0348$) and juiciness liking (point > flat; $P = 0.0004$), Set 2 differed for overall liking (flat > point; $P = 0.0499$) and juiciness liking (point > flat; $P < 0.0001$), and Set 3 differed for overall liking (flat > point; $P = 0.0296$) and juiciness liking (point > flat; $P = 0.0112$). Our findings indicate postmortem aging did not improve beef brisket palatability, but we did note differences between point and flat portions. Preparing beef briskets as Texas-style barbecue resulted in products with low WBS values and high consumer palatability ratings, which helps demonstrate why barbecued briskets are so popular.

Keywords: aging, beef, brisket, consumer panels, warner-bratzler shear force
Meat and Muscle Biology 1:46–52 (2017) **doi:10.22175/mmb2017.01.0003**
Submitted 9 Jan. 2017 Accepted 30 Mar. 2017

Introduction

The demand for beef brisket has increased due to its rising popularity among Texas Barbecue enthusiasts (Franklin and Mackay, 2015, Goldwyn and Blonder, 2016, Walsh, 2016). Beyond barbecue, this beef commodity is becoming more mainstream in restaurants where chefs are refining the use of brisket for specialty ground beef items. Along with these uses, quick service restaurants and retailers, such as Arby's and H-E-B, have empowered the rise in brisket consumption by offering specialty sandwiches and products that go beyond the traditional hamburger. Therefore, it is important for the beef industry to explore options for adding value to brisket by better understanding and/or enhancing its flavor, juiciness, and tenderness; all important aspects for pit masters, chefs, retailers, and consumers.

A Canadian study evaluated the palatability characteristics of 33 beef muscles and found that the overall tenderness ratings for point (*Mm. pectorales superficiales: M. pectoralis transversus and M. pectoralis descendens* or more simply known as the superficial pectoral) and flat (*M. pectoralis profundus* or deep pectoral) portions that make up the brisket, were ranked by a trained sensory panel as 2 of the least tender of the muscles studied (Jeremiah et al., 2003). In addi-

Funded, in part, by the Beef Checkoff. Special thanks go to Southside Market and Barbeque of Elgin, Texas for graciously providing cooking facilities and expertise for this project.

tion, there have been multiple studies that have evaluated tenderness of beef brisket by Warner-Bratzler Shear (WBS) force (Belew et al., 2003, Johnson et al., 1988, Ramsbottom et al., 1945). In one of the earliest studies characterizing muscles in the beef carcass, Ramsbottom et al. (1945) ranked muscles from most to least tender, with the deep and superficial pectoral muscles falling in the bottom 25% for shear force and organoleptic ratings. This same study identified the deep pectoral as being more tender than the superficial pectoral, whereas Johnson et al. (1988) found the superficial pectoral to be more tender than the deep pectoral. A more recent study conducted by Belew et al. (2003) utilized the tenderness threshold identified by Shackelford et al. (1991) to classify various muscles as "very tough," "tough," "intermediate," "tender," and "very tender" based on WBS force measurements. The superficial pectoral was classified as "tender," whereas the deep pectoral was categorized as "tough" (Belew et al., 2003). Previous studies examining the muscles comprising the brisket have reported conflicting results, showing great variability in WBS force values and tenderness rankings.

Not only has historical research classified muscles based on palatability attributes, but it has also identified useful ways in improving the eating experience of beef. Research has shown that tenderness is 1 of the 3 most important factors in beef eating quality (Legako et al., 2016), and can be improved through postmortem aging (Calkins and Seideman, 1988, Doty and Pierce, 1961, Eilers et al., 1996, Smith et al., 1978). Although most researchers have conducted studies on tenderness for "middle meats" and muscles from the round, there has been limited work evaluating the postmortem aging effect on other muscle groups such as those comprising the brisket. Smith et al. (1978) found the deep and superficial pectoral muscles to achieve maximum postmortem tenderization after 5 d and 28 d, respectively. Thus, there is a possibility of eliciting changes in palatability characteristics that would add value to the previously considered "tough" brisket.

Cookery method is one of multiple factors that can impact the tenderness of beef. Smith et al. (1978) prepared beef samples by roasting to an internal temperature of 75°C in an electric oven. Belew et al. (2003) cooked brisket steaks to 70°C on a flat-top grill. Thus, data from previous studies should be evaluated with cooking difference in mind. Palatability of traditional Texas-style smoked briskets that are cooked at low temperatures (93.3°C to 121.1°C) for extended lengths of time (8 to 12 h) (Franklin and Mackay, 2015, Goldwyn and Blonder, 2016, Walsh, 2016) has not been evaluated. The current study was designed to evaluate the effect of postmortem aging periods on Texas-style smoked briskets. Determination of postmortem aging effects on the palatability of briskets could provide the opportunity to add value and promote more effective merchandising of beef briskets.

Materials and Methods

Consumer panel procedures were approved by the Texas A&M Institutional Review Board (IRB2015–0498M).

Product collection

Twenty-four A-maturity, yield grade 1 to 4 beef carcasses with small, modest, or moderate marbling (USDA, 2016a) and carcass weights ranging from 320.0 kg to 438.4 kg were selected 48 h postmortem at a commercial harvest and processing facility for use in this study. Carcasses were selected by trained individuals who estimated the amount of intramuscular fat (marbling) at the 12th and 13th rib interface along with lean color and skeletal ossification (USDA, 2016a). Paired, untrimmed beef briskets, deckle-on, boneless (IMPS 119), as described by USDA (2010), were removed from each of the selected carcasses. Briskets (n = 48) then were vacuum packaged, boxed, stored under refrigerated conditions, and transported to the Texas A&M Rosenthal Meat Science and Technology Center (College Station, TX).

Treatment assignment and storage

Upon receipt, each pair of briskets was assigned to 1 of 3 aging period comparison sets: 7 versus 21 d (Set 1); 21 versus 35 d (Set 2); and 7 versus 35 d (Set 3). Briskets from 1 carcass side were assigned to a consistent age day treatment within each set. The pack date was identified as Day 0 for all aging periods. Briskets were aged under refrigerated conditions (2°C to 4°C) for each designated treatment length. After each aging period, briskets were frozen (–40°C) and stored (–10°C) for a minimum of 5 d.

Raw product preparation

Briskets were thawed (2°C to 4°C) for 5 to 6 d. Thawed briskets were unpackaged, deckle fat was removed, and sternum and external fat were trimmed to 0.64 cm to create a deckle-off, boneless brisket (IMPS 120) as described by USDA (2010). Trimmed briskets were weighed (Table 1), and a seasoning mix consisting of 89 g Morton's Kosher Salt (Grand Saline, TX) and 42 g 16-mesh coarse ground black pepper (REO Spice and Seasoning, Huntsville, TX)

Table 1. Means and standard deviations for weights, cook yield, temperatures, and cook duration of briskets

Parameter	n[1]	Mean	SD
Raw weight (kg)	48	5.60	0.75
Cooked weight (kg)	48	3.51	0.51
Cook yield (%)	48	62.60	2.01
Initial raw temperature (°C)	48	3.03	0.73
Final cooked temperature (°C)	48	85.42	2.28
Cook duration (h)	39	11.00	0.58

[1]Number of briskets evaluated.

was applied to all surfaces of each brisket. Briskets were held in insulated containers, transported (~132 km) to Southside Market and Barbeque (Elgin, TX), and cooked using typical commercial methods.

Cooking

After initial internal raw brisket temperatures were recorded, briskets were spaced evenly on one of six racks in an Oyler Barbecue Pit (J&R Manufacturing, Inc., Mesquite, TX) and smoked using oak wood at a pit temperature of 98.8°C for approximately 11 h. As brisket internal temperatures approached the doneness threshold (approx. 85°C internal temperature), an experienced pit master assessed each brisket manually for pliability as an indicator that the desired level of tenderness had been achieved. Final internal temperatures were recorded before finished briskets were removed from the pit, weighed, wrapped in peach treated butcher paper (Norpak, Newark, NJ) and stored in an insulated container for transport to the Texas A&M University sensory facilities (College Station). Brisket weights and cooking data are reported in Table 1.

Sensory evaluation

Cooked briskets were held in the insulated containers for approximately 2 h, which included transportation and staging before the sensory panels. Ten minutes before serving, briskets were taken out of the insulated containers and the peach paper wrapping was removed. A knife was used to separate the point from flat portion at the most posterior edge of the hard sternum fat. Each portion was rewrapped in a new sheet of peach paper and held in an oven (Alto-Shaam, Milwaukee, WI) set at 93.3°C until subsequent slicing and serving.

Slicing varied for each portion. The point portion was divided in half with a knife cut starting at the apex of the brisket (cranial end) and continuing to the cut face (perpendicular to the point/flat separation). The half furthest from the hard sternum fat (craniodorsal half) was used to remove a 2.54 cm thick slice (from the cut surface) for WBS force, followed by six subsequent center cut slices, each 1.27 cm thick and 12.7 cm wide. Slices from the flat portion were removed according to the following: the first slice (2.54 cm thick), destined for WBS force, was removed at the interface of point/flat separation; 6 subsequent center cut slices 1.27 cm thick and 12.7 cm wide (accomplished by removing 2 equidistant ends to make a center cut slice) were separated. Prepared slices from each portion destined for consumer evaluation were placed on individually labeled, clear serving plates and served to consumer panelists. A plastic knife and fork were provided with each sample to assist in sample tasting.

The panel was conducted at the Kleberg Animal and Food Sciences Center at Texas A&M University (College Station). Panelists (n = 83) were recruited from the Bryan/College Station area via electronic survey. Compensation in the amount of $25 USD was awarded to all panelists who completed the study. Before beginning each session, panelists were given verbal instructions and asked to complete a consent form, demographics survey (Table 2), and a meat consumption questionnaire (Table 3). Panelists then were seated in individual testing booths equipped with red theater gel lights. Samples were served warm, in a random order, and identified with random 3-digit codes. Nabisco Unsalted Tops Premium Saltine Crackers (Kraft Foods Global, Inc., East Hanover, NJ) and double distilled, deionized water were provided to panelists to cleanse their palate between samples. Panelists were asked to evaluate brisket slice attributes based on a 9-point scale. Attributes included: overall liking (1 = dislike extremely; 9 = like extremely), flavor liking (1 = dislike extremely; 9 = like extremely), juiciness liking (1 = dislike extremely; 9 = like extremely), and tenderness liking (1 = dislike extremely; 9 = like extremely).

Warner Bratzler shear force

Single slices taken from the point and flat portions of each cooked brisket were placed in a single layer on a plastic tray, covered with plastic wrap and stored (2°C to 4°C) for 12 h. Slices were equilibrated to room temperature before being trimmed of bark (exterior crust formed during cooking), visible fat, and heavy connective tissue to expose muscle fiber orientation. Six cores, 1.27 cm in diameter, were removed parallel to the muscle fiber for testing. Each core was sheared once perpendicular to the muscle fiber on a United Testing machine (United SSTM-500, Huntington

Table 2. Demographic summary of consumer panelists (n = 83)

Demographic	n[1]	%
Sex		
Male	40	48
Female	43	52
Age		
20 yr or younger	5	6
21 to 25 yr	23	28
26 to 35 yr	18	22
36 to 45 yr	7	8
46 to 55 yr	11	13
56 to 65 yr	9	11
66 yr and older	10	12
Working status		
Not employed	11	12
Part-time	12	13
Full-time	33	37
Student	33	37
Annual household income		
Below $25,000	17	20
$25,001 to 49,999	14	17
$50,000 to 74,999	17	20
$75,000 to 99,999	13	16
$100,000 or more	22	27
Ethic background		
White	71	86
Hispanic	10	12
Asian or Pacific Islander	1	1
Black	1	1
American Indian	0	0
Other	0	0

[1]Number of responses.

Beach, CA) at a cross-head speed of 200 mm/min using a 10.0 kg load cell and a 1.02-cm-thick V-shape blade with a 60° angle and a half-round peak. The peak force needed to shear each core was recorded, and the average of the six cores was used for analysis.

Statistical analysis

Data were analyzed using the PROC GLM function of SAS (v9.3; SAS Inst. Inc., Cary, NC) with $\alpha < 0.05$. Data were analyzed so that only aging treatments within carcass were evaluated and carcass was included as a fixed effect. Therefore, 3 analyses were conducted that compared 7 d versus 21 d aging, 21 d versus 35 d aging, and 7 d versus 35 d aging. Main effects included in the model were aging time, portion (flat versus point) and their interaction. Least squares means were calculated and were separated using the PDIFF option ($P < 0.05$) where appropriate.

Table 3. Meat consumption profile of consumer panelists (n = 83)

Meat consumption pattern	n[1]	%
Meat consumption		
Yes	82	99
No	1	1
Type of meat consumption		
Beef	83	100
Pork	82	99
Chicken	83	100
Fish	77	93
Frequency of beef consumption		
Daily	7	8
5 or more times per wk	18	22
3 or more times per wk	40	48
Once per wk	16	19
Once every 2 wk	1	1
Less than once every 2 wk	1	1
Frequency of beef consumption		
At home		
None	2	3
Once weekly	20	25
Twice weekly	26	33
3 times weekly	18	23
4 times weekly	7	9
5 or more times weekly	7	9
At a restaurant		
None	3	4
Once weekly	40	49
Twice weekly	20	25
3 times weekly	7	9
4 times weekly	7	9
5 or more times weekly	4	5
Preferred degree of doneness		
Rare	3	4
Medium rare	21	25
Medium	6	7
Medium well	38	45
Well done	17	20
Type of beef purchased		
Grass-fed	11	12
Traditional	71	75
Aged	6	6
Organic	7	7

[1]Number of responses.

Results and Discussion

Warner-Bratzler shear force

There were no interactions ($P > 0.05$) between aging treatment and portion for WBS values (data not reported in tabular form). Least squares means for WBS force values for Set 1, 2, and 3 main effects are

reported in Table 4. Though briskets aged for a greater number of days were not more tender ($P > 0.05$) than those aged for fewer days, all WBS force values fell well within the "very tender" threshold (< 31.38 N) as defined by Belew et al. (2003).

For all treatment comparison sets, point portions had lower ($P < 0.05$) WBS force values than flat portions, regardless of length of age (Table 4). This is consistent with the findings of Belew et al. (2003) and Johnson et al. (1988). In contrast, Ramsbottom et al. (1945) reported the flat as having lower shear force values than the point. This inconsistency could be attributed to the varying cook methods and postmortem aging durations among these studies. Ramsbottom et al. (1945) cooked the brisket portions in lard to an internal temperature of 76.7°C, and Johnson et al. (1988) cooked briskets to 70°C in a water bath. In contrast, we used a commercial pit barbecue smoker to cook product to approximately 85°C. Additionally, the briskets evaluated by Ramsbottom et al. (1945) and Johnson et al. (1988) were aged 5 d and 21 d, respectively, compared to the 7 d, 21 d, and 35 d aging periods we used. These factors created differences among the studies that are important to consider when comparing results.

Table 4. Least squares means and SE for WBS force values obtained from each set comparison for aging treatment and brisket portion

Aging treatment and brisket portion comparison	n[1]	WBS force (N)
Set 1		
Age		
7 d	16	19.27
21 d	16	18.14
SEM		1.01
P-value		0.4396
Portion		
Flat	16	23.20
Point	16	14.21
SEM		1.01
P-value		< 0.0001
Set 2		
Age		
21 d	16	16.92
35 d	16	17.60
SEM		1.06
P-value		0.6543
Portion		
Flat	16	22.05
Point	16	12.47
SEM		1.06
P-value		< 0.0001
Set 3		
Age		
7 d	16	17.99
35 d	16	17.16
SEM		0.93
P-value		0.5297
Portion		
Flat	16	22.95
Point	16	12.20
SEM		0.93
P-value		< 0.0001

[1]Number of observations evaluated.

Consumer sensory evaluations

There were no ($P > 0.05$) interactions between aging treatment and portion for the consumer sensory traits for any of the 3 sets (data not presented in tabular form). Least squares means for rankings in overall liking, flavor liking, tenderness liking, and juiciness liking for Set 1, 2, and 3 are reported in Table 5. Consumer ratings did not differ ($P > 0.05$) between aging treatments within each comparison set. However, consumers did detect differences ($P < 0.05$) between point and flat portions within each comparison.

Overall liking ratings were greater for the flat compared to the point sections in Set 2 ($P = 0.0499$) and Set 3 ($P = 0.0296$). Flavor liking ratings for flat portions within Set 1 were higher ($P = 0.0348$) than point portions, although there were no ($P > 0.05$) flavor attribute differences found for the 2 portions in sets 2 and 3. Jeremiah et al. (2003) found the point and flat portion flavor intensity and desirability ratings to reside between 4 and 6 on a 9-point hedonic scale, and the flat portion had higher scores than the point. The values in the past study were still lower and less desirable than the values found in our study. In addition, there are multiple influences on flavor in beef, one in particular being lipid type, amount, and composition (Wood et al., 2004). With regards to lipid type and amount, Mason et al. (2009) dissected point and flat portions of the brisket to determine the percentages of external fat, seam fat, and extractable fat, finding the flat portion had a higher percent fat and lower percent lean when compared to the point. In addition, the USDA's National Nutrient Database for Standard Reference (USDA, 2016b) gives information on total lipid within each portion; on a raw basis, the flat portion has a higher fat content (22.18 g/100 g vs. 20.98 g/100 g) than the point. However, this is reversed on a cooked basis. Both resources show that there is variability in the fat content of the point and flat portions of beef brisket. Further studies should be conducted on the lipid composition of the point and flat portions and how this pertains to consumer preferences

Table 5. Least squares means and SEM for consumer sensory rankings of beef palatability attributes for Sets 1[1], 2[1], and 3[1] stratified by aging treatment and brisket portion main effects

Aging treatment and brisket portion comparison	n[2]	Overall like/dislike[3]	Flavor like/dislike[3]	Tenderness like/dislike[3]	Juiciness like/dislike[3]
Set 1					
Age					
7 d	16	6.3	6.6	6.2	6.0
21 d	16	6.9	6.9	6.8	6.5
SEM		0.21	0.18	0.28	0.23
P-value		0.0818	0.1728	0.1456	0.1393
Portion					
Flat	16	6.8	7.0a	6.2	5.6b
Point	16	6.4	6.5b	6.9	6.9a
SEM		0.21	0.18	0.28	0.23
P-value		0.1807	0.0348	0.0864	0.0004
Set 2					
Age					
21 d	16	6.4	6.9	6.7	6.6
35 d	16	6.9	7.3	7.0	6.6
SEM		0.24	0.19	0.26	0.19
P-value		0.1381	0.1073	0.5269	0.8533
Portion					
Flat	16	7.0a	7.4	6.7	5.8b
Point	16	6.3b	6.8	7.1	7.3a
SEM		0.24	0.19	0.26	0.19
P-value		0.0499	0.0602	0.2571	< .0001
Set 3					
Age					
7 d	16	6.8	7.1	6.8	6.6
35 d	16	6.4	6.8	6.7	6.4
SEM		0.22	0.22	0.24	0.22
P-value		0.1719	0.3031	0.6498	0.4669
Portion					
Flat	16	7.0a	7.2	6.5	6.1b
Point	16	6.2b	6.7	6.9	6.9a
SEM		0.22	0.22	0.24	0.22
P-value		0.0296	0.1028	0.2285	0.0112

[1]Set 1: 7 d versus 21 d aging; Set 2: 21 d versus 35 d aging; Set 3: 7 d versus 35 d aging.

[2]Number of observations evaluated.

[3]Rankings were assigned based on a nine-point hedonic scale for each attribute (1 = dislike extremely and 9 = like extremely).

of each; this may help clarify the differences found in our study for flavor like/dislike.

Surprisingly, there were no ($P > 0.05$) tenderness liking differences detected among the point and flat portions in any of the set comparisons, even though there were WBS value differences between the portions. Because the WBS force values fell below the "very tender" threshold defined by Belew et al. (2003), it may be that consumers were unable to detect slight differences in tenderness ratings between samples. In comparison, Jeremiah et al. (2003), using a trained sensory panel and a nine-point scale, found the tenderness rankings for both portions of the brisket to be slightly lower (~5.5 to 6.0) than what we found.

Finally, it is interesting to note consumers preferred ($P < 0.05$) the juiciness of point portions as compared to flat portions in all three comparison sets, paralleling what was found by Jeremiah et al. (2003). Interestingly, the preference in point portion juiciness seen in Set 2 and Set 3 did not drive overall like or dislike preferences, as flats obtained higher rankings in this category. This finding may indicate that consumers preferred samples from the leaner flat portion, even though they gave higher ratings for specific traits to samples from the point portion.

Although there were similarities between results from our study and those from Jeremiah et al. (2003), the differences seen are most likely attributable to the difference in sample preparation. Jeremiah et al. (2003) roasted 6 d aged 1 kg roasts in an electric convection oven to 72°C; a method very different than smoking to higher temperatures (approx. 85°C) for longer times (~11 h). It may be that cooking technique has a large effect on palatability for muscles such as those that make up the brisket. Furthermore, differences in sensory panel type could contribute to the differing results; a trained consumer panel was utilized by Jeremiah et al. (2003), whereas a consumer panel was used in our study.

Conclusions

Significant aging treatment differences were not found for the objective (WBS force) and subjective (consumer sensory panel) techniques used to assess palatability attributes. Therefore, if smoked briskets are prepared using a Texas-style barbecue method, cooking at low temperatures for long durations of time, no added palatability benefits would be achieved through using product with extended postmortem aging periods. However, based on WBS force and consumer differences detected between point and flat portions, pit masters and barbecue enthusiasts may find value in buying individual muscle pieces or marketing the 2 portions individually.

In addition, despite previous studies that ranked the brisket point and flat portion as being tough cuts/muscles, this study revealed there is an advantage to preparing briskets Texas-style, as the WBS force values fell well below the thresholds determined as "very tender" by previous studies, and palatability ratings were relatively high on average (6 and 7 on 9-point scale).

Literature Cited

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. doi:10.1016/S0309-1740(02)00242-5

Calkins, C. R., and S. C. Seideman. 1988. Relationships among calcium-dependent protease, cathepsins B and H, meat tenderness and the response of muscle to aging. J. Anim. Sci. 66:1186–1193. doi:10.2527/jas1988.6651186x

Doty, D. M., and J. C. Pierce. 1961. Beef muscle characteristics as related to carcass grade, carcass weight, and degree of aging. Technical Bulletin No. 1231. Agricultural Marketing Service, U.S. Department of Agriculture, Washington, DC.

Eilers, J. D., J. D. Tatum, J. B. Morgan, and G. C. Smith. 1996. Modification of early-postmortem muscle pH and use of postmortem aging to improve beef tenderness. J. Anim. Sci. 74:790–798. doi:10.2527/1996.744790x

Franklin, A., and J. Mackay. 2015. Franklin Barbecue: A meat-smoking manifesto. Ten Speed Press, Berkeley, California.

Goldwyn, M., and G. Blonder. 2016. Meathead: The science of great barbecue and grilling. A Rux Martin Book, Houghton Mifflin Harcourt, Boston.

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

Johnson, R. C., C. M. Chen, T. S. Muller, W. J. Costello, J. R. Romans, and K. W. Jones. 1988. Characterization of the muscles within the beef forequarter. J. Food Sci. 53:1247–1250, 1257. doi:10.1111/j.1365-2621.1988.tb09249.x

Legako, J. F., T. T. Dinh, M. F. Miller, K. Adhikari, and J. C. Brooks. 2016. Consumer palatability scores, sensory descriptive attributes, and volatile compounds of grilled beef steaks from three USDA Quality Grades. Meat Sci. 112:77–85. doi:10.1016/j.meatsci.2015.10.018

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. doi:10.1016/j.meatsci.2008.08.010

Ramsbottom, J. M., E. J. Standine, and C. H. Koonz. 1945. Comparative tenderness of representative beef muscles. J. Food Sci. 10:497–508. doi:10.1111/j.1365-2621.1945.tb16198.x

Shackelford, S. D., J. B. Morgan, H. R. Cross, and J. W. Savell. 1991. Identification of threshold levels for Warner-Bratzler shear force in beef top loin steaks. J. Muscle Foods 2:289–296. doi:10.1111/j.1745-4573.1991.tb00461.x

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

USDA. 2010. Institutional meat purchase specifications: Fresh beef– Series 100. United States Department of Agriculture, Agricultural Marketing Service, Washington, DC. https://www.ams.usda.gov/sites/default/files/media/IMPS_100_Fresh_Beef%5B1%5D.pdf. Accessed 12 October 2016.

USDA. 2016a. United States standards for grades of carcass beef. Agricultural Marketing Service, United States Department of Agriculture, Washington, DC. https://www.ams.usda.gov/sites/default/files/media/Carcass Beef Standard.pdf. Accessed 10 October 2016.

USDA. 2016b. USDA National Nutrient Database for Standard Reference, Release 28. Version Current: September 2015, slightly revised May 2016. United States Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory, Washington, DC. https://www.ars.usda.gov/northeast-area/beltsville-md/beltsville-human-nutrition-research-center/nutrient-data-laboratory/docs/usda-national-nutrient-database-for-standard-reference/. Accessed 26 December 2016.

Walsh, R. 2016. Legends of Texas Barbecue cookbook: Recipes and recollections from the pitmasters. Chronicle Books LLC, San Francisco, CA.

Wood, J. D., R. I. Richardson, G. R. Nute, A. V. Fisher, M. M. Campo, E. Kasapidou, P. R. Sheard, and M. Enser. 2004. Effects of fatty acids on meat quality: A review. Meat Sci. 66:21–32. doi:10.1016/S0309-1740(03)00022-6