Evaluation of the Impact of Bone-in Versus Boneless Cuts on Beef Palatability[1]

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Abstract: Palatability traits of ribeye, strip loin, and tenderloin steaks were evaluated in a bone-in versus boneless format. Sensory characteristics of these cuts were also evaluated in 2 quality grade categories; upper 2/3 USDA Choice and USDA Select to evaluate the interactions of marbling level and bone state. Subprimals were collected from both sides of 12 beef carcasses per quality grade and aged for 28 d. Product was fabricated into 2.5-cm-thick steaks and designated for either trained sensory analysis, consumer sensory analysis, Warner-Bratzler shear force (WBSF), or fat and moisture determination. Results from trained sensory analysis showed bone-in tenderloins and bone-in ribeyes as more flavorful ($P < 0.05$) than boneless cuts from the same muscle. Bone state had no effect ($P > 0.05$) on trained sensory initial juiciness, myofibrillar tenderness, and overall tenderness scores, or WBSF for any cut. Furthermore, tenderloin samples were rated higher ($P < 0.05$) by trained sensory panelists for myofibrillar and overall tenderness than strip loin and ribeye steaks, which were similar ($P > 0.05$). Bone state had no impact ($P > 0.05$) on consumer tenderness and flavor ratings for any of the 3 cuts. However, bone-in strip loin samples were rated juicier and higher ($P < 0.05$) overall than boneless strip loin steaks by consumers. Tenderloin steaks were juicier, more tender, more flavorful, and rated higher overall ($P < 0.05$) than ribeyes and boneless strip loin steaks by consumers. Moreover, there were no differences ($P > 0.05$) between strip loin and ribeye steaks for flavor liking by consumers and no difference ($P > 0.05$) in overall liking rating between ribeyes and boneless strip loin steaks. Overall, bone status had a minimal impact on beef palatability traits, providing evidence that eating quality is not greatly impacted by bone status for any of the cuts evaluated.

Introduction

The evolution of consumer demands and processing practices over the past several decades in the beef industry has caused a shift away from traditional bone-in primals and subprimals to the marketing of primarily boneless subprimals. However, there is still an increased interest and novelty surrounding bone-in cuts in high-end steakhouses and retail markets (Bass, 2018). Millennials have used the term "foodie" to describe those who have a passion for eating and learning about the overall eating experience (Ulver, 2019). As a result, these consumers prefer the aesthetic and visual stimulation that bone-in beef cuts offer in comparison with boneless alternatives (Bass, 2018). Boneless subprimals are marketed at a higher price per pound than bone-in cuts—yet most restaurants sell bone-in steaks at a greater premium than boneless steaks of the same cut (USDA-AMS, 2022). This discrepancy in price illustrates that consumers are willing to pay a higher price for bone-in steaks and allows restaurants to capture a greater value with these cuts (Bass, 2018).

Moreover, bone-in cuts are believed to have a more flavorful eating experience for consumers (Chicago Steak Company, 2016; López-Alt, 2018;

Goldwyn, 2021). This added flavor has been proposed to come from the bone itself and the marrow inside (Goldwyn, 2021). It is possible that the yellow marrow found inside the bone gets transferred to the steak itself, resulting in a more buttery flavor (Chicago Steak Company, 2016). However, Jansen et al. (2015) described yellow bone marrow as a viscous substance found in the medullary cavity of bone, making it unlikely to seep through the bone and into the muscle during cooking. It has also been speculated that the bone provides more insulation to the muscle, resulting in a slower cooking time and less surface area to lose moisture through, and thus produces an improved eating experience (López-Alt, 2018).

Mixed results have been reported for eating quality in research comparing bone-in versus boneless cuts. McCullough (2013) found only minimal differences between bone-in and boneless steaks; however, different USDA quality grades were compared in their study. Thus, it is unclear whether the impact of bone is dependent on marbling level, as many of the bone-in cuts marketed in restaurants are often from only the premium quality grades of USDA Prime and upper 2/3 Choice. Jeremiah et al. (2003) reported that when compared with boneless cuts, bone-in steaks cut from beef ribs and short loins had improved tenderness and flavor attributes. Data from the National Beef Tenderness Surveys have also produced mixed results (Morgan et al., 1991; Brooks et al., 2000; Voges et al., 2007; Guelker et al., 2013; Martinez et al., 2017). Many of these studies have shown that there are no palatability differences between bone-in and boneless cuts of the same quality grade, whereas others have even reported improved palatability within boneless cuts (Voges et al., 2007; Guelker et al., 2013; Martinez et al., 2017). With the exception of the McCullough (2013) study, none of the cited studies had the objective to evaluate the impact of bone-in versus boneless cuts and thus, in many cases, lack the appropriate experimental control or replication to draw meaningful conclusions regarding the impact of bone state on beef palatability.

Therefore, the objective of the current study was to evaluate palatability traits of beef cuts (ribeye, strip loin, tenderloin) in a bone-in versus boneless format and compare the palatability characteristics of these cuts in a high quality (upper 2/3 USDA Choice) and a lower quality (USDA Select) product to evaluate the interactions of marbling level and bone state.

Materials and Methods

The Kansas State University (KSU) Institutional Review Board (IRB) approved all procedures for use of human subjects in sensory panel evaluation (IRB #7440.7, February 2, 2021).

Sample preparation

Left and right sides of 12 beef carcasses representing USDA Choice (upper 2/3) and USDA Select quality grades were selected by trained KSU personnel at a commercial abattoir in the Midwest, with carcass characteristics reported previously by Farmer (2022). KSU research personnel collected quality and yield grade data prior to fabrication (data not presented). Cuts from both sides of carcasses ($n = 12$) were fabricated into beef short loins (IMPS #174), and the rib from one side was fabricated into a bone-in ribeye roll (IMPS #109E) and the other into a boneless ribeye roll (IMPS #112A). All cuts were vacuum-packaged and transported under refrigeration to the KSU Meat Laboratory (Manhattan, KS).

After arriving at KSU, short loins from each animal were fabricated into either a boneless strip loin (IMPS #180) with a corresponding bone-in tenderloin (IMPS #188) or a bone-in strip loin (IMPS #175) with a paired boneless tenderloin (IMPS #190B) at 3 d postmortem. Following the initial fabrication, product was vacuum-packaged. No further fabrication was necessary for ribeye rolls; thus, they remained in vacuum packaging from the processing facility. All product was then aged in dark storage for a total 28 d postmortem at 0°C to 4°C.

At the completion of the aging period subprimals were frozen (−20°C). Frozen subprimals were fabricated into 2.5-cm-thick steaks using a band saw (Model #3344, Biro, Marblehead, OH). Strip loin steaks for use in the study were selected anterior to the *m. gluteus medius*, and tenderloin steaks were selected from the posterior end of the cuts where the steaks were largest. For ribeye rolls, steaks were taken from the approximate center of the cut. Following cutting, steaks were randomly assigned to 1 of 4 assays: (1) consumer sensory analysis; (2) trained sensory analysis; (3) Warner-Bratzler shear force (WBSF) evaluation; or (4) chemical fat and moisture analysis. Steaks were then individually vacuum-packaged and kept frozen (−20°C) until further analysis.

Trained sensory panel evaluation

Steaks designated for trained sensory analysis were thawed at 2°C to 4°C for 24 h prior to cooking. Testing procedures followed those previously described by

Drey et al. (2019), Olson et al. (2019), and Prill et al. (2019a). Steaks were cooked to a peak temperature of 71°C (medium) following the postcooking temperature rise on clamshell style grills (Cuisinart Griddler Deluxe, East Windsor, NJ), and temperatures were monitored using a probe thermometer (Thermapen Mk4, ThermoWorks, American Fork, UT). For ribeye samples, only the *m. longissimus thoracis* muscle was evaluated by panelists. Following cooking, samples were cut into 2.5-cm thick × 1-cm × 1-cm cuboids and held in warming dishes (> 38°C) for no more than 10 min following cooking, and 2 pieces were served warm to each trained sensory panelist.

Trained sensory panelists were trained according to the American Meat Science Association (AMSA) sensory guidelines (AMSA, 2016). Panelists were trained over 4 sessions leading up to the panels with anchors and methods similar to those described by Lucherk et al. (2016) and Vierck et al. (2018). A total of 18 panels were conducted at the KSU Meat Science Sensory Lab (Manhattan, KS). For each session, 8 panelists were seated at individual booths under low-intensity red incandescent lights and fed 8 samples representing treatments in a randomized order. A warm-up sample was fed to panelists and discussed to calibrate participants and prevent panel drift at the beginning of each panel session. Panelists evaluated the samples for initial juiciness, sustained juiciness, myofibrillar tenderness, connective tissue amount, overall tenderness, beef flavor intensity, and off-flavor intensity. Samples were rated on 100-point continuous line scales with descriptive anchors at 0, 50, and 100. The scales anchor of 0 corresponded to extremely dry/tough/none/extremely bland/no off-flavor; 50 neither dry nor juicy/neither tough nor tender; and 100 extremely juicy/tender/abundant/extremely intense.

Trained sensory panelists recorded their responses using a digital survey (Qualtrics Software, Provo, UT) on an electronic tablet (Lenovo TB-8505F, Morrisville, NC). Additionally, final peak temperature and steak weights (raw and cooked) were collected for the calculation of cooking loss ([(raw weight – cooked weight)/raw weight] × 100). All external fat, connective tissue, and bone was separated from the lean of the steaks and weighed. The weight of the inedible portion of the steak was used to calculate cooking yield ([(cooked weight – inedible weight)/raw weight] × 100).

Consumer sensory panel evaluation

Consumer sensory panelists ($N = 144$) were recruited from Manhattan, Kansas, and the surrounding area and monetarily compensated for their participation in the study. Eighteen 8-person panel sessions were conducted, with 3 sessions conducted simultaneously, for a total of 24 panelists seated together in a large lecture-style classroom at KSU. Steaks designated for consumer sensory analysis were thawed at 2°C to 4°C for 24 h prior to testing and all exterior fat was removed prior to analysis. Testing followed procedures previously described McKillip et al. (2017), Nyquist et al. (2018), Rice et al. (2019), and Davis et al. (2021). Steaks were cooked and prepared for the consumer panelists using the procedures previously described for trained sensory panel evaluation. Following cooking, steaks were cut and served immediately, warm, to consumer panelists.

Each consumer evaluated 8 samples representing various treatments in a random order for juiciness, tenderness, flavor liking, beef-like flavor intensity, beef-fat like flavor intensity, and overall liking on a 100-point continuous line scale anchored on both ends with descriptive terms. Additionally, panelists were asked to classify each sample as acceptable or unacceptable for each of the sensory traits previously listed and to assess the quality of the sample by identifying if the sample was unsatisfactory, everyday quality, better than everyday quality, or premium quality. All samples were identified using random 4-digit codes.

Consumers were provided apple juice, water, and unsalted saltine crackers to use as palate cleansers in addition to a napkin, plastic fork, and expectorant cup. Consumer sensory panelists recorded their responses using a digital survey (Qualtrics Software) on an electronic tablet (Lenovo TB-8505F). Additionally, final peak temperatures of all samples were recorded.

Warner-Bratzler shear force analysis

WBSF analysis was performed using the protocol described by the AMSA meat cookery and sensory guidelines (AMSA, 2016). A total of 6 cores (1.27-cm diameter) were cut from each cooked steak parallel to the muscle fiber orientation. The cores were then sheared perpendicular to the muscle fiber orientation using an Instron testing machine (model 5569, Instron Corp., Canton, MA) with a crosshead speed of 250 mm/min and a load cell of 100 kg. Measurements of the 6 cores per steak were averaged and results were recorded as average peak force (kilograms).

Fat and moisture analysis

Steaks designated for fat and moisture analysis were thawed at 2°C to 4°C for 24 h prior to homogenization.

All exterior fat and bone were trimmed from samples and only the muscle of interest was cut into small cubes and submerged in liquid nitrogen. Samples were then ground to a fine powder using a blender (Waring Commercial, Stamford, CT). Once powdered, the samples were stored at −80°C until further analysis. A modified Folch method described by Martin et al. (2013) was utilized to analyze intramuscular fat percentage. Moisture content of samples was determined by an oven drying method described by the AOAC (2016). Both analyses were performed in duplicate.

Statistical analysis

Statistical analysis was completed using the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, NC) with α set at 0.05. Carcass served as the experimental unit for statistical analyses and data were analyzed as a split-plot with the whole plot factor of quality grade and a subplot factor of bone state/ muscle. Because all treatment comparisons were not possible within a single panel session, treatments were assigned to panels in an unbalanced, incomplete block design and optimized to ensure treatments were compared within panels as close to an equal number of times as possible using PROC OPTEX. The overall design had a calculated efficiency of over 95% as compared with if the model would have been both balanced and complete and a calculated λ of 7.6, indicating each treatment combination was directly compared within the same panel an average of 7.6 times. Peak temperature was used as a covariant, and a model with a binomial error distribution was utilized for acceptability and perceived quality level data. Additionally, the Kenward-Roger approximation was used for all analyses.

Results

Consumer panel demographics and purchasing motivators

Table 1 presents the demographic profile of the 144 consumers who participated in the consumer sensory panels. Participants were primarily Caucasian/White (93.8%) and consisted of predominately men (66.7%) versus women (33.3%). Of the consumers, 36.1% were between the age of 20 to 29 y old, and more than 50% were over 40 y of age. Over half of the participants were married (52.8%), with 76.4% of consumers having a household size of 2 or more people. Most (86.2%)

Table 1. Demographic characteristics of consumers ($N = 144$) who participated in consumer sensory panels

Characteristic	Response	Percentage of consumers
Gender	Male	66.7
	Female	33.3
Household size	1 person	23.6
	2 people	38.2
	3 people	6.9
	4 people	13.9
	5 people	7.6
	6 people	6.9
	Greater than 6 people	2.8
Marital status	Married	52.8
	Single	47.2
Age	Under 20	5.6
	20-29	36.1
	30-39	5.6
	40-49	15.3
	50-59	20.1
	Over 60	17.4
Ethnic origin	African American	0.7
	Asian	1.4
	Caucasian/White	93.8
	Hispanic	2.1
	Mixed race	1.4
	Native-American	0.7
	Other	0.7
Household income level	Under $25,000	26.6
	$25,000-$34,999	2.8
	$35,000-$49,999	7.7
	$50,000-$74,999	9.8
	$75,000-$99,999	19.6
	$100,000-$149,999	16.1
	$150,000-$199,999	8.4
	Greater than $199,999	9.1
Education level	Non-high school graduate	0.7
	High school graduate	16.7
	Some college/technical school	36.1
	College graduate	29.2
	Post-college graduate	17.4
Most important palatability trait when consuming beef	Tenderness	25.2
	Juiciness	16.1
	Flavor	58.7
Preferred degree of doneness when consuming beef	Very rare	1.4
	Rare	6.9
	Medium rare	45.1
	Medium	29.2
	Medium well	12.5
	Well done	4.2
	Very well done	0.7
Weekly beef consumption	1-3 times	52.8
	4-6 times	36.8
	7-9 times	6.3
	10 or more times	4.2

consumers had completed some college/technical school or more. The majority (53.2%) of consumers had an annual household income level of $75,000 or greater. When asked what beef palatability trait was most important, 45.1% of consumers rated flavor the highest, followed by tenderness (25.2%) and juiciness (16.1%). Medium rare was the most preferred degree of doneness (45.1%), and over half (52.8%) of participants consumed beef 1 to 3 times a week.

Participants were asked to rate the importance of 16 different beef purchasing motivators when purchasing fresh steaks at retail (Table 2). "Price" and "color" were more ($P < 0.05$) important than all other purchasing motivators other than "size, weight, and thickness." "Marbling," "USDA grade," and "familiarity with cut" were rated similar ($P > 0.05$) but more important ($P < 0.05$) to consumers than "nutrient content," "animal welfare," "eating satisfaction claims," "antibiotic use in animal," and "packaging." Additionally, traits identified as "animal fed grain-based diet," "natural or organic claims," "animal fed a grass-based diet," and "brand of product" were among the least important ($P < 0.05$) purchasing motivators to participants of this study.

Table 2. Fresh beef steak purchasing motivators of consumers ($N = 144$) who participated in consumer sensory panels

Characteristic	Importance of each trait[1]
Price	75.1[a]
Color	74.3[a]
Size, weight, and thickness	71.1[ab]
Marbling	67.3[bc]
USDA Grade	65.5[bc]
Familiarity with cut	61.3[c]
Nutrient content	53.8[d]
Animal welfare	52.1[d]
Eating satisfaction claims	50.4[de]
Antibiotic use in animal	44.8[ef]
Packaging	44.5[efg]
Growth hormone used in animal	41.7[fgh]
Animal fed a grain-based diet	41.4[fgh]
Natural or organic claims	38.4[gh]
Animal fed a grass-based diet	37.3[h]
Brand of product	37.0[h]
SEM[2]	2.3
P value	< 0.01

[abcdefgh]Least-squares means lacking a common superscript differ ($P < 0.05$).

[1]Purchasing motivators: 0 = extremely unimportant, 100 = extremely important.

[2]SEM (largest) of the least-squares means.

Consumer sensory evaluation

There were no ($P > 0.05$) interactions found between quality grade and cut/bone state for any of the traits evaluated by consumers. The means for the main effects of quality grade and cut/bone state are reported in Table 3. When evaluating the main effect of quality grade, all Choice steaks were rated higher ($P < 0.05$) than Select steaks for juiciness, tenderness, flavor, and overall liking. Bone state had no impact ($P > 0.05$) on consumer juiciness and overall liking for tenderloins and ribeyes, but in the strip loin, bone-in steaks were rated juicier ($P < 0.05$) and higher ($P < 0.05$) for overall liking when compared with boneless steaks. Moreover, bone state had no impact ($P > 0.05$) on consumer tenderness and flavor ratings for any of the 3 cuts. Regardless of bone state, tenderloin steaks were juicier, more tender, more flavorful, and rated higher overall ($P < 0.05$) than ribeyes and boneless strip loin steaks. However, bone-in strip loin steaks were similar ($P > 0.05$) in juiciness to bone-in tenderloins. There were no differences ($P > 0.05$) between strip loins and ribeyes for flavor liking. Additionally, boneless ribeye steaks were similar ($P > 0.05$) to bone-in and boneless strip loin samples for tenderness and similar ($P > 0.05$) to boneless strip loins for overall liking ratings.

Consumers were also asked to rate palatability traits as either acceptable or unacceptable as they were evaluating each sample (Table 3). No ($P > 0.05$) interactions were found between quality grade and cut/bone state. Choice steaks had a higher ($P < 0.05$) percentage of consumers who rated juiciness as acceptable when compared with Select steaks. But quality grade did not impact ($P > 0.05$) the percentage of samples rated acceptable by consumers for tenderness, flavor, and overall acceptability. Furthermore, bone state had no impact ($P > 0.05$) on the percentage of consumers that rated juiciness as acceptable for tenderloins and ribeyes, but in strip loins, bone-in steaks had a higher ($P < 0.05$) percentage of acceptable consumer responses than boneless cuts. The percentage of acceptable samples for tenderness and overall acceptability was not ($P > 0.05$) impacted by bone state in tenderloins and strip loins; however, in ribeyes, the percentage of acceptable consumer ratings was higher ($P < 0.05$) for bone-in cuts for both traits. Tenderloins had a higher ($P < 0.05$) percentage of acceptable ratings for tenderness than strip loins and ribeyes. Likewise, tenderloins also had a higher ($P < 0.05$) percentage of acceptable ratings for juiciness and overall acceptability when compared with boneless strip loins and boneless ribeyes. Strip loin and ribeye

Table 3. Least-squares means for consumer sensory panel ratings, percentage of samples rated acceptable, and perceived quality level for strip loin, tenderloin, and ribeye steaks of varying bone states and USDA quality grade[1]

Trait	Strip loin		Tenderloin		Ribeye		SEM[2]	P value	Choice	Select	SEM[2]	P value
	Bone-in	Boneless	Bone-in	Boneless	Bone-in	Boneless						
Palatability rating[3]												
Juiciness rating	58.5[bc]	51.1[d]	63.7[ab]	66.6[a]	57.2[cd]	52.7[cd]	2.5	< 0.01	66.7[a]	54.0[b]	1.8	< 0.01
Tenderness rating	53.1[bc]	49.7[c]	73.5[a]	78.4[a]	56.5[b]	51.2[bc]	2.6	< 0.01	64.9[a]	55.9[b]	1.9	< 0.01
Flavor rating	59.7[b]	55.6[b]	66.2[a]	64.7[a]	58.3[b]	56.0[b]	2.2	< 0.01	63.0[a]	57.1[b]	1.7	< 0.01
Overall like rating	60.0[b]	53.2[c]	69.0[a]	72.2[a]	58.2[bc]	54.5[c]	2.4	< 0.01	65.2[a]	57.2[b]	1.9	< 0.01
Acceptability rating[4]												
Juiciness acceptability	83.7[ab]	72.1[c]	87.5[a]	89.0[a]	81.7[ab]	76.1[bc]	0.04	< 0.01	87.3[a]	76.3[b]	0.03	< 0.01
Tenderness acceptability	77.3[bc]	74.2[c]	95.0[a]	96.9[a]	83.8[b]	70.1[c]	0.04	< 0.01	89.7	82.8	0.03	0.08
Flavor acceptability	86.1	79.2	87.2	85.6	82.9	79.1	0.03	0.20	85.4	81.7	0.02	0.20
Overall acceptability	84.6[abc]	78.1[cd]	91.2[a]	89.1[ab]	82.2[bc]	73.4[d]	0.04	< 0.01	86.7	80.7	0.03	0.08
Perceived quality level[5]												
Unsatisfactory	13.6[bc]	15.5[ab]	7.2[cd]	6.8[d]	15.0[b]	23.4[a]	0.04	< 0.01	9.9	16.0	0.03	0.07
Everyday	50.9[a]	55.8[a]	37.0[b]	34.2[b]	57.2[a]	47.4[a]	0.04	< 0.01	43.0	51.0	0.03	0.09
Better than everyday	28.2[abc]	20.9[c]	31.6[ab]	33.8[a]	19.4[c]	23.6[bc]	0.04	0.02	31.0[a]	21.3[b]	0.03	0.02
Premium	4.5[b]	2.0[b]	21.4[a]	23.0[a]	6.4[b]	3.8[b]	0.04	< 0.01	9.5	5.3	0.02	0.10

[abcd]Least-squares means in the same section of the same row without a common superscript differ (P < 0.05).

[1]Quality grade: Choice = USDA Choice (upper 2/3) with marbling scores ranging from modest[00] to moderate[100]; Select = USDA Select with marbling scores ranging from slight[00] to slight[100].

[2]SEM (largest) of the least-squares means in the same section of the same row.

[3]Sensory scores: 0 = extremely dry/tough/extremely bland; 50 neither dry nor juicy/neither tough nor tender; 100 = extremely juicy/tender/extremely intense.

[4]Percentage of samples rated as acceptable (yes/no) by consumer sensory panelists.

[5]Percentage of samples classified at various quality levels by consumer sensory panelists.

steaks had similar (P > 0.05) percentages of acceptable juiciness ratings, except for boneless strip loin steaks, which was a lower (P < 0.05) percentage than either bone-in cut.

Additionally, consumer panelists were asked to identify the quality level at which they perceived each sample. Once again, there were no (P > 0.05) interactions observed between quality grade and cut/bone state. Likewise, no (P > 0.05) quality grade effects were observed for the percentage of steaks rated as unsatisfactory, everyday, and premium quality. However, a greater (P < 0.05) percentage of Choice samples were rated as better than everyday quality than Select. Moreover, bone state did not (P > 0.05) impact quality perception on strip loin and tenderloin samples. Bone state also did not (P > 0.05) impact premium, better than everyday, and everyday quality perceptions among ribeye steaks; but the percentage of consumers rating ribeye samples unsatisfactory was higher (P < 0.05) for boneless ribeye steaks. Fewer (P < 0.05) samples from tenderloins were perceived as unsatisfactory quality when compared with boneless strip loin and ribeye steaks. Likewise, a greater (P < 0.05) percentage of consumer ratings for tenderloin

samples were perceived as premium quality than either other cut.

Trained sensory evaluation

Overall, bone state had a minimal impact on palatability traits evaluated by trained sensory panelists (Table 4). There was an interaction (P < 0.05) between quality grade and cut/bone state (Table 5) for connective tissue amount. Within USDA Select cuts, bone-in strip loins had a greater (P < 0.05) amount of connective tissue than boneless cuts; however, there were no differences (P > 0.05) found between bone states for any other cut at either quality grade. For the main effect of quality grade, Choice steaks were rated higher (P < 0.05) than Select steaks for all other palatability traits evaluated. Bone state had no impact (P > 0.05) on initial juiciness, sustained juiciness, myofibrillar tenderness, overall tenderness, or off-flavor intensity in strip loin, tenderloin, and ribeye steaks. Other than strip loins, bone-in samples had a more (P < 0.05) intense beef flavor. Furthermore, tenderloin samples were rated higher (P < 0.05) for myofibrillar and overall

Table 4. Least-squares means for trained sensory panel ratings[1] for strip loin, tenderloin, and ribeye steaks of varying bone states and USDA quality grades[2]

Trait	Strip loin		Tenderloin		Ribeye		SEM[3]	P value	Choice	Select	SEM[3]	P value
	Bone-in	Boneless	Bone-in	Boneless	Bone-in	Boneless						
Initial juiciness	60.6	59.0	56.2	55.7	58.0	56.4	1.4	0.06	60.5[a]	54.8[b]	0.8	< 0.01
Sustained juiciness	55.0	53.8	51.3	50.9	52.4	51.2	1.6	0.24	55.6[a]	49.2[b]	0.9	< 0.01
Myofibrillar tenderness	63.2[b]	63.7[b]	85.9[a]	85.1[a]	63.1[b]	61.9[b]	1.6	< 0.01	73.3[a]	67.7[b]	1.1	< 0.01
Overall tenderness	59.7[b]	61.2[b]	85.2[a]	83.9[a]	60.5[b]	59.0[b]	1.8	< 0.01	71.4[a]	65.1[b]	1.6	< 0.01
Beef flavor intensity	37.3[ab]	37.5[a]	37.1[ab]	34.6[c]	37.8[a]	35.8[bc]	0.9	< 0.01	38.1[a]	35.2[b]	0.6	< 0.01
Off-flavor intensity	0.0	0.1	0.0	0.0	0.2	0.0	1.0	0.55	0.04	0.05	0.1	0.85

[abc]Least-squares means in the same section of the same row without a common superscript differ (P < 0.05).

[1]Sensory scores: 0 = extremely dry/tough/extremely bland/no off-flavor; 50 neither dry nor juicy/neither tough nor tender; 100 = extremely juicy/tender/extremely intense.

[2]Quality grade: Choice = USDA Choice (upper 2/3) with marbling scores ranging from modest[00] to moderate[100]; Select = USDA Select with marbling scores ranging from slight[00] to slight[100].

[3]SEM (largest) of the least-squares means in the same section of the same row.

Table 5. Least-squares means for the interaction of bone state within each cut and USDA quality grade[1] for fat and moisture percentages and connective tissue amount of beef strip loin, tenderloin, and ribeye steaks

Trait	Choice						Select						SEM[2]	P value
	Strip loin		Tenderloin		Ribeye		Strip loin		Tenderloin		Ribeye			
	Bone-in	Boneless	Bone-in	Boneless	Bone-in	Boneless	Bone-in	Boneless	Bone-in	Boneless	Bone-in	Boneless		
Fat percentage (%)	10.7[ab]	9.3[bc]	10.6[ab]	9.9[ab]	10.3[ab]	11.3[a]	4.4[e]	5.1[de]	6.3[d]	8.4[c]	4.8[de]	5.1[de]	0.7	< 0.01
Moisture percentage (%)	66.4[f]	67.9[def]	68.1[de]	68.9[cd]	68.1[de]	66.8[ef]	72.1[a]	71.7[ab]	71.1[ab]	70.2[bc]	71.9[a]	71.5[ab]	0.4	< 0.01
Connective tissue amount[3]	6.0[bc]	4.7[c]	1.1[d]	1.3[d]	5.8[bc]	5.6[c]	10.9[a]	6.7[bc]	1.3[d]	1.3[d]	7.4[bc]	8.6[ab]	1.5	0.04

[abcdef]Least-squares means within the same row without a common superscript differ (P < 0.05).

[1]Quality grade: Choice = USDA Choice (upper 2/3) with marbling scores ranging from modest[00] to moderate[100]; Select = USDA Select with marbling scores ranging from slight[00] to slight[100].

[2]SEM (largest) of the least-squares means within the same row.

[3]Trained sensory rating for connective tissue amount: 0 = none; 100 = extremely abundant.

tenderness than strip loin and ribeye steaks. Strip loin and ribeye samples were similar (P > 0.05) for all traits evaluated other than beef flavor intensity.

Warner-Bratzler shear force, cooking characteristics, and moisture and fat analyses

The main effects of quality grade and cut/bone are reported in Table 6 for WBSF and cooking characteristics. When evaluating WBSF, Choice steaks were more (P < 0.05) tender than Select samples. Bone state did not (P > 0.05) have an impact on shear force values within any of the cuts. However, tenderloin steaks had lower (P < 0.05) shear force values than strip loin and ribeye samples. Strip loin and ribeye steaks had similar (P > 0.05) WBSF values.

When evaluating cooking characteristics between quality grades, cooking time did not differ (P > 0.05). However, Select steaks were higher (P < 0.05) yielding and had a greater (P < 0.05) cooking loss percentage than Choice samples. Bone state also had an impact (P < 0.05) on cooking time, yield, and cooking loss of strip loin, tenderloin, and ribeye samples. Bone-in strip loin, tenderloin, and ribeye steaks had a longer (P < 0.05) cooking time than all boneless steaks, with all 3 bone-in steaks taking a similar (P > 0.05) length of time to cook. Similarly, boneless strip loin and boneless ribeye steaks also had similar (P > 0.05) cooking times, which were longer (P < 0.05) than boneless tenderloin steaks. Furthermore, when evaluating cooking yield, in strip loin, tenderloin, and ribeye steaks, boneless samples had a higher (P < 0.05) percentage of

Table 6. Least-squares means for Warner-Bratzler Shear Force (WBSF) and cooking characteristics of strip loin, tenderloin, and ribeye steaks of varying bone states and USDA quality grades[1]

Trait	Strip loin		Tenderloin		Ribeye		SEM[3]	P value	Choice	Select	SEM[3]	P value
	Bone-in	Boneless	Bone-in	Boneless	Bone-in	Boneless						
Cooking time (s)	663.1[a]	502.6[b]	679.0[a]	334.6[c]	684.1[a]	532.2[b]	21.7	< 0.01	567.3	564.6	13.0	0.87
Yield (%)[3]	41.2[e]	54.5[c]	42.0[e]	67.6[a]	47.1[d]	60.3[b]	1.4	< 0.01	50.8[b]	53.4[a]	0.8	0.02
Cooking loss (%)[4]	14.9[d]	16.8[bc]	14.5[d]	20.0[a]	15.6[cd]	17.4[b]	0.5	< 0.01	16.0[b]	17.2[a]	0.4	0.02
Shear force (kgf)	3.7[a]	3.6[a]	2.7[b]	2.7[b]	3.8[a]	3.8[a]	0.1	< 0.01	3.1[b]	3.7[a]	0.1	< 0.01

[abcde]Least-squares means in the same section of the same row without a common superscript differ ($P < 0.05$).

[1]Quality grade: Choice = USDA Choice (upper 2/3) with marbling scores ranging from modest[00] to moderate[100]; Select = USDA Select with marbling scores ranging from slight[00] to slight[100].

[2]SEM (largest) of the least-squares means in the same section of the same row.

[3]Cooking yield percentage = [(cooked weight − inedible weight)/raw weight] × 100.

[4]Cooking loss percentage = [(raw weight − cooked weight)/raw weight] × 100.

edible lean when compared with bone-in steaks. Moreover, boneless steaks had a greater ($P < 0.05$) amount of cooking loss than bone-in cuts for all 3 cuts. Boneless tenderloins yielded the most ($P < 0.05$) edible lean and had the greatest ($P < 0.05$) cooking loss when compared with strip loin and ribeye steaks of both bone states. Boneless ribeyes were higher ($P < 0.05$) yielding than strip loin samples but similar ($P > 0.05$) in cooking loss to boneless strip loin samples. Alternatively, bone-in tenderloin and strip loin steaks were the lowest ($P < 0.05$) yielding cuts.

There was a significant ($P < 0.05$) interaction between quality grade and cut/bone state for moisture and fat percentages (Table 5). As expected, all Choice samples from each cut/bone state had a greater ($P < 0.05$) fat percentage than Select samples of the same cut/bone state. Bone state only impacted fat percentage in Select tenderloin steaks, with boneless steaks having a greater ($P < 0.05$) amount of fat than bone-in steaks. For all other cuts, there was no difference ($P < 0.05$) in fat percentage between the bone states at either quality grade. Similarly, the moisture percentage did not differ ($P > 0.05$) between bone states for each cut at each quality grade. As expected, the moisture content was higher ($P < 0.05$) for the Select samples of each cut/bone state than the Choice samples, though boneless Choice tenderloins had a similar ($P > 0.05$) moisture percentage as boneless Select tenderloin samples.

Discussion

Consumer demographics and purchasing motivators

About two-thirds of consumers in our study were male, whereas the ratio of male to female consumers

in studies conducted by Drey et al. (2019), Olson et al. (2019), Prill et al. (2019a), and Davis et al. (2021), all at KSU, was split closer to half and half. Most consumers consumed beef 1 to 3 times a week, similar to findings also found by Drey et al. (2019), Olson et al. (2019), and Prill et al. (2019a). The preferred degree of doneness by most consumers was medium rare, which is slightly more rare than the degree of doneness steaks were cooked to in this study. These findings are consistent with results reported by Nyquist et al. (2018), Drey et al. (2019), Olson et al. (2019), Beyer et al. (2021), and Prill et al. (2019b), which also found that a majority of consumers preferred medium rare beef steaks.

Purchasing motivator data provide insight into how consumers prioritize beef steak characteristics when selecting meat at retail. Previous beef palatability studies have determined that color, price, and size are the most important purchasing motivators for consumers (Lucherk et al., 2016; Vierck et al., 2018; Olson et al., 2019). Consumers in our study also found steak color to be of equal importance to price. Size, degree of marbling, quality grade, and familiarity with cut were also highly important to consumers in this study when selecting fresh beef steaks to purchase at retail.

Effect of bone state on palatability

Previous research evaluating the impact of bone state on beef eating quality is limited and has produced inconsistent results. Our study found that bone state had no impact on consumer ratings for tenderness, flavor, juiciness, and overall liking in tenderloin and ribeye steaks. However, in the strip loin, bone-in steaks were rated 7.4% higher for juiciness and 6.8% higher for overall liking. Similarly, DeGeer et al. (2009), McCullough (2013), and Lepper-Blilie et al. (2016) have noted that there are no detectable palatability

differences among bone-in and boneless steaks of the same quality grade. However, other studies have found that bone-in samples are juicier and more flavorful than boneless steaks (Jeremiah et al., 2003; Voges et al., 2007). Conversely, Igo et al. (2015) found that boneless strip loin steaks were rated 1% higher for juiciness and 0.9% higher for overall liking than bone-in steaks, which differs from our and many previous study results. In their study, boneless strip loin steaks were also rated higher for tenderness and flavor than bone-in steaks (Igo et al., 2015). The small magnitude of difference observed between bone states by Igo et al. (2015) may be due to their much larger sample size, differing project objectives, and study design that included an unbalanced number of samples from USDA Prime, Choice, Select, and ungraded quality grades. Most of the other previously discussed studies only evaluated a single quality grade and did not have the primary study objective of evaluating the impact of bone state on beef palatability. Thus, results from these studies are often confounded by insufficient replication or study design components to draw meaningful conclusions.

No previous studies have collected acceptability data for bone-in versus boneless steaks. In our study, bone state had no impact on the percentage of steaks rated acceptable by consumers for tenderloins. Results did indicate that bone-in strip loin and ribeye steaks provided consumers in our study with a more acceptable eating experience for some traits despite palatability ratings showing minimal differences between the bone states. Despite bone-in ribeye samples having close to 10% more consumers deeming them acceptable overall, boneless steaks still had over 73% of consumers rating them as acceptable, indicating that bone-in and boneless steaks both provide a highly acceptable eating experience for consumers.

Studies comparing bone-in and boneless cuts via trained sensory analysis have produced mixed results as well. Studies conducted by DeGeer et al. (2009) and Lepper-Blilie et al. (2016) found no palatability differences between bone-in and boneless strip loins. McCullough (2013) utilized trained sensory analysis to evaluate specific palatability attributes in strip loin, ribeye, and tenderloin steaks of varying aging periods. Their study revealed no differences in beef flavor among differing bone states and cuts (McCullough, 2013). However, they found bone-in tenderloin and ribeye steaks aged for 21 d were rated higher for initial juiciness, first impression tenderness, and overall tenderness than boneless alternatives (McCullough, 2013). This result was not mirrored in tenderloin or

ribeye steaks aged for 28 d. In this case, bone-in tenderloin steaks were rated lower for initial and sustained juiciness, whereas bone-in ribeye steaks were rated lower for just initial juiciness (McCullough, 2013). The magnitude of difference between each of these traits reported was less than 1%, indicating that inherent variability between the samples may have contributed to the observed differences. McCullough (2013) concluded that overall palatability differences between bone-in and boneless samples were minimal, which is consistent with our study. We found that bone state had no impact on initial juiciness, sustained juiciness, myofibrillar tenderness, overall tenderness, or off-flavor intensity for any of the cuts evaluated. However, when evaluating beef flavor, bone-in tenderloin and ribeye steaks were more flavorful than their boneless counterparts, though Guelker et al. (2013) found boneless ribeye steaks to be more flavorful than bone-in. Other than the McCullough (2013) study and similar to the studies that have utilized consumers, none of the other studies discussed had the objective to evaluate the impact of bone state on beef palatability and should be considered within the context of this limitation.

Effect of cut on palatability

Muscles within a beef carcass vary in palatability based on muscle function and anatomical location. Typically, steaks from the beef rib and loin are more tender and desirable in terms of eating quality (Belew et al., 2003; Calkins and Sullivan, 2007; Jung et al., 2016) and is why we chose to evaluate strip loin, tenderloin, and ribeye steaks in the current study. Our study found that untrained and trained sensory panelists rated tenderloin steaks higher for sensory attributes than strip loin and ribeye steaks, whereas strip loin and ribeyes were also consistently rated similar. McKeith et al. (1985) reported similar results. In their study, tenderloin samples were also rated highest for tenderness and flavor, whereas strip loin and ribeye steaks were rated similar (McKeith et al., 1985). However, different from our findings, tenderloin samples were similar in juiciness to strip loin and ribeye steaks (McKeith et al., 1985). Similarly, Shackelford et al. (1995) found that tenderloin samples evaluated by trained sensory panelists were rated higher for overall tenderness when compared with steaks from the *m. longissimus dorsi*. Moreover, Shackelford et al. (1995) reported that flavor ratings for tenderloin samples were the lowest when compared with other muscles from the chuck, loin, and round. However, this study did not compare all 3 beefs cuts that were utilized in the present

study. Overall, tenderloin steaks have repeatedly been shown to offer one of the most tender and palatable eating experiences, which is consistent with the current results.

Effect of quality grade on palatability

It has been well documented that quality grade or degree of marbling has a large impact on the palatability of beef (Smith et al., 1984; Smith et al., 1987; O'Quinn et al., 2012; Emerson et al., 2013; Lucherk et al., 2016; O'Quinn et al., 2018; Drey et al., 2019). Many studies have shown a positive linear relationship between quality grade and sensory analysis ratings (Smith et al., 1984; Emerson et al., 2013; O'Quinn et al., 2018). Our results are consistent with these studies. Consumers rated USDA Choice samples higher for juiciness, tenderness, and flavor, and 11% more consumers rated juiciness as acceptable when compared with Select steaks, though quality grade did not impact the percentage of samples rated acceptable for tenderness, flavor, and overall acceptability. It is worth noting that consumers in this study found the majority (> 73%) of samples of all cuts, bone states, and quality grades acceptable for these same traits, likely contributing to the lack of observed difference between Choice and Select samples. Smith et al. (1984) reported similar findings in a study evaluating palatability of top loin steaks. They concluded that differences in palatability were not always significant between consecutive marbling scores, though trends across a larger range are often present (Smith et al., 1984). Our results from trained sensory analysis were also in line with previous findings, with Choice steaks rated higher for all palatability traits when compared with Select steaks.

Warner-Bratzler shear force

WBSF, an objective measurement of tenderness, can be influenced by a variety of factors. In our case, we found that bone state did not impact shear force values for strip loin, tenderloin, or ribeye steaks. McCullough (2013) found shear force values of strip loin and ribeye steaks aged 28 d to be about 1% lower than in our study. This nuance can be explained by the fact McCullough (2013) only evaluated steaks of the USDA Choice quality grade, whereas we evaluated both Choice and Select. The only difference in WBSF McCullough (2013) observed was between bone-in and boneless ribeye steaks aged for 14 d. In this case, boneless steaks had lower shear force values than bone-in alternatives (McCullough, 2013).

Consistent with our sensory findings, tenderloin steaks had lower shear force values than strip loin and ribeye steaks. Belew et al. (2003) found similar WBSF values for strip loin, tenderloin, and ribeye steaks, as were reported in the current work. However, they found all 3 cuts to be similar in shear force values (Belew et al., 2003).

Numerous previous studies have shown that lower shear force values are associated with higher quality grades or degrees of marbling (Gruber et al., 2006; Emerson et al., 2013; Guelker et al., 2013; Nyquist et al., 2018). Our results also showed that Choice steaks had lower shear force values than Select samples, providing further evidence that Choice steaks from the middle meats are more tender than Select cuts.

Cooking characteristics

When evaluating cooking time of steaks within our study, quality grade did not have a significant effect. Bone-in steaks, however, were found to have a longer cooking time due to the presence of bone. Interestingly, bone-in tenderloins took the longest to cook, despite their smaller size in comparison with both ribeyes and strip loins; whereas boneless tenderloins cooked the fastest, likely for the same reason. Perhaps no data in the study better illustrate the impact of bone state on cooking than this difference within tenderloins.

As previously mentioned, all exterior fat and bone was removed from samples, and cooking yield (edible lean) was measured. Our results showed that Select steaks were higher yielding than Choice steaks. This can be explained by differences in carcass characteristics (Farmer, 2022). Select steaks used in this study had a larger ribeye area and lower adjusted preliminary yield grade than Choice steaks and thus contained a greater amount of muscle on a per cut basis. Despite being trimmed to a similar external trim level prior to cooking, some fat differences may have been present between the grades. This combined with the muscling difference likely explains the observed difference in cooking yield between the 2 grades in this study.

Bone-in steaks were lower yielding than boneless steaks due to the weight of the bone. Boneless cuts were 13.3%, 25.6%, and 13.2% higher yielding than bone-in cuts for strip loin, tenderloin, and ribeye steaks, respectively. To no surprise, the smaller size of the tenderloin steaks in relation to the bone weight had a noticeable impact on the edible yield of these cuts. However, boneless tenderloin steaks had the greatest yield percentage of all cuts evaluated, likely due to the lack of external fat of this cut in comparison with both strip loin and

ribeye steaks. These yield differences are critical to understand for both consumers and meat purveyors when purchasing and selling bone-in beef cuts. In food-service, this difference in yield is often passed along to the consumer in the form of increased premiums placed on bone-in cuts (Bass, 2018). Similarly, consumers purchasing bone-in cuts at retail at discounted prices should also consider the impact of this yield loss when comparing bone-in and boneless cuts.

Results from cooking loss calculations largely mirrored findings of cooking yield. Select steaks had a higher cooking loss than Choice steaks. This difference is attributed to Select steaks losing more moisture throughout the cooking process, as has been demonstrated by previous studies (Drey et al., 2019). Moreover, boneless steaks had a higher cooking loss than bone-in steaks. This is likely due to the bones in these cuts not losing moisture at the same rate through cooking as the muscle tissue and thus disproportionally impacting the weight that remains in the cooked form for these steaks. In our study, tenderloin steaks also had the greatest cooking loss. The percentage of weight lost through cooking in boneless tenderloin steaks in our study was similar to findings by O'Quinn et al. (2015), and the cooking loss of boneless strip loin and ribeye steaks was also similar to values reported by DeGeer et al. (2009). Alternatively, Yancey et al. (2011) reported cooking loss values for the *m. longissimus dorsi* that were close to 10% higher than steaks in our study. This difference could be attributed to the different cooking methodologies used and the fact that only USDA Select steaks were used by Yancey et al. (2011).

Conclusions

Overall, bone state had a minimal impact on beef palatability factors in this study. USDA Choice and tenderloin steaks were shown to be more palatable than lower quality grades and other cuts of beef. As the popularity of bone-in beef cuts rises across the U.S. food-service and retail industries, consumers and meat purveyors should be mindful of the impact of bone state on beef palatability, yield, and cooking characteristics of these products. Our results show that though differences exist between bone states for cooking traits, eating quality is only minimally impacted. Thus, consumers can receive a similar eating experience at a restaurant from an often lower-priced boneless steak as opposed to a bone-in alternative, which is often marketed at a premium price.

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