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Evaluation of Beef Top Sirloin Steaks of Four Quality Grades Cooked to Three Degrees of Doneness[1]

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Abstract: The objective of this study was to evaluate the impact of USDA quality grade on beef eating quality of top sirloin steaks when cooked to multiple degrees of doneness (DOD). Beef top sirloin butts ($N = 60$; 15/quality grade) were collected to equally represent 4 quality grades [Prime, Top Choice (modest^{00} to moderate^{100}), Low Choice, and Select]. Steaks were assigned to 1 of 3 DOD: rare (60°C), medium (71°C), and well-done (77°C). Steaks were allocated to either consumer sensory analysis, trained sensory analysis, fat and moisture analysis, or Warner-Bratzler shear force (WBSF). There were no interactions ($P > 0.05$) for all consumer ratings of palatability traits, indicating increases in DOD had the same impact across all quality grades. Prime steaks had greater ($P < 0.05$) juiciness ratings than all other quality grades, except for Top Choice. As DOD increased, consumer ratings and the percentage of steaks rated acceptable for each palatability trait decreased ($P < 0.05$; rare > medium > well-done). There was a quality grade × DOD interaction ($P < 0.05$) for trained sensory panel juiciness scores. When cooked to medium, Prime and Top Choice steaks were rated higher ($P < 0.05$) for juiciness than Low Choice and Select steaks, while there were no differences at all other DOD. Similar to consumer ratings, trained panel ratings of tenderness decreased ($P < 0.05$) as DOD increased (rare > medium > well-done). Lastly, there was no quality grade by DOD interaction ($P > 0.05$) for Warner-Bratzler shear force. These results indicate that regardless of the DOD top sirloin steaks are cooked to, quality grade had minimal impact on palatability. Therefore, it is unnecessary for consumers, retailers, and foodservice to pay premium prices for higher quality top sirloin steaks, as the same eating experience will be provided.

Keywords: beef, consumer, degree of doneness, marbling, palatability, top sirloin steak
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Introduction

Top sirloin steaks are one of the most common steaks ordered in restaurants (Schmidt et al., 2002). Foodservice establishments commonly offer these steaks as a less expensive alternative to more expensive cuts, such as strip steaks, ribeyes, and tenderloins (USDA, 2019a, 2019b). This price advantage is because this cut is typically tougher, with more inconsistent palatability characteristics compared to other middle meats (Morgan et al., 1991; Neely et al., 1998).

Previous research has demonstrated degree of doneness (DOD) plays a key role in steak palatability (Parrish et al., 1973; Smith et al., 1985) and has shown beef sensory traits decrease as endpoint temperature increases (Cross et al., 1976; Smith et al., 1985; Luchak et al., 1998). One strategy to compensate for decreased palatability at increased endpoint temperatures is the use of cuts with higher degrees of marbling. Multiple studies have demonstrated that within the *M. longissimus lumborum* (LL), as DOD increases, elevated marbling compensates for the decreased palatability associated with elevated DOD (Lucherk et al., 2016; Drey et al., 2019). This compensation for decreased palatability at elevated

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DOD is termed the "insurance theory", as marbling provides "insurance" for steaks cooked to increased temperatures to maintain an acceptable level of eating quality (Smith and Carpenter, 1974; Savell and Cross, 1988).

Several previous studies have evaluated the palatability characteristics of top sirloin steaks (Harris et al., 1992; Brooks et al., 2000; Lorenzen et al., 2003; Legako et al., 2015), but to date, these studies have only evaluated top sirloin steaks of differing marbling levels at a single DOD, rather than across multiple DOD. Moreover, studies that have utilized more than 1 DOD, have typically included only a single marbling category. Thus, it is unclear if marbling can provide the same protection to the palatability of top sirloin steaks cooked to higher DOD as has been documented in more tender cuts, such as the LL. Therefore, the objective of this study was to evaluate the impact of marbling level on the eating quality of top sirloin steaks when cooked to multiple DOD.

Materials and Methods

The Kansas State University (KSU) Institutional Review Board approved all procedures for use of human subjects in sensory panel evaluations (IRB #7440.5, September 2018)

Sample collection and steak fabrication

Beef top sirloin butts (N = 60; 15/quality grade; Institutional Meat Purchasing Specifications #184; North American Meat Institute, 2014) were collected to equally represent 4 quality grades (Prime [slightly abundant^{00} to abundant^{100} marbling], Top Choice [modest^{00} to moderate^{100} marbling], Low Choice [small^{00} to small^{100} marbling], and Select [slight^{00} to slight^{100} marbling]) from a commercial Midwestern beef processor (USDA, 2017). Kansas State University research team members selected carcasses prior to fabrication and collected carcass yield and quality grade information (data reported by Olson, 2019). Following subprimal fabrication on Day 2 postmortem, top sirloin butts were vacuum packaged and transported under refrigeration (2 to 4°C) to the KSU Meat Laboratory (Manhattan, KS) for fabrication. At approximately 4 d postmortem, the *M. biceps femoris*, *M. gluteus accessorius*, and *M. gluteus profundus* were removed and top sirloin butts leaving only the *M. gluteus medius* for all analyses. Top butts were then were fabricated into 2.54-cm thick steaks from posterior to anterior using a horizontal slicer (Model Puma 700F, Treif, Oberlahr, Germany). From each top sirloin butt, 6 consecutive steaks were cut and randomly assigned to testing procedures. Steaks designated for sensory evaluation were randomly assigned to 1 of 3 DOD: rare (60°C), medium (71°C), and well-done (77°C). Sensory steaks were then divided in half laterally with one-half of each steak being assigned to either consumer sensory testing or trained sensory testing. The remaining 3 steaks were divided in half laterally and each of the 6 pieces were randomly assigned to either Warner-Bratzler shear force (WBSF) testing at 1 of the 3 DOD, fat and moisture analyses, or were designated as extra. Finally, steaks were given a randomized 4-digit number for identification, vacuum-packaged, stored at 2 to 4°C, and aged for 28 d postmortem to be consistent with aging times commonly used for top sirloin steaks (Martinez et al., 2017). Following aging, steaks were frozen (–40°C) until further analysis.

Consumer sensory panel evaluation

Panelists (N = 236) were recruited from Manhattan, KS and the surrounding areas, and monetarily compensated for their time at the end of each panel. Panels were conducted at the KSU Meat Science Sensory Laboratory, with 8 panelists fed per session. Each panelist was placed in an individual sensory booth, and 6 samples were served under low intensity (<107.64 lumens) red incandescent lighting to remove DOD bias among samples. Panelists were provided with napkins, toothpicks, an expectorant cup, plastic fork, and apple juice, unsalted crackers, and water to use as palate cleansers between samples. Before evaluation, panelists were given verbal directions to explain the use of palate cleansers, evaluation procedures, and the digital survey.

Steaks evaluated were thawed for 24 h prior to panels at 2 to 4°C. Prior to cooking, a raw weight was taken for each steak. Steaks were cooked on a clamshell grill (Cuisinart Griddler Deluxe, East Windsor, NJ) to 1 of the 3 preassigned DOD (rare [60°C], medium [71°C], or well-done [77°C]). Internal temperatures were monitored using a probe thermometer (Thermapen Mk4, ThermoWorks, American Fork, UT). Steaks were removed from the grill approximately 5- 6°C below their assigned DOD temperature to allow for the steaks to rise to their assigned DOD. Peak temperatures were recorded, and steaks were weighed for cooked weight to be used in cooking loss calculations. Average steak cooked temperatures were 60.7°C for rare, 71.2°C for medium and 76.9°C for well-done steaks, with a standard error of 0.2°C. Steaks were then cut into 2.5-cm thick × 1-cm × 1-cm cuboids, and 2 pieces were served immediately to consumers.

Panelists were given an electronic tablet (Model 5709 HP Steam 7; Hewlett-Packard, Palo Alto, CA) with a digital survey generated using Qualtrics Survey Software (Version 2417833; Provo, UT). Each survey contained a demographic questionnaire, a purchasing motivator page, and 6 sample ballots. Consumers were asked to evaluate each sample for tenderness, juiciness, flavor, and overall like on 0 to 100 continuous line scales. Anchors were set at 0 and 100, with 0 anchored as extremely tough, extremely dry, and dislike extremely. At 100, anchors were extremely tender, extremely juicy, and like extremely. An additional neutral anchor was labeled at the 50-midpoint of the lines as neither tough nor tender, neither dry nor juicy, and neither dislike or like. Lastly, panelists were asked to rate each trait evaluated as either unacceptable or acceptable (yes/no), as well as to classify each sample as 1 of 4 levels of quality: unsatisfactory, everyday quality, better than everyday quality, or premium quality. No additional information was provided to the consumers related to the definitions of the quality levels to allow for the consumers' own interpretations of these terms related to their normal eating experiences. Consumers evaluated 6 samples that represented differences in quality grade and DOD. Sensory panels were designed as an unbalanced incomplete block design so every quality treatment × DOD combination were compared in the same panel session as close to an equal number of times as possible across all consumer panel sessions.

Trained sensory panel evaluation

Trained sensory panelists were trained according to the American Meat Science Association (AMSA) sensory guidelines (AMSA, 2016). Panelists were trained at 6 training sessions in the week prior to the start of panels, with the anchors and training methods used similar to those described by Lucherk et al. (2016) and Vierck et al. (2018). A total of 30 panels were conducted with 6 samples fed in each panel, with 8 panelists served during each panel session. Trained panelists were served samples representing the same combinations of quality grade and DOD as were served to the consumer panelists. All scales were anchored at both ends and midpoints with descriptive terms. Panelists evaluated samples on 0 to 100 continuous line scales for initial and sustained juiciness, myofibrillar tenderness, connective tissue amount, overall tenderness, beef flavor intensity, and off flavor intensity. Anchors set at 0 were labeled as extremely dry, extremely tough, none, and extremely bland. Midpoint anchors were labeled as neutral points of neither juicy nor dry, and neither tough nor tender. At 100, anchors were labeled as extremely juicy, extremely tender, abundant, and extremely intense. Additionally, a "not applicable" box was available for samples where no off-flavor was detected. Steaks were cooked using the procedures previously described for consumer sensory evaluation to 1 of the 3 pre-assigned DOD. Panelists were served in individual sensory booths under low-intensity (<107.64 lumens), red incandescent lights. During each session, panelists were given an electronic tablet (Model 5709 HP Steam 7) with the survey ballot, deionized water, apple slices, and unsalted crackers for palate cleansers, as well as an expectorant cup and napkins.

Warner-Bratzler shear force

Warner-Bratzler shear force analysis was completed using the protocol described by AMSA Meat Cookery and Sensory Guidelines (AMSA, 2016). In brief, 6 cores (1.27-cm diameter) from each cooked steak were taken parallel to the muscle fiber orientation and sheared perpendicular to the muscle fiber orientation using an Instron testing machine (model 5569, Instron Corp., Canton, MA) with a cross-head speed of 250 mm/min and a load cell of 100 kg. Measurements were averaged across all 6 cores per steak and recorded as the average peak force (kg).

Moisture and fat analysis

Steaks designated for moisture and fat analyses were thawed 24 h prior to homogenization, trimmed of external fat, diced, and frozen in liquid nitrogen. Samples were homogenized using a Waring Blender (Waring Products Division; Hartford, CT), and stored at –80°C until further analysis. The percentage of intramuscular fat was determined through a modified chloroform:methanol extraction method described by Folch et al. (1957). The percentage of moisture was determined through the AOAC approved oven-drying method (950.46 and 934.01; AOAC, 1995). Both fat and moisture analysis samples were performed in duplicates.

Statistical analysis

Statistical analysis was completed using SAS (Version 9.4; SAS Inst. Inc., Cary, NC) PROC GLIMMIX, with treatment comparisons considered significant with an α of 0.05. Fat and moisture data were analyzed as a completely randomized design using a model with the fixed effect of quality grade. For sensory panel, cooking loss, and WBSF data, data were analyzed as a split-plot, with a whole-plot factor of quality grade, and sub-plot factor of DOD. Statistical analyses were performed using top

sirloin butt as the whole-plot experimental unit and steak as the sub-plot experimental unit. For sensory data, panel was included in the model as a random effect. The PDIFF option was used to compare treatment means when the overall *P*-value on the main effect or effect interaction was significant. For all significant interactions, the SLICE option was used to restrict the comparisons among quality grades to within a single DOD. Additionally, PROC FREQ was used for summarizing demographic data. All consumer panel acceptability data were analyzed with a model that included a binomial error distribution. The Kenward-Roger adjustment was used in all analyses to estimate denominator degrees of freedom.

Results

Consumer panel demographics and purchasing motivators

Table 1 presents the demographic profile of the 236 consumers who participated in the consumer sensory panels. Participants were primarily Caucasian/white (84.8%) and consisted of an almost equal number of males (49.6%) and females (50.4%). Over half of the participants were married (56.4%), with 23.7% of consumers having a household size of 2 people. Additionally, most (31.8%) of the panelists who participated had completed some college/technical school or were college graduates (32.2%). When asked what palatability trait was most important when eating beef, consumers rated flavor most important (51.7%), followed by tenderness (32.6%), and juiciness (15.7%). Medium-rare was the most preferred degree of doneness (42.4%), and almost one-half (47.5%) of consumers ate beef 1 to 3 times a week.

When asked to rate the importance of a series of 15 purchasing motivators for fresh beef steaks, consumers rated "price", "size, weight, and thickness", "marbling level", "steak color", and "USDA grade" similar ($P > 0.05$) in importance, but these factors were more important ($P < 0.05$) than all other traits except "familiarity with cut" (Table 2). "Antibiotic use in the animal" was similar in importance to "hormone use in the animal", but more important ($P < 0.05$) to consumers than "animal fed a grass-based diet", "animal fed a corn-based diet", "natural/organic claims", "brand of product", and "packaging type." Additionally, "hormone use in the animal" was more important ($P < 0.05$) to consumers than "natural or organic claims", "brand of product", and "packaging type".

Table 1. Demographic characteristics of consumers ($N = 236$) who participated in consumer sensory panels

Characteristic	Response	Percentage of consumers
Gender	Male	49.6
	Female	50.4
Household size	1 person	8.9
	2 people	23.7
	3 people	20.3
	4 people	21.2
	5 people	14.8
	6 people	6.4
	> 6 people	4.7
Marital status	Married	56.4
	Single	43.6
Age	Under 20	8.5
	20 to 29	27.7
	30 to 39	25.9
	40 to 49	15.7
	50 to 59	10.2
	Over 60	12.3
Ethnic origin	African-American	3.4
	Asian	3.4
	Caucasian/White	84.8
	Hispanic	2.1
	Mixed Race	3.8
	Native American	0.4
	Other	2.1
Income	Under $25,000	12.7
	$25,000 to $34,999	4.2
	$35,000 to $49,999	7.6
	$50,000 to $74,999	21.6
	$75,000 to $99,999	16.9
	$100,000 to $149,999	23.7
	$150,000 to $199,999	7.6
	> $199,999	5.5
Education level	Non-high school graduate	2.1
	High school graduate	7.2
	Some college/technical school	31.8
	College graduate	32.2
	Post college graduate	26.7
Most important palatability trait	Tenderness	32.6
	Juiciness	15.7
	Flavor	51.7
Preferred degree of doneness	Rare	9.3
	Medium rare	42.4
	Medium	31.4
	Medium well	12.3
	Well-done	3.4
	Very well-done	1.3
Weekly beef consumption	1 to 3 times	47.5
	4 to 6 times	32.6
	7 or more times	19.9

Table 2. Fresh beef steak purchasing motivators[1] of consumers (N = 236) who participated in consumer sensory panels

Trait	Importance
Price	67.0[a]
Size, weight, and thickness	65.3[a]
Marbling level	63.7[ab]
Steak color	63.2[ab]
USDA grade	62.8[ab]
Familiarity with cut	59.6[b]
Nutrient content	54.5[c]
Animal welfare	54.4[c]
Eating satisfaction claims	52.2[c]
Antibiotic use in the animal	46.7[d]
Hormone use in the animal	43.5[de]
Animal fed a grass-based diet	40.2[ef]
Animal fed a corn-based diet	39.9[ef]
Natural or organic claims	37.7[f]
Brand of product	36.2[f]
Packaging type	35.7[f]
SEM[2]	1.8
P-value	< 0.01

[a–f]Least squares means without a common superscript differ ($P < 0.05$).

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

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

Table 3. Least squares means for consumer (N = 236) ratings[1] of palatability traits of top sirloin steaks from 4 quality grades and cooked to 3 degrees of doneness (DOD)

Treatment	Juiciness	Tenderness	Flavor	Overall like
Quality grade				
Prime	63.6[a]	60.4	59.7	60.2
Top Choice[2]	61.6[ab]	60.5	55.7	58.2
Low Choice	57.6[b]	59.7	55.1	56.4
Select	56.7[b]	56.5	54.1	54.3
SEM[3]	2.0	2.0	1.9	2.2
P-value	0.02	0.42	0.10	0.16
DOD				
Rare, 60°C	75.9[a]	71.5[a]	63.8[a]	67.2[a]
Medium, 71°C	58.1[b]	57.6[b]	56.1[b]	56.1[b]
Well-done, 77°C	45.6[c]	48.6[c]	48.5[c]	48.5[c]
SEM[3]	1.7	1.5	1.7	1.7
P-value	< 0.01	< 0.01	< 0.01	< 0.01
QG × DOD				
P-value	0.80	0.99	0.96	0.93

[a–c]Least squares means within the same main effect (quality grade or degree of doneness) without a common superscript differ ($P < 0.05$).

[1]Sensory scores: 0 = extremely dry/tough/dislike; 50 = neither dry nor juicy, neither tough nor tender, neither like nor dislike; 100 = extremely juicy/tender/like extremely.

[2]USDA marbling score of modest[00]– moderate[100].

[3]SE (largest) of the least square means.

Consumer sensory evaluation

There were no ($P > 0.05$) quality grade × DOD interactions for all consumer palatability ratings (Table 3). Across quality grades, no differences ($P > 0.05$) were found for consumer ratings of tenderness, flavor, and overall like, with all treatments varying by no more than 10%. However, Prime steaks were juicier ($P < 0.05$) than all other quality treatments, except for Top Choice. Top Choice, Low Choice, and Select steaks were all similar ($P > 0.05$) for consumer ratings of juiciness. As DOD increased, there was a concurrent decrease in sensory ratings ($P < 0.05$; rare > medium > well-done) for all traits, with steaks becoming dryer, tougher, and liked less overall with increased DOD.

No interactions ($P > 0.05$) were found for the percentage of steaks rated acceptable for juiciness, tenderness, flavor, and overall liking (Table 4). Also, no differences were observed ($P > 0.05$) among quality grades for the percentage of samples rated acceptable for all palatability traits evaluated, with all quality grades having more than 75% of samples rated acceptable for all traits and no 2 treatments differing by more than 10.1%. Consistent with consumer rating data, the percentage of steaks rated acceptable decreased as DOD increased ($P < 0.05$; rare > medium > well-done) for all palatability traits. The percentage of steaks rated acceptable for tenderness, juiciness, and flavor decreased by 28, 17.8, and 17.8%, respectively, as DOD increased from rare to well-done.

An interaction was present for the percentage of steaks rated as everyday quality (Table 5). Steaks cooked to rare and well-done presented no differences ($P > 0.05$) among quality grades for the percentage of samples rated as everyday quality. However, when cooked to medium, Top Choice steaks were perceived as everyday quality less often ($P < 0.05$) than both Low Choice and Select steaks. No interactions or quality grade effects ($P > 0.05$) were observed for the percentage of steaks perceived as unsatisfactory, better than everyday quality, and premium quality (Table 6). Within DOD, steaks cooked to rare (4.4%) had a lower ($P < 0.05$) percentage of samples rated as unsatisfactory than medium (14.8%) and well-done (22.3%), with a lower ($P < 0.05$) percentage of medium samples rated in this category than well-done. As DOD increased, the percentage of samples identified as better than everyday quality and premium quality decreased ($P < 0.05$; rare > medium > well-done).

Table 4. Percentage of top sirloin steaks of 4 quality grades cooked to 3 degrees of doneness (DOD) rated as acceptable for tenderness, juiciness, flavor, and overall liking by consumers ($N = 236$)

Treatment	Juiciness	Tenderness	Flavor	Overall like
Quality grade				
Prime	90.6	88.3	83.2	87.3
Top Choice[1]	87.0	86.0	77.5	80.0
Low Choice	87.4	88.0	80.4	83.9
Select	80.5	85.9	75.9	78.8
SEM[2]	3.5	2.7	3.4	3.2
P-value	0.10	0.86	0.35	0.13
DOD				
Rare, 60°C	96.1[a]	94.5[a]	86.7[a]	91.1[a]
Medium, 71°C	83.7[b]	83.7[b]	78.1[b]	80.3[b]
Well-done, 77°C	69.1[c]	77.7[c]	71.2[c]	72.6[c]
SEM[2]	2.8	2.3	2.5	2.5
P-value	< 0.01	< 0.01	< 0.01	< 0.01
QG × DOD				
P-value	0.54	0.52	0.06	0.80

[a–c]Least squares means within the same main effect (quality grade or degree of doneness) without a common superscript differ ($P < 0.05$).

[1]USDA marbling score of modest[00]– moderate[100].

[2]SE (largest) of the least square means.

Table 5. Interaction ($P = 0.01$) between quality grade and degree of doneness for the percentage of beef top sirloin steaks classified as everyday quality

Treatment	Everyday quality
Rare, 60°C	
Prime	30.8
Top Choice[1]	40.9
Low Choice	40.0
Select	39.3
SEM[2]	5.0
P-value	0.47
Medium, 71°C	
Prime	45.9[ab]
Top Choice	33.9[b]
Low Choice	56.3[a]
Select	56.5[a]
SEM[2]	5.1
P-value	0.01
Well-done, 77°C	
Prime	57.8
Top Choice[1]	57.4
Low Choice	63.7
Select	46.4
SEM[2]	5.1
P-value	0.12

[a,b]Least squares means within a degree of doneness without a common superscript differ ($P < 0.05$).

[1]USDA marbling score of modest[00]-moderate[100].

[2]SE (largest) of the least square means.

Trained sensory evaluation

There were quality grade × DOD interactions ($P < 0.05$; Table 7) for myofibrillar tenderness, initial juiciness, and sustained juiciness. When steaks were cooked to medium, Prime and Top Choice steaks had higher ($P < 0.05$) panelist ratings for initial and sustained juiciness than Low Choice and Select steaks. Low Choice and Select steaks were similar ($P > 0.05$) in juiciness, both initially and sustained, when cooked to a medium DOD. Similar to trained panelist ratings of juiciness, Prime and Top Choice steaks had higher ($P < 0.05$) ratings of myofibrillar tenderness than Select steaks. Prime and Top Choice steaks had similar ($P > 0.05$) ratings of myofibrillar tenderness when compared to Low Choice steaks. Moreover, Low Choice and Select steaks were similar ($P > 0.05$) in ratings of myofibrillar tenderness. For DOD, each successive increase in DOD resulted in a concurrent decrease ($P < 0.05$; rare > medium > well) in trained panelist ratings of myofibrillar tenderness, initial juiciness, and sustained juiciness. As DOD increased from rare to well-done, there was a 23.9, 45.7, and 51.7% decrease in ratings of myofibrillar tenderness, initial juiciness, and sustained juiciness, respectively (data not presented in tabular form).

Trained sensory panel ratings for all other sensory traits are shown in Table 8. There were no quality grade × DOD interactions ($P > 0.05$) for all other traits. Prime and Top Choice steaks had greater ($P < 0.05$) ratings of beef flavor intensity than Select steaks but were similar ($P > 0.05$) to Low Choice. There were no differences ($P > 0.05$) among quality grades for connective tissue amount, overall tenderness, and off flavor intensity with means varying by only 1, 4, and 0.7%, respectively, among all grades. Similar to consumer sensory ratings, as DOD increased, ratings of overall tenderness decreased ($P < 0.05$; rare > medium > well-done) with a 26.8% decrease in tenderness as steaks were cooked from rare to well-done. No differences ($P > 0.05$) were observed across DOD for connective tissue amount, beef flavor intensity, and off flavor intensity, with all DOD means differing by less than 2%.

Warner-Bratzler shear force, cook loss, and moisture and fat analyses

There were no quality grade × DOD interactions ($P > 0.05$) for WBSF (Table 9). Prime steaks had lower ($P < 0.05$) shear force values than Low Choice and Select steaks, but were similar ($P > 0.05$) to Top Choice. Additionally, Top Choice, Low Choice, and

Table 6. Percentage of beef top sirloin steaks of varying quality grades and degrees of doneness (DOD) identified as different perceived quality levels by consumer panelists ($N = 236$)

Treatment	Unsatisfactory	Better than everyday quality	Premium quality
Quality grade			
Prime	8.2	30.7	8.8
Top Choice[1]	13.9	25.1	8.9
Low Choice	10.6	24.6	6.2
Select	15.5	24.2	4.1
SEM[2]	3.1	2.9	2.0
P-value	0.21	0.33	0.15
DOD			
Rare, 60°C	4.4[c]	41.7[a]	13.8[a]
Medium, 71°C	14.8[b]	25.6[b]	7.0[b]
Well-done, 77°C	22.3[a]	15.1[c]	3.0[c]
SEM[2]	2.5	2.5	1.9
P-value	< 0.01	< 0.01	< 0.01
QG × DOD			
P-value	0.25	0.83	0.52

[a–c]Least squares means within the same main effect (quality grade or degree of doneness) without a common superscript differ ($P < 0.05$).

[1]USDA marbling score of modest[00]– moderate[100].

[2]SE (largest) of the least square means.

Table 7. Least squares means for the interaction ($P < 0.05$) between quality grade and degree of doneness for trained sensory panel ratings[1] of initial juiciness, sustained juiciness, and myofibrillar tenderness

Treatment	Myofibrillar tenderness	Initial juiciness	Sustained juiciness
Rare, 60°C			
Prime	76.0	75.1	70.9
Top Choice[2]	72.7	71.2	67.1
Low Choice	72.5	73.0	69.4
Select	74.7	74.7	69.8
SEM[3]	2.2	2.2	2.3
P-value	0.63	0.53	0.66
Medium, 71°C			
Prime	65.8[a]	52.5[a]	47.1[a]
Top Choice[2]	65.1[a]	55.3[a]	49.3[a]
Low Choice	60.6[ab]	44.4[b]	38.5[b]
Select	56.3[b]	42.3[b]	36.1[b]
SEM[3]	2.2	2.2	2.3
P-value	< 0.01	< 0.01	< 0.01
Well-done, 77°C			
Prime	58.4	42.6	36.7
Top Choice[2]	53.4	37.6	31.0
Low Choice	56.6	40.3	34.3
Select	56.7	38.9	31.9
SEM[3]	2.2	2.2	2.3
P-value	0.44	0.37	0.26

[a,b]Least squares means within the same section of the same column differ ($P < 0.05$).

[1]Sensory scores: 0 = extremely tough/dry; 50 = neither tough nor tender, neither dry nor juicy; 100 = extremely tender/juicy.

[2]USDA marbling score of modest[00]– moderate[100].

[3]SE (largest) of the least square means.

Select steaks all had similar ($P > 0.05$) WBSF values. Moreover, as DOD increased, WBSF concurrently increased ($P < 0.05$; well-done > medium > rare), with well-done steaks having WBSF values 0.8 kg tougher than rare steaks. For cooking loss, no differences ($P > 0.05$) were found among quality grades, with all treatments differing by less than 1%. However, as DOD increased, the percentage of cooking loss also increased ($P < 0.05$; well-done > medium > rare). There were no differences ($P > 0.05$) in fat percentage among Prime (9.0%), Top Choice (8.8%), and Low Choice (7.8%) steaks; however, Select (5.2%) steaks contained a lower ($P < 0.05$) fat percentage than all other quality grades. Additionally, no differences ($P > 0.05$) in moisture were found between Prime and Top Choice steaks (71.5% vs. 71.4%), nor between Low Choice and Select steaks (74.1% vs. 73.3%); however, Low Choice steaks had a greater ($P < 0.05$) amount of moisture than Prime and Top Choice steaks.

Discussion

The impact marbling level has on beef palatability has been thoroughly evaluated in previous literature (Parrish et al., 1973; Smith et al., 1985; Akinwunmi et al., 1993; O'Quinn et al., 2012; Emerson et al., 2013; Corbin et al., 2015; McKillip et al., 2017). Studies have noted a linear increase in tenderness, juiciness, flavor, and overall acceptability of beef steaks as marbling level increases (Emerson et al., 2013; O'Quinn et al., 2018; Drey et al., 2019); however, many of these studies have only evaluated marbling level within the LL. Cuts from the strip loin are moderate in connective tissue, with greater amounts of connective tissue typically found within muscles of locomotion, such as the chuck and round (McKeith et al., 1985). The greater amount of connective tissue within these muscles has the possibility of masking the effects of quality grade otherwise found in the strip loin. Nyquist et al. (2018) found no differences within consumer ratings of tenderness and overall like, as well as consumer acceptability of tenderness and flavor in Choice and Select muscles from the round and chuck. Likewise, authors have found that the *M. psoas major* (PM), a muscle low in connective tissue, is also minimally impacted by marbling (Shackelford et al., 1995; O'Quinn et al., 2015). In comparison, top

Table 8. Least squares means for trained sensory panel ratings[1] of top sirloin steaks of 4 quality grades cooked to 3 degrees of doneness (DOD)

Treatment	Connective tissue amount	Overall tenderness	Beef flavor intensity	Off flavor intensity
Quality grade				
Prime	14.0	61.2	39.0[a]	0.9
Top Choice[2]	13.0	58.8	39.9[a]	0.5
Low Choice	14.0	57.9	38.9[ab]	0.5
Select	14.1	57.3	37.6[b]	0.7
SEM[3]	1.3	2.0	0.5	0.2
P-value	0.92	0.46	0.02	0.59
DOD				
Rare, 60°C	13.3	69.3[a]	39.0	0.5
Medium, 71°C	13.6	56.5[b]	39.3	0.7
Well-done, 77°C	14.5	50.7[c]	38.2	0.8
SEM[3]	1.1	1.5	0.5	0.2
P-value	0.62	< 0.01	0.10	0.55
QG × DOD				
P-value	0.46	0.06	0.13	0.96

[a–c]Least squares means within the same main effect (quality grade or degree of doneness) without a common superscript differ ($P < 0.05$).

[1]Sensory scores: 0 = extremely dry/tough/dislike; 50 = neither dry nor juicy, neither tough nor tender, neither like nor dislike; 100 = extremely juicy/tender/like extremely.

[2]USDA marbling score of modest[00]– moderate[100].

[3]SE (largest) of the least square means.

Table 9. Least squares means for proximate and objective analyses of beef top sirloin steaks cooked to 3 degrees of doneness (DOD)

Treatment	Warner-Bratzler shear force, kg	Fat, %	Moisture, %	Cook loss[1], %
Quality grade				
Prime	3.1[b]	9.0[a]	71.5[b]	20.1
Top Choice[2]	3.3[ab]	8.8[a]	71.4[b]	21.0
Low Choice	3.4[a]	7.8[a]	74.1[a]	20.3
Select	3.4[a]	5.2[b]	73.3[ab]	21.0
SEM[3]	0.1	0.5	0.7	0.4
P-value	0.05	< 0.01	0.02	0.42
DOD				
Rare, 60°C	2.9[c]			15.8[c]
Medium, 71°C	3.4[b]			20.1[b]
Well-done, 77°C	3.7[a]			26.0[a]
SEM[3]	0.1			0.4
P-value	< 0.01			< 0.01
QG × DOD				
P-value	0.59			0.59

[a–c]Least squares means within the same main effect (quality grade or degree of doneness) without a common superscript differ ($P < 0.05$).

[1]Cook loss = [(raw weight– cooked weight)/raw weight] × 100

[2]USDA marbling score of modest[00]– moderate[100].

[3]SE (largest) of the least square means.

sirloin steaks have been found to be more variable in tenderness and lower in consumer palatability ratings when compared to cuts in the rib and loin (Luchak et al., 1998; Voges et al., 2007; Martinez et al., 2017).

Studies involving top sirloin steaks have evaluated palatability traits across multiple quality grades; however, no authors have examined the interaction of quality grades cooked to multiple DOD (Voges et al., 2007; Hunt et al., 2014; Legako et al., 2015). Previous literature has established that as DOD increases, tenderness, juiciness, flavor, and overall acceptability of steaks decrease linearly (Parrish et al., 1973; Akinwunmi et al., 1993; O'Quinn et al., 2018). More notably, recent studies have demonstrated enhancement and higher degrees of marbling can compensate for detrimental effects on palatability that are associated with increasing DOD in the LL (Lucherk et al., 2016; Drey et al., 2019). This compensation for decreased palatability that marbling provides is commonly known as the "insurance theory" (Smith and Carpenter, 1974; Savell and Cross, 1988). To date, only 1 study has thoroughly evaluated the interaction between marbling and DOD in depth through sensory evaluation (Drey et al., 2019). In our study, no quality grade × DOD interactions were present in all consumer sensory rating data. Studies by Lucherk et al. (2016), McKillip et al. (2017), and Drey et al. (2019) have also noted the lack of this interaction in consumer ratings; however, these authors have strictly evaluated the LL. Consumer sensory and acceptability ratings in our study are also inconsistent with this theory, as the impact of increased DOD on juiciness, tenderness, flavor, and overall like ratings were independent of quality grade. Thus, marbling level did not compensate for the decreased palatability related to elevated DOD within top sirloin steaks.

Our study found that quality grade had no effect on the consumer palatability ratings of tenderness, flavor, and overall like in top sirloin steaks, with juiciness being the only trait impacted by quality grade. In the current study, Prime steaks had 11% higher juiciness ratings than Select steaks, whereas Legako et al. (2015) reported Prime steaks rated 21% higher for juiciness than Select steaks. Similarly, Voges et al. (2007) found Prime steaks rated 20% higher for juiciness than Select top sirloin steaks. Moreover, Hunt et al. (2014) evaluated Top Choice and Select top sirloin steaks only, and reported Top Choice steaks had 15% higher ratings for juiciness than Low Choice steaks. However, Guelker et al. (2013) noted no differences in consumer ratings of juiciness, with ratings across all marbling levels evaluated (Prime to ungraded), with scores differing by less than 4%. Similarly, Neely et al. (1998) and Savell et al. (1999) found no differences between Top Choice and

Low Choice top sirloin steaks, with consumer juiciness ratings differing by less than 2%. Though variation on the impact of marbling on juiciness of top sirloin steaks exists in the published literature, it noteworthy the differences in methodology used between the cited studies and the current work. In each of the cited studies (excluding Savell et al., 1999), the authors evaluated multiple muscles and had consumers evaluate top sirloin steaks in direct comparison with at least 1 other muscle, each varying in marbling level. The other muscles fed within the same panel sessions ranged from very tender muscles (PM) to much tougher muscles (*M. semimembranosus*). It is unknown what the impact of the inclusion of additional muscles and the resulting cross comparison of samples by consumers within sensory sessions may have had on consumer ratings of top sirloin steaks within these studies. However, despite these methodological differences, our results are similar, with juiciness being the palatability trait most impacted by marbling level, with few differences being found for tenderness, juiciness, and overall liking ratings found among steaks of differing marbling levels (Neely et al., 1998; Voges et al., 2007; Legako et al., 2015).

Of additional importance, most of the cited studies only cooked steaks to a medium DOD. Of studies that have utilized consumers, only two—Savell et al. (1999) and Neely et al. (1998)—have evaluated steaks cooked to multiple DOD. Yet, the methods used by these authors were very different than those used in the current work. In these studies, the authors had consumers evaluate samples through an in-home evaluation and were asked to cook steaks to their preferred DOD. Though there are some advantages to in-home trials, including having consumers evaluate samples in as close to a "real-world" use scenario as possible, it limits the authors' ability to control the degree of doneness and preparation methods used by the consumers. Instead, these are self-reported by the panelists without verification as to the accuracy in which they are reported. In the current work, consumer ratings declined as DOD increased from rare to well-done. In comparison, Savell et al. (1999) reported as DOD increased from "medium-rare or less" to "well-done or more", juiciness ratings decreased by just under 9%, while ratings of overall like, tenderness, and flavor decreased by less than 3%. These results are drastically lower when compared to the current study, where juiciness ratings alone decreased by 30.3% as DOD increased from rare to well-done. The study by Neely et al. (1998) did not compare the difference in palatability traits of steaks differing by DOD, thus preventing our ability to make such comparisons.

Within the trained sensory panel ratings, an interaction was observed for initial and sustained juiciness. Previous studies involving top sirloin steaks have not evaluated samples for initial and sustained juiciness, rather, trained panelists have evaluated 1 combined trait of juiciness. Additionally, the observed interactions in the current study indicated marbling level only had an impact when steaks were cooked to a medium DOD and had no impact when steaks were cooked to either rare or well-done. When steaks were cooked to medium, Prime steaks were rated 24% higher than Select steaks for initial juiciness, and 30% higher for sustained juiciness. Other authors who have reported a similar interaction have shown a larger difference in juiciness when steaks were cooked to medium. Lucherk et al. (2016) reported Prime steaks receiving 51 and 68% higher juiciness ratings than Select steaks at medium; and Drey et al. (2019) found Prime steaks cooked to medium rated 66 and 38% higher than Select steaks for initial and sustained juiciness, respectively. Moreover, McKillip et al. (2017) reported a 34% greater initial juiciness rating for Prime steaks cooked to medium rather than Select. It is worth noting that all of these studies evaluated the LL, a muscle which is much more tender with a lower connective tissue amount than the top sirloin steaks used in the current work, likely contributing to these differences. In the present study, an interaction for myofibrillar tenderness was also found, with Prime steaks cooked to medium receiving 15.5% higher ratings than Select, indicating that marbling level only impacted tenderness at this intermediate level of doneness, whereas when cooked to both higher and lower DOD, the effect of marbling on tenderness was masked by other factors contributing to myofibrillar tenderness. No previous work evaluating top sirloin steaks have reported such interactions.

In our study, marbling level had no or minimal impact on most of the other factors evaluated by trained sensory panelists. These results are consistent with many previous reports that have reported trained panelists found few differences among top sirloin steaks of differing quality grades (Luchak et al., 1998; Pringle et al., 1998; Lorenzen et al., 2003). Our results within quality grade agree with both Lorenzen et al. (2003) and Luchak et al. (1998), who both reported Choice and Select steaks differing by less than 0.1% in connective tissue amount. King et al. (2009) also found only a minimal increase (1.2%) in ratings of overall tenderness as quality grade increased from Select to Choice. But, a larger difference was reported by Luchak et al. (1998), who reported Choice steaks rated 10% higher for overall tenderness than Select steaks.

In comparison, our study found no differences among quality grades for overall tenderness with Choice and Select top sirloin steaks differing by less than 3%. Within our study, only differences within quality grade for beef flavor intensity were found, with Prime and Top Choice steaks having greater ratings than Select steaks. Nonetheless, these differences were less than 2% across all quality grades. Trained sensory panelists from Lorenzen et al. (2003) gave Top Choice steaks higher ratings than Low Choice; however, less than a 1% difference separated the ratings between the two. Inconsistent with our study and others, Luchak et al. (1998) found an interaction for flavor intensity. In that study, Select top sirloin steaks cooked to 74°C had lower flavor intensity ratings than those cooked to 54°C, as well as Choice steaks cooked to 54 and 74°C.

Moreover, no interactions were observed for WBSF in our study, but with both quality grade and DOD having an effect. Prime steaks had a lower WBSF value than Low Choice and Select steaks. Additionally, Top Choice, Low Choice, and Select steaks were all similar in WBSF value. These results are contradictory when compared to Luchak et al. (1998) and Gruber et al. (2006), who both found a decrease in WBSF values when quality grade increased from Select to Choice. However, Gruber et al. (2006) subjected top sirloin steaks to 1 of 7 different aging periods beforehand (2, 4, 6, 10, 14, 21, or 28 d). Similarly, our study subjected steaks to a 28 d aging period; however, the magnitude of difference between Top Choice and Select steaks within this aging period was greater in Gruber et al. (2006; 0.44 kg) than in the current study; but steaks in the Gruber et al. (2006) study also had WBSF values at d 28 of aging 24 to 36% greater than those found in the current work. It is important to note that while there were no differences found in our study, we had a much smaller sample size (180 steaks) than Gruber et al. (2006; 560 steaks), providing the authors a greater amount of power to find smaller significant differences. George-Evins et al. (2004) reported a WBSF interaction for top sirloin steaks of 3 quality classifications (Certified Angus Beef [CAB], Choice, and Select) cooked to 3 DOD (65.5, 71, or 76.6°C). In their study, steaks cooked to 65°C had similar WBSF values, regardless of quality classification; however, when cooked to 71 and 76.6°C, CAB and Choice steaks had lower WBSF values than Select steaks. While no interaction was present in our study, there was a steady increase in WBSF as DOD increased from rare to well-done. The significant effect of DOD in our study does agree with findings from Lorenzen et al. (2003), who noted an increase in WBSF as endpoint temperature increased from 65.5 to 76.6°C. Previous literature evaluating top sirloin steaks has concluded that higher quality top sirloin steaks should be selected to decrease toughness from cooking to higher endpoint temperatures (George-Evins et al., 2004); however, results from the current study would contradict this statement. Our study shows that objectively and subjectively, higher quality top sirloin steaks do not necessarily decrease toughness caused by increasing DOD.

The majority of previous literature evaluating the palatability of top sirloin steaks have cooked top sirloin steak samples only to a medium DOD (Harris et al., 1992; Lorenzen et al., 2003; George-Evins et al., 2004; Hunt et al., 2014; Legako et al., 2015; Martinez et al., 2017). Within these studies, few, if any differences in palatability of steaks from multiple quality grades have been observed from both consumer and trained sensory panelists. However, results of the current study contradict these findings and indicate that marbling level may have an impact on both juiciness and myofibrillar tenderness when steaks are cooked to medium, but no impact when steaks are cooked either rare or well-done. Though, these effects on juiciness and tenderness were not reflected by the consumers in the current study.

Conclusion

Currently, USDA Prime, Choice, and Select prices for the top sirloin butt (IMPS # 184) are $8.97, $6.83, and $5.51 per kg, respectively (USDA, 2019a, 2019b). Although these are current prices for the wholesale cut itself and not individual steaks, these values still present retailers and foodservice establishments with an opportunity to save money that would otherwise be spent on product premiums. Results from this study do not support the premise that marbling has a large impact on the eating quality of top sirloin steaks, as it does in the LL. Consumers, as well as retail and foodservice establishments, could ultimately find themselves paying premium prices for higher quality top sirloin steaks that would, in the end, provide the same level of eating satisfaction as steaks of lower quality grades.

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