Meat and Muscle Biology™

Steak Thickness, Cook Surface Temperature and Quality Grade Affected Top Loin Steak Consumer and Descriptive Sensory Attributes[1]

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Abstract: Beef flavor attributes of USDA Top Choice and Select beef top loin steaks were evaluated that differed in thickness (1.3 or 3.8 cm) and grill surface temperature (177 or 232°C) when cooked on a commercial flat top grill. A trained descriptive attribute panel and consumer sensory panels were used to evaluate steak flavor and texture. As thickness and temperature increased, beef identity and brown/roasted flavor aromatics increased ($P < 0.05$). Steaks cooked at 232°C and cut 3.8-cm thick had the highest ($P < 0.05$) levels of burnt flavor and bitter basic tastes. Thicker steaks cooked at 177°C had more intense umami basic taste and beef identity ($P < 0.05$). Steaks cut 1.3 cm had lower levels of beef identity and brown/roasted flavor aromatics and the thin cut steaks cooked at 177°C had more sour basic taste ($P < 0.05$). Consumers rated 232°C, 3.8 cm steaks lowest ($P < 0.05$) for overall, beef flavor, overall flavor, and grilled flavor liking; whereas, the 177°C, 3.8 cm steaks were highest ($P < 0.05$) in beef flavor liking. Beef identity, brown/roasted, bloody/serumy, fat-like, umami, sweet, salty, overall sweet, overall tenderness, and muscle fiber tenderness were positive attributes, and metallic, bitter, and burnt were negative attributes in predicting consumer overall liking. Thick steaks cooked at low temperatures or thin steaks cooked at high temperatures resulted in more positive sensory panel traits and consumer liking scores.

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Introduction

Uncooked meat has little to no aroma with only a bloody/serumy taste and thus must be heated or cooked for flavors to develop (Mottram, 1998). The cooking process is crucial for positive flavor development. Beef flavor attributes have been implicated as a major component of consumer liking. Traditionally, tenderness was identified as a driving factor for consumer liking and has been the key factor examined (Cross et al., 1973; Guelker et al., 2013; Hunt et al., 2014), but consumers acceptability also has been shown to be driven by flavor (Kerth and Miller, 2015; Legako et al., 2015). Lately, research has been focused on factors impacting beef flavor development as impacted by cooking methodology (Kerth and Miller, 2015; Legako et al., 2015; Mottram et al., 1982).

Beef flavor is comprised of multiple sensory attributes that are ever evolving. The beef industry took the first big step in addressing beef flavor by the development of the beef flavor lexicon that identified major and minor beef flavor descriptors (Adhikari et al., 2011). The development of the lexicon enabled the identification of flavors and their intensity. Without the beef flavor lexicon, it would be nearly impossible to identify and quantify flavor attributes of beef and how it is perceived

One method to control the formation of flavor attributes is to manipulate grill temperature and steak thickness. Kerth (2016) examined different levels of Maillard reaction products on steaks that were cut to different thicknesses and grilled at different temperatures. By varying the levels of steak thickness

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and cook surface temperatures, aromatic volatiles associated with beef flavor were altered. However, understanding how steak thickness and grill temperature impact consumer and trained descriptive attributes has not been reported for top loin steaks.

Therefore, the objective was to evaluate the effects of cut thickness (1.3 or 3.8 cm) and commercial flat top grill temperature (177 or 232°C) on expert trained flavor and texture descriptive attributes and consumer liking attributes using Top Choice and Select top loin steaks. Additionally, relationships between flavor and texture descriptive attributes and consumer liking attributes were examined.

Materials and Methods

Trained sensory panelist training, testing, and consumer evaluation procedures were approved by the Texas A&M Institutional Review Board (IRB2014–0490D).

Sample selection and preparation

Beef strip loins (IMPS 180) from 32 random carcasses were selected on 2 selection trips from a commercial beef processing facility in Corpus Christi, TX. USDA Select (*n* = 16) and upper two-thirds USDA Choice (*n* = 16) carcasses were selected after grading by a USDA grader and by Texas A&M University Meat Science personnel trained in grading to confirm USDA quality grade (USDA, 2016). Vacuum-packaged strip loins were transported to Texas A&M University Rosenthal Meat Science and Technology Center and stored at 4°C for 14 d. Since steak thickness was a primary treatment, strip loins were frozen (–40°C) and held for 24 h after aging to allow for uniform and precise cutting of the steaks by a band saw (400, Marel, Norwich, England). After intact strip loins were frozen, both strip loins from each animal were cut to 1.3- or 3.8-cm thick steaks with no more than 0.25 cm external fat and randomly assigned to either trained or consumer sensory evaluation across treatments. Each treatment was randomly assigned by location within carcass for expert, trained flavor and texture descriptive attribute sensory evaluation in College Station, TX, and each consumer sensory evaluation in State College, PA; Portland, OR; Griffin, GA; and Olathe, KS. Therefore, 20 steaks were cut from 1 carcass. Four steaks (1 per thickness level and 1 per cooked grill temperature level) were randomly assigned to each of 4 cities for consumer evaluation and 4 steaks were used for expert descriptive flavor and texture analysis. Steaks were labeled and vacuum-packaged individually ([B2470, Cryovac Sealed Air Corporation, Duncan, SC] with an oxygen transmission rate of 3 to 6 cc at 4°C [m^2, 24 h at 4°C, 0% RH] and a water vapor transmission rate of 0.5 to 0.6 g at 38°C [100% RH, 0.6 m^2, 24 h]). Packaged steaks were placed into frozen storage (-23.3°C) for up to 7 mo until evaluated.

For each analysis, individual steaks were selected and thawed in refrigerated storage (4°C) for 24 h. Steaks were cooked on commercial flat top grill (Star Max 536TGF 91.4 cm Countertop Electric Griddle with Snap Action Thermostatic Controls, Star International Holdings Inc. Company, St. Louis, MO) set at either 177 or 232°C. Internal steak temperatures were monitored by iron-constantan thermocouples (Omega Engineering, Stanford, CT) inserted into the geometric center of each steak. For both the trained panel and consumer panels, steaks were cooked to an internal temperature of 37°C, flipped, and removed when the internal temperature reached 71oC to allow optimal cooking time on both sides of the steak for development of Maillard reaction products. Temperatures of the steak surfaces were taken when placed on the grill, at the time of turning, and when the final internal temperature was reached on the surface exposed to the grill using an iron-constantan surface probe (Model 88402E, Omega Engineering). Also, the grill surface temperature was taken in the location where the steak was to be placed at the beginning, time of turning, and once the final internal temperature was reached. These measurements were used to determine if the grill and steak surface temperature change during cooking due to the evaporative cooling caused by water loss of the steak during the cooking process (data presented in Berto, 2015). Temperatures were displayed using an Omega HH501BT Type T thermometer (Omega Engineering). Trained sensory panelist training, testing and consumer evaluation was conducted as defined by the American Meat Science Association (2016) and Meilgaard et al. (2007).

Expert, trained flavor, and texture descriptive sensory analysis

Steaks were evaluated by a 5-member, expert trained beef flavor and texture descriptive attribute panel (ASTM, 1981) with more than 200 h of experience that helped develop and validate the beef lexicon. The panel was retrained using the beef lexicon for 14 d or 28 h using 16-point intensity scales, where 0 = none and 15 = extremely intense (Table 1; Adhikari et al., 2011). After training was complete, panelists were presented 12 samples per day, divided into 2 sessions. Prior to the

Table 1. Definition and reference standards for meat descriptive flavor aromatics[1], basic tastes, and texture attributes and their intensities; where 0 = none, 15 = extremely intense from Adhikari et al. (2011) and American Meat Science Association (2016)

Item	Definition	Reference standard flavor scale value unless otherwise defined
Sensory attribute		
Beef identity	Amount of beef flavor identity in the sample	Swanson's beef broth = 5.0 80% lean ground beef = 7.0 Beef brisket = 11.0
Bitter	The fundamental taste factor associated with a caffeine solution	0.01% caffeine solution = 2.0 0.02% caffeine solution = 3.5
Bloody/serumy	The aromatics associated with blood on cooked meat products, closely related to metallic aromatic	USDA choice strip steak = 5.5 Beef brisket = 6.0
Brown/roasted	A round, full aromatic generally associated with beef suet that has been broiled	Beef suet = 8.0 80% lean ground beef = 10.0
Burnt	The sharp/acrid flavor note associate with over-roasted beef muscle, something over-baked or excessively browned in oil	Alf's red wheat Puffs = 5.0
Fat-like	The aromatics associated with cooked animal fat	Hillshire farms Lit'l beef smokies = 7.0 Beef suet = 12.0
Metallic	The impression of slightly oxidized metal, such as iron, copper, and silver spoons	0.10% potassium chloride solution = 1.5 USDA choice strip steak = 4.0 Dole canned pineapple juice = 6.0
Overall sweet	A combination of sweet taste and sweet aromatics. The aromatics associated with the impression of sweet	Post-shredded wheat spoon size = 1.5 Hillshire farms Lit'l beef smokies = 3.0 SAFC ethyl maltol 99% = 4.5 (a)
Salty	The fundamental taste factor of which sodium chloride is typical	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5
Sour	The fundamental taste factor associated with citric acid	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Sweet	The fundamental taste factor associated with sucrose	2.0% sucrose solution = 2.0
Umami	Flat, salty, somewhat brothy; the taste of glutamate, salts of amino acids and other molecules called nucleotides	0.035% accent flavor enhancer solution = 7.5
Texture		
Juiciness	The amount of perceived juice that is released from the product during mastication	Carrot = 8.5; Mushroom = 10.0; Cucumber = 12.0; Apple = 13.5; Watermelon = 15.0 Choice top loin steak cooked to 80°C = 9.0 Choice top loin steak cooked to 58°C = 11.0
Muscle fiber tenderness	The ease in which the muscle fiber fragments during mastication	Select eye of round steak cooked to 70°C = 9.0 Select tenderloin steak cooked to 70°C = 14.0
Connective tissue amount	The structural component of the muscle surrounding the muscle fiber that will not break down during mastication	Cross-cut beef shank cooked to 70°C = 7.0 Select tenderloin cooked to 70°C = 14.0
Overall tenderness	Average of muscle fiber tenderness and connective tissue amount when connective tissue amount is 11 or less	If connective tissue amount is 12 to 15, then overall tenderness = the value of muscle fiber tenderness; If connective tissue amount is less than 12 then overall tenderness is the average of connective tissue amount and muscle fiber tenderness.

[1]Attributes are tasted flavors unless denoted with an (a) for aroma.

start of each trained panel evaluation day, panelists were calibrated using 1 orientation or "warm up" sample that was evaluated and discussed orally. Double-distilled, deionized water, unsalted saltine crackers (Unsalted Tops Premium Saltine Crackers, Nabisco, East Hanover, NJ), and fat-free ricotta cheese (Hill Country Fare fat-free ricotta, HEB, San Antonio, TX) were available for cleansing the palette between samples.

After cooking, samples were cut into 1.3 × 1.3 cm × steak thickness cuboidal sections. Two cubes per sample were served in 59 mL clear, plastic soufflé cups (translucent plastic 2 oz. portion cups, Georgia-Pacific, Asheboro, NC) tested to assure that they did not impart flavors. Samples were identified with random 3-digit codes and served in random order. Samples were cut and served immediately to assure samples were approximately 37°C on time of serving. During evaluation, panelists were seated in individual breadbox-style booths separated from the preparation area and samples were evaluated under red lights

(44.2 lux). To prevent taste fatigue, each evaluation day was 2 h and divided into two 1-h sessions, with a 10-min break between sessions. Samples were served with at least 4 min after completion of the evaluation and evaluation of the next sample. This resulted with each sample evaluation spanning about 10 min.

Consumer evaluation

Consumers (n = 314) were randomly selected in 4 cities (Olathe, KS; State College, PA; Griffin, GA; and Portland, OR) so that geographical areas represented the Midwest, the east coast, the Southeast, and the West Coast. In each city, 4 consumer sessions with approximately 20 consumers per session were conducted.

Consumer panelists were recruited by the individual research institution in each state, and all consumers were required to pass a screener guaranteeing them to be over 18 years of age, have no food allergies, and consume beef 1 or 2 times per week (including ground beef). On the day of evaluation, each consumer panelist was asked to sign an informed consent document. An instructional document, demographic ballot, and 8 individual sample ballots were provided. Consumer demographics for age, sex, income, household income, type of employment, dietary restrictions, protein sources consumed, meat consumption levels of beef, meat shopping habits, cook surface temperature preference, steak thickness preference, beef types, and flavor types were collected.

The ballot included overall, overall flavor, beef flavor, grilled flavor, juiciness,s and tenderness liking using 9-point hedonic scales. On each ballot, 2 open-ended questions were asked to describe any positive or good flavors and any negative or bad flavors. Panelists were provided 8 random samples in a random order approximately 4-m apart. Samples were served in clear, plastic soufflé cups, as previously described, labeled with a random 3-digit number corresponding to their ballot. Double distilled, deionized water, and unsalted saltine crackers, were available for cleansing the palette between samples. Samples were cut and prepared as defined for expert, trained beef flavor descriptive analysis.

Statistical analyses

The trained panel flavor and texture descriptive and consumer liking attributes were analyzed by analysis of variance with SAS (version 9.3, SAS Inst. Inc., Cary, NC) and a predetermined α of 5%. The data were analyzed as a completely random design with steak thickness, cooked surface temperature, and quality grade as main. Carcass within quality grade, sensory day, and order served were defined as random variables. Two and three-way interactions of main effects were included in the models. For trained panel data, the effect of panelist and main effects were evaluated to understand efficacy of the panelists. Panelist by main effect two-way and three-way interactions and main effects were included in the model. For attributes presented in Table 1, significant ($P < 0.05$), panelist by main effect interactions were reported for some attributes. Of the attributes evaluated in Table 1, animal hair, apricot, asparagus, barnyard, beet, buttery, cardboard, chemical, cocoa, cooked milk, cumin, dairy, fishy, floral, green, green-hay, heated-oil, leather, liver-like, medicinal, painty, petroleum-like, rancid, refrigerator stale, smoky-wood, smoky charcoal, sour aromatics, sour dairy, spoiled, and warmed-over flavor attributes had values less than 0. This was not surprising, as off-flavors were not expected and data were not presented. When least squares means were examined, least squares means for each interaction was less than 1.0 on the 16-point scale. This is the sensitivity that the panelists were trained to and defined panelist effects were not identifiable. Therefore, descriptive sensory data were averaged across panelists. For consumer data, city, steak thickness, cooked surface temperature, quality grade, and their interactions were included as main effects and order served was identified as a random variable. City by thickness interaction least squares means were not presented. Olathe, KS, consumers tended to rate thicker steaks lower for consumer sensory attributes than consumers in other locations. Least squares means were calculated and the Fishers test was used to determine differences between least squares means when significance was defined in the analysis of variance. Multivariate analysis was conducted using XLSTAT (Addinsoft, New York, NY) where partial least squares regression functions were used. Data were presented in bi-plots.

Results and Discussion

Expert trained descriptive sensory evaluation

To determine if treatments affected beef flavor and texture attributes, least squares means were reported in Tables 2 and 3. Three-way and quality grade by grill temperature interactions were not present ($P > 0.05$) for flavor and texture attributes and were not included in the final statistical models. Select steaks had slightly lower beef identity, fat-like, and overall sweet flavor aromatics, and umami and sweet basic tastes; and more sour basic taste when compared to the Top

Table 2. Beef flavor descriptive attribute[1] least squares means for USDA Select and Top Choice beef top loin steaks across grill temperature and steak thickness

Treatment	Beef identity	Brown/ roasted	Bloody/ serumy	Fat-like	Metallic	Umami	Sweet	Sour	Salty	Bitter	Overall sweet	Burnt
Thickness (TH)[2]	< 0.0001	< 0.0001	0.0008	0.02	0.03	0.15	0.002	0.006	0.57	< 0.0001	0.008	0.0001
1.3 cm	6.2^{b}	1.4^{b}	1.1^{a}	1.1^{a}	2.1^{b}	0.5	0.4^{a}	1.8^{a}	1.5	1.7^{b}	0.6^{a}	0.3^{b}
3.8 cm	6.7^{a}	2.2^{a}	0.8^{b}	1.0^{b}	2.2^{a}	0.6	0.2^{b}	1.7^{b}	1.6	2.7^{a}	0.4^{b}	1.9^{a}
Grill temperature (GT)[2]	0.05	< 0.0001	0.0001	0.02	0.89	0.0009	0.0004	0.004	0.93	< 0.0001	0.008	< 0.0001
177°C	6.4	1.6^{b}	1.2^{a}	1.1^{a}	2.1	0.7^{a}	0.4^{a}	1.8^{a}	1.5	1.8^{b}	0.6^{a}	0.3^{b}
232°C	6.5	2.0^{a}	0.7^{b}	1.0^{b}	2.1	0.5^{b}	0.2^{b}	1.7^{b}	1.5	2.6^{a}	0.4^{b}	1.9^{a}
Quality grade (QG)[2]	0.01	0.08	0.90	0.0001	0.06	0.0002	0.003	0.0003	0.06	0.74	< 0.0001	0.90
Top Choice	6.5^{a}	1.9	1.0	1.1^{a}	2.1	0.7^{a}	0.4^{a}	1.6^{b}	1.6	2.2	0.6^{a}	1.1
Select	6.3^{b}	1.7	1.0	0.9^{b}	2.2	0.4^{b}	0.3^{b}	1.9^{a}	1.5	2.2	0.4^{b}	1.2
TH by GT[2]	< 0.0001	< 0.0001	0.11	< 0.0001	0.002	0.0009	0.0005	0.01	0.005	< 0.0001	0.0002	< 0.0001
1.3 cm, 177°C	5.9^{d}	0.9^{c}	–	1.0^{a}	2.1^{ab}	0.5^{b}	0.4^{a}	2.0^{a}	1.5^{b}	1.6^{b}	0.5^{a}	0.1^{b}
1.3 cm, 232°C	6.4^{c}	1.9^{b}	–	1.2^{a}	2.0^{c}	0.5^{b}	0.4^{a}	1.7^{b}	1.6^{ab}	1.8^{b}	0.6^{a}	0.5^{b}
3.8 cm, 177°C	6.8^{a}	2.3^{a}	–	1.2^{a}	2.1^{bc}	0.8^{a}	0.4^{a}	1.7^{b}	1.6^{a}	1.9^{b}	0.6^{a}	0.5^{b}
3.8 cm, 232°C	6.6^{b}	2.2^{a}	–	0.8^{b}	2.3^{a}	0.4^{b}	0.1^{b}	1.7^{b}	1.5^{b}	3.4^{a}	0.3^{b}	3.3^{a}
TH by QG[2]	0.09	0.01	0.04	0.03	0.62	0.17	0.82	0.93	0.25	0.51	0.55	0.68
1.3 cm, Top Choice	–	1.4^{c}	1.2^{a}	1.2^{a}	–	–	–	–	–	–	–	–
1.3 cm, Select	–	1.4^{c}	1.0^{a}	1.2^{a}	–	–	–	–	–	–	–	–
3.8 cm, Top Choice	–	2.4^{a}	0.7^{c}	1.2^{a}	–	–	–	–	–	–	–	–
3.8 cm, Select	–	2.1^{b}	0.9^{bc}	0.8^{b}	–	–	–	–	–	–	–	–
Root mean square error	0.31	0.15	0.45	0.27	0.26	0.32	0.20	0.30	0.24	0.64	0.24	1.11

[a–d]Least squares means within a column and treatment followed by the same letter are not significantly different ($P > 0.05$).

[1]Descriptive flavor attribute: 0 = none, 15 = extremely intense.

[2]P-values from the analysis of variance table.

Choice steaks. Differences were 0.4 units or less on a 16-point scale indicating that these differences were minor, but consist. Juiciness, muscle fiber tenderness, connective tissue amount, and overall tenderness did not differ in steaks by quality grade (Table 3). However, steaks cooked on a 232°C grill had slightly lower muscle fiber and overall tenderness. These differences were small and most likely not meaningful. Previous research has reported that Top Choice top loin steaks cooked to the same degree of doneness using a standard cooking method and thickness were juicier and more tender than Select top loin steaks (Smith et al., 1987). However, electric open-hearth grills were used. The electric flat top grill from the current study provided a solid cooking surface with consistent heat contact on the surface of the steaks and may have in-

Table 3. Beef texture attributes[1] least squares means for USDA Select and Top Choice beef top loin steaks across grill temperature and steak thickness

Treatment	Juiciness	Muscle fiber tenderness	Connective tissue amount	Overall tenderness
Thickness, cm[2]	0.69	0.0008	0.17	0.0008
1.3	10.5	11.5^{a}	12.2	11.5^{a}
3.8	10.4	11.1^{b}	12.3	11.1^{b}
Grill temperature, °C[2]	0.35	0.03	0.38	0.03
177	10.5	11.4	12.3	11.4^{a}
232	10.4	11.2	12.2	11.2^{b}
Quality grade[2]	0.05	0.10	0.81	0.10
Top Choice	10.6	11.4	12.2	11.4
Select	10.3	11.2	12.2	11.2
Root mean square error	0.56	0.55	0.39	0.55

[a,b]Least squares means within a column and effect followed by the same letter are not significantly different ($P > 0.05$).

[1]Descriptive texture attribute: 1 = extremely dry, tough, abundant and tough and 15 = extremely juicy, tender, none, and tender, respectively.

[2]P-values from the analysis of variance table.

fluenced the texture attributes. Thinner top loin steaks were slightly more ($P = 0.001$) tender than thicker steaks. This effect may have been influenced by the shorter cooking times for thinner versus thicker steaks (11.5 and 11.1 min, respectively). As thinner steaks had less contact with the heat source, there was potential for less protein heat denaturation during cooking. As protein heat denaturation was not measured, this hypothesis cannot be evaluated.

Thickness by grill temperature interactions were not significant ($P > 0.05$) for bloody/serumy flavor attributes, and for texture attributes. Therefore, 1.3- and 3.8-cm thick top loin steaks had similar bloody/serumy flavor and were also similar in juiciness, muscle fiber tenderness, connective tissue amount and overall tenderness when cooked using a grill temperature of either 177 or 232°C ($P > 0.05$). No research could be located comparing the effect of steak thickness on bloody/serumy flavor. When comparing least squares means, the thinner steaks had slightly more ($P = 0.001$) bloody/serumy flavor. Steaks across thickness levels were cooked to the same internal temperature. Thinner steaks had shorter cook times that would have limited heat denaturation of myoglobin, one of the factors contributing to bloody/serumy flavor. Luckemeyer (2015) and Glascock (2014) found that as internal cook temperature increased, bloody/serumy flavor levels decreased.

Thickness by quality grade interactions were significant ($P > 0.05$) for brown/roasted, bloody/serumy, and fat-like flavor attributes. These results indicate that 1.3-cm Select and Top Choice top loin steaks cut had similar brown/roasted, bloody/serumy, and fat-like flavor attributes. However, thicker (3.8 cm) Top Choice steaks were more intense in brown/roasted and similar in fat-like flavor than thinner steaks. Thicker steaks, regardless of quality grade, had slightly lower bloody/serumy flavor. These results were in agreement that thinner steaks did not develop the same level of beef identity and brown/roasted as thicker steaks. Again, as thinner steaks had less cook time and exposure to the heat source, protein heat denaturation associated with development of these flavors was most likely responsible for the lower beef identity and brown/roasted flavors.

The 1.3-cm thick top loin steaks cooked using the lowest grill temperature had lower ($P < 0.05$) beef identity and brown/roasted flavors and slightly more ($P < 0.05$) sour basic taste. Whereas, thick (3.8 cm) top loin steaks cooked with the highest cooking temperature (232°C) had more bitter basic taste and burnt flavor; and were slightly lower in fat-like and overall sweet flavor, and sweet basic tastes. These results indicate that thinner steaks cooked using the lower grill temperature most likely did not have sufficient heat exposure to develop the beef identity and brown/roasted flavor attributes that have been associated with positive beef flavor attributes (Glascock, 2014; Laird, 2015; Luckemeyer 2015). Sour basic taste may have been more easily identified in these steaks with the lower levels of beef identity and brown/roasted flavors. In general, thicker steaks had more ($P < 0.05$) beef identity and brown/roasted flavors. As grill temperature increased, brown/roasted flavors and bitter basic taste increased, and bloody/serumy flavors decreased ($P < 0.05$; Table 2). Kerth and Miller (2015) showed that the aforementioned flavor and basic taste attributes were positive attributes for consumers. The thicker steaks cooked at the higher temperature had more negative attributes of metallic, bitter, and burnt flavors. This was contradictory to Cross et al. (1976), who reported that temperature did not affect beef flavor when roasting in an oven. It was found that temperature was a major factor in the development and differences in flavor of beef top loin steaks. Temperature played a major role eliciting differences ($P < 0.05$) in 4 of the 14 flavor attributes that were present in the samples. Cross et al. (1976) used a more indirect cooking method where heat was not in direct contact with the meat. It can be hypothesized that making contact with the heated surface during beef cooking will have a greater impact on the flavor development in the meat. The direct heat transfer has the ability to impact either Maillard or lipid denaturation reactions that have been shown to contribute to cooked meat flavor. Steak thickness and surface temperature impacted flavor development as previously discussed; however, final peak steak internal temperature was not obtained. Internal temperature of each steak was monitored on the grill until final cooked internal temperature was reached and steaks were removed from the grill. It can be hypothesized that after removal from the grill, internal cook temperature continued to rise differentially, defined as final peak steak internal temperature. Thicker steaks would be expected to have a greater final peak steak internal temperature than thinner steaks, as these data were not collected. The impact of final peak steak internal temperature on beef flavor attributes and consumer liking may have influenced or contributed to the effect of flavor differences between steaks that differed in thickness.

To understand multivariate relationships between treatments (presented as the means of the three-way interactions) and flavor attributes, partial least squares regression (PLS) was conducted and results are presented in Fig. 1. While consumer attributes are also pre-

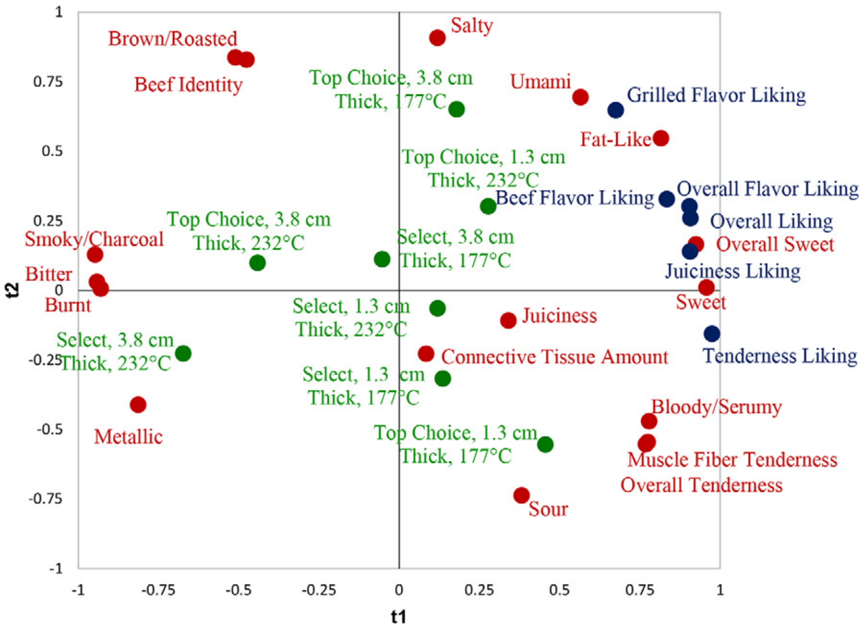

Figure 1. Partial least squares regression bi-plot of trained flavor and texture descriptive flavor attributes (in red), consumer sensory attributes (in blue), and treatments (in green). Correlations on axes t1 and t2 where Y accounted for 88.2% of the variation in X, and X accounted for 78.1% of the variation in Y.

sented in Fig. 1, these relationships will be discussed later. Thick, Select top loin steaks cooked at the higher temperature were most closely associated with metallic flavor, whereas thick, Top Choice top loin steaks cooked using higher grill temperatures were more closely associated with bitter basic tastes and burnt flavor aromatics. Top Choice and Select, thin cut top loin steaks cooked using the 177°C grill temperature had similar flavor attributes and were closely clustered with bloody/serumy flavor, and sour basic taste, and negatively associated with beef identity and brown/roasted flavor attributes. This further substantiates that thinner steaks cooked using lower grill temperatures, regardless of quality grade, most likely had less protein heat denaturation due to less total cook time and insufficient time for heat associated flavor development of beef identity and brown/roasted flavors. Thick Top Choice steaks cooked at either 232 or 177°C were closely associated and somewhat clustered with salty and umami basic tastes and fat-like flavor.

Consumer demographics

To understand consumer perceptions of the effects of quality grade, grill temperature and steak thickness, consumer central-location sensory tests were conducted. Consumer demographics are reported in Table 4. There were slightly more females than males and around 55% of consumers came from 2- to 3-person size households. Nearly 66% of the consumers were between 26 and 55 yr old, with ages ranging from 18 to 66 or older. Consumers had a balance of income levels and about 60% of the consumers had full time jobs. As expected, consumers mainly consumed beef, pork, chicken, and fish either at home or in a restaurant. Eighty percent of consumers ate beef 5 to 6 times a week followed most closely by 75.2% of consumers who ate pork 1 to 2 times a week, 73.4% who ate fish 1 to 2 times a week, and 48.5% ate chicken 3 to 4 times a week. Lamb and soy-based products were seldom consumed. Of the beef purchased, consumers mainly purchased traditional beef at the retail store with a few consumers preferring grass-fed and even fewer preferring organic beef. Outdoor grilling was the preferred method of cooking a beef steak with the grill set at either 177 or 204°C by most of the consumers. The majority of consumers preferred beef steaks cooked to either medium, medium rare, or medium well visual degrees of doneness.

Over half of the consumers preferred purchasing a steak that was cut to a thickness of 2.54 cm; fewer consumers preferred a thinner 1.3 cm steak or one over 3.8 cm. The National Beef Tenderness Survey (Brooks et al., 2000) found that the average top loin steak was 2.98 cm thick, slightly thicker than what was indicated by consumers as their perceived preferred thickness. Another National Beef Tenderness Survey (Guelker et al., 2013) found that top loin steaks had gotten slightly thinner being on average 2.77 cm thick. This thickness

Table 4. Demographics and attitudes of beef consumers across 4 cities

Question		No. of respondents	Percentage of respondents
Sex	Male	141	45.5
	Female	169	54.5
Household size, including yourself	1	44	14.0
	2	106	33.8
	3	69	22.0
	4	61	19.4
	5	21	6.7
	6 or more	13	4.1
Age	20 yr or younger	18	5.7
	21 to 25 yr	41	13.1
	26 to 35 yr	67	21.3
	36 to 45 yr	71	22.6
	46 to 55 yr	63	20.0
	56 to 65 yr	51	16.2
	66 yr and older	2	1.0
Household income	Below $25,000	76	24.4
	$25,001 to $49,999	73	23.4
	$50,000 to $74,999	59	18.9
	$75,000 to $99,999	45	14.4
	$100,000 or more	58	18.6
Employment level	Not employed	66	21.0
	Part-time	60	19.1
	Full-time	188	59.9
Weekly consumption of protein			
Beef	0	2	0.6
	1 to 2	149	47.9
	3 to 4	123	39.6
	5 to 6	25	80.4
	7 or more	12	3.9
Pork	0	27	8.9
	1 to 2	228	75.2
	3 to 4	35	11.6
	5 to 6	10	3.3
	7 or more	3	1.0
Lamb	0	205	65.3
	1 to 2	49	15.6
	3 to 4	5	1.6
	5 to 6	1	0.3
	7 or more	0	0.0
Chicken	0	2	0.7
	1 to 2	95	31.1
	3 to 4	148	48.5
	5 to 6	47	15.4
	7 or more	13	4.3
Fish	0	38	13.0
	1 to 2	215	73.4
	3 to 4	33	11.3
	5 to 6	4	1.4
	7 or more	3	1.0
Soy-based products	0	137	54.8
	1 to 2	84	33.6
	3 to 4	21	8.4
	5 to 6	7	2.8
	7 or more	1	0.4

Continued

Table 4. (cont.)

Question		No. of respondents	Percentage of respondents
Degree of doneness preference	Rare	10	3.2
	Medium rare	90	28.6
	Medium	96	30.6
	Medium well	77	24.5
	Well	27	8.6
	Very well	11	3.5
At what temperature do you typically set the cook surface (grill, pan, oven, etc.)?			
	Lower than 177°C	10	3.2
	177°C	118	37.6
	204°C	118	37.6
	232°C	38	12.1
	Higher than 232°C	20	6.5
When purchasing beef, what thickness do you prefer to buy at the retail store?			
	Less than 1.3 cm	13	4.1
	1.3 cm	70	22.3
	2.5 cm	185	58.9
	3.8 cm	41	13.1
	Thicker than 3.8 cm	5	1.6
When purchasing beef, what do you typically tend to buy at the retail store?			
	Grass-fed	69	22.1
	Dry-aged	13	4.2
	Organic	38	12.2
	Traditional beef	237	76.0

Proteins consumed at home or at a restaurant (away from home)

	Protein	Number do not consume	Number consume	Percentage do not consume	Percentage consume
At home	Chicken	6	305	1.9	98.1
	Beef	11	300	3.5	96.5
	Pork	31	280	10.0	90.0
	Fish	52	259	16.7	83.3
	Lamb	238	73	76.5	23.5
	Eggs	10	301	3.2	96.8
	Soy-based	199	112	64.0	36.0
Away from home/restaurant	Chicken	11	299	3.5	96.5
	Beef	8	302	2.6	97.4
	Pork	44	266	14.2	85.8
	Fish	44	266	14.2	85.8
	Lamb	189	121	61.0	39.0
	Eggs	30	280	9.7	90.3
	Soy-based	205	105	66.1	33.9

Continued

was more in line with consumer-desired thickness for this study.

Consumer evaluation

Consumers evaluated beef top loin steaks from the same treatments used for expert descriptive sensory evaluation (Table 5). Quality grade by steak thickness and quality grade by cook surface temperature did not impact consumer sensory ratings ($P > 0.05$). However, steak thickness by grill temperature impacted ($P < 0.05$) overall, flavor, beef flavor, grill flavor, and juiciness liking. Thick top loin steaks cooked using a higher grill temperature were rated lower in overall, flavor, beef flavor grill flavor, and juiciness liking than thick top loin steaks cooked using a lower grill temperature or thinner top loin steaks cooked at either high or lower grill temperatures. Flavor and grill flavor liking were highest ($P < 0.05$) for either thin steaks cooked with a grill temperature of 232°C or thick steaks cooked us-

Table 4. (cont.)

Question	No. of respondents		Percentage of respondents	
What cooking method do you prefer to use when cooking a beef steak?				
	Number do not use	Number use	Percentage do not use	Percentage use
Pan-frying or using a skillet on the stove	152	159	48.9	51.1
Stir fry	205	106	65.9	34.1
Grilling outside	44	267	14.1	85.9
Oven broiling	224	87	72.0	28.0
Oven baking	215	96	69.1	30.9
Microwave	301	10	96.8	3.2
Electric appliance (George Foreman Grill or other grill)	251	60	80.7	19.3
	Do not eat	Eat	Do not eat	Eat
American	20	292	6.4	93.6
Barbeque	19	293	6.1	93.9
Mexican/Spanish	25	287	8.0	92.0
Indian	191	121	61.2	38.8
Chinese	30	282	9.6	90.4
Greek	155	157	49.7	50.3
Japanese	140	172	44.9	55.1
Italian	74	298	19.9	80.1
French	187	125	59.9	40.1
Thai	146	166	46.8	53.2
Lebanese	235	77	75.3	24.7

ing a grill temperature of 177°C. Consumer juiciness was highest ($P = 0.01$) for thick or thin top loin steaks cooked using a 177°C grill temperature. These results were similar to trained descriptive attribute flavor attributes where the thicker steaks cooked using a higher grill temperature had lower beef flavor attributes and more burnt and bitter flavors.

Thicker steaks had lower ($P < 0.05$) consumer tenderness liking. Additionally, consumers liked Top Choice top loin steaks more than Select top loin steaks and rated the flavor, grill flavor, juiciness, and tenderness liking higher ($P < 0.05$). These results are similar to Legako et al. (2015) who found that Select and Top Choice strip steaks cut to 2.5 cm and cooked on a clamshell grill at 225°C for 5 min did not differ in juiciness, flavor, or overall liking. Conversely, Hunt et al. (2014) cooked and prepared steaks similarly to the previous study, but found differences in all consumer attributes. Hunt et al. (2014) reported that Top Choice steaks were rated higher by consumers. Smith et al. (1987) found that broiled Choice top loin steaks had more flavor, juiciness, and overall palatability than Select top loin steaks when evaluated using a trained meat descriptive attribute sensory panel. However, Luchak et al. (1998) reported that Choice and Select top loin steaks did not differ in trained meat descriptive attributes of juiciness and flavor intensity. Luchak et al. (1998) additionally found that cooking method affected the sensory properties for eye of round steaks.

Berry and Bigner (1995) examined palatability of steaks cooked using 2 cooking methods and 2 temperatures within cooking method. While palatability differences were not extensive, steaks cooked on a slatted grill at either 204 or 232°C did not differ in beef flavor intensity or juiciness. These results differed from the current study. In the current study, steaks were cooked using a flat top grill where the actual cooking surface was either 177 or 232°C. Berry and Bigner (1995) used a slatted grill that sat 1.2 cm above the heat source and actual cook surface temperatures were between 74 and 99°C. This temperature difference most likely affected steak flavor development, mainly in the rate of the Maillard reaction. The Maillard reaction requires high heat (>130°C to 140°C) for the reaction to occur rapidly during the cooking process but can also occur at room temperature over time (Shahidi et al., 2004). It should be noted that the temperatures of the reactions are highly debated and there is not consensus on when the reaction occurs.

Figure 1 shows the relationships between descriptive flavor and tenderness attributes, consumer sensory attributes, and three-way interaction treatments. Consumer attributes were clustered. Overall, overall flavor and beef flavor liking were very closely associated. Grilled flavor, juiciness, and tenderness lik-

Table 5. Least squares means for consumer attributes[1] for USDA Select and Top Choice beef top loin steaks across grill temperature and steak thickness

Treatment	Overall liking	Flavor liking	Beef flavor liking	Grill flavor liking	Juiciness liking	Tenderness liking
Quality grade2	0.07	0.03	0.07	0.01	0.02	0.02
Top Choice	6.3	6.4[b]	6.6	6.2[b]	6.2[b]	6.4[b]
Select	6.2	6.2[a]	6.4	6.0[a]	6.0[a]	6.2[a]
Thickness, cm × Temperature, °C[2]	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.002	0.03
1.3, 177	6.4[b]	6.4[b]	6.6[b]	5.9[b]	6.2[bc]	6.6[c]
1.3, 232	6.5[b]	6.5[b]	6.6[b]	6.4[a]	6.1[b]	6.5[c]
3.8, 177	6.6[b]	6.6[b]	6.8[c]	6.5[c]	6.3[c]	6.2[b]
3.8, 232	5.5[a]	5.6[a]	6.0[a]	5.5[a]	5.7[a]	5.8[a]
City × thickness, cm	0.001	0.0001	0.0004	0.0002	0.0004	0.0001
Griffin, GA × 1.3	6.7[d]	6.8[f]	6.9[e]	6.5[b]	6.8[e]	7.0[d]
Olathe, KS × 1.3	6.1[b]	6.1[bc]	6.2[ab]	6.0[a]	6.0[bc]	6.4[c]
State College, PA × 1.3	6.4[c]	6.5[e]	6.7[cde]	5.9[a]	5.9[b]	6.4[c]
Portland, OR × 1.3	6.4[c]	6.4[cde]	6.5[bc]	6.0[a]	5.9[ab]	6.3[bc]
Griffin, GA × 3.8	6.0[b]	6.0[b]	6.3[b]	5.9[a]	6.4[d]	6.2[bc]
Olathe, KS × 3.8	5.7[a]	5.7[a]	6.0[a]	5.7[a]	5.6[a]	5.5[a]
State College, PA × 3.8	6.0[b]	6.2[bcd]	6.5[bcd]	6.0[a]	5.8[ab]	6.0[b]
Portland, OR × 3.8	6.5[c]	6.4[de]	6.8[de]	6.4[b]	6.3[cd]	6.4[c]
Root mean square error	1.73	1.78	1.68	2.83	1.85	1.87

[a–f]Least squares means within a column and treatment followed by the same letter are not significantly different ($P > 0.05$).

[1]1 = dislike extremely, 9 = like extremely.

[2]*P*-values from the analysis of variance table.

ing were closely related to overall liking, but not as closely associated as beef flavor liking to overall liking. Descriptive flavor and basic taste attributes of overall sweet, sweet, and fat-like were clustered most closely with consumer liking attributes. Umami and fat-like descriptive attributes were associated with grilled flavor liking and tenderness liking was closely related to bloody/serumy, muscle fiber tenderness and overall tenderness. Consumer liking attributes were negatively associated with bitter, burnt, and metallic descriptive sensory attributes. Select and Top Choice 3.8-cm thick steaks cooked on a 232°C grill were most negatively associated with consumer liking. Other treatments were similarly associated with consumer liking attributes indicating similar consumer responses across these treatments.

Conclusions

In examining USDA quality grade, steak thickness, and grill temperature effects on the descriptive and consumer sensory attributes of beef top loin steaks, steak thickness and grill temperature affected the subsequent flavor of these steaks to a greater degree than USDA quality grade. Top Choice and Select beef top loin steaks differed in beef flavor and consumer sensory attributes, but did not differ in texture attributes. Thin steaks cooked using low or high grill temperatures had similar descriptive flavor and texture attributes and consumer liking attributes; however, Top Choice and Select thick steaks (3.8-cm thick) cooked on a high temperature grill had more bitter, burnt, and metallic descriptive flavor attributes that were negative consumer attributes. Overall liking of beef top loin steaks can be predicted using trained descriptive flavor and texture attributes.

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