Meat and Muscle Biology™

2018 United States Beef Flavor Audit: Consumer and Descriptive Sensory Attributes[1]

Rhonda K. Miller[2]*, Cassandra A. Pena[2], Jerrad F. Legako[3], Dale Woerner[3], Chance Brooks[3], Bailey Schilling[3], Mahesh N. Nair[4], Traci Cramer[4], Paige Smith[2], Kayley R. Wall[2], and Chris R. Kerth[2]

[2]Department of Animal Science, Texas A&M University, College Station, TX, 77843-2471, USA
[3]Department of Animal and Food Science, Texas Tech University, Lubbock, TX, 79409, USA
[4]Department of Animal Science, Colorado State University, Fort Collins, CO, 80523, USA
*Corresponding author. Email: rmiller@tamu.edu (Rhonda K. Miller)
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Abstract: Beef flavor has been identified as a driver of consumer acceptability; however, little is known about variability of flavor in major United States retail beef cuts. Four beef cuts (chuck roast; top sirloin steaks; top loin steaks; and 80/20 ground beef) were obtained from retail stores (n = 30 per cut per city) in Miami, Los Angeles, Portland, New York, and Denver during a 2-mo period in 2018. Production systems or package claims were documented. An expert trained flavor and texture descriptive attribute sensory panel evaluated beef flavors, aromas, and textures (n = 10 cuts per city or 50 cuts evaluated). Consumer sensory panels in Fort Collins, CO (n = 10 per cut/city), and Lubbock, TX (n = 10 per cut/city), evaluated beef for overall liking, overall flavor, beef flavor, grilled flavor, juiciness, and texture liking. Ground beef patties (GB) were more intense ($P < 0.0001$) in brown, fat-like, green hay-like, and sour milk/sour dairy flavor aromatics and salty and sweet basic taste than steak or roast cuts. Additionally, GB had the lowest levels ($P < 0.0001$) of bloody/serumy, metallic, and liver-like flavor aromatics. Chuck roasts had the lowest levels of ($P < 0.0001$) beef flavor identity, brown, and roasted flavor aromatics and salt and umami basic tastes. Top sirloin steaks were lowest ($P < 0.0001$) in fat-like flavor aromatics and most intense ($P < 0.0001$) in burnt, cardboardy, bitter, and sour attributes. Top sirloin steaks and chuck roasts were more intense in metallic and liver-like ($P < 0.0001$) flavor aromatics. Consumers rated chuck roasts lowest for overall, overall flavor, grilled flavor, and juiciness liking ($P < 0.04$). GB and top loin steaks had the highest consumer texture liking ($P < 0.0002$). Beef descriptive flavor and texture attributes were related to consumer liking, and negative flavor aromatic attributes were identified. Variation in beef flavor attributes were reported in retail beef cuts and ground beef that impact consumer liking.

Key words: beef, flavor, sensory, consumer
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Introduction

Positive flavor attributes have been closely associated with consumer acceptability of beef (Shahidi, 1994; Huffman et al., 1996; Maughan et al., 2012; Glascock, 2014; Laird, 2015; Luckemeyer, 2015; Miller, 2020). Understanding differences in beef tenderness and the impact on consumer acceptability or satisfaction has been extensively evaluated (Savell et al., 1989; Shackelford et al., 1991; Neely et al., 1998; Lorenzen et al., 1999; Roeber et al, 2000; Miller et al., 2001; Watson et al., 2008; Miller, 2020; Warner et al., 2021). As the beef industry addressed improving tenderness and reducing the variability in tenderness (Morgan et al., 1991; Brooks et al., 2000; Voges et al., 2007; Guelker et al., 2013; Martinez et al., 2017), the impact of flavor on consumer acceptability became a focus (Maughan et al., 2012; O'Quinn et al., 2012; Glascock, 2014; Corbin et al., 2015; Laird, 2015; Luckemeyer, 2015; Legako et al., 2016). Understanding the impact of cooking method, marbling level, degree of doneness, beef cut, and production systems have been examined. Beef flavor aromatics and basic

tastes were identified by Adhikari et al. (2011) and have been used to identify descriptive sensory flavor attributes that are positively and negatively associated with consumer acceptability. Through this research, flavor attributes that are either positive or negative drivers of consumer acceptability of beef flavor are apparent.

Although it has been established that beef flavor varies and is influenced by many factors, an understanding of how variable beef in the retail meat case is for flavor attributes was needed. Our objective was to determine descriptive flavor and texture sensory attributes and consumer acceptability for 4 beef retail products selected across 5 cites to understand variability in retail beef flavor attributes.

Materials and Methods

Trained sensory panelist training, testing, and consumer evaluation procedures were approved by the Texas A&M Institutional Review Board (IRB2018-0958M).

Sample selection and preparation

Top loin steak packages (n = 30/city), top sirloin steak packages (n = 30/city), chuck roast packages (n = 30/city), and 80/20 ground beef packages (n = 30/city) were selected in major retail stores in Miami, FL, Denver, CO, Portland, OR, New York City, NY, and Los Angeles, CA, from August 29 to September 25, 2018. Meat selection occurred in 6 to 8 high volume retail stores that significantly contributed to major beef retail sales in each city. Any available packaging information was recorded by Texas Tech University personnel. No specific quality grade, package type, or claim was selected, but cuts were purchased that represented retail cuts present when selection occurred. Meat was shipped to Texas Tech University under refrigeration in coolers with ice (temperatures were verified upon receipt at Texas Tech University to assure samples were maintained at less than 4°C upon arrival), vacuum packaged (3.5 mil thermoform vacuum packaging, moisture vapor transmission: 4.8 g/m^2 127/d; Multivac F100; Kansas City, MO) and identified with a unique 4-digit identification code. Vacuum-packaged meat was frozen to −20°C. Steaks, roasts, and ground beef within a city and cut were randomly assigned to evaluation method where 10 packages per cut per city were assigned for trained descriptive flavor and texture attribute evaluation at Texas A&M University; 10 packages per cut per city were segmented to consumer evaluation by Texas Tech University in Lubbock, TX; and 10 packages per cut per city were assigned to consumer evaluation by Colorado State University in Fort Collins, CO. Frozen samples were shipped with dry ice to Texas A&M University and Colorado State University, respectively. Therefore, 50 packages per cut were evaluated for descriptive flavor and texture sensory analysis, and 50 packages per cut, respectively, were evaluated in Lubbock, TX, and Fort Collins, CO, for consumer sensory analysis.

For trained descriptive flavor and texture evaluation, packages per cut and city were assigned a random 3-digit code and randomly assigned a cook date and order of cooking within date. Loose or open vacuum packages were repackaged (B2470, Cryovac, Sealed Air Corporation, Duncan, SC; oxygen transmission rate of 3 to 6 cc at 4°C (m^2, 24 h atmosphere @ 4°C, 0% relative humidity [RH]) and 0.5 to 0.6 g at 38°C (100% RH, 0.6 m^2, 24 h) for water vapor transmission)). Samples were stored at −9°C for up to 4 mo until 24 h prior to sensory evaluation.

Twenty-four hours prior to cooking, meat was placed in a 4°C cooler so that samples did not overlap. As chuck roasts varied in thickness and size, each roast was cut into sections (10.16 × 12.7 cm by the natural thickness of the roast) from the center of the roast, ensuring that all muscles in the roast would be present. Each ground beef sample was formulated into three 150 g patties flattened using a patty press (approximately 11 cm diameter by about 1 cm thick; Cuisinart Outdoor Grilling CABP-300 Cuisinart Adjustable Burger Press, Cuisinart, Stamford, CT) and to ensure consistent patty thickness. Top loin and top sirloin steaks were maintained in the size and shape as when purchased. Sample raw weight was obtained, and copper constantan thermocouples (Omega Engineering, Stamford, CT) were placed in the geometric center of whole muscle cuts to monitor cooking temperature. Ground beef patty temperatures were taken using a thermocouple probe (Omega Engineering) to monitor cook temperature. Temperatures were monitored using a handheld thermometer (model HH-72T, Omega Engineering).

Cooking

Chuck roast sections were placed in 35 × 26 cm roasting pans with a roasting rack and 473 ml of double-distilled, deionized water placed in the bottom of the pan. Roasting pans were placed uncovered in a gas-heated conventional oven (GE Profile, General Electric Co., Boston, MA) preheated to 177°C. Roast sections were cooked to an internal temperature of 71°C and then removed from the oven. Steaks and ground beef patties were cooked on a stainless steel

electric stove top grill (StarMax 536GF 36 inch Countertop Electric Griddle, Star Manufacturing International, Inc., St. Louis, MO) set at 177°C. Grill and oven temperatures were verified prior to initiation of cooking. Initial internal temperatures and time were recorded. All samples were cooked until reaching an internal temperature of 71°C; steaks and patties were flipped when internal temperature reached 35°C. Final internal temperature, time, and cooked weight were recorded. Samples were wrapped in aluminum foil and placed in a Bain Marie warmer (APW Wyott W-3Vi 30.5 × 50.8 cm, Allen, TX) with water held at 63°C in warmer pans and lids (Royal Industries, 15.2 × 25.4 cm, Brooklyn, NY) for no more than 20 min prior to being served to the trained descriptive flavor and texture panel. Chuck roasts were cut into 1.27 cm cubes with no visible connective tissue, fat, or outside browning. The outside browning was removed from roasts as roast sections were smaller than the original roasts and the exterior browning would have contributed a greater proportion to the overall flavor of roasts. By evaluating the internal roast samples, flavor and texture attributes were related to the internal flavor of the cut. Steaks were cut into 1.27 cm by the natural thickness of the steak with no visible connective tissue or fat. Patties were cut into 6 approximately similar wedges as defined by AMSA (2016). Panelists were served either 2 wedges (ground beef) or two 1.27 cm random samples of chuck roast or steaks for evaluation.

Descriptive flavor and texture attribute panels

Five expert descriptive flavor and texture attribute panelists with more than 400 h of experience were used. Panelists were trained for 13 d reintroducing flavor and texture attributes from the beef lexicon (Adhikari et al., 2011) and AMSA (2016). Forty-seven flavor and texture attributes were used (Table 1). Texture attributes differed for ground beef (cohesiveness of mass, hardness, initial juiciness, particle size, and springiness) and steaks and roasts (juiciness, connective tissues, and muscle fiber tenderness). References for flavor and texture were provided to panelists continually during training and testing. Panelists were provided an expectorant cup, double-distilled, deionized water, napkins, and saltless saltine crackers (Premium Unsalted Tops Saltine Crackers, Nabisco, East Hanover, NJ) and were required to use the crackers followed by water as palate cleansers between samples.

For testing, panelists evaluated steaks, ground beef, and roasts (n = 199) for 17 testing days wherein 12 samples were tested within a 2-h period with a 10-min break approximately after 1 h to prevent fatigue. Fifteen minutes before each testing session a "warmup" sample was given to panelists and group leader, and each attribute was discussed and given a score (0 = none and 15 = extremely intense) for daily calibration. The warmup was rotated between top sirloin steaks, top loin steaks, ground beef patties, and chuck roasts. Warmup samples were served as defined for testing.

Each panelist was seated in separate breadbox-style booths that contained red lights (44.2 lux) to mask color effects. Samples were identified with random 3-digit codes and served at least 5 min apart in soufflé cups that would not impart flavor. Panelists recorded their scores using a 16-point scale from 0 = none to 15 = extremely intense on an electronic ballot on an iPad (Apple Inc., Cupertino, CA).

Consumer sensory

Beef cuts and ground beef were randomly assigned to consumer evaluation at 2 locations. Cuts for descriptive attribute evaluation were similar or companion samples to consumer sensory samples. Fifty packages per cut type were used by Texas Tech University and Colorado State University where 95 and 100 consumers, respectively, were selected randomly from consumer data banks. Consumers were selected who normally eat beef 3 or more times per week. Within a location, 6 consumer sessions with approximately 20 consumers per session were conducted. Consumers were seated individually under white lights and provided the same palate cleansers as previously defined. Consumer demographics for age, sex, income, household income, type of employment, protein sources consumed, consumption levels of beef, and meat shopping habits were determined. The electronic ballot included overall liking and overall flavor, beefy flavor, grilled flavor, juiciness, and tenderness liking questions using end and middle anchored 9-point hedonic scales. Two open-ended questions were asked: 1) describe any positive or good flavors, and 2) describe any negative or bad flavors within each sample. Panelists were provided 8 preidentified random samples in a predetermined random order 4 min apart. Each consumer evaluated 2 ground beef patties, 2 top loin steaks, 2 top sirloin steaks, and 2 chuck roast samples in random order. Four consumers evaluated each beef cut. Samples were served in clear plastic soufflé cups labeled with a random 3-digit number corresponding to their ballot. Samples were cut and prepared as

Table 1. Definition and reference standards for beef descriptive flavor aromatics, basic taste, and texture/tenderness sensory attributes and their intensities where 0 = none and 15 = extremely intense

Attributes	Definition	Reference
Flavor aromatics		
Animal hair	The aromatic perceived when raw wool is saturated with water	Caproic acid (1 drop) on cotton ball = 12.0 (a)
Asparagus	The slightly brown, slightly earthy green aromatics associated with asparagus	Fresh asparagus (40 g) diced in water with cooked green asparagus (200 mL) microwave (3 min) = 7.5 (a), 6.5 (f)
Barnyard	Combination of pungent, slightly sour, hay-like aromatics associated with farm animals and the inside of a horn	White pepper (0.45 g) steeped in water (30 min). Filter = 4.5 (a), 4.0 (f)
Beef identity	Amount of beef flavor identity in the sample	Swanson Beef Broth = 5.0; 80% lean ground chuck = 7.5 Beef brisket (160°F) = 11.0
Beet	A dark damp-musty-earthy note associated with canned red beets	Food Club sliced beets and water (1:2) = 6.0 (a), 4.0 (f)
Bloody/serumy	The aromatics associated with blood on cooked meat products closely related to metallics	Choice strip steak (140°F) = 5.5 (a), (f) Beef brisket (160°F) = 6.0 (a), (f)
Brown	A round, full aromatic generally associated with beef suet that has been broiled	Beef suet (broiled) = 8.5
Burnt	The sharp/acrid flavor note associated with overroasted pork muscle, something overbaked or excessively browned in oil	Arrowhead Mills Puffed Barley Cereal = 3.0
Buttery	Sweet, dairy-like aromatic associated with natural butter	Land O'Lakes unsalted (1/2 tbsp) = 7.0
Cardboardy	Aromatic associated with slightly oxidized fats and oils, reminiscent of wet cardboard packaging	Dry cardboard (1 in square) = 5.0 Wet cardboard soaked in water (1 cup) for 30 min = 7.0
Chemical	The aromatics associated with garden hose, hot Teflon pan, plastic packaging, and petroleum-based products such as charcoal liter fluid	Clorox (1 drop) in water (200 mL) = 6.5 (a)
Cocoa	Aromatic associated with cocoa beans, powdered cocoa, and chocolate bars; brown, sweet, dusty, often bitter aromatics	Hershey's cocoa (1/2 tsp) water (1/2 cup) = 3.0 Hershey's chocolate kiss = 7.5 (a), 8.5 (f)
Cooked milk	The combination of sweet, brown flavor notes and aromatics associated with heated milk	Mini Babybel original Swiss cheese regular = 2.5 Whole milk microwaved (2 min) = 4.5
Cumin	The aromatics commonly associated with cumin and characterized as dry, pungent, woody, and slightly floral	McCormick ground cumin (1/4 tsp) = 10.0 (a), 7.0 (f)
Dairy	Aromatics associated with products made from cow's milk containing reduced fat 2% milk butter fat, such as cream, milk, sour cream, or butter milk	2% Dillon's reduced fat milk serve 1/2 oz = 8.0
Fat-like	Aromatics associated with cooked animal fat	Hillshire Farms Beef Lit'l Smokies = 7.0; beef suet (broiled) = 12.0 (a, f)
Floral	Sweet, light, slightly perfumed impression associated with flowers	Welch's white grape juice in water (1:1 parts) = 5.0
Green	Sharp, slightly pungent aromatics associated with green/plant/vegetable matters such as parsley, spinach, pea pod, fresh cut grass, etc.	Geraniol (2 drops) on cotton ball = 7.5 (a) Fresh parsley (25 g) steeped in water for 15 min then drained = 9.0
Green hay	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley, and tea leaves	Dry parsley (1/4 tsp) in 2 oz cup = 5.0 (a)
Heated oil	The aromatics associated with oil heated to a high temperature	Wesson vegetable oil (1/2 cup) microwaved (3 min) = 7.0 (a) Lay's potato chips = 4.0 (a)
Leather	Musty, old leather (like old book bindings)	Leather cord in medium snifter = 3.0 (a)
Liver-like	Aromatics associated with cooked organ meat/liver	Beef liver (1 in) = 7.5 (a, f) Braunschweiger liver sausage = 10.0 (a, f)
Metallic	The impression of slightly oxidized metal, such as iron, copper, and silver spoons	0.10 potassium chloride solution = 1.5; Choice strip steak (140°F) = 4.0; Dole canned pineapple juice = 6.0
Overall sweet	The combination of sweet taste and sweet aromatics	Post Shredded Wheat spoon size = 1.5; Hillshire Farms Beefl Lit'l Smokies = 3.0; Lorna Doone cookies = 5.0
Petroleum-like	A specific chemical aromatic associated with crude oil and its refined products that have heavy oil characteristics	Vaseline petroleum jelly = 3.0 (a)
Rancid	The aromatics commonly associated with oxidized fats and oils; these may include cardboard, painty, varnish, and fishy	Wesson vegetable oil (1/2 cups) microwave (3 min) = 7.0 (a)
Refrigerator stale	Off-flavor associated with a product that has absorbed odors from the refrigerator	Ground beef (165°F) stored overnight = 4.5 (a), 5.0 (f)

Table 1. (*Continued*)

Attributes	Definition	Reference
Roasted	A round, full aromatic generally associated with beef that has been broiled/roasted	80% lean ground chuck = 10.0; Hormel pot roast = 6.0
Soapy	An aromatic commonly found in unscented hand soap	Clorox liquid (0.12 oz) in water (4 oz) = 3.0 (a); 0.5 g Ivory bar soap in water (100 mL) = 6.5 (a)
Smoky charcoal	An aromatic associated with meat juices and fat drippings on hot coals which can be acrid, sour, burnt, etc.	Wright's Natural Hickory Seasoning (1/4 tsp) in water (100 mL) = 9.0 (a)
Smoky wood	Dry, dusty aromatic reminiscent of burning wood	Wright's Natural Hickory Seasoning (1/4) tsp in water (100 mL) = 7.5 (a)
Sour aromatics	Aromatics associated with sour substances	Buttermilk (1/2) oz = 5.0
Sour milk/sour dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream	HEB Swiss cheese = 3.0 (a), 7.0 (f); buttermilk = 4.0 (a), 9.0 (f)
Warmed over	Perception of a product that has been previously cooked and reheated	Reheated ground beef (165°F) = 6.0
Basic tastes		
Bitter	The fundamental taste factor associated with a caffeine solution	0.01% caffeine solution = 2.0; 0.02% caffeine solution = 3.5
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
Sweet	The fundamental taste factor associated with sucrose	2.0% sucrose solution = 2.0
Sour	The fundamental taste factor associated with citric acid	0.015% citric acid solution = 1.5; 0.050% citric acid solution = 3.5
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 (flavor)
Whole muscle meat texture		
Connective tissue	The structural component of the muscle surrounding the tissue amounts during mastication	Brisket steak cooked to 70°C = 7.0; tenderloin cooked to 70°C = 14.0
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 58°C = 11.0; Choice top loin steak cooked to 80°C = 9.0
Muscle fiber tenderness	The ease in which the muscle fiber fragments during mastication	Select eye of round cooked to 70°C = 9.0; tenderloin cooked to 70°C = 14.0
Ground beef textures		
Cohesiveness of mass	The amount to which sample deforms rather than crumbles, cracks, or breaks	Licorice (1 piece) = 0.0; carrots (1/2 in) = 2.0; mushrooms (1/2 in) = 4.0; Hebrew National frankfurter cooked (5 min) = 7.5; yellow American cheese (1/2 in) = 9.0; Little Debbie soft brownie (frosting removed) = 13.0; Pillsbury/country biscuit dough = 15.0
Hardness	The force to attain a given deformation, such as force to compress with the molars, compression between tongue and palate, or force to bite through with incisors.	Philadelphia cream cheese = 1.0; yellow American cheese = 4.5; Goya Foods olive = 6.0; Hebrew National frankfurter cooked 10 min = 7.0; Planters peanut = 9.5; carrot (1/2 in) = 11.0; Life Savers = 14.5
Initial juiciness	The amount of perceived juice that is released from the product during the initial 2-3 chews	Carrot (1/2 in) = 8.5; mushroom (1/2 in) = 10.0; cucumber = 12.0; apple = 13.5; watermelon = 15.0; Choice top loin steak cooked to 58°C = 11.0; Choice top loin steak cooked to 80°C = 9.0
Particle size	The degree to how big the particle is	Small pearly tapioca = 4.0; boba tea tapioca = 8.0
Springiness	The degree to which samples returns to original shape or the rate with which sample returns to original shape	Philadelphia cream cheese (1/2 in) = 0.0; Hebrew National frankfurter cooked 10 min = 5.0; marshmallow = 9.5; gelatin dessert = 15.0

a = aroma; f = flavor.

defined for expert trained beef flavor and texture descriptive analysis.

Statistical analysis

Data were analyzed using SAS (version 9.4, SAS Institute, Cary, NC) with an alpha of $P < 0.05$. For descriptive attributes data, analysis of variance using the PROC GLM procedure was used. Testing day and order were defined as random effects, and beef cuts were defined as a main effect. The first analysis utilized panelist evaluation within a beef cut as an experimental unit. Data were analyzed with panelist and panelist by beef cut interaction included in the model. Panelist by beef cut interactions were not significant ($P > 0.05$) for individual sensory flavor and texture attributes, so data were averaged across sensory panelists within a cut and

analyzed as previously defined. It should be noted that final cook temperature was used as a covariate to determine if variation associated with accuracy of cooking to the defined cook temperature endpoint (71°C) accounted for variation. The covariate was not significant ($P > 0.20$) and therefore was not included in the final analyses. Least-squares means were calculated, and when significance was identified in the analysis of variance, differences between least-squares means were determined using the adjusted Tukey function. Frequency distributions for flavor descriptive attributes by cut were calculated using PROC FREQ and PROC MEANS was used to generate unadjusted mean data.

For consumer sensory data, consumer demographic data was calculated using the PROC FREQ function and presented as number and percentages. To determine if the consumer data were normally distributed, the Box-Cox function of PROC TRANSREG was used. For consumer sensory data, overall, flavor, beef, grill, and texture liking were transformed by 1.4, 1.3, 1.3, 1.1, and 1.2 logs, respectively. It should be noted that juiciness liking was normally distributed. Least-squares means and root mean square errors were retransformed to 9-point data for ease of interpretation. Consumer data from Colorado State were collected using 10-point scales. These data were converted to 9-point scales by identifying a 0 and 1 consumer data point as a 1. The PROC GLM procedure was used to analyze transformed consumer sensory data where order served and consumer within location were defined as random effects. The fixed effects of location (defined as location of consumer evaluation as either Lubbock, TX, or Fort Collins, CO), location by cut, cut and city (defined as city where the cut was purchased) by cut were included as main effects. City and city by cut were not significant for consumer traits, and therefore, least-squares means were deleted. Least-squares means were calculated for consumer sensory attributes by cut, and if differences were reported in the analysis of variance, adjusted Tukey function was used to determine differences between transformed means. Least-squares means were transformed back to the original scale for ease of interpretation; however, root mean square errors were reported for the transformed data.

To understand relationships between trained descriptive flavor and texture attributes and consumer sensory attributes, XLSTAT (v2020, Addinsoft, New York, NY) was used. Principal component analysis (PCA) was used, and results were presented as biplots. In the PCA comparing descriptive and consumer sensory attributes, descriptive attributes that were defined as barely detectable (1 on the 15 point scale) or higher were included in the analysis. Agglomerative hierarchical cluster analysis was used to understand segmentation of consumer responses for consumer sensory attributes.

Results and Discussions

Packaging information

Package types and quality grade for top loin and sirloin steaks, ground beef, and chuck roasts are reported in Table 2. The majority of top loin steaks (54%)

Table 2. Package information and quality grade frequencies of top loins and top sirloin steaks, ground beef, and chuck roasts

	Top loin steaks		Top sirloin steaks		Ground beef		Chuck roasts	
Package type	n	%	n	%	n	%	n	%
Overwrap	27	54	33	67	19	38	40	80
Overwrap-MAP	1	2	2	4	1	2	0	0
Vacuum packaged	13	26	9	18	13	26	10	20
Chub	0	0	0	0	5	10	0	0
MAP	8	16	4	8	8	16	0	0
MAP-CO	1	2	1	2	2	4	0	0
Unknown	0	0	0	0	2	4	0	0
USDA beef quality grades								
Standard	0	0	0	0	0	0	0	0
Select	0	0	0	0	1	2	0	0
Choice	26	52	31	63	0	0	40	80
Top Choice Programs[1]	1	2	0	0	0	0	0	0
Prime	6	12	3	6	0	0	0	0
Not identified	17	34	15	31	49	98	10	20

[1]Top Choice Programs included beef marbling scores of moderate and modest.

MAP = modified atmosphere packaged; MAP-CO = modified atmosphere packaged containing carbon monoxide.

were purchased in overwrap packaging. However, 26% of top loin steaks were vacuum packaged, and 16% were purchased in modified atmosphere packaging. Interestingly, 2% of top loin steaks were packaged in modified atmosphere packaging with carbon monoxide or overwrap packaging with a modified atmosphere, respectively. Top sirloin steaks were similarly packaged with a slightly higher percentage of top sirloin steaks overwrap packaged, and less were vacuum packaged. Although 38% of ground beef samples were in overwrap packaging, 26% were in vacuum packaging, 16% were in modified atmosphere packaging, and 10% were in chub packaging. Chuck roasts were mostly packaged with overwrap (80%) and vacuum packaged (20%).

Overwrap packaging is the most common type of packaging used for fresh meat due to positive bright cherry red color and product visibility (Mancini and Hunt 2005; McMillan, 2017). Overwrap packaging is commonly used for short-term shelf life in the retail meat case, whereas modified atmosphere packaged is used for long-term storage (McMillin, 2017). Vacuum packaging and modified atmosphere packaging are widely utilized packaging systems in the retail meat case. Extensive research has been conducted on variant atmospheres for modified atmosphere packaging and the relationship of atmosphere and meat shelf life (Jeremiah, 2001; Hunt et al. 2004; Mancini and Hunt, 2005; McMillan, 2017; Polkinghorne et al., 2018). Additionally, vacuum packaging extends storage life and quality and reduces off-flavor and odor development in beef (Jeremiah, 2001; Polkinghorn et al., 2018). Young et al. (1988) stated that beef that had been vacuum packaged lasted up to about 28 d. At about 34 d, off odors began to appear in meat (Erichsen et al., 1981). McMillin (2017) found about 88% of consumers bought ground beef in overwrapped packaging, whereas 54% intended to buy ground beef in chub form. Although packaging type may impact flavor and texture of beef cuts purchased, packaging types were representative of beef in the retail case and thus were acceptable for use in assessing variation in flavor.

Beef quality grade or grade-associated claims on retail beef packages are reported (Table 2). Top loin and top sirloin steaks and chuck roasts were not identified as Standard or Select USDA Beef Quality grades. One sample of Select ground beef was purchased and was the only ground beef package identifying a USDA quality grade. However, 34%, 31%, 98%, and 20% of top loin steaks, top sirloin steaks, ground beef, and chuck roasts, respectively, did not have a quality grade designation. It could be hypothesized that a portion of these cuts were from the Select quality grade. Eighty percent of beef chuck roasts were defined as Choice on the package, whereas 52% and 63% of top loin and top sirloin steaks, respectively, were identified as Choice. Top loin and top sirloin steaks were 12% and 6% Prime, respectively. These grade designations for the experimental beef cuts are relevant, as they impact flavor characteristics. As a high percentage of cuts did not have an identified quality grade, quality grade was not used in data analysis.

Flavor and texture descriptive analysis

Beef flavors and texture descriptive attributes differed ($P < 0.05$) across beef cuts (Table 3). Of these flavor attributes, beef flavor identity, brown, roasted, bloody, fat-like, sweet, salty, and umami have been reported as positive flavors or flavors associated with increased consumer overall liking (Miller and Kerth, 2012; Glascock, 2014; Miller et al., 2019). Additionally, metallic, barnyard, bitter, burnt, cardboardy, leather, liver-like, and sour milk/sour dairy have been defined as negative flavors or flavors associated with decreased consumer overall liking (Adhikari et al., 2011; Glascock, 2014; Miller et al., 2019; Miller, 2020). Flavor attributes that were not reported as they were not present or were at nonidentifiable levels (below 0.1) were animal hair, beet, chemical, cocoa, rancid, smoky wood, sour aromatics, warmed over, soapy, floral, petroleum, cumin, and dairy (data not presented).

Top loin steaks and ground beef were highest ($P < 0.0001$) in beef identity, roasted, and umami flavor aromatics and lowest ($P < 0.0001$) in liver-like flavor aromatics. Ground beef was lowest ($P < 0.05$) in bloody, metallic, cardboardy, and leather flavor aromatics and highest ($P < 0.05$) in fat-like, salty, sweet, overall sweet, buttery, smoky charcoal, green hay-like, green, and cooked milk flavor aromatics and basic tastes. Top sirloin steaks were highest in bitter ($P < 0.0001$) and sour ($P < 0.05$) basic tastes and cardboardy ($P < 0.0001$) flavor aromatic. Chuck roast were lowest ($P < 0.0001$) in beef identity, brown, and roasted flavor aromatics and bitter and umami flavor basic tastes. As chuck roasts were cooked using a different cooking method, some of these effects were due to cooking method; however, roasting is the most common cooking preparation method for this cut. The exterior surface was removed from chuck roast samples that may have reduced brown and roasted flavor aromatics. Chuck roasts and top sirloin steaks were highest ($P < 0.0001$) in liver-like flavor aromatics.

Table 3. Least-squares means for beef flavor aromatics[e] and basic tastes[e] by 4 beef cuts; whole muscle beef texture[f] by 3 cuts; and unadjusted means for ground beef texture[g]

Effect	*P* value	Top loin steaks	Top sirloin steaks	Chuck roast	80% lean ground beef	Root mean square error
Flavor aromatics						
Beef identity	<0.0001	9.2^{c}	8.7^{b}	7.2^{a}	9.1^{c}	0.7
Brown	<0.0001	9.9^{b}	9.9^{b}	3.3^{a}	10.5^{c}	1.03
Roasted	<0.0001	7.6^{bc}	7.4^{b}	5.9^{a}	7.7^{c}	0.75
Bloody	<0.0001	1.4^{b}	1.5^{b}	2.0^{c}	1.1^{a}	0.48
Fat-like	<0.0001	2.1^{b}	1.8^{a}	2.3^{b}	5.4^{c}	0.56
Metallic	<0.0001	2.1^{b}	2.2^{c}	2.2^{c}	1.9^{a}	0.26
Overall sweet	<0.0001	0.5^{b}	0.3^{a}	0.3^{a}	0.7^{c}	0.25
Burnt	0.0007	0.2^{ab}	0.4^{c}	0.0^{a}	0.2^{bc}	0.46
Buttery	<0.0001	0.1^{ab}	0.2^{a}	0.2^{b}	0.6^{c}	0.29
Cardboardy	<0.0001	1.6^{b}	2.0^{d}	1.8^{c}	1.4^{a}	0.42
Cooked milk	0.001	0.0^{a}	0.0^{a}	0.0^{a}	0.1^{b}	0.08
Green	0.005	0.0^{a}	0.0^{a}	0.0^{a}	0.1^{b}	0.14
Green hay-like	<0.0001	0.0^{ab}	0.0^{a}	0.2^{b}	1.1^{c}	0.32
Leather	0.003	0.2^{b}	0.2^{b}	0.2^{b}	0.0^{a}	0.22
Liver-like	<0.0001	1.6^{a}	2.0^{b}	1.9^{b}	1.5^{a}	0.45
Smoky charcoal	<0.0001	0.3^{b}	0.3^{b}	0.0^{a}	0.5^{c}	0.33
Sour milk/sour dairy	0.0320	0.2^{a}	0.4^{bcd}	0.3^{ac}	0.4^{ad}	0.45
Barnyard	<0.0001	0.1^{a}	0.1^{a}	0.3^{b}	0.1^{a}	0.22
Animal hair	0.002	0.1^{a}	0.0^{a}	0.1^{b}	0.1^{a}	0.32
Basic tastes						
Bitter	<0.0001	2.5^{b}	2.7^{c}	2.1^{a}	2.3^{b}	0.40
Salty	<0.0001	1.8^{a}	1.6^{a}	1.5^{a}	1.9^{c}	0.28
Sour	0.0002	2.5^{a}	2.9^{b}	2.5^{a}	2.4^{a}	0.50
Sweet	<0.0001	1.1^{b}	0.8^{a}	0.7^{a}	1.4^{c}	0.40
Umami	<0.0001	4.2^{c}	3.5^{b}	2.7^{a}	4.3^{c}	0.76
Whole muscle beef texture						
Connective tissue	<0.0001	11.7^{c}	10.8^{b}	9.8^{a}		1.29
Juiciness	0.01	9.1^{b}	8.6^{a}	8.7^{a}		0.72
Muscle fiber tenderness	<0.0001	11.2^{b}	10.2^{a}	10.0^{a}		1.29
Ground beef texture						
Cohesiveness of mass					6.9	
Hardness					4.6	
Initial juiciness					10.6	
Particle size					3.3	
Springiness					4.3	

[a–d]Mean values within a row and cut followed by the same letter are not significantly different ($P > 0.050$).

[e]0 = none; 15 = extremely intense.

[f]0 = extremely abundant, extremely dry, and extremely tough; 15 = none, extremely juicy, and extremely tender.

[g]0 = none, soft, extremely dry, extremely small particles, none; 15 = very cohesive, hard, extremely juicy, extremely large particles, and extremely springy.

Wall (2017) examined flavor attributes in ribeye, top sirloins, and top loin steaks and found that top loins were more intense in beef identity, brown, and roasted flavor aromatics. When comparing top loin with top sirloin steaks, top loin steaks had more intense beef identity, umami, and overall sweet as similarly reported in Table 2 (Wall, 2017). Glascock (2014) and Luckemeyer (2015) reported more intense brown/roasted and lower liver-like and cardboardy flavor aromatics in grilled top loin and top sirloin steaks compared with bottom round roasts. Laird (2015) found more intense beef identity, brown/roasted, and umami and less intense liver-like and cardboardy flavor attributes in Choice top loin steaks compared with Select beef bottom round roasts. Differences in descriptive flavor attributes across whole muscle beef steaks and roasts were reflective of flavor differences previously reported.

Beavers (2017) examined descriptive flavor and texture attributes of ground beef across multiple sources, grind size, and fat content. Variation in beef

identity, brown, roasted, umami, and cardboardy flavor attributes was as similarly reported in Table 3. Beavers (2017) showed that fat level and meat source impacted descriptive flavor attributes, whereas grind type mainly affected texture attributes. More intense levels of buttery and green hay-like flavor attributes were not surprising as ground beef can be formulated from multiple meat sources that potentially impact flavor attributes.

To further understand difference in descriptive flavor aromatics and basic tastes across beef cuts, the frequency of negative attributes was reported in Table 4 by cut. All beef cuts had very low, but identifiable, levels of cardboardy and liver-like flavor aromatics. Negative flavor attributes were at barely detectable levels and averaged less than 2. Burnt flavor aromatic was about 5, detectable and slightly intense, in one top sirloin steak, but on average, burnt was reported to be 0.38 and was detected only in 22 of the top sirloin steaks. Interestingly, ground beef samples had the highest frequencies of negative flavor attributes and had the highest, but barely detectable, level of green hay-like and overall sweet. These data show that beef cuts across types had low levels of negative flavor attributes and that top loin steaks tended to have slightly lower levels of negative attributes. However, ground beef had a higher number of negative attributes with higher frequency of detection. Other researchers have reported differences in positive and negative flavor attributes in beef cuts. Yeh et al. (2018) examined 2 cuts from the sirloin and 2 cuts from the chuck. They found that the *gluteus medius* ranked the highest in sour flavor. Stetzer et al. (2008) found that the *gluteus medius* ranked the highest in liver-like flavor compared with 10 different muscles throughout the round, chuck, and loin. A high amount of iron has been found in the *gluteus medius* that has been associated with increase liver-like flavors (Yancey et al., 2006).

These results indicate that there is variation in positive and negative flavor attributes in 4 major US beef retail cuts. Although there were inherent differences in flavor that were cut specific, negative flavor attributes were present at low but detectable levels in all cuts. As univariate statistics showed that there were differences in least-squares means and frequency of flavor attributes, PCA was conducted to understand relationships between descriptive flavor attributes and beef cuts (Figure 1). Factors 1 and 2 accounted for 88% of the variation with sweet, salty, bloody/serumy, metallic, overall sweet, liver-like, and smoky charcoal contributing between 7% and 5% to Factor 1 based on the contribution of variable from the PCA. For Factor 2, burnt, bitter, and sour contributed about 11% to 15% of the variation, and brown and barnyard contributed about 7% of the variation, respectively. Brown, roasted, beef identity, smoky charcoal, umami, and salty were clustered with top loin steaks. Ground beef was most closely associated with sweet, overall sweet, fat-like, green, green hay-like, cooked milk, and buttery attributes. Similar results were reported by Beavers (2017), wherein ground beef containing varying fat levels was evaluated for descriptive flavor attributes and 20% fat ground beef had the most intense levels of buttery, fat-like, smoky charcoal, and sweet. Top sirloin steaks were clustered with metallic, liver-like, leather, cardboardy, and sour flavor attributes, and chuck roasts were closely associated with bloody/serumy and barnyard flavor aromatics. In Table 3, top sirloin steaks and chuck roasts had similar levels of liver-like, and the frequency distribution for liver-like was similar for these 2 cuts, as reported in Table 4. Top sirloin steaks and chuck roasts were more closely associated with negative flavors. Wadhwani et al. (2010) reported that muscles within the chuck ranked high in liver-like flavors, and Carmack et al. (1995) reported that the *gluteus medius* possessed more beefy flavors like brown and roasted flavor aromatics when comparing 5 muscles from the chuck. As both the chuck and top sirloin are defined as locomotion muscle and inherent characteristics of these muscle have been shown to differ from structural support muscles like the *Longissimus dorsi lumborum* in top loin steaks. Locomotive muscles tend to not have as much intramuscular fat and to have more connective tissue compared with cuts in the loin (Belew et al., 2003). Flavor development in beef that occurs during cooking has been associated with the Maillard reaction and the subsequent products (Dinh et al., 2018) and heat denaturation of lipids (Mottram, 1998; Van Ba et al., 2012; Kerth and Miller, 2015). Chuck roasts were roasted with water present. Some Maillard reaction products would expectantly be created during cooking. It should also be noted that when chuck roasts were served to panelists, the outside crust was trimmed. Maillard reaction products associated with searing and beef identity and browned flavor aromatics would most likely be reduced. However, chuck roasts were multiple muscle cuts that contained seam fat. Lipid in seam fat may have influenced the amount of lipid heat degradation that occurred during cooking and most likely resulted in higher levels of lipid-like flavor development, specifically cardboardy flavor, compared with top loin and top sirloin steaks. Additionally, steaks were grilled, and higher levels of Maillard reaction product flavors would be expected. Cooking methods such as grilling

Table 4. Minimum, maximum, mean, standard deviation, and frequencies (n = 50) for negative flavor attributes in 4 beef cuts

Descriptive attribute	Minimum	Maximum	Mean	Standard deviation	Frequency of presence of attribute	Percentage of samples with attribute
80% lean ground beef (n = 50)						
Overall sweet	0.00	1.25	0.69	0.27	49	98.0
Animal hair	0.00	0.60	0.08	0.13	16	32.0
Barnyard	0.00	1.00	0.09	0.22	10	20.0
Burnt	0.00	1.40	0.19	0.33	18	36.0
Cardboardy	0.50	2.20	1.39	0.42	50	100.0
Chemical	0.00	0.80	0.04	0.15	5	10.0
Cocoa	0.00	0.40	0.01	0.06	1	2.0
Cooked milk	0.00	0.80	0.08	0.16	12	24.0
Green	0.00	1.60	0.10	0.29	9	18.0
Green hay-like	0.00	2.75	1.04	0.52	49	98.0
Heated oil	0.00	0.40	0.01	0.06	2	4.0
Leather	0.00	0.60	0.04	0.13	5	10.0
Liver-like	0.50	2.50	1.50	0.46	50	100.0
Musty earthy	0.00	0.40	0.04	0.12	6	12.0
Rancid	0.00	0.40	0.02	0.07	3	6.0
Sour aromatics	0.00	0.67	0.06	0.17	6	12.0
Sour milk/sour dairy	0.00	1.40	0.37	0.43	28	56.0
Warmed over	0.00	0.60	0.07	0.16	8	16.0
Soapy	0.00	0.50	0.02	0.09	4	8.0
Chuck roasts (n = 50)						
Animal hair	0.00	1.20	0.15	0.22	23	46.0
Barnyard	0.00	1.00	0.31	0.23	9	18.0
Burnt	0.00	0.20	0.00	0.03	1	2.0
Cardboardy	1.20	2.60	1.81	0.30	50	100.0
Chemical	0.00	0.40	0.03	0.10	4	8.0
Cooked milk	0.00	0.20	0.02	0.07	6	12.0
Green hay-like	0.00	2.75	0.15	0.40	18	36.0
Leather	0.00	1.00	0.15	0.22	21	42.0
Liver-like	1.20	3.00	1.89	0.37	50	100.0
Musty earthy	0.00	0.50	0.01	0.07	1	2.0
Sour aromatics	0.00	0.60	0.05	0.13	7	14.0
Sour milk/sour dairy	0.00	1.40	0.28	0.32	29	58.0
Warmed over	0.00	0.20	0.00	0.03	1	2.0
Soapy	0.00	0.60	0.03	0.12	3	6.0
Petroleum	0.00	2.00	0.08	0.40	2	4.0
Top sirloin steaks (n = 49)						
Animal hair	0.00	0.25	0.04	0.08	9	18.4
Barnyard	0.00	1.20	0.09	0.24	9	18.4
Burnt	0.00	4.80	0.38	0.81	22	44.9
Buttery	0.00	0.80	0.09	0.17	15	30.6
Cardboardy	1.00	2.75	2.04	0.42	49	100.0
Chemical	0.00	1.20	0.04	0.19	3	6.1
Cocoa	0.00	0.20	0.00	0.03	1	2.0
Cooked milk	0.00	0.20	0.01	0.05	3	6.1
Green	0.00	0.60	0.02	0.09	3	6.1
Green hay-like	0.00	0.40	0.01	0.06	2	4.1
Heated oil	0.00	0.50	0.04	0.12	6	12.2
Leather	0.00	1.20	0.18	0.28	21	42.9

Table 4. (*Continued*)

Descriptive attribute	Minimum	Maximum	Mean	Standard deviation	Frequency of presence of attribute	Percentage of samples with attribute
Liver-like	1.00	3.40	1.98	0.55	49	100.0
Musty earthy	0.00	0.40	0.02	0.08	3	6.1
Rancid	0.00	0.80	0.03	0.14	3	6.1
Sour aromatics	0.00	0.80	0.05	0.16	7	14.3
Sour milk/sour dairy	0.00	2.80	0.45	0.62	34	69.4
Warmed over	0.00	1.25	0.05	0.19	6	12.2
Floral	0.00	0.25	0.01	0.04	1	2.0
Petroleum	0.00	0.40	0.01	0.06	1	2.0
Top loin steaks (n = 50)						
Animal hair	0.00	0.80	0.05	0.14	8	16.0
Barnyard	0.00	0.80	0.04	0.16	4	8.0
Burnt	0.00	1.60	0.18	0.34	17	34.0
Buttery	0.00	0.80	0.17	0.19	28	56.0
Cardboardy	0.60	2.75	1.56	0.53	50	100.0
Chemical	0.00	1.00	0.06	0.19	7	14.0
Green	0.00	0.20	0.01	0.04	2	4.0
Green hay-like	0.00	0.25	0.02	0.07	5	10.0
Heated oil	0.00	0.40	0.01	0.06	1	2.0
Leather	0.00	1.00	0.20	0.23	28	56.0
Liver-like	0.80	3.00	1.55	0.56	50	100.0
Rancid	0.00	0.25	0.01	0.04	1	2.0
Smoky charcoal	0.00	1.50	0.28	0.38	27	54.0
Smoky wood	0.00	0.25	0.02	0.07	5	10.0
Sour aromatics	0.00	0.60	0.05	0.13	9	18.0
Sour milk sour dairy	0.00	2.40	0.17	0.42	15	30.0
Warmed over	0.00	0.60	0.02	0.09	3	6.0
Soapy	0.00	0.25	0.01	0.04	2	4.0
Petroleum	0.00	2.00	0.08	0.40	2	4.0

versus roasting created obvious differences in the types of flavors produced that are confounded with muscle type. Kerth and Miller (2015) found that cuts cooked on stove top grills produced higher amounts of Maillard reaction products compared with cuts cooked in crock pots or using low heat sources.

For whole muscle beef cuts, top loin steaks had less connective tissue, were juicier, and were more tender than top sirloin steaks and chuck roasts ($P < 0.01$) (Table 3). Top sirloin steaks had less connective tissue than chuck roasts ($P < 0.0001$). Extensive research to document differences in texture attributes between top loin, top sirloin, and chuck muscle cuts has been reported (Morgan et al., 1991; Brooks et al., 2000; Belew et al., 2003; Nyquist et al., 2018).

Ground beef patties were evaluated for texture attributes that are reflective of structural differences in ground meat as defined in Table 1. Ground beef patties tended to be slightly cohesive, moderately soft, very juicy with smaller particle sizes, and slightly springy. As differences across cities purchased were not reported, overall means are presented. These values are similar to those reported by Beavers (2017) and Troutt et al. (1992) for ground beef patties containing 20% fat.

Consumer sensory

Although differences in descriptive flavor and texture attributes were reported, understanding if consumers detected differences in liking attributes of these beef cuts was needed. Consumers (n = 95 in Fort Collins, CO; n = 100 in Lubbock, TX) were recruited randomly from consumers who eat beef 3 or more times per week (Table 5). Although consumers were recruited to eat beef 3 or more times per week on the recruitment questionnaire, 41% and 36% indicated that they ate beef less than 3 times per week when they filled out the

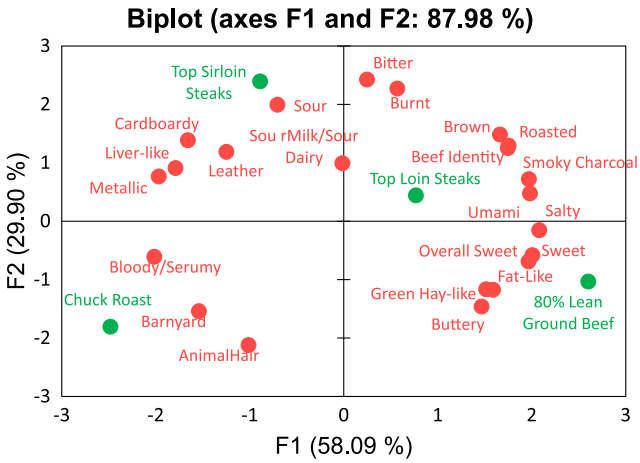

Figure 1. Principal component analysis biplot for descriptive sensory attributes (in red) and 4 beef cuts (in green).

demographic section of the consumer ballot. These consumers remained in the study. Consumer demographics indicated that consumer groups differed slightly between locations. Consumers in Fort Collins, CO, were almost equally male and female, about 25% were 21 to 25 y, and they were predominantly Caucasian. In contrast, consumers in Lubbock, TX, were almost 60% male and more evenly distributed across age categories, with the highest percentage of consumers being Latino/Hispanic and then Caucasian. The ethnic differences were reflective of ethnicity differences in each city. Consumer income and household size were somewhat equally distributed across classes. Over 70% of Lubbock, TX, consumers were employed, whereas about 40% of Fort Collins, CO, were part-time and full-time employed. Consumers tended to eat beef, poultry, and pork 1 to 4 times per week. Two consumers in Fort Collins, CO, did not consume beef and were maintained in the study. Consumers tended to eat fish and lamb 0 to 2 times per week and eggs 1 to 6 times per week. Soy protein was not consumed by 68% and 60% of consumers in Fort Collins, CO, and Lubbock, TX, respectively. Consumers predominantly cooked steaks using outside grilling and pan frying in a skillet. Microwave cooking was used as a steak cooking method by 11 consumers. Consumers across cities tended to prefer steaks cooked to either medium rare or medium degree of doneness. When examining purchase categories of consumers, the majority of consumers purchased traditional beef at retail with a very low percentage of consumers purchasing dry-aged, grass-fed, and organic beef.

Consumer sensory least-squares means are reported in Tables 6 and 7. The effect of city purchased was included in the statistical model; however, it was not significant ($P > 0.48$) for consumer attributes. There was a treatment by location interaction for juiciness liking (Table 6). Consumers in Fort Collins, CO, rated juiciness liking similarly for the 4 beef cuts; however, consumers in Lubbock, TX, rated ground beef and top loin steaks higher for juiciness liking than chuck roasts. Consumer demographics previously discussed most likely affected difference in consumer juiciness liking ratings. Bonny et al. (2017) showed that demographics affected consumer juiciness ratings. Although they were utilizing consumers in European countries, they determined that consumer's perception of beef in the diet may influence juiciness as well as other consumer sensory responses (Bonny et al., 2017). Additionally, although cooking methods were the same in both locations, random cooking effects for steaks, roasts, and ground beef in Fort Collins, CO, and Lubbock, TX, may have contributed.

Consumer liking ratings across the 4 beef cuts are presented in Table 7. Consumers rated chuck roasts lower in overall, overall flavor, beef flavor, grilled flavor, juiciness, and texture liking compared with ground beef. Ground beef, top loin steaks, and top sirloin steaks had similar consumer ratings across most consumer attributes. Glascock (2014), Luckemeyer (2015), and Laird (2015) found similar differences between top loin and sirloin steaks.

To understand issues associated with disliking for beef cuts and ground beef, the frequency distribution for consumer ratings of 4 to 1 are reported in Table 8. Of the 383 consumer responses for chuck roasts, 89 consumers rated the chuck roast within the dislike categories of 4, 3, 2, and 1. For ground beef, there were only 76 samples rated in the dislike categories, whereas for top sirloin and top loin steaks, there were 68 and 76 negative or dislike consumer responses, respectively. It is apparent from these data that the consumer data were not normally distributed, further justifying transformation of the data prior to analysis. Additionally, the data showed that there tended to be more dislike ratings for chuck roasts compared with the other beef cuts. In trying to understand what factors may have contributed to dislike of beef cuts, in store data of packaging type, external fat thickness, minimum and maximum cut thickness, lean color, fat color, package weight, cuts per package, price per kilogram, total price, quality grade, brand and nutritional claims, and consumer demographics were examined for beef cuts with overall liking ratings of 4 or less. The frequency distributions for location of consumer testing and packaging type are presented as other factors that were almost evenly distributed across cuts and other

Table 5. Consumer frequency demographic information by consumer sensory location

	Colorado State University		Texas Tech University	
Question	Respondents	Percentage	Respondents	Percentage
Sex				
Male	48	50.5	58	58.0
Female	47	49.5	42	42.0
Age				
20 y or younger	19	20.0	13	13.0
21-25 y	26	27.4	18	18.0
26-35 y	7	7.4	22	22.0
36-45 y	12	12.6	24	24.0
46-55 y	12	12.6	18	18.0
56-65 y	9	9.5	3	3.0
66 y and older	10	10.6	2	2.0
Ethnicity				
Caucasian	78	82.1	36	36.0
Latino/Hispanic	3	3.2	53	53.0
African American	2	2.1	5	5.0
Asian/Pacific Islander	6	6.3	1	1.0
Native American	2	2.1	1	1.0
Other	4	4.2	4	4.0
Household income				
Below $25,000	26	27.37	19	19.0
$25,001-$49,999	13	13.68	34	34.0
$50,000-$74,999	10	10.53	20	20.0
$75,000-$99,999	19	20.00	12	12.0
$100,000 or more	27	28.42	15	15.0
Household size				
1	13	13.7	12	12.0
2	30	31.6	23	23.0
3	16	16.8	15	15.0
4	19	20.0	24	24.0
5	12	12.6	18	18.0
6 or more	13	5.3	7	7.0
Employment level				
Not employed	24	25.3	13	13.0
Part time	24	35.8	16	16.0
Full time	37	39.0	71	71.0
Weekly consumption of protein				
Chicken				
0	2	2.1	2	2.0
1-2	50	53.2	38	38.0
3-4	32	34.0	41	41.0
5-6	7	7.5	11	11.0
7 or more	3	3.2	7	7.0
Beef				
0	2	2.1	0	0.0
1-2	37	39.4	36	36.0
3-4	36	38.4	37	37.0
5-6	11	11.7	19	19.0
7 or more	8	8.5	8	8.0
Pork				
0	8	8.5	12	12.0
1-2	56	59.6	59	59.0
3-4	25	26.6	13	13.0
5-6	3	3.2	5	5.0
7 or more	2	2.1	5	5.0
Fish				
0	30	31.9	32	32.0
1-2	58	61.7	48	48.0
3-4	5	5.3	7	7.0
5-6	0	0.0	1	1.0
7 or more	1	1.1	2	2.0
Lamb				
0	73	77.7	67	67.0
1-2	18	19.2	10	10.0
3-4	2	2.1	0	0.0
5-6	0	0.0	0	0.0
7 or more	1	1.1	1	1.0
Eggs				
0	0	0.0	8	8.0
1-2	35	37.2	41	41.0
3-4	28	29.8	27	27.0
5-6	25	26.6	14	14.0
7 or more	6	6.4	6	6.0
Soy-based products				
0	64	68.1	60	77.9
1-2	15	16.0	12	15.6
3-4	9	9.6	3	3.9
5-6	2	2.1	0	0.0
7 or more	4	4.3	2	2.6
What cooking method do you prefer to use when cooking a beef steak? (multiple answers per consumer)				
Grill outside	84		77	
Electric grill	12		6	
Bake	25		24	
Broil	11		8	
Stir fry	26		22	
Microwave	4		7	
Pan fry in a skillet	44		57	
Degree of doneness				
Rare	2	2.1	3	3.0
Medium rare	40	42.6	30	30.0
Medium	26	27.7	26	26.0
Medium well	18	19.2	24	19.2
Well done	8	8.5	11	11.0
When purchasing beef, what do you typically tend to buy at the retail store?				
Traditional	80	85.1	73	73.0
Dry aged	6	6.4	11	11.0
Grass fed	7	7.5	2	2.0
Organic	1	1.1	3	3.0
Other	0	0.0	11	11.0

Table 6. Least-squares means for consumer juiciness[d] liking ratings for the interaction of cut and location of consumer testing ($P = 0.001$)

City	Chuck Roast	80% Lean Ground Beef	Top Sirloin Steak	Top Loin Steak
Fort Collins, CO	4.9[abc]	5.1[abc]	4.5[a]	4.6[a]
Lubbock, TX	4.6[ab]	5.3[c]	5.2[bc]	5.3[c]

[a–c]Mean values across rows and cut followed by the same letter are not significantly different ($P > 0.050$).

[d]1 = dislike extremely; 9 = like extremely.

Table 7. Least-squares means for consumer liking attributes[d] by cut

Attribute	*P* value	Chuck roast	80% lean ground beef	Top sirloin steak	Top loin steak	Root mean square error
Overall liking	0.01	5.7[a]	6.1[b]	5.9[ab]	6.0[b]	3.37
Overall flavor liking	0.02	5.2[a]	5.6[b]	5.4[ab]	5.5[ab]	2.94
Beef flavor liking	0.02	5.2[a]	5.6[b]	5.4[ab]	5.5[ab]	2.94
Grilled flavor liking	0.001	4.9[a]	5.4[b]	5.1[ab]	5.3[b]	2.32
Juiciness liking	0.02	4.8[a]	5.2[b]	4.9[ab]	4.9[ab]	2.02
Texture liking	<0.0001	5.0[a]	5.6[c]	5.1[ab]	5.4[bc]	2.68

[a–c]Mean values within a row and cut followed by the same letter are not significantly different ($P > 0.050$).

[d]1 = dislike extremely; 9 = like extremely.

Table 8. Frequency distributions for negative consumer overall liking scores (n = 309), consumer location, and packaging type for 4 beef cuts

	Chuck roasts		80% lean ground beef		Top sirloin steaks		Top loin steaks	
Attribute	n	%	n	%	n	%	n	%
Number of consumer responses								
	89		76		68		76	
Consumer overall liking score[a]								
1 (Dislike extremely)	35	39	21	28	26	38	23	30
2	17	19	19	25	13	19	18	24
3	18	20	24	32	19	28	17	22
4	19	21	12	16	10	15	18	24
Location for consumer evaluation								
Fort Collins, CO	53	60	35	46	27	40	30	39
Lubbock, TX	36	40	41	54	41	60	46	61
Packaging type								
Chub			9	13				
MAP			12	17	10	15	10	13
MAP-CO					1	2	2	3
Overwrapped	64	72	27	38	40	60	48	63
Overwrap from MAP					2	3	8	11
Vacuum packaged	25	28	23	32	13	20	8	11

[a]1 = dislike extremely; 9 = like extremely.

CO = carbon monoxide added to the package atmosphere; MAP = modified atmosphere packaging.

store data. There was a tendency for a higher number of consumers in Fort Collins, CO, to dislike chuck roasts, whereas there was a tendency for a slightly higher number of consumers in Lubbock, TX, to dislike top sirloin and top loin steaks. As previously stated, this is most likely a location or city effect. Van Mezemael et al. (2014) presented consumer sensory differences for pessimistic, average, and optimistic consumers. They found that attitudes toward beef affected consumers' perception of beef consumer sensory characteristics. Optimistic consumers were less concerned with beef safety issues, more positive about beef's healthiness, and were rated as lower for food neophobia. As a result, consumers who were less critical of beef tenderness also had more positive attitudes toward new food products. Van Wezemael et al. (2014) also found that consumers with younger children tended to be classified more often as optimistic consumers. Although we did not measure these consumer attitudes, differences in consumer attitudes may have influenced consumer ratings in this study.

Within cuts that consumers disliked, consumer responses were affected by packaging type. For whole muscle beef cuts rated as disliked, 72% of the roasts, 60% of top sirloin steaks, and 63% of top loins steaks were overwrap packaged. Although a small percentage of the whole muscle cuts that were rated as disliked were vacuum packaged and modified atmosphere packaged, the predominant packaging type that appeared to contribute to consumer disliking was overwrap packaging. It has been well documented that beef cuts have a shorter shelf life when aerobically stored in overwrapped packaging (Mancini and Hunt, 2004; McMillan, 2017); all beef cuts were purchased and frozen prior to defined sell-by dates on packages (data not presented). These results indicate the interrelationships between packaging and consumer liking.

To understand relationships between descriptive and consumer attributes with beef cuts, a principal component biplot is presented (Figure 2). Ground beef was closely segmented with consumer sensory

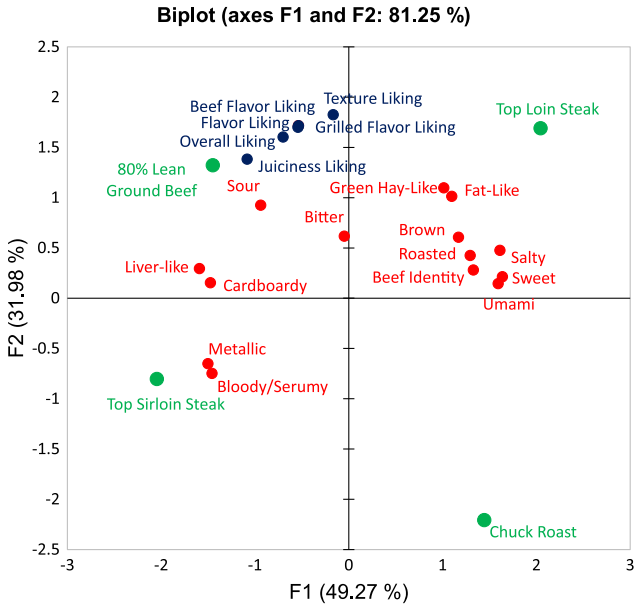

Figure 2. Principal component biplot for descriptive (in red) and consumer sensory attributes (in blue) and 4 beef cuts (in green).

attributes. Top sirloin steaks and chuck roasts were segmented furthest from consumer liking attributes. These results are similar as those reported in Table 6. Brown, roasted, beef identity, salty, sweet, and umami descriptive attributes were closely related and tended to be most closely related to top loin steaks. Interestingly, some descriptive attributes that were described as negative flavor attributes—liver-like, cardboardy, and sour attributes—were segmented in the same quadrant as 80% lean ground beef and all consumer liking attributes. As ground beef was liked by consumers and contained low levels of cardboardy and liver-like aromatics compared with the other cuts, it is not surprising that attributes segmented. Top sirloin steaks were closely clustered with metallic and bloody/serumy aromatics and were segmented negatively away from consumer liking attributes. Least-squares means for flavor aromatics (Table 3) showed that ground beef samples had the highest levels of fat-like and green hay-like and the highest frequency of green hay-like flavor of samples evaluated (98%, Table 4). As ground beef would have the highest lipid content, higher levels of fat-like would be expected. Additionally, formulations or sources of lean for 80% lean ground beef may vary. Ground beef originating from major beef processing plants would be formulated using lean and fat trimmings from grain-fed young beef animals. However, ground beef can be formulated using raw materials from other sources, especially beef trimmings from locally grown and medium to small beef processing plants. Label claims for ground beef (data not presented) indicated that 42% of samples did not have any defined claims, but 30% of packages were defined as natural, 12% were grass fed, 14% were antibiotic free, and 16% were hormone free. It should be noted that associated percentage of samples defined as natural, grass-fed, antibiotic free, and hormone free were based on random collection of samples present in the retail meat case at the time of selection. These results indicate that ground beef came from varying sources, and as some ground beef were derived from grass-fed animals, it is not surprising that green and green hay-like would be associated with ground beef and with fat-like flavor aromatics. However, green hay-like and fat-like clustered closely with ground beef using Factor 2, but Factor 1 segmented these attributes to be associated with top loin steaks and the brown, roasted, beef identity, salty, sweet, and umami descriptive attributes. As top loin steaks and 80% ground beef were similar in the aforementioned descriptive attributes (Table 3), it is not surprising that they were clustered.

To more fully understand consumer sensory responses (n = 1,546) to beef cuts, all consumer responses were subjected to agglomerative hierarchical clustering analysis. Six consumer clusters were defined (Table 9). The centroids for each cluster show that overall liking decreased as clusters moved from 1 to 6 (variance decomposition for optimal classification accounted for 75.6% of between class variation, and 24.4% was within class variation). Other consumer attributes followed similar trends as overall liking across the 6 clusters, indicating the strong relationships between overall liking and other consumer liking attributes. These results indicate that consumer sensory attributes may be autocorrelated. The highest number of consumers was in Cluster 3, which tended to represent the neutral portion of the scales. Cluster 3 and 4 were similar for overall, flavor, beef, and grilled liking, but consumers in Cluster 4 rated beef cuts lower

Table 9. Class centroids for agglomerative hierarchical clustering of consumer responses

Clusters (n = 1,546)	Overall liking	Flavor liking	Beef liking	Grilled flavor liking	Juiciness liking	Texture liking
1 (n = 178)	8.7	8.1	8.1	8.0	7.9	8.1
2 (n = 337)	7.5	7.0	7.0	6.7	6.5	6.7
3 (n = 425)	6.2	5.6	5.6	5.4	5.4	5.6
4 (n = 135)	5.7	5.3	5.2	4.8	3.4	4.1
5 (n = 311)	4.1	3.6	3.6	3.5	3.7	3.8
6 (n = 160)	1.7	1.4	1.4	1.5	1.5	1.8

Table 10. Frequency distributions for consumer responses (n = 160) for Cluster 6 of agglomerative hierarchical cluster analysis.

Attribute	Respondent	Percentage	Combined percentage from Table 6
Location			
Fort Collins, CO	70	43.8	
Lubbock, TX	90	56.2	
Sex			
Male	110	71.4	54.4
Female	44	28.6	45.6
Age			
20 y or younger	32	20.8	16.4
21-25 y	31	20.1	22.6
26-35 y	21	13.6	14.9
36-45 y	27	17.5	18.5
46-55 y	24	15.6	15.4
56-65 y	11	7.1	6.2
66 y and older	8	5.2	6.2
Ethnicity			
Caucasian	77	50.0	40.0
Latino/Hispanic	54	35.1	28.7
African American	10	6.5	3.6
Asian/Pacific Islander	8	5.2	3.6
Native American	5	3.2	1.5
Other	0	0	4.1
Household income			
Below $25,000	37	24.0	23.1
$25,001-$49,999	31	20.13	24.1
$50,000-$74,999	20	13.0	15.4
$75,000-$99,999	15	9.7	15.9
$100,000 or more	51	33.12	21.5
Household size			
1	18	11.7	12.8
2	35	22.7	27.2
3	29	18.8	15.9
4	30	19.5	22.1
5	27	17.5	15.4
6 or more	15	9.7	10.3
Employment level			
Not employed	33	21.4	19.0
Part time	42	27.3	20.5
Full time	79	51.3	55.4
Weekly consumption of protein			
Chicken			
0	4	2.6	2.1
1-2	164	41.8	45.1
3-4	59	38.6	37.4
5-6	19	12.4	9.2
7 or more	7	4.6	5.1
Beef			
0	2	1.3	1.0
1-2	56	36.6	37.4
3-4	57	37.2	37.4
5-6	28	18.3	15.4
7 or more	10	6.5	8.2
Pork			
0	21	14.4	10.3
1-2	84	57.5	59.0
3-4	31	21.2	19.5
5-6	3	2.0	4.1
7 or more	7	4.8	3.6
Fish			
0	46	32.6	31.8
1-2	81	57.4	*54.4*
3-4	10	7.1	6.2
5-6	4	2.8	0.5
7 or more	0	0.0	1.5
Lamb			
0	107	81.7	71.8
1-2	20	15.3	14.4
3-4	4	3.0	1.0
5-6	0	0.0	0.0
7 or more	0	0.0	1.0
Eggs			
0	16	11.0	4.1
1-2	50	34.2	39.0
3-4	41	28.1	28.2
5-6	34	23.3	20.0
7 or more	5	3.4	6.2
Soy-based products			
0	109	81.3	63.6
1-2	15	11.2	13.8
3-4	7	5.2	6.2
5-6	0	0.0	1.0
7 or more	3	2.2	3.1
Degree of doneness			
Rare	4	2.6	2.6
Medium rare	48	31.4	35.9
Medium	30	19.6	26.7
Medium well	36	23.5	21.5
Well done	25	16.3	9.7
Very well done	10	6.5	0.0
When purchasing beef, what do you typically tend to buy?			
Traditional	118	77.1	78.5
Dry aged	5	3.3	8.7
Grass fed	9	5.9	4.6
Organic	4	1.3	2.1
Other	19	12.3	5.6

for juiciness liking and texture liking. Consumers in Cluster 1 rated the beef cuts the highest values for liking extremely, and consumers in Cluster 6 rated beef cuts the lowest or closest to disliking extremely. To identify characteristics of consumers in Cluster 6 and

to examine potential reasons for the high ratings for dislike, consumer responses were examined. Demographics for Cluster 6 consumer responses are reported in Table 10. Slightly higher number of respondents were from Lubbock, TX, and respondents were about 70% male. Cluster 6 respondents tended to be from age groups 20 to 55 y of age, and 50% of respondents were Caucasian. Across income levels, these respondents tended to be in the highest income level, tended to live in household sizes of 2 to 5, and were employed full time. The majority of Cluster 6 respondents consumed chicken, pork, and fish 1 to 2 times per week, consumed beef 1 to 4 times per week, did not consume lamb and soy-based products, and consumed eggs 1 to 6 times per week. The majority of consumers in Cluster 6 preferred beef cooked to medium rare, medium well, and medium degrees of doneness. Cluster 6 consumers purchased mainly traditional beef. These data indicate that the consumers who responded negatively to beef cuts were mainly male and tended to have a slightly higher percentage of Caucasian and Latino/Hispanic ethnicity with a slight increase in percentage from higher income levels. Additionally, there tended to be a higher percentage of individuals who did not eat soy-based products. Van Wezemael et al. (2014) classified consumers as optimistic, average, or pessimistic based on evaluations of 3 steaks. Pessimistic consumers rated 2 out of 3 samples 1 unit below the average tenderness rating. They reported that pessimistic consumers were more often female and that other sociodemographic characteristics (education, occupation, and income) tended to not differ between groups. This was not in agreement with results from our study. Van Wezemael et al (2014) used European consumers and designed their study to address consumer demographics on perceptions of tenderness. Our study had a limited consumer base from the Texas panhandle and the front range of Colorado that may have contributed to differences. It is apparent that understanding negative perceptions of beef by consumers is complex and additional research is needed.

Data from Cluster 6 responses were examined to determine if cuts that were rated higher for disliking differed in flavor and texture descriptive attributes. Cuts were segmented to consumer and descriptive evaluation in units from beef cuts purchased in the same retail case next to each other. Although consumer and descriptive panelists did not eat from the same sample, it was assumed that samples were representative of each other. Of the 160 responses from Cluster 6, the corresponding cut that was assigned to descriptive analysis was segmented from the 199 descriptive responses. There were 109 beef cuts used for descriptive evaluation that received negative responses by Cluster 6 consumers. Data were analyzed as previously defined for the 199 observations in which day and order were random variables and city, cut, and their interactions were defined as fixed effects. Least-squares means and *P* values were similar values across flavor and texture attributes (data not presented) as reported in Table 3, indicating that although some consumers rated these cuts as dislike extremely, descriptive flavor and texture attributes did not segment differently. Attempts with these data to understand why 106 consumer responses out of 1,546 were extremely disliked were not ascertained.

Conclusions

Retail beef cuts in this study varied in flavor, and off-flavors were present at low levels. The magnitude of differences in off-flavors was low, but the combined effect of off-flavors appeared to influence consumer ratings for flavor liking, especially for ground beef. Variation in potential raw material sources most likely impacted the variation in favor in ground beef. As variation in raw material sources continue to expand for ground beef, variation in flavor attributes would be expected, especially for branded programs using meat from forage-based production systems. Although consumer ratings for ground beef were similarly rated by consumers with top loin steaks, greater incidence of off-flavor descriptive sensory attributes indicate that a reduction in off-flavor variation in ground beef most likely would improve consumer liking attributes.

Chuck roasts had the lowest consumer ratings for overall and flavor liking and had moderate incidence of off-flavors. Although chuck roasts were lower in key positive beef descriptive flavor attributes that most likely contributed to this effect as well, it is apparent that flavor variation in chuck roasts, a multimuscle cut, may result in a decrease in consumer liking.

Top loin and top sirloin steaks, although slightly variable in flavor and containing some off-flavor descriptive attributes, were liked similarly by consumers, except that top sirloin steaks had lower texture liking ratings. The incidence of off-flavor attributes most likely was not associated with driving consumer ratings.

Negative consumer ratings tended to be associated with beef that had been overwrapped across cuts, and for chuck roasts and ground beef, some incidence of negative consumer liking was associated with

vacuum-packaged beef. However, the incidence of negative consumer liking scores were low (309 out of 1,546 consumer individual responses). This low level of negative consumer responses provides additional support that there is not a high incidence of off-flavor in the retail beef cuts evaluated in this study. Although consumers responded to off-flavors, the low incidence resulted in few negative responses.

This study was the first to evaluate beef flavor attributes and consumer liking for 4 major beef cuts in the retail meat case and can be used by the industry as a benchmark for flavor variation. The introduction of brand-identified beef programs, especially those that utilize alternative beef production systems, have the potential to increase variation in beef flavor and off-flavor attributes and result in decreased consumer liking. Flavor remains an important component of overall consumer liking and should continue to be evaluated. Although consumer preparation, cooking methods, and degree of doneness impact beef flavor, understanding how off-flavor components, especially cardboardy and liver-like flavor attributes that were present in 100% of the samples, are magnified or masked is needed.

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Literature Cited

Adhikari, K., E. Chambers, IV, R. Miller, L. Vázquez-Araújo, N. Bhumiratana, and C. Philip. 2011. Development of a lexicon for beef flavor in intact muscle. J. Sens. Stud. 26:413–420. https://doi.org/10.1111/j.1745-459X.2011.00356.x.

AMSA. 2016. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. Version 1.02. AMSA, Champaign, IL.

Beavers, B. A. 2017. Relationship between descriptive flavor and texture attributes and consumer acceptance in ground beef patties. M.S. thesis, Texas A&M Univ., College Station, TX.

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

Bonny, S. P. F, G. E. Gardner, D. W. Pethick, P. Allen, I. Legrand, J. Wierzbicki, L. J. Farmer, Legrand, R. J. Polkinghorne, and J.-F. Hocquette. 2017. Untrained consumer assessment of the eating quality of beef: 2. Demographic factors have only minor effects on consumer scores and willingness to pay. Animal 11:1399–1411. https://doi.org/10.1017/S1751731117000076.

Brooks, J. C., J. B. Belew, D. B. Griffin, B. L. Gwartney, D. S. Hale, W. R. Henning, D. D. Johnson, J. B. Morgan, F. C. Parrish, Jr., J. O. Reagan, and J. W. Savell. 2000. National Beef Tenderness Survey–1998. J. Anim. Sci. 78:1852–1860. https://doi.org/10.2527/2000.7871852x.

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

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

Dinh, T. T. N., J. F. Legako, M. F. Miller, and J. C. Brooks. 2018. Effects of USDA quality grade and cooking on water-soluble precursors of beef flavor. Meat Sci. 146:122–130. https://doi.org/10.1016/j.meatsci.2018.08.008.

Erichsen, I., G. Molin, and B.-M. Möller. 1981. Carbon dioxide packaging as a means of controlling the spoilage flora of DFD meat. In: O. Prändl, editor, *Proceedings of the 27th European Meeting of Meat Research Workers*, Vienna, Austria, 24–28 August 1981. Vol. 1: p. 683–687.

Glascock, R. A. 2014. Beef flavor attributes and consumer perception. M.S. thesis, Texas A&M Univ., College Station, TX.

Guelker, M. R., A. N. Haneklaus, J. C. Brooks, C. C. Carr, R. J. Delmore, Jr., D. B. Griffin, D. S. Hale, K. B. Harris, G. G. Mafi, D. D. Johnson, C. L. Lorenzen, R. J. Maddock, J. N. Martin, R. K. Miller, C. R. Raines, D. L. VanOverbeke, L. L. Vedral, B. E. Wasser, and J. W. Savell. 2013. National Beef Tenderness Survey–2010: Warner-Bratzler shear force values and sensory panel ratings for beef steaks from United States retail and food service establishments. J. Anim. Sci. 91:1005–1014. https://doi.org/10.2527/jas.2012-5785.

Huffman, K. L., M. F. Miller, L. C. Hoover, C. K. Wu, H. C. Brittin, and C. B. Ramsey. 1996. Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. J. Anim. Sci. 74:91–97. https://doi.org/10.2527/1996.74191x.

Hunt, M. C., R. A. Mancini, K. A. Hachmeister, D. H. Kropf, M. Merriman, G. de Lduca, and G. Milliken. 2004. Carbon monoxide in modified atmosphere packaging affects color, shelf life, and microorganisms of beef steaks and ground beef. J. Food Sci. 69:FCT45–FCT52. https://doi.org/10.1111/j.1365-2621.2004.tb17854.x.

Jeremiah, L. E. 2001. Packaging alternatives to deliver fresh meats using short- or long-term distribution. Food Res. Int. 34:749–772. https://doi.org/10.1016/S0963-9969(01)00096-5.

Kerth, C. R., and R. K. Miler. 2015. Beef flavor: A review from chemistry to consumer. J. Sci. Food Agr. 95:2783–2798. https://doi.org/10.1002/jsfa.7204.

Laird, H. L. 2015. Millennial's perception of beef flavor. M.S. thesis, Texas A&M Univ., College Station, TX.

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

Lorenzen, C. L., T. R. Neely, R. K. Miller, J. D. Tatum, J. W. Wise, J. F. Taylor, M. J. Buyck, J. O. Reagan, and J. W. Savell. 1999. Beef customer satisfaction: Cooking method and degree of doneness effects on the top loin steak. J. Anim. Sci. 77:637–644. https://doi.org/10.2527/1999.773637x.

Luckemeyer, T. J. 2015. Beef flavor attributes and consumer perception of light beef eaters. M.S. thesis, Texas A&M Univ., College Station, TX.

Mancini, R. A., and M. C. Hunt. 2005. Current research in meat color. Meat Sci. 71:100–121. https://doi.org/10.1016/j.meatsci.2005.03.003.

Martinez, H. A., A. N. Arnold, J. C. Brooks, C. C. Carr, K. B. Gehring, D. B. Griffin, D. S. Hale, G. G. Mafi, D. D. Johnson, C. L. Lorenzen, R. J. Maddock, R. K. Miller, D. L. VanOverbeke, B. E. Wasser, and J. W. Savell. 2017. National Beef Tenderness Survey—2015: Palatability and shear force assessments of retail and foodservice beef. Meat Muscle Biol. 1. https://doi.org/10.22175/mmb2017.05.0028.

Maughan, C., R. Tansawat, D. Cornforth, R. Ward, and S. Martini. 2012. Development of a beef flavor lexicon and its application to compare the flavor profile and consumer acceptance of rib steaks from grass- or grain-fed cattle. Meat Sci. 90:116–121. https://doi.org/10.1016/j.meatsci.2011.06.006.

McMillin, K. W. 2017. Advancements in meat packaging. Meat Sci. 132:153–162. https://doi.org/10.1016/j.meatsci.2017.04.015.

Miller, R. 2020. Drivers of consumer liking for beef, pork, and lamb: A review. Foods 9:428. https://doi.org/10.3390/foods9040428.

Miller, M. F., M. A. Carr, C. B. Ramsey, K. L. Crockett, and L. C. Hoover. 2001. Consumer thresholds for establishing value of beef tenderness. J. Anim. Sci. 79:3062–3068. https://doi.org/10.2527/2001.79123062x.

Miller, R. K., and C. R. Kerth. 2012. Identification of compounds responsible for positive beef flavor. Texas A&M University, College Station, TX.

Miller, R. K., C. R. Kerth, M. C. Berto, H. L. Laird, and J. W. Savell. 2019. Steak thickness, cook surface temperature and quality grade effect on top loin steak consumer and descriptive sensory attributes. Meat Muscle Biol. 3:467–478. https://doi:10.22175/mmb2018.07.0020.

Morgan, J. B., J. W. Savell, D. S. Hale, R. K. Miller, D. B. Griffin, H. R. Cross, and S. D. Shackelford. 1991. National beef tenderness survey. J. Anim. Sci. 69:3274–3283. https://doi.org/10.2527/1991.6983274x.

Mottram, D. S. 1998. Flavour formation in meat and meat products: A review. Food Chem. 62:415–424. https://doi.org/10.1016/S0308-8146(98)00076-4.

Neely, T. R., C. L. Lorenzen, R. K. Miller, J. D. Tatum, J. W. Wise, J. F. Taylor, M. J. Buyck, J. O. Reagan, and J. W. Savell. 1998. Beef customer satisfaction: Role of cut, USDA quality grade, and city on in-home consumer ratings. J. Anim. Sci. 76:1027–1033. https://doi.org/10.2527/1998.7641027x.

Nyquist, K. M., T. G. O'Quinn, L. N. Drey, L. W. Lucherk, J. C. Brooks, M. F. Miller, and J. F. Legako. 2018. Palatability of beef chuck, loin, and round muscles three USDA quality grades. J. Anim. Sci. 96:4276–4292. https://doi.org/10.1093/jas/sky305.

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

Polkinghorne, R. J., J. Philpott, J. Perovic, J. Lau, I. Davies, W. Mudannayake, R. Watson, G. Tarr, and J. M. Thompson. 2018. The effect of packaging on consumer eating quality of beef. Meat Sci. 142:59–64. https://doi.org/10.1016/j.meatsci.2018.04.002.

Roeber, D. L., R. C. Cannell, K. E. Belk, R. K. Miller, J. D. Tatum, and G. C. Smith. 2000. Implant strategies during feeding: Impact on carcass grades and consumer acceptability. J. Anim. Sci. 78:1867–1874. https://doi.org/10.2527/2000.7871867x.

Savell, J. W., H. R. Cross, J. J. Francis, J. W. Wise, D. S. Hale, D. L. Wilkes, and G. C. Smith. 1989. National consumer retail beef study: interaction of trim level, price and grade on consumer acceptance of beef steaks and roasts. J. Food Quality 12:251–274. https://doi.org/10.1111/j.1745-4557.1989.tb00328.x.

Shackelford, S. D., M. Koohmaraie, M. F. Miller, J. D. Crouse, and J. O. Reagan. 1991. An evaluation of tenderness of the longissimus muscle of Angus by Hereford versus Brahman crossbred heifers. J. Anim. Sci. 69:171–177. https://doi.org/10.2527/1991.691171x.

Shahidi, F. 1994. Flavor of meat and meat products. 1st ed. Chapman and Hall, London.

Stetzer, A. J., K. Cadwallader, T. K. Singh, F. K. McKeith, and M. S. Brewer. 2008. Effect of enhancement and ageing on flavor and volatile compounds in various beef muscles. Meat Sci. 79:13–19. https://doi.org/10.1016/j.meatsci.2007.07.025.

Troutt, E. S., M. C. Hunt, D. E. Johnson, J. R. Claus, C. L. Kastner, D. H. Kropf, and S. Stroda. 1992. Chemical, physical, and sensory characterization of ground beef containing 5 to 30 percent fat. J. Food. Sci. 57:25–29. https://doi.org/10.1111/j.1365-2621.1992.tb05416.x.

Van Ba, H., I. Hwang, D. Jeong, and A. Touseef. 2012. Principle of meat aroma flavors and future prospect. In: I. Akyar, editor, Latest research in quality control. IntechOpen, London. p. 145–176. https://doi.org/10.5772/51110.

Van Wezemael, L., S. De Smet, Ø. Ueland, and W. Verbeke. 2014. Relationships between sensory evaluations of beef tenderness, shear force measurements and consumer characteristics. Meat Sci. 97:310–315. http://doi.org/10.1016/j.meatsci.2013.07.029.

Voges, K. L., C. L. Mason, J. C. Brooks, R. J. Delmore, D. B. Griffin, D. S. Hale, W. R. Henning, D. D. Johnson, C. L. Lorenzen, R. J. Maddock, R. K. Miller, J. B. Morgan, B. E. Baird, B. L. Gwartney, and J. W. Savell. 2007. National beef tenderness survey – 2006: Assessment of Warner–Bratzler shear and sensory panel ratings for beef from US retail and foodservice establishments. Meat Sci. 77:357–364. https://doi.org/10.1016/j.meatsci.2007.03.024.

Wadhwani, R., L. K. Murdia, and D. P. Cornforth. 2010. Effect of muscle type and cooking temperature on liver-like off-flavour of five beef chuck muscles. Int. J. Food Sci. Tech. 45:1277–1283. https://doi.org/10.1111/j.1365-2621.2010.02275.x.

Wall, K. R. 2017. Effects of grilling temperature on tenderness, juiciness, and flavor of ribeye, strip loin, and top sirloin steaks. M.S. thesis, Texas A&M Univ., College Station, TX.

Warner, R., R. Miller, M. Ha, T. L. Wheeler, F. Dunshea, X. Li, R. Xaskoska and P. Purslow. 2021. Meat tenderness: Underlying mechanisms, instrumental measurement, and sensory assessment. Meat Muscle Biol. 4:17, 1–25. https://doi.org/10.22175/mmb.10489.

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

Yancey, E. J., J. P. Grobbel, M. E. Dikeman, J. S. Smith, K. A. Hachmeister, E. C. Chambers IV, P. Gadgil, G. A. Milliken, and E. A. Dressle. 2006. Effects of total iron, myoglobin, hemoglobin, and lipid oxidation of uncooked muscles on livery flavor development and volatiles of cooked beef steaks. Meat Sci. 73:680–686. https://doi.org/10.1016/j.meatsci.2006.03.013.

Yeh, Y., S. T. Omaye, F. A. Ribeiro, C. R. Calkins, and A. S. de Mello. 2018. Evaluation of palatability and muscle composition of novel value-added beef cuts. Meat Sci. 135:79–83. https://doi.org/10.1016/j.meatsci.2017.08.026.

Young, L. L., R. O. Riviere, and A. B. Cole. 1988. Fresh red meats. A place to apply modified atmospheres. Food Technol.-Chicago. 42:65–69.