Meat and Muscle Biology™

Muscle Source Influences Ground Beef Quality

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Abstract: Six muscle-specific ground beef products along with conventional chuck ground beef were evaluated for proximate composition, objective color, descriptive flavor attributes, texture attributes, fatty acid composition, and volatile compound profile. Ground products were derived from beef chuck shoulder clods, chuck boneless short ribs, whole briskets, loin tenderloin tips, loin top sirloin caps, round sirloin tip knuckles, and 81:19 chuck-sourced trimmings. Each grind type was formulated to a target fat percent of 15%. Proximate analysis determined actual fat content to range from 12.0% to 19.5%. Percent fat was tested as a covariate and included in model statements when significant. Sirloin caps, brisket, and 81:19 chuck each had greater beefy/brothy ratings compared with shoulder clods and tenderloins ($P < 0.05$). Tenderloin grinds also had lower browned/grilled, buttery/beef fat attributes compared to all others ($P < 0.05$). Additionally, tenderloins had greater sour/acidic flavor compared to all others ($P < 0.05$). Oleic acid (C18:1 *cis*-9) percent was lower in tenderloin compared to all others ($P < 0.05$). Percent C18:1 *cis*-9 of 81:19 chuck was comparable with short rib and sirloin cap grinds ($P > 0.05$) but lower than shoulder clods, brisket, and knuckles ($P < 0.05$). Tenderloin grinds had the greatest percent of stearic acid (C18:0) compared to all others ($P < 0.05$). Tenderloin grinds also expressed the greatest content of 1-hexanol, hexanal, acetic acid, and 3-methylbutanal ($P < 0.05$). Methional content was greater from 81:19 chuck compared to all others ($P < 0.05$). Likewise, the knuckle had greater dimethyl sulfide compared to all other grinds ($P < 0.05$). Interestingly, short rib grinds frequently had the lowest ($P < 0.05$) or were comparable ($P > 0.05$) with other grinds low in the quantity of multiple volatile compounds. The results of this study imply that muscle source influences flavor and flavor-related compounds of ground beef. Therefore, processors and retailers may manage muscle sources and thus ground beef flavor through subprimal selection.

Key words: ground beef, fatty acid profile, muscle source, sensory analysis, texture profile, volatile compounds
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Introduction

Ground beef is one of the most popular beef items sold in retail and food service due to its affordable price and versatility (Slagle, 2012). Ground beef alone accounts for 60% of the total beef consumed in the United States (Close, 2014). Traditionally, ground beef provides an avenue to utilize trimmings produced during beef production to recover value. Additionally, muscles from the chuck and round, which have inherently low palatability, are routinely utilized as lean sources for ground beef (Nyquist et al., 2018).

Specialty blends or "premium grinds" may be composed of a blend of trimmings from a beef primal, such as ground chuck (Ohman et al., 2015). Previous work that targeted specific muscle blends from the beef chuck found few differences in color stability and lipid oxidation among blends (Ohman et al., 2015). However, retailers may utilize further cuts beyond the chuck for the production of premium grinds, such as ground sirloin. To date, less information is available

regarding the utilization of other muscles beyond the chuck.

Beef muscles vary in their biochemical composition due to morphological and metabolic differences associated with proportions of muscle fiber type (Kirchofer et al., 2002). It is also established that beef muscles vary in their predisposition towards lipid oxidation (McKenna et al., 2005). Finally, many prior studies have demonstrated that intact whole beef muscles vary in perceived flavor and tenderness (Gruber et al., 2006; Hunt et al., 2014; Colle et al., 2016; Tuell et al., 2022). However, little published research exists documenting flavor and texture differences of individual muscles in ground form.

Grinding is well known to increase surface area, exposure to oxygen, and intermix formerly sequestered metabolites. It is therefore plausible that any muscle-specific characteristics that influence flavor or texture may be appreciably profound once muscles are ground. Consequently, there is an opportunity to further address the fundamental flavor of individual beef muscles and to develop a practical understanding of individual muscle palatability when ground. Therefore, the objectives of this study were to evaluate the effects of trimming source (individual muscles) on ground beef flavor and texture in comparison with traditional ground chuck.

Materials and Methods

Experimental treatments and sample preparation

Beef subprimals representing 7 different whole-muscle grind sources were purchased for use in the study. Treatments were specifically chosen to represent beef subprimals that are commonly ground and merchandized as single-muscle grinds. The following were collected by Colorado State University (CSU) personnel from a commercial processing facility in northern Colorado: US Department of Agriculture (USDA) Low Choice shoulder clods North American Meat Processors (NAMP #114) containing the *M. Infraspinatus, Teres major*, and *Triceps Brachii*; boneless chuck short ribs (NAMP #130A) containing the *M. Serratus ventralis*; briskets (NAMP #120) containing the deep and superficial *M. Pectoral*; sirloin caps (NAMP #184D) containing the *M. Biceps femoris*; knuckles (NAMP #167) containing the *M. Vastus intermedius, Vastus lateralis, Vastus medialis*, and *Rectus femoris*; and 81:19 beef chuck trimmings. Tenderloins (NAMP #1190C) were purchased from a commercial meat purveyor in northeast Texas. All subprimals were transported under refrigeration (2°C) to the CSU Meat Laboratory where they were vacuum packaged and wet-aged in the absence of light at 2–4°C for 10 d postmortem.

On day 3 of the postmortem aging period, to standardize fat percentage, subprimals were unpackaged and separated into lean and external fat portions. Then, lean and fat portions were cut into cubes of a standard size equal to or smaller than 12.9 cm^3. Within each treatment, 5 batches (replicates; 13.6 kg each) were created by randomly assigning an equal number of subprimals to each batch. Using crude fat estimates for each cut from the USDA Nutrient Database Standard Reference (USDA Agricultural Research Service, 2012), batches were formulated to contain 15% fat using the Pearson square formula. Each batch of each treatment was repackaged in vacuum-sealed bags and continued the wet-aging process stated above.

Following postmortem aging (10 d), all product was transported, under refrigeration (2°C), to a research and development pilot plant in northern Colorado. Each batch of each treatment was then ground using a meat grinder (Biro, Model 7552 L04; Marblehead, OH) equipped with a coarse grinding plate (1.27 cm). After coarse grinding, each batch was blended for 3 min in a double-action mixer (Blentech, Model DM-10028-PVS; Rohnert Park, CA). During the first 1.5 min of mixing, CO_2 was continuously added to the mixer to simulate CO_2 chilling processes that are commonly used in large, commercial grinding operations. Following mixing, batches were ground a second time using a fine grinding plate (3.175 mm). Each batch was then formed into patties at a targeted weight of 151 g using a Formax (Formax F6, equipped with the 2874-6 plate; Mokena, IL). Each piece of equipment was rinsed in between treatments except for the patty-forming device, which was disassembled and cleared in between batches. Patties from each batch were separated and held in a CO_2 blast freezer (Martin-Baron Inc., MBI 1-18-0002-19; Irwindale, CA) for no longer than 5 h. After blast freezing, patties were vacuum packaged and placed in frozen storage at −20°C until further analysis.

Objective color analysis

Following patty forming, but before blast freezing, objective color measurements were attained from patties ($n = 9$) from the beginning, middle, and end of each batch within each treatment. Measurements were taken using a spectrophotometer using illuminant A, 10° observer angle, and a 3.175 cm aperture (Miniscan Model 4500S, Hunter Laboratories; Reston, VA).

Final color values for each sample were recorded as the mean of 3 individual L^*, a^*, and b^* values from each patty.

Proximate analysis

Three patties from each batch within each treatment were frozen in liquid nitrogen and homogenized into a fine powder using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc.; Ridgeland, MS). After homogenization, samples were placed in Whirl-Pak bags (Nasco; Ft. Atkinson, WI), individually labeled, and stored at −80°C until further analysis. Proximate analysis was conducted using the methods described below adhering to data quality control as described by Martin et al. (2013).

Total lipid was extracted from 1 g of sample using the methods described by Folch et al. (1957) and Bligh and Dyer (1959). After extraction, lipid extracts were dried under N_2 gas and placed into a 100°C drying oven for 3 h. Samples were then cooled to room temperature (22°C) in a desiccator. Once samples were cooled to room temperature, they were weighed, and the percentage of lipids was reported on a wet-weight basis. The total percentage of sample weight comprising lipids was calculated by dividing the final weight of the remaining sample by the initial sample weight and multiplying by 100.

Moisture was analyzed using the AOAC (2005) method. For each sample, 2 g was weighed into an aluminum tin (low form, aluminum, fluted, Fisher Scientific; Pittsburgh, PA) and placed in a forced air-drying oven (Thelco lab oven, Mandel, Inc.; Guelph, Ontario, Canada) set at 100°C for 24 h. After drying, samples were cooled to room temperature (22°C) in a desiccator. Samples were then reweighed, and percent moisture was reported as the difference between initial weight and final weight.

Nitrogen content was determined using the AOAC Official Method 992.15 (2005; LECO TruSpec CN or LECO FP-2000, LECO Corporation, St. Joseph, MI and Rapid N cube, Elementar, Hanau, Germany) and multiplied by 6.25 to determine crude protein content (Merrill and Watt, 1973). Ash was analyzed using AOAC 920.153 (AOAC, 2005). For each sample, 1 g was weighed into a dry crucible. Crucibles were then set in a Thermolyne box furnace (Thermo Fisher Scientific; Pittsburgh, PA), which was set at 600°C for 24 h. After removal from the incinerator, samples were cooled to room temperature (22°C) in a desiccator. Samples were then reweighed to obtain the ash percentage. The total percentage of ash was determined by dividing the sample weight in the crucible post-incineration by the initial weight and multiplying by 100.

Fatty acid analysis

For the determination of fatty acids (FA), total lipid was extracted from 1 g of homogenized sample as described above. Saponification and methylation of lipids to form fatty acid methyl esters (FAMES) were carried out using the methods of Park and Goins (1994) and Phillips et al. (2010). Analysis of FAMES was conducted using a Hewlett Packard (Avondale, PA) Model 6890 series II gas chromatograph (GC) fixed with a series 7683 injector and flame ionization detector. The GC was equipped with a 100-m × 0.25-mm (i.d.) fused silica capillary column (SP-2560 Supelco Inc.; Bellefonte, PA). Helium was used as the carrier gas with a flow rate of 2.0 mL/min. Column oven temperature increased from 40°C to 150°C at a rate of 8°C/min, held for 20 min at 150°C, and then increased from 150°C to 160°C at 0.5°C/min and from 160°C to 190°C at 0.2°C/min. The detector was maintained at 300°C and the inlet at 250°C throughout the run. Individual FA were quantified as a percentage of the total amount of FA identified. Fatty acid standards were obtained from Nu-Check Prep (Elysian, MN). Results were reported in units of g FA per 100 g original sample.

Texture profile analysis

Textural differences of raw ground beef patties ($n = 3$) from each batch of all treatments were objectively quantified using an analyzer (CT3 50K Texture Analyzer, Brookfield Engineering Laboratories; Middleboro, MA). Samples were randomized and thawed to 0–5°C prior to analysis. For each sample, a 3.8 cm × 3.8 cm^2 piece was cut from the middle of the patty and placed in the CT3 Texture Analyzer equipped with the Fixture Base Table (TA-BT-KIT, Brookfield Engineering Laboratories; Middleboro, MA) and the Ottawa Cell (TA-OC, Brookfield Engineering Laboratories; Middleboro, MA). A compression test was run with the following test parameters: target type = distance; target value = 57.0 mm; hold time = 0 s; trigger load = 0 kg; test speed = 300 mm/min; cycle count = 1. Results were reported as a measure of hardness or the maximum load value (kg) of the compression cycle. Results from each sample within each batch were averaged to obtain a single measurement for each batch within each treatment.

Descriptive sensory analysis

Sensory analysis was conducted at CSU. Prior to evaluating samples, panelists were introduced to standard beef flavor attributes using the lexicon developed by Adhikari et al. (2011) and trained to objectively quantify the intensity of each attribute using an unstructured 10 cm line scale. Samples designated for sensory analysis were randomly assigned to sensory sessions so that all treatments were represented in each panel. Two panel sessions were conducted each day with 10–11 samples per session, so 3 full replicates representing all 7 treatments were evaluated in one day. Samples were thawed for 12–24 h at 2°C before each sensory session. All samples were cooked on griddle pans (Cephalon Contemporary Non-Stick 11" Square Griddle) over open gas burners on a commercial range (Southbend 4602DD-2TR; Fuquay-Varina, NC). Pans were heated for 20 min prior to cooking to reach a surface temperature of 204°C. Patties were cooked to an internal temperature of 71°C and monitored by a Type K Thermocouple Thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation; Middlefield, CT). Following cooking, patties were cut into 8 wedge-shaped, equally sized portions and held in a warming box (Cambro MFR #: UPHC400110; 52°C) for no more than 15 min before being served to panelists.

Samples were served under red incandescent lights to mask color variation among samples. Panelists were supplied with distilled water, apple juice, and unsalted saltine crackers to cleanse their palettes between samples. Panelists evaluated each sample for beefy/brothy, browned/grilled, buttery/beef fat, bloody/metallic, gamey, earthy/mushroom, nutty/roasted nut, livery, sour/acidic, and bitter flavor attributes on a 10-cm unstructured line scale (0 = not present; 10 = very intense). Panelists also evaluated 7 texture characteristics, including hardness, cohesiveness, tenderness, connective tissue, particle size, moisture content, and beef fat/oily mouthfeel on the same 10 cm line scale (0 = very soft, crumbly, very tough, no presence, fine, very dry, and very low intensity; 10 = very hard, dense, very tender, very high-intensity course, very moist, and very high intensity). After each panel session, individual panelist ratings were averaged to obtain a single panel rating for each sensory attribute of each sample.

Volatile compound analysis

Frozen samples were transported to the Texas Tech University Gordon W. Davis Meat Laboratory for volatile compound analysis according to the methods of Legako et al. (2015) and Legako et al. (2016). One patty from each batch within each treatment was thawed at 2–4°C and cooked according to the same method as previously described in sensory analysis. Immediately after cooking, 3 cores (1.27 cm in diameter) were collected from each sample using a Warner-Bratzler coring tool. A 3.5 g (± 0.1 g) sample from the cores was weighed and placed into a 15 mL clear glass vial (Supelco; Bellefonte, PA) and closed with a screw cap (093640-040-00, Gerstel Inc.; Linthicum, MD). Each vial was submerged up to the neck in a 65°C water bath (Thermo Scientific; Waltham, MA) and allowed to equilibrate for 5 min. After the equilibration period, an 85-µm film thickness carboxen polydimethylsiloxane solid phase microextraction (SPME) fiber was used to extract the volatile compounds. The SPME fiber, contained in a manual SPME needle and holder (Supelco; Bellefonte, PA), was exposed to the headspace in the vial above the sample for 10 min. After 10 min of extraction, the SPME fiber was retracted into the needle and capped with a septum to prevent contamination from volatiles present in the atmosphere. Samples were held for no more than 3 h before injection for analysis via gas chromatography-mass spectrometry.

Volatile compound analysis was conducted using Agilent 6890 series GC (Agilent Technologies; Santa Clara, CA) equipped with a 5975-mass selection detector (Agilent Technologies; Santa Clara, CA). Before each sample run, the GC column was cryogenically focused to 0°C using liquid N_2. Once the column reached 0°C, the SPME fiber was injected into the GC inlet and the software program was started. The SPME fiber was desorbed in the GC inlet for 5 min to allow the volatile compounds to be extracted onto the GC column. Extracted volatile compounds were separated using a VF-5 ms capillary column (30 m × 0.25 mm × 1.00 µm; Agilent J&W GC Columns, Netherlands).

Ions within 33–500 m/z range were detected by the MS in the electron impact mode at 70 eV. Chromatography data were collected in the selective ion monitoring/scan mode (SIM/Scan; Agilent MSD Chemstation D.03.00.611 software, Agilent Technologies; Santa Clara, CA). Three primary ions from compounds of interest were selected and used for identification, detection, and in-run measurement. An alkane standard mix (C8-C22, Supelco; Bellefonte, PA) was used to calculate expected linear retention indexes (LRI) for compounds of interest. Lastly, volatile compound identities were validated by authentic external standards, in addition to the MS library. Quantitative estimates of compounds of interest were conducted by an external standard method (Legako et al., 2015; Legako et al., 2016).

Statistical analysis

All analyses were conducted using statistical procedures of SAS (SAS 9.3; Cary, NC). Treatment comparisons were tested for significance using generalized linear model procedures (PROC GLM). Least-squares means were calculated for each flavor and texture characteristic across treatments, with differences determined at $\alpha = 0.05$. To account for variations in lipid content, percent lipid was tested as a covariate in each model. In cases where the covariate was significant (buttery/beef fat, cohesiveness, and beef fat/oily mouthfeel), the covariate was included in the model statement. When percent lipid as a covariate was not significant, it was removed from the model. Additionally, Pearson correlation coefficients were calculated to show relationships between sensory attributes, FA composition, and volatile compound composition.

Results and Discussion

Objective color analysis

Results from objective color analysis are detailed in Table 1. Chuck trim patties possessed the greatest L^* values compared with all other treatments ($P < 0.05$). Brisket patties produced the darkest, least red patties with the lowest L^*, a^*, and b^* measurements compared with all other treatments ($P < 0.05$). In comparison, short rib patties produced the highest a^* and b^* values compared with all other treatments ($P < 0.05$), whereas chuck trim patties produced the lowest a^* and b^* values ($P < 0.05$). For a^* values or redness, the greatest difference observed was 6.2 between short ribs and chuck trim patties, whereas all other mean comparisons were 4.0 or less. Recent research indicates a difference in a^* values of 4.56 equates to a meaningful change in visual assessment (Mancini et al., 2022). Therefore, it may not be likely that the instrumental a^* value differences equate to large visual differences in redness outside of short ribs compared with ground chuck. In general, differences in function and biochemical stability, particularly muscle type, have been well-studied as factors influencing color stability in beef products (O'keeffe and Hood, 1982; Lanari and Cassens, 1991; McKenna et al., 2005; Ramanathan et al., 2020). Among these biochemical factors, the influence of fiber type composition is frequently cited to influence muscle tissue redness and stability in which more oxidative fiber-laden muscles are established to possess greater myoglobin content and be more susceptible to discoloration during storage (Hunt and Hedrick, 1977; Gagaoua et al., 2015). With the focus of this study on flavor, it is noteworthy that muscle fiber type has been demonstrated to influence volatile flavor compounds, total heme iron, and total antioxidant capacity (Li et al., 2023). Each of these may play a strong role in the development of volatile compounds and perceived flavor.

Table 1. Least-squares means for objective color measurements from ground beef patties ($n = 315$) from 7 muscle sources

Treatment[1]	L^*	a^*	b^*
Shoulder clods	47.55^{e}	17.26^{b}	20.41^{c}
Short ribs	49.67^{d}	19.52^{a}	21.96^{a}
Brisket	49.39^{d}	15.40^{d}	18.85^{d}
Sirloin caps	51.04^{bc}	16.70^{c}	21.13^{b}
Knuckles	50.02^{cd}	17.30^{b}	20.13^{c}
Tenderloins	52.10^{b}	16.58^{c}	21.08^{b}
81:19 chuck trim	54.04^{a}	13.32^{e}	18.49^{e}
SEM[2]	0.40	0.17	0.12
***P* value**	<0.001	<0.001	<0.001

[1]Treatments: shoulder clods (beef chuck, shoulder clods; NAMP #114); short ribs (beef chuck, boneless short ribs; NAMP #130A); briskets (beef briskets; NAMP #120); sirloin caps (beef loin, top sirloin caps; NAMP #184D); knuckles (beef round, sirloin tip knuckles; NAMP #167); tenderloins (beef loin, tenderloin tips; NAMP #1190C); trimmings (chuck-sourced trimmings 81% lean/19% fat).

[2]Largest standard error of least square means (SEM).

[a–e]Least-squares means in the same column lacking a common superscript differ ($P < 0.05$).

Proximate composition

Percentages of lipid, moisture, protein, and ash of all treatments are summarized in Table 2. Patties from sirloin caps and chuck trimmings possessed a greater lipid percentage than those from shoulder clods, briskets, knuckles, and tenderloins ($P < 0.05$). During the formulation of subprimal treatments, each batch was formulated to contain approximately 15% fat utilizing the Pearson square formula and the USDA Nutrient Database Standard Reference (USDA Agricultural Research Service, 2012). However, not all cuts in the database have updated nutrient content information, which could explain why treatments differed in percent lipid. Due to these differences, percent lipid was used as a covariate in the model for analyzing sensory results, when it was significant. As expected, percent protein and moisture were generally inversely related to percent lipid, as shown by knuckle patties having more protein and moisture than patties from sirloin caps and chuck trimmings ($P < 0.05$). No differences were seen in percent ash due to treatment ($P > 0.05$).

Table 2. Least-squares means for percentage lipid, protein, moisture, and ash as determined by proximate analysis of raw samples

Treatment[1]	Lipid, %	Protein, %	Moisture, %	Ash, %
Shoulder clods	14.20^{bcd}	17.79^{bc}	65.74^{ab}	0.81
Short ribs	17.12^{ab}	17.06^{bc}	63.33^{bc}	0.72
Briskets	13.72^{cd}	18.35^{ab}	65.20^{ab}	0.86
Top sirloin caps	19.18^{a}	16.55^{c}	60.59^{c}	0.76
Knuckles	12.04^{d}	19.39^{a}	66.99^{a}	0.88
Tenderloins	15.35^{bc}	18.03^{abc}	64.67^{ab}	0.82
81:19 chuck trim	19.52^{a}	16.75^{c}	60.75^{c}	0.74
SEM[2]	0.73	0.33	0.70	0.04
***P* value**	<0.001	<0.001	<0.001	0.120

[1]Treatments: shoulder clods (beef chuck, shoulder clods; NAMP #114); short ribs (beef chuck, boneless short ribs; NAMP #130A); briskets (beef briskets; NAMP #120); sirloin caps (beef loin, top sirloin caps; NAMP #184D); knuckles (beef round, sirloin tip knuckles; NAMP #167); tenderloins (beef loin, tenderloin tips; NAMP #1190C); trimmings (chuck-sourced trimmings 81% lean/19% fat).

[2]Largest standard error of least square means (SEM).

[a–d]Least-squares means in the same column lacking a common superscript differ ($P < 0.05$).

Descriptive flavor attributes

Descriptive flavor characteristics of ground beef patties are presented in Table 3. Chuck-sourced trimmings were included as an industry standard to compare with other whole-muscle sources. It is worth noting that from a flavor standpoint, no whole-muscle grind was rated higher than traditional chuck-sourced trimmings for any positive flavor attribute. Patties sourced from sirloin caps were the only whole-muscle blend consistently rated similar to chuck-sourced trimmings for desirable flavor attributes: beefy/brothy, browned/grilled, and buttery/beef fat ($P > 0.05$). Except for tenderloins, each of the whole-muscle grinds was rated similarly to chuck trimmings for beefy/brothy intensity ($P > 0.05$). Of the whole-muscle sources, patties from sirloin caps had a more intense beefy/brothy flavor than those sourced from shoulder clods, short ribs, knuckles, and tenderloins ($P < 0.05$). Tenderloins received the lowest ratings for beef/brothy intensity of all treatments evaluated ($P < 0.05$). Sirloin caps and knuckles produced similar browned/grilled flavor notes as chuck-sourced trimmings ($P > 0.05$). Sirloin caps provided a more intense browned/grilled flavor than shoulder clods, short ribs, briskets, and tenderloins ($P < 0.05$), with patties sourced from tenderloins having the least intense browned/grilled flavor of all treatments ($P < 0.05$). Panelists rated shoulder clod, brisket, and sirloin cap-sourced trimmings similarly to chuck-sourced trimmings for buttery/beef fat flavors ($P > 0.05$). Again, tenderloins had the least intense buttery/beef fat flavor of all treatments ($P < 0.05$). Although intensities were low for each treatment, patties from sirloin caps were the only whole-muscle source that was similar to chuck-sourced trimmings for nutty/roasted nut ($P > 0.05$).

Panelists found patties sourced from tenderloins to be the most sour among all treatments evaluated ($P < 0.05$). Knuckles were found to be more livery than patties from briskets, sirloin caps, tenderloins, and chuck-sourced trimmings ($P < 0.05$). Additionally, knuckles had a more intense gamey flavor than any other treatment ($P < 0.05$).

Table 3. Trained sensory panel ratings[1] for beef flavor attributes of ground beef samples representing 7 muscle source treatments

Treatment[2]	Beefy/ brothy	Browned/ grilled	Buttery/ beef fat	Bloody/ metallic	Gamey	Earthy/ mushroom	Nutty/ roasted nut	Livery	Sour/ acidic	Bitter
Shoulder clods	6.61^{c}	6.64^{b}	6.25^{ab}	0.21	0.09^{b}	0.42	0.26^{bc}	0.34^{ab}	0.14^{b}	0.10
Short ribs	6.72^{bc}	6.48^{b}	6.10^{b}	0.07	0.02^{b}	0.34	0.31^{b}	0.16^{abc}	0.19^{b}	0.21
Brisket	6.85^{ab}	6.65^{b}	6.12^{ab}	0.20	0.03^{b}	0.27	0.26^{bc}	0.01^{c}	0.29^{b}	0.09
Sirloin caps	7.02^{a}	7.03^{a}	6.18^{ab}	0.05	0.04^{b}	0.20	0.38^{ab}	0.01^{c}	0.15^{b}	0.17
Knuckles	6.69^{bc}	6.76^{ab}	6.00^{b}	0.21	0.19^{a}	0.30	0.31^{b}	0.36^{a}	0.16^{b}	0.20
Tenderloins	6.04^{d}	6.09^{c}	5.38^{c}	0.03	0.01^{b}	0.09	0.08^{c}	0.11^{bc}	3.29^{a}	0.51
81:19 chuck trim	6.80^{abc}	7.04^{a}	6.58^{a}	0.12	0.00^{b}	0.33	0.51^{a}	0.01^{c}	0.01^{b}	0.28
SEM[3]	0.08	0.13	0.10	0.07	0.04	0.07	0.08	0.06	0.08	0.11
***P* value**	<0.001	<0.001	<0.001	0.190	0.002	0.169	0.004	0.011	<0.001	0.374

[1]Sensory scores: 0 = very low intensity for flavor notes; no presence of off-flavors; 10 = very high intensity for all flavor notes.

[2]Treatments: shoulder clods (beef chuck, shoulder clods; NAMP #114); short ribs (beef chuck, boneless short ribs; NAMP #130A); briskets (beef briskets; NAMP #120); sirloin caps (beef loin, top sirloin caps; NAMP #184D); knuckles (beef round, sirloin tip knuckles; NAMP #167); tenderloins (beef loin, tenderloin tips; NAMP #1190C); trimmings (chuck-sourced trimmings 81% lean/19% fat).

[3]Largest standard error of least square means (SEM).

[a–d]Least-squares means in the same column lacking a common superscript differ ($P < 0.05$).

Variation in flavor among beef muscles is well-established for whole-muscle steaks (Hunt et al., 2014; Nyquist et al., 2018). Precursors to beef flavor in the aqueous and lipid fractions and subsequent volatile compounds developed during cooking frequently vary by beef muscle or product type and relate to perceived flavor (Dinh et al., 2018; Foraker et al., 2020; Ponce et al., 2020; Vierck et al., 2020). This report will aim to further evaluate relationships among beef flavor compounds and sensory attributes below.

Texture profile analysis

Table 4 shows trained sensory ratings and objective measurements of ground beef texture attributes. Patties from chuck-sourced trimmings, briskets, and knuckles were found to be the hardest ($P < 0.05$) and patties from tenderloins to be the softest ($P < 0.05$). Similarly, patties sourced from tenderloins were found to be the most tender of all treatments ($P < 0.05$), with brisket and knuckle-sourced patties being among some of the toughest ($P < 0.05$). Patties from tenderloins were more tender than patties from chuck-sourced trimmings ($P < 0.05$); however, patties from shoulder clods, short ribs, sirloin caps, and knuckles provided similar tenderness ratings to patties from chuck-sourced trimmings ($P > 0.05$). Additionally, patties from chuck-sourced trimmings by far had the greatest amount of perceived connective tissue among all treatments ($P < 0.05$). Collagen content is known to vary among beef muscles, where the tenderloin possesses the lowest amount among the muscles of this study (Jeremiah et al., 2003). Collagen content variation among beef muscles is known to influence beef tenderness of whole-muscle cuts (Rhee et al., 2004). Furthermore, when collagen is added to restructured beef products as a fat replacer, it was shown to affect texture by increased tensile strength (Kenney et al., 1992). Therefore, it is likely that the inherent collagen content of beef muscles influences the perception of texture attributes in ground products.

Although patties from tenderloins were the most tender, they were the least cohesive and most crumbly of all treatments ($P < 0.05$). Patties from short ribs were more cohesive than patties from sirloin caps and knuckles ($P < 0.05$); however, apart from the tenderloin, each muscle source provided similar cohesiveness to patties from chuck-sourced trimmings ($P > 0.05$). Patties from chuck-sourced trimmings were the most course and patties from tenderloins had the finest particle size among all treatments ($P < 0.05$). Compared with the other muscle sources, patties from sirloin caps were the most moist ($P < 0.05$); however, patties from shoulder clods, short ribs, briskets, and sirloin caps were similar in moisture content to those from chuck-sourced trimmings ($P > 0.05$). Patties from knuckles and tenderloins were drier than those from chuck-sourced trimmings ($P < 0.05$), with patties from knuckles being the driest among all treatments ($P < 0.05$). Few differences in beef fat/oily mouthfeel were observed due to ground beef source. Only patties from tenderloins produced a less intense beef fat/oily

Table 4. Trained sensory panel ratings[1] and objective measurements for beef texture of ground beef samples representing 7 muscle source treatments

Treatment[2]	Hardness	Cohesiveness	Tenderness	Connective tissue	Particle size	Moisture content	Beef fat/ oily mouthfeel	Peak load, kg
Shoulder clods	4.58^{b}	5.75^{ab}	6.11^{bc}	0.47^{bcd}	4.96^{bc}	5.74^{bc}	6.24^{a}	15.99^{bc}
Short ribs	4.49^{b}	6.28^{a}	5.90^{bc}	0.45^{cd}	4.66^{cd}	5.74^{bc}	6.06^{a}	16.79^{bc}
Brisket	5.25^{a}	5.76^{ab}	4.90^{e}	0.61^{bc}	5.34^{b}	5.79^{bc}	6.16^{a}	13.11^{c}
Sirloin caps	4.43^{b}	5.75^{b}	6.30^{b}	0.37^{cd}	4.35^{d}	6.28^{a}	6.20^{a}	16.77^{bc}
Knuckles	5.48^{a}	5.46^{b}	5.27^{de}	0.77^{b}	4.94^{bcd}	5.27^{d}	5.97^{ab}	16.47^{bc}
Tenderloins	3.65^{c}	4.48^{c}	6.90^{a}	0.19^{d}	3.37^{e}	5.62^{c}	5.66^{b}	18.73^{b}
81:19 chuck trim	5.34^{a}	6.07^{ab}	5.75^{cd}	1.88^{a}	6.02^{a}	5.96^{ab}	6.45^{a}	25.37^{a}
SEM[3]	0.21	0.17	0.15	0.09	0.18	0.14	0.11	1.26
***P* value**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[1]Sensory scores: 0 = very soft; crumbly; very tough; no presence; fine; very dry; very low intensity; 10 = very hard; dense; very tender; very high intensity; coarse; very moist; very high intensity.

[2]Treatments: shoulder clods (beef chuck, shoulder clods; NAMP #114); short ribs (beef chuck, boneless short ribs; NAMP #130A); briskets (beef briskets; NAMP #120); sirloin caps (beef loin, top sirloin caps; NAMP #184D); knuckles (beef round, sirloin tip knuckles; NAMP #167); tenderloins (beef loin, tenderloin tips; NAMP #1190C); trimmings (chuck-sourced trimmings 81% lean/19% fat).

[3]Largest standard error of least square means (SEM).

[a–e]Least-squares means in the same column lacking a common superscript differ ($P < 0.05$).

mouthfeel than patties from chuck-sourced trimmings ($P < 0.05$). Furthermore, patties sourced from shoulder clods, short ribs, briskets, sirloin caps, and knuckles all provided a similar beef fat/oily mouthfeel to trained panelists ($P > 0.05$).

Batches of each ground product in this study were formulated to be equal in total fat content. However, beef muscles may vary in proportion of triglycerides and phospholipids (Hergenreder et al., 2016; Hunt et al., 2016). Additionally, beef muscles vary in FA composition among different muscles (Gruffat et al., 2021). Different proportions of lipid classes and FA among beef muscles may be related to the perceived mouthfeel and cohesiveness of ground products observed in this study.

Fatty acid composition

Of the 20 FA reported, 14 were affected by treatment ($P \leq 0.031$; Table 5). Palmitic acid (C16:0) was the most abundant saturated fatty acid (SFA), accounting for roughly 25% of the total FA content of each treatment, similar to that of past works (Burnett et al., 2020). Each of the muscle sources had similar proportions of C16:0 compared with patties from chuck-sourced trimmings ($P > 0.05$). Among the different whole muscle sources, patties from shoulder clods had greater proportions of C16:0 than short ribs and briskets ($P < 0.05$), with the remaining muscles having similar C16:0 levels to all whole muscle sources ($P > 0.05$). Patties produced from tenderloins possessed a greater proportion of stearic acid (C18:0) than any other treatment ($P < 0.05$). Furthermore, patties from short ribs had similar C18:0 proportions compared with patties from chuck-sourced trimmings ($P > 0.05$); however, all remaining whole muscle sources provided lower proportions of C18:0 ($P < 0.05$). Except for shoulder clod patties, brisket patties had the lowest proportion of C18:0 among all treatments ($P < 0.05$). Prior evaluations of FA among different muscles determined greater proportions of C18:0 in tenderloins and other muscles categorized to possess higher proportions of oxidative muscle fibers (Rhee et al., 1988; Alfaia et al., 2007; Sexten et al., 2012). Patties from shoulder clods, briskets, knuckles, and tenderloins all contained similar

Table 5. Percentages[1] of identified fatty acids in ground beef samples representing 7 muscle source treatments

	Treatment[2]								
Fatty acid	Shoulder clods	Short ribs	Brisket	Sirloin caps	Knuckles	Tenderloin	81:19 chuck trim	SEM[4]	*P* value
C10:0	0.07	0.06	0.08	0.06	0.05	0.06	0.07	0.007	0.226
C12:0	0.11^{a}	0.08^{bc}	0.10^{ab}	0.08^{c}	0.09^{abc}	0.09^{abc}	0.09^{abc}	0.005	0.004
C12:1	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.003	0.277
C14:0	3.66^{a}	3.15^{e}	3.39^{bcd}	3.28^{de}	3.58^{ab}	3.34^{cde}	3.53^{abc}	0.053	<0.001
C14:1	1.09^{a}	0.55^{c}	0.98^{a}	0.74^{b}	0.76^{b}	0.35^{d}	0.66^{bc}	0.029	<0.001
C15:0	0.62^{bc}	0.61^{bc}	0.63^{bc}	0.64^{abc}	0.69^{a}	0.59^{c}	0.67^{ab}	0.013	<0.001
C15:1	0.05	0.04	0.05	0.04	0.04	0.02	0.06	0.007	0.061
C16:0	26.88^{a}	25.36^{bc}	25.16^{c}	26.10^{abc}	26.06^{abc}	25.85^{abc}	26.48^{ab}	0.293	0.004
C16:1 *cis*-9	4.05^{a}	2.75^{c}	3.86^{a}	3.08^{bc}	3.64^{a}	2.02^{d}	3.18^{b}	0.096	<0.001
C17:0	1.37^{d}	1.77^{ab}	1.65^{bc}	1.88^{a}	1.62^{bc}	1.54^{cd}	1.65^{bc}	0.046	<0.001
C17:1	0.92^{b}	0.87^{b}	1.16^{a}	1.01^{ab}	1.03^{ab}	0.52^{c}	0.85^{b}	0.042	<0.001
C18:0	13.17^{cd}	17.21^{b}	12.20^{d}	14.28^{c}	13.94^{c}	23.75^{a}	16.18^{b}	0.359	<0.001
C18:1 t (total)	1.99^{c}	3.56^{ab}	3.48^{ab}	4.01^{a}	2.94^{bc}	3.11^{ab}	3.53^{ab}	0.217	<0.001
C18:1 *cis*-9	33.74^{a}	32.58^{ab}	35.03^{a}	32.82^{ab}	33.60^{a}	26.88^{c}	30.10^{b}	0.663	<0.001
C18:2 total	1.95^{b}	1.65^{c}	2.29^{a}	1.81^{bc}	1.98^{b}	1.31^{d}	1.72^{bc}	0.058	<0.001
C18:2 *trans*[3]	0.53	0.48	0.58	0.45	0.59	0.56	0.49	0.056	0.512
C18:3 gamma/delta	0.73^{ab}	0.74^{ab}	0.59^{ab}	0.57^{ab}	0.94^{a}	0.96^{a}	0.45^{b}	0.104	0.011
C18:3 n-3	0.16	0.22	0.11	0.19	0.11	0.20	0.18	0.043	0.469
C20:1 *cis*-11	0.22^{ab}	0.20^{ab}	0.27^{a}	0.20^{ab}	0.19^{ab}	0.16^{b}	0.21^{ab}	0.019	0.031
C20:2	0.71	0.75	0.69	0.87	0.37	0.39	0.95	0.143	0.057

[1]Data presented are least-squares means for the normalized weight percentage of each fatty acid, expressed as a percentage of total fatty acid weight.

[2]Treatments: shoulder clods (beef chuck, shoulder clods; NAMP #114); short ribs (beef chuck, boneless short ribs; NAMP #130A); briskets (beef briskets; NAMP #120); sirloin caps (beef loin, top sirloin caps; NAMP #184D); knuckles (beef round, sirloin tip knuckles; NAMP #167); tenderloins (beef loin, tenderloin tips; NAMP #1190C); trimmings (chuck-sourced trimmings 81% lean/19% fat).

[3]Included C18:2 c9 t11, C18:2 t10 c12, C18:2 c11 t13, and C18:2.

[4]Largest standard error of least square means (SEM).

[a–e]Least-squares means in the same row lacking a common superscript differ ($P < 0.05$).

proportions of myristic acid (C14:0) to chuck-sourced trimmings ($P > 0.05$). Nonetheless, among whole-muscle grinds, patties from shoulder clods increased C14:0 proportions over those from short ribs, briskets, sirloin caps, and tenderloins ($P < 0.05$).

Oleic acid (C18:1 *cis*-9) was the most abundant monounsaturated fatty acid (MUFA), similar to many prior works (Wood et al., 2004). In this study, C18:1 *cis*-9 was different among ground beef samples ($P < 0.001$). Shoulder clods, briskets, and knuckles had greater proportions of C18:1 *cis*-9 compared with chuck-sourced trimmings ($P < 0.05$). Patties from short ribs and sirloin caps produced similar C18:1 *cis*-9 proportions as patties derived from briskets, knuckles, and chuck-sourced trimmings ($P > 0.05$); however, patties from tenderloins had lower proportions of C18:1 *cis*-9 than all others ($P < 0.05$). Proportions of total elaidic acid (C18:1 *trans*) were similar among patties from chuck-sourced trimmings and each whole-muscle source ($P > 0.05$), with the exception of patties from shoulder clods, which was lower in total C18:1 *trans* than all others ($P < 0.05$). Additionally, among whole-muscle sources, sirloin cap patties had a greater proportion of C18:1 *trans* FA than both shoulder clods and knuckles ($P < 0.05$). Like C18:1 *cis*-9, tenderloins patties had the least palmitoleic acid (C16:1 *cis*-9) compared with all other treatments ($P < 0.05$). Furthermore, patties from shoulder clods, briskets, and knuckles had greater proportions of C16:1 *cis*-9 than those from chuck-sourced trimmings ($P < 0.05$). Sirloin cap patties had similar levels of C16:1 *cis*-9 as those of chuck-sourced trimming patties ($P > 0.05$). In comparison, tenderloin and short rib-derived patties had lower proportions of C16:1 *cis*-9 than chuck-sourced trimmings ($P < 0.05$). Tenderloin-sourced patties also had the least of both myristoleic (C14:1) and heptadecenoic (C17:1) acids among all treatments ($P < 0.05$). Patties from shoulder clods and briskets had greater proportions of C14:1 than chuck-sourced trimmings ($P < 0.05$). However, short ribs, sirloin caps, and knuckle patties were similar to chuck-sourced trimming patties ($P > 0.05$). Patties from briskets had greater proportions of C17:1 than those from shoulder clods, short ribs, and chuck-sourced trimmings ($P < 0.05$). With the exception of brisket and tenderloin-sourced patties, each of the muscle sources provided similar proportions of C17:1 to chuck-sourced trimmings ($P > 0.05$).

Polyunsaturated fatty acids (PUFA) did not greatly differentiate, with the exception of linoleic acid (C18:2 total) and linolenic acid (C18:3 gamma/delta) each differing among muscle grinds ($P \leq 0.011$). Low proportions of PUFA in beef are generally recognized to be the result of the biohydrogenation of FA in the rumen (Smet et al., 2004). The greatest proportion of C18:2 total was in brisket patties and the lowest in tenderloins among all treatments ($P < 0.05$). Patties from shoulder clods, short ribs, sirloin caps, and knuckles had similar proportions of C18:2 total compared with chuck-sourced trimmings ($P < 0.05$). Chuck trim patties had less C18:3 gamma/delta compared with patties produced from knuckles and tenderloins ($P < 0.05$), but C18:3 gamma/delta of chuck trim patties was comparable with all other treatments ($P > 0.05$), which did not differ from each other ($P > 0.05$).

Fatty acid correlations with descriptive flavor attributes

Pearson correlation coefficients between FA and descriptive flavor attributes are presented in Table 6. The most prominent SFA, C16:0, was not correlated with any flavor attribute ($P > 0.05$). However, C18:0 was negatively correlated with beefy/brothy ($r = -0.71$), browned/grilled ($r = -0.57$), buttery/beef fat ($r = -0.41$), bloody/metallic ($r = -0.43$), gamey ($r = -0.34$), and nutty/roasted nut ($r = -0.34$), while being positively correlated with sour/acidic ($r = 0.86$) and bitter ($r = 0.40$). Previously, C18:0 was associated with grassy, gamey, livery, sour/acidic, and fishy off-flavors and negatively associated with beefy, browned, buttery, desirable flavors (Dryden and Marchello, 1970; O'Quinn et al., 2016).

In addition to C18:0, pentadecanoic acid (C15:0) was positively correlated with beefy/brothy ($r = 0.42$), browned/grilled ($r = 0.43$), gamey ($r = 0.34$), and nutty/roasted nut ($r = 0.38$) while negatively correlated with sour/acidic ($r = -0.44$). Margaric acid (C17:0) was positively correlated with beefy/brothy ($r = 0.48$) and negatively correlated with bloody/metallic ($r = -0.42$) and livery ($r = -0.51$). Counter to these results, prior studies have found these odd-chain FA to be negatively correlated with beefy and buttery while positively correlated with bloody/metallic (Dryden and Marchello, 1970; Baublits et al., 2009).

Among MUFA, C14:1, C16:1 cis-9, C17:1, and C18:1 *cis*-9 were positively correlated with beefy/brothy ($r \geq 0.40$), browned/grilled ($r \geq 0.36$), and bloody/metallic ($r \geq 0.36$). Many prior studies have determined similar positive associations between MUFA, such as C16:1 *cis*-9, and beefy/beef fat flavors (Dryden and Marchello, 1970; Baublits et al., 2009; Garmyn et al., 2011). Additionally, in agreement with this study, C18:1 *cis*-9 is frequently described as having a beneficial effect on beef flavor (Dryden and

Table 6. Pearson correlation coefficients showing relationships between fatty acid concentrations and sensory flavor attributes for 7 muscle source treatments

	Flavor Attribute									
Fatty acid	Beefy/ brothy	Browned/ grilled	Buttery/ beef fat	Bloody/ metallic	Gamey	Earthy/ mushroom	Nutty/ roasted nut	Livery	Sour/ acidic	Bitter
C10:0	−0.09	−0.22	−0.07	−0.11	−0.28	0.06	−0.12	0.01	−0.05	−0.07
C12:0	−0.16	−0.22	−0.22	0.25	0.01	0.22	−0.19	0.32	−0.12	−0.19
C12:1	−0.01	−0.08	−0.12	−0.08	0.00	−0.02	0.02	0.27	−0.20	−0.21
C14:0	0.00	0.18	0.01	0.16	0.27	0.24	0.15	0.26	−0.18	−0.05
C14:1	0.45*	0.36*	0.24	0.45*	0.30	0.36*	0.13	0.23	−0.64*	−0.36*
C15:0	0.42*	0.43*	0.20	−0.03	0.34*	0.04	0.38*	0.02	−0.44*	-0.09
C15:1	0.24	0.08	0.41*	−0.06	−0.31	0.28	0.20	−0.12	−0.40*	−0.30
C16:0	−0.09	0.05	0.18	−0.05	−0.01	0.22	0.10	0.14	−0.09	−0.05
C16:1 *cis*-9	0.51*	0.47*	0.28	0.55*	0.39*	0.36*	0.24	0.23	−0.71*	−0.34*
C17:0	0.48*	0.30	0.26	−0.42*	−0.09	−0.30	0.25	−0.51*	−0.21	0.09
C17:1	0.74*	0.57*	0.32	0.36*	0.35*	0.13	0.31	−0.09	−0.74*	−0.31
C18:0	−0.71*	−0.57*	−0.41*	−0.43*	−0.34*	−0.31	−0.34*	−0.09	0.86*	0.40*
C18:1 t (total)	0.40*	0.31	0.21	−0.39*	−0.21	−0.30	0.30	−0.45*	−0.07	0.13
C18:1 *cis*-9	0.61*	0.42*	0.22	0.50*	0.41*	0.20	0.15	0.11	−0.71*	−0.36*
C18:2 total	0.57*	0.44*	0.20	0.48*	0.35*	0.21	0.16	0.06	−0.64*	−0.31
C18:2 *trans*[3]	−0.25	−0.18	−0.27	0.32	0.07	0.15	−0.05	0.30	0.13	−0.12
C18:3 gamma/delta	−0.33	−0.19	−0.45*	0.19	0.39*	−0.21	−0.34*	0.40*	0.35*	0.09
C18:3 n-3	−0.14	−0.19	0.01	−0.12	−0.24	0.27	−0.22	0.08	0.11	0.16
C20:1 *cis*-11	0.36*	0.27	0.16	0.08	−0.05	0.07	0.19	−0.11	−0.34*	−0.18
C20:2	0.19	0.10	0.46*	−0.15	−0.38*	0.08	0.23	−0.29	−0.32	−0.09

*Correlation coefficient differs from 0 ($P < 0.05$).

Marchello, 1970; Westerling and Hedrick, 1979; Rule et al., 2002; Garmyn et al., 2011). This study further reveals that prominent MUFA are also frequently negatively ($P < 0.05$) correlated with detrimental flavor attributes. Specifically, C14:1, C16:1 cis-9, and C18:1 *cis*-9 were each negatively correlated with sour/acid ($r \leq -0.64$) and bitter ($r \leq -0.34$). Generally, these results imply that when prominent MUFA are in abundance flavor outcomes are positive, and when MUFA are less prominent flavor outcomes are less favorable.

O'Quinn et al. (2016) and Garmyn et al. (2011) found linoleic acid to have a negative effect on beef flavor. However, the results of this study indicate the opposite; C18:2 total was correlated with beefy/brothy ($r = 0.57$), browned/grilled ($r = 0.44$), and bloody/metallic ($r = 0.48$) and negatively correlated to sour/acidic ($r = -0.64$). Meanwhile, C18:3 gamma/delta was negatively correlated with buttery/beef fat ($r = -0.45$) and nutty/roasted nut ($r = -0.34$), while also being correlated with gamey ($r = 0.39$), livery ($r = 0.40$), and sour/acidic ($r = 0.35$). In agreement with this study, others have identified n-3 FA as detrimental to beef flavor (French et al., 2000; Wood et al., 2004; Chail et al., 2017). The reason for this differentiation among PUFA may be due to a greater propensity for lipid oxidation by n-3 FA compared with n-6 (Romeu-Nadal et al., 2007; Arab-Tehrany et al., 2012).

Volatile compounds

Among the volatile compounds evaluated, 18 were influenced by treatment ($P \leq 0.047$; Tables 7 and 8). Hexanal was the only lipid-derived aldehyde that differed due to treatment ($P < 0.001$). Tenderloin patties had the greatest amount of hexanal compared with all others ($P < 0.05$). Each other whole-muscle grind had hexanal concentrations similar to chuck-sourced trimmings ($P > 0.05$). Hexanal is a short-chain carbonyl related to lipid oxidation during storage (Lyte et al., 2016; Legako et al., 2018).

A similar trend existed for lipid-derived alcohols. Tenderloin-produced patties produced the greatest concentration of 1-hexanol compared with all other treatments ($P < 0.05$). 1-hexanol is an alcohol that results from lipid oxidation (Brewer, 2007). Sirloin cap patties possessed a higher concentration of 1-octen-3-ol compared with patties derived from shoulder clods, short ribs, and knuckles ($P < 0.05$), but were similar in concentration to patties from briskets and tenderloins ($P > 0.05$). For lipid-derived alkenes and alkanes, 1-octene was present in the greatest concentration ($P < 0.05$) in

Table 7. Concentrations (ng/g) of lipid-derived volatiles from cooked ground beef samples representing 7 muscle source treatments

	Treatment[1]								
Volatile (ng/g)	Shoulderclods	Short ribs	Brisket	Sirloin caps	Knuckles	Tenderloin	81:19 chuck trim	SEM[2]	*P* value
Alcohols									
1-Hexanol	0.4^{b}	0.4^{b}	0.4^{b}	0.4^{b}	0.5^{b}	2.4^{a}	0.3^{b}	0.1	<0.001
1-Heptanol	0.4	0.3	0.5	0.4	0.4	0.6	0.3	0.1	0.132
1-Octen-3-ol	0.3^{bc}	0.3^{c}	0.4^{abc}	0.6^{a}	0.3^{bc}	0.5^{ab}	0.3^{bc}	0.1	0.001
n-Aldehydes									
Pentanal	2.3	1.8	2.5	2.6	2.0	2.8	2.3	0.3	0.495
Hexanal	5.8^{bc}	4.0^{c}	7.9^{bc}	9.7^{b}	5.5^{bc}	15.4^{a}	7.3^{bc}	1.2	<0.001
Heptanal	1.1	0.6	1.6	0.8	0.6	1.2	1.0	0.3	0.332
Octanal	0.8	0.4	1.5	0.5	0.4	1.0	0.7	0.4	0.452
Nonanal	9.5	0.8	24.1	3.5	1.2	12.1	8.8	9.2	0.599
Decanal	0.5	0.1	2.1	0.2	0.1	1.0	0.7	0.8	0.612
Alkane and alkene									
1-Octene	1.5^{ab}	1.1^{b}	1.1^{b}	1.2^{b}	1.1^{b}	2.5^{a}	0.9^{b}	0.3	0.002
Octane	4.9	3.0	7.2	3.3	2.7	5.2	4.3	1.6	0.467
Carboxylic acids									
Acetic acid	37.2^{b}	38.3^{b}	21.9^{b}	51.8^{b}	42.7^{b}	219.3^{a}	29.9^{b}	13.0	<0.001
Butanoic acid	2.5^{b}	1.7^{b}	1.5^{b}	3.9^{ab}	7.4^{ab}	8.6^{a}	1.4^{b}	1.3	0.002
Hexanoic acid	0.9	0.6	1.2	1.1	0.8	1.6	0.7	0.3	0.128
Heptanoic acid	0.6	0.4	0.9	0.5	0.5	0.7	0.6	0.2	0.617
Octanoic acid	0.6	0.4	0.9	0.5	0.5	0.7	0.6	0.2	0.632
Nonanoic acid	2.4	0.7	7.4	1.5	0.8	4.5	2.7	2.9	0.654
Decanoic acid	1.0	0.9	1.6	0.9	0.8	1.3	1.0	0.3	0.653
Ketones									
2-Propanone	121.9^{bc}	191.7^{ab}	135.3^{abc}	223.8^{a}	173.9^{abc}	8.2^{c}	104.0^{bc}	22.4	0.001
2-Butanone	7.0	7.8	7.4	9.2	11.9	6.8	6.2	1.4	0.107
2-Heptanone	0.2	0.2	0.2	0.3	0.2	0.3	0.2	0.1	0.023

[1]Treatments: shoulder clods (beef chuck, shoulder clods; NAMP #114); short ribs (beef chuck, boneless short ribs; NAMP #130A); briskets (beef briskets; NAMP #120); sirloin caps (beef loin, top sirloin caps; NAMP #184D); knuckles (beef round, sirloin tip knuckles; NAMP #167); tenderloins (beef loin, tenderloin tips; NAMP #1190C); trimmings (chuck-sourced trimmings 81% lean/19% fat).

[2]Largest standard error of least square means (SEM).

[a–c]Least-squares means in the same row lacking a common superscript differ ($P < 0.05$).

tenderloin patties compared with all other treatments with the exception of shoulder clods.

Acetic acid was unquestionably highest in tenderloin samples, as it was present in approximately 4 times the concentration compared with other treatments ($P < 0.05$). Acetic acid is a carboxylic acid that is found in organic acids and typically imparts a sour flavor (Brewer, 2007). Butanoic acid followed a similar trend; however, it was not as extreme as acetic acid. Tenderloin patties produced the highest concentration of butanoic acid compared with patties from shoulder clods, short ribs, and brisket patties ($P < 0.05$), but they were similar to patties from the sirloin cap and knuckle ($P > 0.05$). Butanoic acid has a rancid odor and has been associated with negative flavors present in beef (Stetzer et al., 2008). 2-propanone, also referred to as acetone, was present in the highest concentration in sirloin cap patties compared with patties from tenderloins, shoulder clods, and chuck trim ($P < 0.05$).

The Maillard reaction is responsible for the production of many volatile compounds that are associated with cooked beef, as well as the characteristic brown color (Mottram, 1993). Strecker degradation is an important segment of the Maillard reaction, as it is responsible for the degradation of amino acids to produce specific aldehydes, which are positively correlated with flavor. Acetaldehyde, also known as ethanal, is a Strecker aldehyde that is produced through the degradation of alanine or cysteine (Resconi et al., 2013). Patties produced from sirloin caps possessed a higher concentration of acetaldehyde compared with patties from short ribs ($P < 0.05$). No differences were

Table 8. Concentrations (ng/g) of volatiles derived from the Maillard reaction from cooked ground beef samples representing 7 muscle source treatments

	Treatment[1]								
Volatile (ng/g)	Shoulder clods	Short ribs	Brisket	Sirloin caps	Knuckles	Tenderloin	81:19 chuck trim	SEM[2]	*P* value
Strecker aldehydes									
Acetaldehyde	7.7^{ab}	4.3^{b}	6.8^{ab}	10.8^{a}	8.1^{ab}	5.2^{ab}	6.2^{ab}	1.3	0.047
Isobutanal	0.6	0.5	0.7	0.9	1.0	0.5	0.6	0.1	0.044
2-methylbutanal	5.7^{ab}	3.0^{b}	7.5^{ab}	13.4^{a}	13.0^{a}	7.8^{ab}	6.7^{ab}	2.1	0.018
3-methylbutanal	10.4^{b}	6.5^{b}	10.4^{b}	18.6^{b}	20.6^{b}	62.0^{a}	9.2^{b}	6.4	<0.001
Methional	0.2^{b}	0.3^{b}	0.2^{b}	0.3^{b}	0.2^{b}	0.2^{b}	0.4^{a}	0.1	<0.001
Benzaldehyde	0.8	0.4	0.7	0.6	0.9	0.9	0.5	0.1	0.124
Ketones									
2,3-butanedione	4.6^{ab}	0.5^{c}	2.2^{bc}	6.1^{a}	4.2^{ab}	0.7^{c}	2.3^{bc}	0.7	<0.001
3-hydroxy-2-butanone	4.5^{b}	5.1^{c}	27.9^{bc}	73.7^{a}	43.3^{ab}	1.7^{c}	18.8^{bc}	7.2	<0.001
Pyrazines									
Methyl pyrazine	0.6	0.4	0.7	0.9	0.8	0.4	0.7	0.1	0.110
2,5-dimethylpyrazine	0.9^{ab}	0.6^{ab}	1.0^{ab}	1.3^{a}	1.2^{ab}	0.5^{b}	0.9^{ab}	0.2	0.013
Trimethylpyrazine	0.3	0.2	0.3	0.4	0.4	0.1	0.4	0.1	0.047
3-ethyl-2,5-dimethylpyrazine	0.2	0.1	0.2	0.2	0.2	0.1	0.2	0.0	0.173
2-ethyl-3,5-dimethylpyrazine	0.4	0.2	0.4	0.4	0.5	0.2	0.4	0.1	0.243
Sulfur-containing compounds									
Dimethyl sulfide	6.9^{b}	4.4^{b}	8.6^{b}	7.9^{b}	20.3^{a}	3.1^{b}	3.4^{b}	1.8	<0.001
Carbon disulfide	3.3	1.3	0.8	1.6	6.8	2.0	1.1	2.2	0.523
Dimethyl disulfide	0.2^{ab}	0.1^{b}	0.3^{ab}	0.3^{ab}	0.5^{a}	0.4^{a}	0.2^{ab}	0.1	0.006

[1]Treatments: shoulder clods (beef chuck, shoulder clods; NAMP #114); short ribs (beef chuck, boneless short ribs; NAMP #130A); briskets (beef briskets; NAMP #120); sirloin caps (beef loin, top sirloin caps; NAMP #184D); knuckles (beef round, sirloin tip knuckles; NAMP #167); tenderloins (beef loin, tenderloin tips; NAMP #1190C); trimmings (chuck-sourced trimmings 81% lean/19% fat).

[2]Largest standard error of least square means (SEM).

[a–c]Least-squares means in the same row lacking a common superscript differ ($P < 0.05$).

observed between the additional treatments ($P > 0.05$). Similar to acetaldehyde, 2-methylbutanal was present in the greatest concentration in patties from sirloin caps and knuckles compared with patties produced from short ribs ($P < 0.05$). 2-methylbutanal is produced from the degradation of isoleucine during cooking and has been associated with mushroom, earthy flavors (Resconi et al., 2013). Methional is a Strecker aldehyde that has been shown to provide a meaty aroma, due to the sulfur contained in its structure (Resconi et al., 2013). It is the result of the degradation of methionine during cooking and is also one of the 7 compounds uniquely prominent in beef (Brewer, 2007; Resconi et al., 2013). Methional was present in the highest concentration in chuck-sourced trimmings ($P < 0.05$). 3-methylbutanal is also a Strecker aldehyde that results from the degradation of leucine during cooking (Elmore et al., 1999; Resconi et al., 2013). Previous research has indicated that 3-methylbutanal is correlated with browned, buttery, nutty, and sweet flavors as well as present in coffee, hazelnuts, chocolate, bread crust, and cheddar cheese (Larick and Turner, 1990; Zehentbauer and Grosch, 1998; Whetstine et al., 2006; Burdack-Freitag and Schieberle, 2012; O'Quinn, 2016). 3-methylbutanal was present in the greatest concentration in tenderloin patties compared with all other treatments ($P < 0.05$). This result is in agreement with recent work that found similar oxidative Type I–laden muscles, like tenderloin, to produce significant amounts of 3-methylbutanal (Li et al., 2023).

2,3-butanedione and 3-hydroxy-2-butanone are 2 ketones that develop during the Maillard reaction and have been known to impart buttery, beefy, positive flavors (Hirai et al., 1973; Peterson et al., 1975; El-Magoli et al., 1996; Brewer, 2007). Both of these compounds were found in the highest concentration in sirloin cap patties compared with patties from short ribs and tenderloins ($P < 0.05$).

Sulfur-containing compounds, particularly dimethyl sulfide and dimethyl disulfide were detected in differing concentrations between treatments. Sulfur-containing compounds are often known as the most powerful aroma volatiles because they have such a low odor threshold (Shahidi, 1994; Resconi et al., 2013). Low concentrations of these compounds can have a meaty aroma, but high concentrations have strong, objectionable aromas

(Mottram, 1993; Shahidi, 1994; Mottram, 1998). Sulfur-containing compounds are produced during the Maillard reaction from sulfur that is freed from amino acids during cooking (Mottram, 1993). In the current study, sulfur-containing compounds diverged in results. Dimethyl disulfide was produced in greater concentration in tenderloin and knuckle patties compared with short rib patties ($P < 0.05$). In contrast, knuckle-derived patties produced a greater concentration of dimethyl sulfide compared with all other treatments ($P < 0.05$). Of the 5 pyrazines evaluated, only one was impacted by treatment. 2,5-dimethylpyrazine, which is produced during heterocyclization in the Maillard reaction, was present in a greater concentration in sirloin cap patties compared with tenderloin patties ($P < 0.05$).

Volatile compound correlations with descriptive flavor attributes

Pearson correlation coefficients showing relationships between volatile concentrations and beef flavor attributes are summarized in Tables 9 and 10. In the current study, hexanal was abundant in tenderloin patties and associated with sour flavors. Additionally, hexanal was negatively correlated with beefy/brothy and earthy/mushroom flavors ($r \leq -0.42$). Hexanal is widely recognized as an indicator of lipid oxidation. A negative correlation between hexanal and beefy/brothy may indicate the detriment lipid oxidation has toward characteristic beef flavor. 1-hexanol was positively correlated to sour/acidic ($r = 0.95$) flavors and negatively correlated with beefy/brothy ($r = -0.80$), browned/grilled ($r = -0.60$), and buttery/beef fat ($r = -0.62$). Acetic acid was also highly correlated ($r = 0.91$) to sour/acidic flavors, coupled with negative correlations to beefy/brothy ($r = -0.73$), browned/grilled ($r = -0.52$), and buttery/beef fat ($r = -0.62$). A strong relationship of acetic acid with sour/acidic flavors is clearly related to the ability of organic acids to impart a sour taste on the tongue. Recently, other studies have pointed to an accumulation of acetic acid during long beef aging, likely due to the growth of spoilage microorganisms (Hernandez et al., 2022; Barker et al., 2023). Additionally, 2-propanone was positively correlated with beefy/brothy ($r = 0.40$) and negatively related to sour/acidic ($r = -0.41$). However, other published studies show 2-propanone to be associated with negative flavor characteristics, as 2-propanone is derived during lipid oxidation (Larick and Turner, 1990; Gorraiz et al., 2002).

Methional was positively correlated with buttery/beef fat ($r = 0.57$) and nutty/roasted nut ($r = 0.65$) flavors. Additionally, 3-methylbutanal was negatively associated with brown/grilled, buttery/beef fat, and nutty/roasted nut ($r = -0.38$, -0.56, and -0.39, respectively). 2,3-butanedione and 3-hydroxy-2-butanone were positively correlated in beefy/brothy ($r = 0.37$, 0.44) and browned/grilled flavors ($r = 0.34$, 0.35). Sirloin cap patties also were rated the highest for these traits, which is likely explained by the increased

Table 9. Pearson correlation coefficients representing 7 muscle sources showing relationships between beef sensory attributes and concentrations of lipid-derived volatile compounds

	Beefy/ brothy	Browned/ grilled	Buttery/ beef fat	Bloody/ metallic	Gamey	Earthy/ mushroom	Nutty/ roasted nut	Livery	Sour/ acidic	Bitter
Alcohols										
1-Hexanol	−0.80*	−0.60*	−0.62*	−0.26	−0.19	−0.37*	−0.48*	0.02	0.95*	0.25
1-Heptanol	−0.30	−0.22	−0.34*	−0.05	−0.09	0.00	−0.24	0.16	0.45*	0.15
1-Octen-3-ol	−0.04	−0.01	−0.08	−0.43*	−0.13	−0.32	0.11	−0.35*	0.36*	0.19
n-Aldehydes										
Hexanal	−0.47*	−0.27	−0.31	−0.28	−0.26	−0.42*	−0.22	−0.27	0.71*	0.39*
Alkanes										
1-Octene	−0.54*	−0.38*	−0.56*	−0.11	−0.19	−0.27	−0.38*	0.07	0.69*	0.17
Carboxylic acids										
Acetic acid	−0.73*	−0.52*	−0.62*	−0.21	−0.21	−0.31	−0.43*	0.06	0.91*	0.37*
Butanoic acid	−0.45*	−0.27	−0.60*	0.00	0.31	−0.05	−0.23	0.22	0.51*	0.24
Hexanoic acid	−0.27	−0.15	−0.26	−0.12	−0.16	−0.08	−0.19	0.02	0.46*	0.14
Ketones										
2-propanone	0.40*	0.16	0.08	−0.07	0.16	0.10	0.23	−0.11	−0.41*	−0.21
2-heptanone	−0.02	0.01	−0.17	−0.18	−0.02	−0.09	0.01	−0.04	0.26	0.14

*Correlation coefficient differs from 0 ($P < 0.05$).

Table 10. Pearson correlation coefficients representing 7 muscle sources showing relationships between beef sensory attributes and concentrations of volatile compounds produced during the Maillard reaction

	Beefy/ brothy	Browned/ grilled	Buttery/ beef fat	Bloody/ metallic	Gamey	Earthy/ mushroom	Nutty/ roasted nut	Livery	Sour/ acidic	Bitter
Strecker aldehydes										
Acetaldehyde	0.32	0.13	0.03	−0.01	0.14	0.08	0.24	0.00	−0.21	−0.17
Isobutanal	0.13	0.07	−0.17	0.19	0.32	0.11	0.06	0.02	−0.20	−0.16
2-methylbutanal	0.04	0.09	−0.24	0.17	0.35*	0.05	−0.04	−0.01	−0.02	−0.02
3-methylbutanal	−0.60*	−0.38*	−0.56*	−0.19	−0.06	−0.26	−0.39*	−0.02	0.74*	0.40*
Methional	0.30	0.45*	0.57*	−0.18	−0.15	0.06	0.65*	−0.25	−0.20	0.24
Ketones										
2,3-butanedione	0.37*	0.34*	0.07	0.09	0.35*	0.06	0.22	0.13	−0.39*	−0.20
3-hydroxy-2-butanone	0.44*	0.35*	0.09	0.15	0.24	0.06	0.18	0.06	−0.44*	−0.27
Pyrazines										
2,5-dimethylpyrazine	0.39*	0.33	0.05	0.12	0.31	0.18	0.16	0.09	−0.37*	−0.14
Trimethylpyrazine	0.42*	0.37*	0.13	0.03	0.31	0.25	0.19	0.12	−0.36*	−0.07
3-ethyl-2,5-dimethylpyrazine	0.39*	0.32	0.08	0.07	0.28	0.30	0.10	0.24	−0.33	−0.07
2-ethyl-3,5-dimethylpyrazine	0.38*	0.35*	0.11	0.01	0.33*	0.17	0.04	0.05	−0.23	0.03
Sulfur compounds										
Dimethyl sulfide	0.15	0.09	−0.27	0.22	0.66*	0.13	0.00	0.24	−0.28	−0.11
Dimethyl disulfide	−0.39*	−0.27	−0.53*	0.09	0.23	−0.20	−0.22	0.17	0.39*	−0.14

*Correlation coefficient differs from 0 ($P < 0.05$).

concentration of these Maillard ketones. Furthermore, O'Quinn et al. (2016) observed these Maillard ketones to be the 2 most highly correlated with overall flavor desirability, which indicates that sirloin caps could be used to improve flavor and overall liking with consumers in muscle blends. Furthermore, dimethyl disulfide was inversely related to buttery/beef fat flavors (r = −0.53) and beefy/brothy flavors (r = −0.39) and positively related to sour/acidic flavors (r = 0.39). Dimethyl sulfide was strongly correlated (r = 0.66) with gamey off-flavors. Previous studies reported associations between dimethyl sulfide and off-flavors as well as negative correlations to flavor desirability, browned, buttery, nutty, and sweet flavors (Larick and Turner, 1990; O'Quinn, 2016). Additionally, 2,5-dimethylpyrazine was also positively associated (r = 0.39) with beefy/brothy flavor and negatively correlated with sour/acidic flavors (r = −0.37).

Conclusions

Utilization of single beef subprimals for ground beef production creates opportunities for processors and retailers. However, this study reveals that muscle source impacts sensory response, texture, FA composition, and volatile profile of resulting ground beef. Muscles known to possess a greater proportion of Type I oxidative muscle fibers expressed a more unique FA composition and volatile profile that manifested different flavor and texture attributes. Because of these biochemical features, processors and retailers should not expect uniform quality attributes among all beef muscle sources. The practical insights of this study imply that sirloin caps present an opportunity to be utilized in grinds and provide a positive eating experience. Furthermore, sirloin caps are moderately priced and would be a cost-effective muscle source for premium grinds.

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