Meat and Muscle Biology™

Flavor Development of Ground Beef from 3 Muscles, 3 USDA Quality Grades, and 2 Wet-Aging Durations

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Abstract: The objective of this study was to understand the influence of USDA quality grade, muscle, and aging duration on ground beef flavor development. Prime (PR), Low Choice, and Standard quality grade beef subprimals were collected and aged for either 21 or 42 d. Following aging, subprimals were fabricated into *gluteus medius* (GM), *biceps femoris* (BF), and *serratus ventralis* (SV) then ground and formed into patties. Raw patties were designated for proximate composition, fractionated fatty acids, and thiobarbituric acid reactive substances (TBARS). Cooked patties were designated for consumer sensory analysis, volatile compound analysis, and TBARS. Patties were cooked on a preheated griddle to 72°C. All data were analyzed as split-split plot where quality grade served as the whole plot factor, muscle as the subplot factor, and aging duration as the sub-subplot factor. Significance was determined at $P < 0.05$. A quality grade × muscle interaction was observed for moisture, where regardless of muscle, PR subprimals had the lowest moisture percentage ($P < 0.05$). Raw TBARS was not influenced by any interactions or main effects ($P > 0.05$). Individually, the BF and 42 d aged subprimals had the greatest cooked malondialdehyde concentration ($P < 0.05$). Patties from GM aged for 21 d were rated higher for flavor liking compared to GM aged for 42 d and SV aged for 21 and 42 d ($P < 0.05$). GM patties aged for 21 d were rated higher for overall liking compared to GM patties aged for 42 d ($P < 0.05$). Quality grade did not influence any lipid-derived volatile compounds ($P > 0.05$). The SV produced less Maillard reaction products ($P < 0.05$). Aging for 42 d increased lipid-derived volatiles ($P < 0.05$). Consumer liking of aged product is dependent on muscle. Aging recommendations should be muscle-specific to maximize beef eating experience.

Key words: aging, beef, muscle, oxidation, quality grade, volatile compounds, sensory, lipids
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Introduction

Of the 3 primary meat palatability attributes, tenderness has been accepted as the driver of beef consumer acceptability (Savell et al., 1987; Miller et al., 2001). However, once tenderness is acceptable, flavor becomes the most important attribute (Huffman et al., 1996; Miller et al., 2001; Killinger et al., 2004). Beef flavor is incredibly complex and can be influenced by various pre- and post-harvest practices. Understanding how these factors influence beef flavor is crucial to producing a consistent product that is acceptable by consumers.

Beef flavor is thermally derived from 3 major pathways: the Maillard reaction, lipid degradation, and thiamine degradation (Mottram, 1998; Kerth and Miller, 2015). Free amino acids, reducing sugars, and fatty acids are the primary flavor precursors for these reactions. Muscles within a beef carcass vary in chemical characteristics, i.e., muscle fiber type and size, metabolism, composition, pH, etc. All of these factors contribute to differences in flavor precursors that can influence flavor development. Moreover, postmortem aging results in the release of free amino acids and reducing sugars (Koutsidis et al., 2008; Foraker et al., 2020; Hernandez et al., 2023). Previous literature seeking

to compare consumer liking of various muscles can be limited due to the inherent "halo effect" of tenderness on flavor liking (Hunt et al., 2014; Legako et al., 2015a; Vierck et al., 2021b). The "halo effect" is defined as the influence of one palatability trait on another (Meilgaard et al., 2006). Generally, if consumers rate a steak sample to be tender, their flavor liking rating could be inflated and vice versa with tough samples. By grinding samples, any tenderness differences between muscles can be eliminated (O'Quinn et al., 2016).

As previously stated, beef flavor can be modulated by various factors. Few studies have evaluated the interactive effects of USDA quality grade, muscle, and aging duration on beef flavor development and consumer liking. Different muscles possess various metabolism and biochemical profiles because of anatomical location and fiber type. These factors cause varying responses to lipid accumulation, aging, and subsequent palatability. Therefore, the objective of this study was to understand the influence of USDA quality grade, muscle, and aging duration on beef flavor development.

Materials and Methods

Product selection and sample processing

Paired top sirloin butts (Institutional Meat Purchasing Specifications [IMPS] #184), bottom rounds (IMPS #171B), and chuck rolls (IMPS #116A) were collected from "A" maturity USDA Prime (PR), Low Choice (LC), and Standard (ST) carcasses from a commercial packing plant ($n = 18$ carcasses; 6 per quality grade) based on visual appraisal. Quality grade data were collected by trained Texas Tech personnel from both sides of the carcass. Subprimals were collected during fabrication, vacuum-packaged, and transported to Texas Tech University. Wet-aging duration (21 or 42 d) was assigned to individual subprimals from each side. Subprimals were aged at 2°C to 4°C in the absence of light. Following the aging period, subprimals were fabricated into individual muscles (*gluteus medius* from the top sirloin [GM]; *biceps femoris* from the bottom round [BF]; and *serratus ventralis* from the chuck roll [SV]). Fabricated muscles were coarse ground (Biro Heavy Horsepower Grinder, Biro, OH) using a 1.27-cm grind plate, followed with fine grinding using a 4.76-mm grind plate. Ground product was vacuum stuffed (Handtmann Inc., Lake Forest, IN) into chub packages, frozen, and stored for 5 weeks at −20°C until portioning the frozen chub into 1.9-cm-thick patties using a bandsaw (Biro). Patties were assigned to consumer sensory, volatile compounds, and chemical analyses. Patties designated for raw chemical analyses were snap frozen in liquid nitrogen and homogenized using a commercial food processor (Robot Coupe BLIXER 6 V; Robot Coupe USA, Inc., Ridgeland, MS). Powdered homogenates were stored at −80°C until subsequent analyses.

Cooking method

Patties for consumer sensory evaluation and volatile compound analysis were cooked using methods from O'Quinn et al. (2016). Briefly, griddle pans (Calphalon Hard-Anodized Nonstick Double Griddle, Perrysburg, OH) were preheated to 246°C over a natural gas burner. Once griddles were preheated, patties were cooked to an internal temperature of 72°C (Cole-Parmer thermometer with Type J thermocouple, Vernon Hills, IL). Peak temperature was recorded 1 min after removal from griddle. If samples were designated for cooked chemical analyses, patties were allowed to cool to 22°C prior to homogenization and stored as described previously.

Proximate analyses

Fat content was determined using the modified methods of Folch et al. (1957). Lipid was extracted from 1 g of sample homogenate using chloroform and methanol (1:1, v/v). The aqueous layer was aspirated and 4 mL of the organic layer was pipetted into a preweighed glass culture tube. The solvent was evaporated using a heating block, and then samples were placed in a forced air oven at 100°C for 16 h. Samples were allowed to cool in a desiccator prior to weighing. Fat percentage was calculated using the following equation:

$$Fat,\% = (residue\ weight \div wet\ weight) \times 100$$

Moisture and ash were determined using methods from AOAC (2006). Five grams of raw homogenate were weighed out into acid-washed, preweighed ceramic crucibles. Samples were dried for at least 16 h in a forced air oven set to 100°C. Samples were removed from the oven and allowed to cool in a desiccator prior to weighing. Percent moisture was calculated using the following equation:

$$Moisture,\% = [(wet\ weight - dry\ weight) \div wet\ weight]$$

Following weighing, samples were placed into a muffle furnace at 550°C for 24 h. After 24 h, samples

were placed in a desiccator to cool and then weighed to calculate percent ash using the following equation:

$$Ash,\% = (ash\ weight \div wet\ weight) \times 100$$

Protein was determined using the AOAC Official Method 992.15 (AOAC, 2006). Nitrogen content of samples was measured via combustion using a LECO TruMacN (LECO Corporation, St. Joseph, MI). Percent protein was calculated by multiplying percent nitrogen by a factor of 6.25.

pH

pH was measured on raw sample homogenates as described in Luqué et al. (2011). Three pH readings were measured per sample using a calibrated benchtop pH meter and averaged prior to statistical analysis.

Thiobarbituric acid reactive substances analysis

Thiobarbituric acid reactive substances (TBARS) was conducted as described by Luque et al. (2011). Both raw and cooked samples were analyzed. In duplicate, 10 g of sample homogenate was homogenized with 30 mL of deionized water and then centrifuged for 10 min at 3,000 rpm. Two milliliters of the resulting supernatant was spiked with 4 mL of a 15% trichloroacetic acid and 20 mM thiobarbituric acid solution as well as 100 µL of 10% butylated hydroxy anisole. The samples were then incubated at 100°C for 15 min, cooled in an ice bath for 15 min, and centrifuged at 3,000 rpm for 10 min. The resulting supernatant was transferred into a cuvette, and absorbance was measured at 531 nm using a spectrophotometer (Genesys 20, ThermoScientific, Waltham, MA). Malondialdehyde concentration was quantified to milligrams per kilogram of sample using a 5-level standard curve.

Fatty acids

Neutral and polar fatty acid profiles of raw samples were analyzed using methods from Legako et al. (2015b). Briefly, total lipid was extracted as described previously. The extracted lipids were then fractionated using Resprep silica gel cartridges (Restek Corporation, Bellefonte, PA). The neutral fraction was eluted using 10 mL of chloroform, whereas the polar fraction was eluted using 15 mL of methanol. Solvent from each fraction was evaporated under a stream of nitrogen then stored at −80°C. Neutral lipid fatty acids were saponified and derivatized with sodium methoxide in methanol. Polar lipid fatty acids were saponified and derivatized with methanolic potassium hydroxide. Prior to derivatization, linolelaidic acid (18:2 n-6 *trans*) was added to each sample as an internal standard. Derivatized fatty acids were analyzed using an Agilent 6890 gas chromatography system (Agilent Technologies, Santa Clara, CA). Fatty acids were separated on a HP-88 capillary column (100 m × 0.25 mm internal diameter) and detected via flame ionization. Fatty acid identity was confirmed by authentic fatty acid methyl ester standards (Supelco 37 Component FAME Mix, Sigma Aldrich, St. Louis, MO).

Consumer sensory evaluation

The Texas Tech University Institutional Review Board approved procedures for use of human subjects for consumer panel evaluation (TTU IRB #504692).

Consumer sensory evaluation was conducted using similar methods reported in Hunt et al. (2014). Consumer panelists ($n = 108$) were recruited from Lubbock, Texas, and surrounding communities. Panels were conducted in the Animal and Food Sciences Building at Texas Tech University. Panelists were monetarily compensated for their participation in the study. Eighteen consumers were served per 60-min panel. The entire study consisted of 6 panels. Consumers were sat in a classroom with individual dividers under florescent lighting. Each consumer was provided with a paper ballot that included a demographic form and 6 sample ballots. Consumers evaluated overall liking and flavor liking using a 100-mm line scale where 0 was defined as "extremely dislike" and 100 was defined as "extremely like." Consumers were asked to designate whether each attribute was acceptable using a "yes/no" scale. Additionally, 4 quality levels of "Unsatisfactory," "Good Everyday Quality," "Better than Everyday Quality," and "Premium Quality" were used to categorize quality level for each sample. Each consumer was also provided with plastic utensils, toothpicks, napkin, expectorant cup, cup of water, diluted apple juice, and saltless crackers.

Patties were cooked as previously described. Two patties per treatment combination were split into 3 equally sized portions to be served to 6 consumers. Each panelist evaluated 6 samples of the 18 treatment combinations. Regardless, no treatment combinations were evaluated in duplicate by a single consumer. Within 1 panel session, all 18 treatment combinations

were evaluated. Panelists scores were averaged per patty prior to statistical analysis.

Volatile compound analysis

Volatile compound analysis was conducted using modified methods from Legako et al. (2015a). Immediately following cooking, 3 g of cooked sample were weighed into a 15 mL glass vial and spiked with an internal standard (1,2-dichlorobenzene; Sigma Aldrich, St. Louis, MO). Samples were sealed with a polytetrafluoroethylene septum and placed in a 65°C water bath. Sample and vial headspace temperatures were allowed to equilibrate for 5 min prior to solid phase microextraction (SPME) using an 85-µm film thickness carboxen polydimethylsiloxane SPME fiber (Supelco, Bellefonte, PA). The extraction period lasted 10 min. Separation and detection of volatile compounds was conducted using an Agilent 6890 series gas chromatograph equipped with a 5975-mass selective detector (gas chromatography-mass spectrometry, Agilent Technologies, Santa Clara, CA). Prior to injection of sample, the VF-5ms capillary column (30 m × 0.25 mm × 1.00 µm; Agilent J&W GC Columns, Santa Clara, CA) was cooled to 0°C using liquid nitrogen oven cooling. The SPME fiber was then injected into the GC-MS in splitless mode. Separated compounds were ionized through electron ionization at 70 eV and were detected by the MS within a 33-500 m/z mass range. Mass spectral data were acquired in selective ion monitoring and scan modes. Authentic external standards were used to validate volatile compound identities via retention time and fragmentation pattern. Volatile compounds were quantitated to nanograms per gram.

Statistical analysis

All data were analyzed as split-split plot where quality grade served as the whole plot factor, muscle as the subplot factor, and aging duration as the sub-subplot factor. Chub served as the experimental unit. A 3-way analysis of variance was conducted using the PROC GLIMMIX procedure of SAS v.9.3 (SAS Institute, Cary, NC). Quality grade, muscle, aging duration, and their 3- and 2-way interactions served as main effects. Carcass ID was included in the model as a random effect. When significant ($P < 0.05$), least-squares means were separated using the PDIFF function. No 3-way interactions were observed for any variables ($P > 0.05$).

Principal component (PC) analysis was conducted to visualize the relationships between TBARS, volatile compound concentration, and consumer liking attributes within the muscle × aging duration treatments using XLSTAT v. 2023.3.0 (Addinsoft, Paris, France). Data are presented as biplots.

Results and Discussion

Muscle composition

A quality grade × muscle interaction was observed for moisture and protein percentage ($P < 0.05$, Figures 1 and 2). Generally, PR muscles had lower moisture percentages compared to lower quality grade muscles ($P < 0.05$), with the SV having the lowest moisture percentage compared to all other treatment combinations ($P < 0.05$). Protein percentage was the lowest in PR and ST SV patties ($P < 0.05$). Moreover, the protein percentage of ST SV patties was lower than ST BF and GM patties ($P < 0.05$).

Quality grade, muscle, and aging duration main effects for fat percentage, ash percentage, and pH are presented in Table 1. Quality grade influenced fat and ash percentage ($P \leq 0.006$) but not pH ($P = 0.127$).

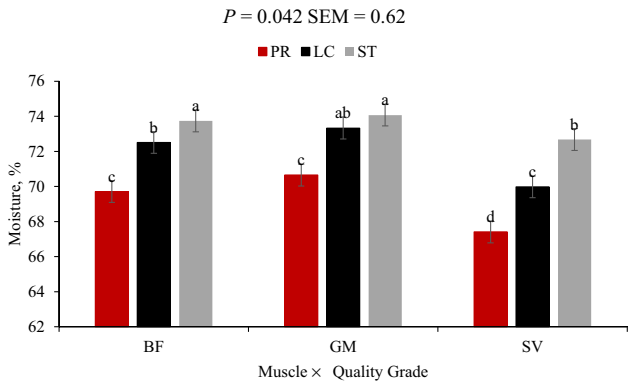

Figure 1. Interaction of moisture percentage of ground beef patties from 3 muscles and 3 quality grades.

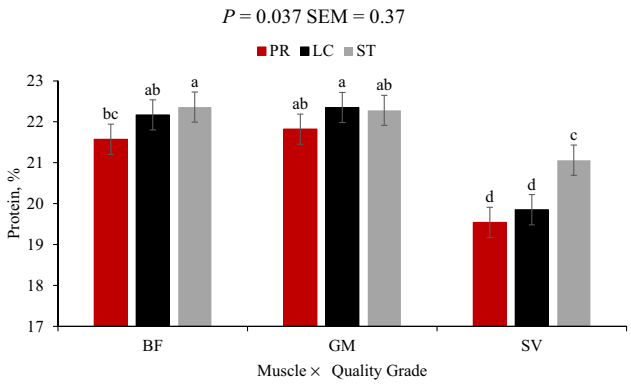

Figure 2. Interaction of protein percentage of ground beef patties from 3 muscles and 3 quality grades.

Table 1. Least-squares means of the composition and oxidative status of raw ground beef patties varying in USDA quality grade,[1] muscle,[2] and wet-aging duration

	Quality Grade					Muscle					Aging Duration			
Item	PR	LC	ST	SEM[3]	*P* Value[4]	BF	GM	SV	SEM	*P* Value	21 d	42 d	SEM	*P* Value
Fat, %	10.58[a]	7.06[b]	4.91[c]	0.63	<0.001	6.48[b]	5.64[c]	10.44[a]	0.34	<0.001	7.59	7.45	0.27	0.581
Ash, %	1.06[b]	1.13[a]	1.17[a]	0.03	0.006	1.15[b]	1.23[a]	0.97[c]	0.03	<0.001	1.14	1.09	0.02	0.021
pH	5.76	5.82	5.72	0.05	0.127	5.67[b]	5.65[b]	5.98[a]	0.03	<0.001	5.80	5.73	0.02	0.004
Malondialdehyde, mg/kg	0.38	0.39	0.39	0.01	0.587	0.38	0.39	0.38	0.01	0.947	0.38	0.39	0.01	0.096

[1]USDA Prime (PR), Low Choice (LC), Standard (ST).

[2]*Biceps femoris* (BF), *gluteus medius* (GM), *serratus ventralis* (SV).

[3]Largest standard error of the least-squares means.

[4]Observed significance level.

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

As expected, PR had the greatest fat content, followed by LC, with ST having the lowest fat percentage ($P < 0.05$). Ash percentage was the greatest in PR product ($P < 0.05$), with no differences observed in LC and ST ($P > 0.05$). Muscle influenced fat and ash percentage as well as pH ($P < 0.001$). The SV had the greatest fat percentage, followed by BF, then GM ($P < 0.05$). Conversely, GM had the greatest ash percentage, followed by BF, then by SV ($P < 0.05$). The SV had an increased pH ($P < 0.05$) compared to GM and BF. Aging duration influenced ash percentage and pH ($P \leq 0.021$) but did not influence fat percentage ($P = 0.581$). Aging for 21 d resulted in decreased ash percentage and increased pH compared to 42 d of aging ($P < 0.05$).

The results of the present study are congruent with previous reports of varying composition of beef muscles (Hunt et al., 2014; Nyquist et al., 2018). As expected, the quality grades possessed varying fat and moisture content. Moreover, each muscle had varying fat and moisture content. The inverse relationship between fat and moisture was evident for both quality grades and muscles in the present study. While differences were observed for protein and ash, the differences in means were nominal.

Lipid oxidation

No interactions or main effects influenced raw TBARS values ($P > 0.05$; Table 1). No interactions or quality grade main effect was observed for cooked TBARS values ($P > 0.05$). However, muscle and aging duration influenced cooked TBARS values ($P < 0.001$; Figure 3A and 3B, respectively). The BF had the greatest TBARS value compared to GM and SV ($P < 0.05$). No difference was observed between the GM and SV ($P > 0.05$). Aging for 42 d resulted in increased TBARS value compared to aging for 21 d ($P < 0.05$).

These data suggest quality grade, muscle, nor aging duration influence lipid oxidation of raw product. However, cooked product was influenced by muscle and aging duration. McKenna et al. (2005) reported the BF was more susceptible to lipid oxidation during retail display compared to the GM and SV. While the

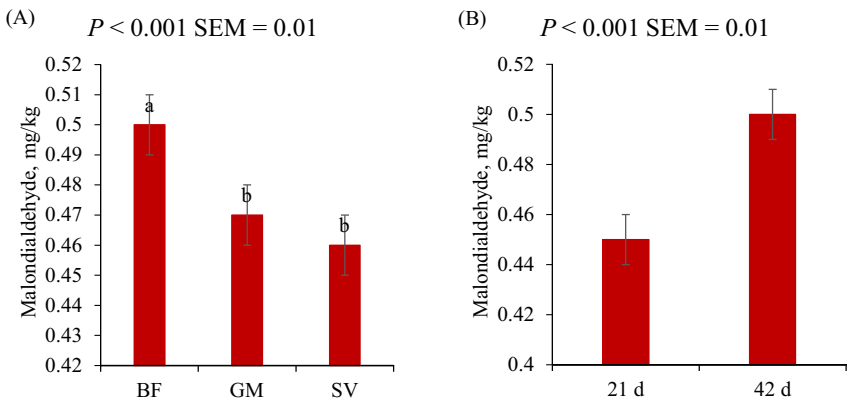

Figure 3. Least-squares means of thiobarbituric acid reactive substances values (malondialdehyde, mg/kg) of cooked ground beef patties from 3 beef muscles (A) and beef muscles aged for 21 or 42 d (B).

present study investigated these muscles during extended wet-aging, similar trends were observed. Recent reports have suggested that lipid oxidation is not a primary driver of off-flavor development in vacuum-packaged subprimals as the anaerobic environment inhibits the progression of lipid oxidation (Watanabe et al., 2015; Foraker et al., 2020; Hernandez et al., 2022, 2023). This is further supported by the results presented herein.

Fatty acid profile

Polar fraction. A quality grade × muscle interaction was observed for total saturated fatty acids (SFA), 16:0, 22:0, 17:1, and 20:3 *n-8* percentages within the polar lipid fraction ($P \leq 0.047$; Table 2). PR GM and SV patties had a greater total SFA percentage compared to PR BF, LC SV, and ST SV patties ($P < 0.05$). PR GM and SV patties and LC BF and GM patties had a greater percentage of 16:0 compared to PR BF, LC SV, and ST SV patties ($P < 0.05$). PR BF had the greatest percentage of 22:0 and 17:1 compared to all other treatment combinations ($P < 0.05$). A quality grade × aging duration interaction ($P = 0.046$; Figure 5) was observed for 16:0 where PR subprimals aged for 21 d had a greater percentage of 16:0 compared to PR subprimals aged for 42 d and ST subprimals aged for 21 or 42 d ($P < 0.05$).

Quality grade, muscle, and aging duration main effects on the polar fraction fatty acids are presented in Table 3. Aging duration did not influence any polar lipid fatty acids ($P > 0.05$). Of the SFA, only 14:0 was influenced by quality grade where PR patties had the greatest 14:0 percentage compared to LC and ST patties ($P < 0.05$). Total monounsaturated fatty acids (MUFA), 14:1, 16:1, and 18:1 *cis 9* percentages were greater in PR patties compared to LC and ST ($P < 0.05$). Conversely, total polyunsaturated fatty acids (PUFA), 18:2, and 20:4 percentages were greater in LC and ST patties compared to PR ($P < 0.05$). LC patties had a greater percentage of 20:3 compared to PR patties ($P < 0.05$).

Muscle influenced various polar fatty acids ($P \leq 0.024$). SV patties had the greatest 14:0, 17:0, and 20:0 percentage compared to BF and GM patties ($P < 0.05$). Moreover, SV patties had the greatest percentage of 14:1, 16:1, and 18:1 *cis 9* compared to BF and GM ($P < 0.05$). BF patties had a greater percentage of 14:1 compared to GM ($P < 0.05$). SV patties had the greatest percentage of 18:3 *n-9* compared to BF and GM patties ($P < 0.05$). Conversely, SV patties had the lowest percentage of 20:2 and C20:4 compared to BF and GM patties ($P < 0.05$). BF patties had a greater percentage of 20:3 compared to SV patties ($P < 0.05$).

Neutral fraction. A quality grade × muscle interaction was observed for percentage of 17:0 ($P = 0.021$, Figure 6). Quality grade did not influence 17:0 percentage in GM patties ($P > 0.05$); however, PR BF patties had a greater percentage of 17:0 compared to ST BF patties ($P < 0.05$). Moreover, both PR and LC SV patties had a greater percentage of 17:0 compared to ST SV patties ($P < 0.05$). A muscle × aging duration interaction was observed for 17:1 percentage ($P = 0.035$, Figure 7), where BF aged for 42 d had a greater percentage of 17:1 compared to BF aged for 21 d, SV aged for

Table 2. Interaction of fatty acid profile within the polar lipid fraction from raw ground beef patties varying in USDA quality grade and muscle[1]

	Prime			Low Choice			Standard				
Fatty Acid, %	BF	GM	SV	BF	GM	SV	BF	GM	SV	SEM[2]	*P* Value[3]
Saturated Fatty Acids[4]	33.49^{c}	36.19^{a}	36.19^{a}	35.89^{ab}	34.84^{abc}	33.76^{c}	34.48^{abc}	34.97^{abc}	33.74^{bc}	1.12	0.036
16:0	14.61^{c}	17.40^{a}	17.14^{a}	17.40^{a}	16.87^{a}	14.90^{bc}	16.36^{abc}	16.52^{ab}	14.95^{bc}	0.95	0.002
22:0	0.70^{a}	0.32^{b}	0.29^{b}	0.31^{b}	0.32^{b}	0.29^{b}	0.35^{b}	0.34^{b}	0.33^{b}	0.12	0.033
Monounsaturated Fatty Acids											
17:1	2.68^{a}	0.16^{b}	0.14^{b}	0.17^{b}	0.18^{b}	0.14^{b}	0.13^{b}	0.20^{b}	0.17^{b}	0.76	0.047
Polyunsaturated Fatty Acids											
20:3 *n-8*	3.65^{a}	2.96^{c}	2.30^{d}	3.35^{abc}	3.47^{abc}	3.55^{ab}	3.29^{abc}	3.05^{bc}	3.04^{bc}	0.28	0.002

[1]*Biceps femoris* (BF), *gluteus medius* (GM), *serratus ventralis* (SV).

[2]Largest standard error of the least-squares means.

[3]Observed significance level.

[4]Sum of saturated fatty acids.

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

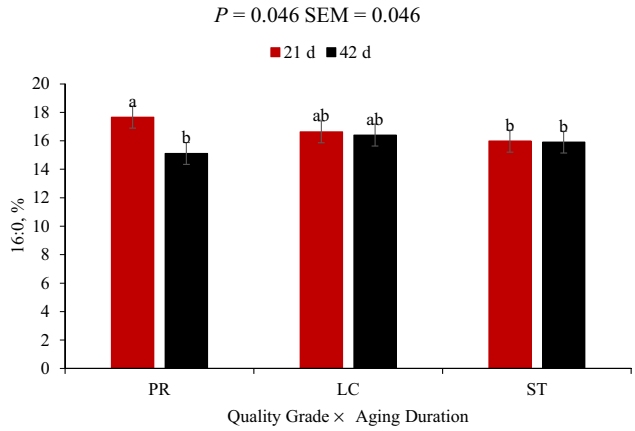

Figure 4. Interaction of polar lipid C16:0 percentage from raw ground beef patties from 3 quality grades wet-aged for 21 or 42 d.

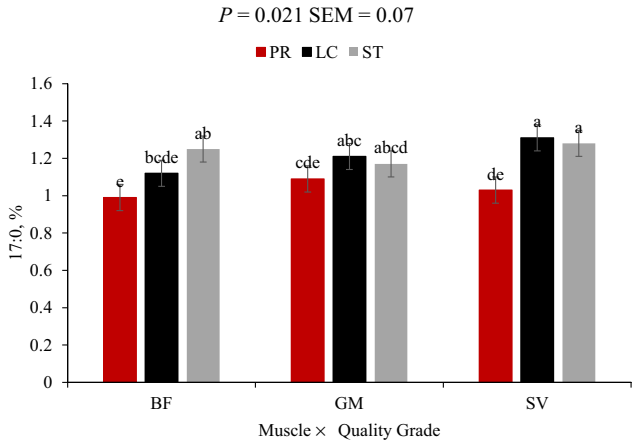

Figure 5. Interaction of neutral lipid C17:0 percentage from raw ground beef patties from 3 muscles and 3 quality grades.

42 d, and GM aged for either 21 or 42 d ($P < 0.05$). A muscle × aging duration interaction was observed for 18:3 n-9 percentage ($P = 0.012$, Figure 8) where GM aged for 42 d had the greatest percentage compared to all other treatments.

The quality grade, muscle, and aging duration main effects on the neutral fraction fatty acids are presented in Table 4. ST patties had the lowest percentage of 10:0 compared to PR and LC patties ($P < 0.05$). PR patties had the lowest percentage of 15:0 compared to LC and ST patties ($P < 0.05$). ST patties had the greatest percentage of 18:0 and 20:0 compared to LC and PR patties ($P < 0.05$). PR patties had a greater percentage of 18:1 *cis 9* compared to ST patties ($P < 0.05$). Conversely, ST patties had a greater percentage of 18:1 *trans* and 20:1 compared to PR patties ($P < 0.05$). PR patties had the lowest percentage of total PUFA and 18:2 compared to LC and ST patties ($P < 0.05$). ST patties had the lowest percentage of 20:3 and the greatest percentage of 20:4 compared to LC and PR patties ($P < 0.05$).

The GM had the greatest percentage of SFA compared to BF and SV patties ($P < 0.05$). The SV patties had the greatest percentage of 10:0 compared to GM and BF patties ($P < 0.05$). BF patties had the greatest percentage of 14:0 compared to GM and SV patties ($P < 0.05$). SV patties had the lowest percentage of 16:0 compared to GM and BF patties ($P < 0.05$). Moreover, SV patties had the greatest percentage of 18:0, followed by GM patties, with BF patties having the lowest percentage of 18:0 ($P < 0.05$). GM patties had the greatest percentage of 20:0, followed by SV patties, with BF patties having the lowest percentage of 20:0 ($P < 0.05$). The percentage of MUFA was the greatest in BF and SV patties compared to GM patties ($P < 0.05$). For both 14:1 and 16:1 percentage, BF patties had the greatest percentage, followed by SV patties, with GM patties having the smallest percentage ($P < 0.05$). BF patties had the smallest percentage of 18:1 *cis* 9 compared to GM and SV patties ($P < 0.05$). GM patties had the greatest percentage of 20:1 compared to BF and SV patties ($P < 0.05$). Total PUFA and 18:2 percentage was greater in GM and SV patties compared to BF patties ($P < 0.05$). For both 20:2 and 20:3 percentage, SV patties had the greatest percentage compared to GM and BF patties ($P < 0.05$). Conversely, SV patties had the smallest percentage of 20:4 compared to BF and GM patties ($P < 0.05$). Aging duration influenced 18:0 percentage where aging for 42 d increased 18:0 percentage ($P < 0.05$).

The present study suggests fatty acid profile is influenced muscle and quality grade. The ground muscles and USDA quality grades evaluated in the present study showed varying fatty acid profiles, which has been reported in the literature (Legako et al., 2015b; Hunt et al., 2016; Hergenreder et al., 2017). Fatty acids influence flavor development through lipid autooxidation, thermal lipid degradation, and subsequent lipid-Maillard interaction during cooking (Mottram, 1998; Wood et al., 2008; Kerth and Miller, 2015; Dinh et al., 2021). Lipids are categorized as neutral or polar lipids, which consist of triacylglycerols and phospholipids, respectively. Neutral lipids do not contribute to beef flavor development (Mottram and Edwards, 1983; Dinh et al., 2021). This is evident through no changes in aroma after triglyceride removal (Mottram and Edwards, 1983) and no changes in neutral lipid fatty acids after cooking (Legako et al., 2015b). Within the polar fraction, the SV generally had a greater percentage of individual SFA and MUFA. However, the SV generally had lower percentages of individual PUFA. Based on the

Table 3. Least-squares means of fatty acid profile within the polar lipid fraction from raw ground beef patties varying in USDA quality grade,[1] muscle,[2] and wet-aging duration

	Quality Grade					Muscle					Aging Duration			
Fatty Acid, %	PR	LC	ST	SEM[3]	*P* Value[4]	BF	GM	SV	SEM	*P* Value	21 d	42 d	SEM	*P* Value
Saturated Fatty Acids														
12:0	0.03	ND	0.01	0.01	0.105	0.02	0.01	0.001	0.01	0.390	0.001	0.02	0.01	0.067
14:0	0.46^{a}	0.28^{b}	0.26^{b}	0.05	<0.001	0.27^{b}	0.25^{b}	0.47^{a}	0.05	<0.001	0.34	0.32	0.04	0.520
15:0	0.10	0.12	0.11	0.51	0.091	1.08	0.09	0.13	0.51	0.096	0.11	0.75	0.42	0.131
17:0	0.35	0.37	0.35	0.03	0.603	0.34^{b}	0.34^{b}	0.39^{a}	0.02	0.032	0.36	0.35	0.02	0.366
18:0	16.43	17.15	17.29	0.56	0.263	16.09^{b}	17.29^{a}	17.49^{a}	0.56	0.031	17.08	16.83	0.46	0.596
20:0	0.10	0.10	0.10	0.01	0.961	0.09^{b}	0.09^{b}	0.12^{a}	0.01	0.024	0.10	0.11	0.01	0.227
Monounsaturated Fatty Acids[5]														
	26.52^{a}	16.63^{b}	16.03^{b}	1.68	<0.001	20.65	17.88	20.66	1.65	0.158	19.08	20.38	1.65	0.338
14:1	0.10^{a}	0.04^{b}	0.02^{b}	0.02	<0.001	0.05^{b}	0.01^{c}	0.10^{a}	0.02	<0.001	0.06	0.05	0.01	0.706
16:1	1.18^{a}	0.60^{b}	0.53^{b}	0.12	<0.001	0.74^{b}	0.69^{b}	0.89^{a}	0.07	0.025	0.81	0.73	0.06	0.223
18:1 *trans*	3.06	2.35	2.07	0.58	0.217	3.23	2.03	2.22	0.58	0.093	2.20	2.79	0.47	0.217
18:1 *cis 9*	20.80^{a}	13.28^{b}	12.65^{b}	1.42	<0.001	15.23^{b}	14.56^{b}	16.95^{a}	0.85	0.197	15.47	15.68	0.67	0.754
20:1	0.39^{b}	0.38^{b}	0.50^{a}	0.04	0.017	0.45	0.45	0.37	0.04	0.096	0.43	0.42	0.03	0.909
Polyunsaturated Fatty Acids[6]														
	38.18^{b}	48.46^{a}	49.61^{a}	1.93	<0.001	44.72	46.77	44.76	1.59	0.339	45.83	45.00	1.29	0.521
18:2	27.73^{b}	35.59^{a}	37.13^{a}	1.57	<0.001	32.23	34.51	33.71	1.32	0.214	33.92	33.04	1.06	0.409
18:3 *n-6*	0.08	0.10	0.10	0.01	0.295	0.10	0.09	0.09	0.01	0.327	0.09	0.09	0.01	0.739
18:3 *n-9*	0.14	0.10	0.13	0.02	0.130	0.10^{b}	0.12^{b}	0.17^{a}	0.01	<0.001	0.13	0.11	0.01	0.081
20:2	0.35	0.40	0.37	0.03	0.171	0.38^{a}	0.40^{a}	0.34^{b}	0.01	<0.001	0.37	0.38	0.01	0.267
20:3	2.97^{b}	3.46^{a}	3.13^{ab}	0.18	0.027	3.43^{a}	3.16^{ab}	2.96^{b}	0.15	0.009	3.11	3.26	0.12	0.206
20:4	6.92^{b}	8.81^{a}	8.72^{a}	0.59	0.002	8.48^{a}	8.50^{a}	7.47^{b}	0.41	0.021	8.19	8.10	0.33	0.780

[1]USDA Prime (PR), Low Choice (LC), Standard (ST).

[2]*Biceps femoris* (BF), *gluteus medius* (GM), *serratus ventralis* (SV).

[3]Largest standard error of the least-squares means.

[4]Observed significance level.

[5]Sum of monounsaturated fatty acids.

[6]Sum of polyunsaturated fatty acids.

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

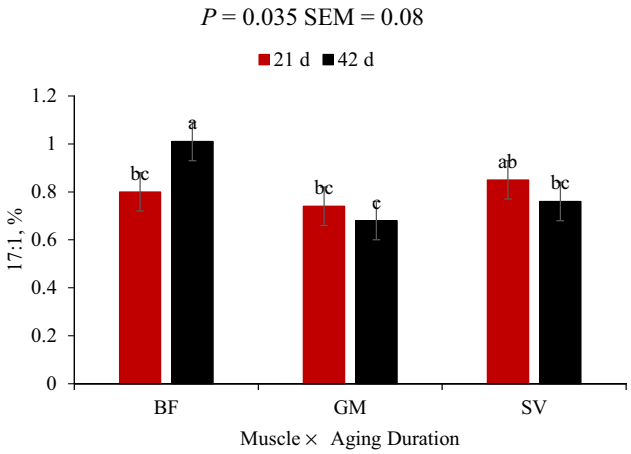

Figure 6. Interaction of neutral lipid C17:1 percentage from raw ground beef patties from 3 muscles wet-aged for 21 or 42 d.

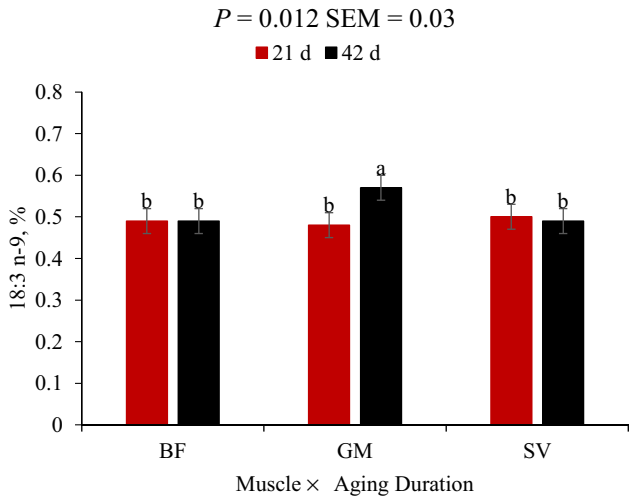

Figure 7. Interaction of neutral lipid C18:3 *n-9* percentage from raw ground beef patties from 3 muscles wet-aged for 21 or 42 d.

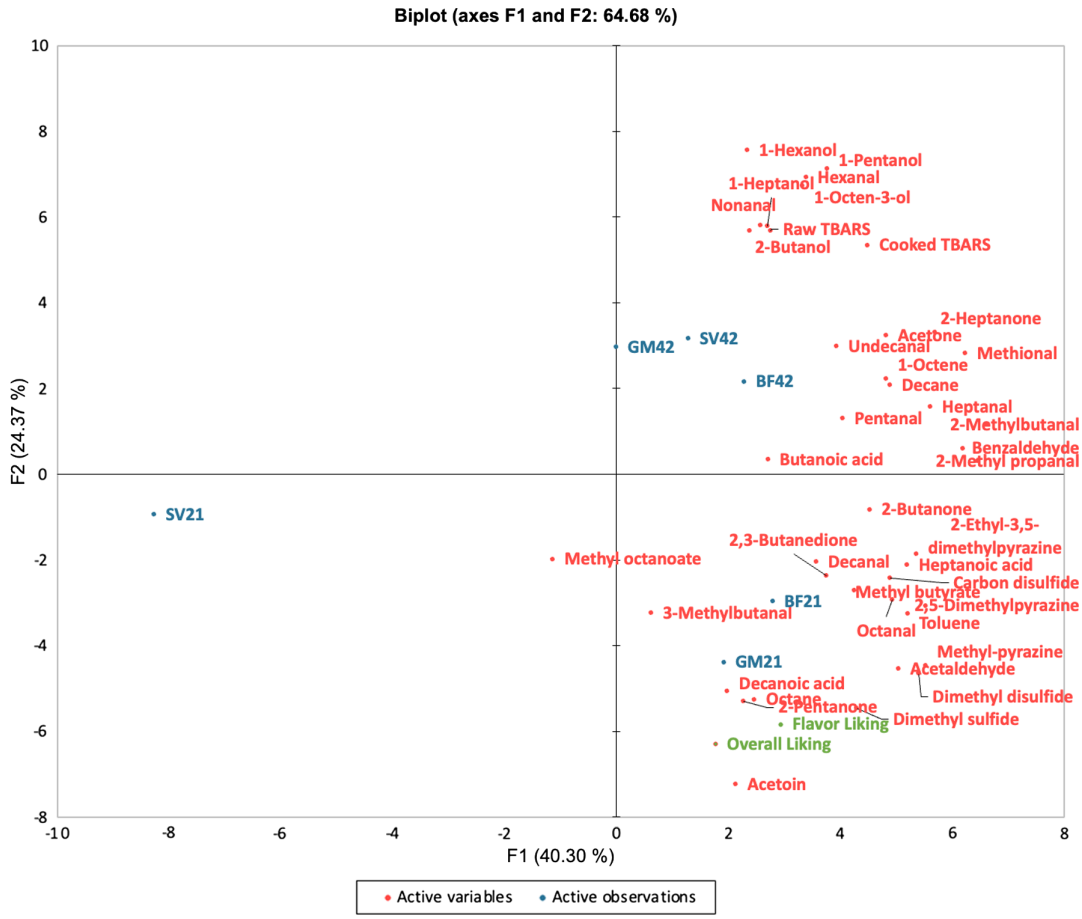

Figure 8. Principal component analysis bi-plot of volatile flavor compounds (red), consumer liking attributes (green), and muscle × aging duration treatments (blue).

fiber type classifications by Kirchofer et al. (2002), the SV is considered to be "intermediate," whereas the BF and GM are "white." Red fibers have been reported to contain increased lipid, specifically phospholipids (De Smet et al., 2004). The polar lipid content between muscles was not directly measured in the present study. Nonetheless, the results of the present study would suggest membrane lipids of the SV are more saturated compared to BF and GM. This would also suggest greater lipid-derived flavor development potential for the GM and BF compared to SV. Contrary to previous reports (Wood et al., 2008; Legako et al., 2015b; Hunt et al., 2016), the present study did not observe increased neutral lipid SFA and MUFA with increased fat content, i.e., USDA quality grade. However, an increase in both neutral and polar oleic acid (18:1 *cis* 9) in tandem with increased fat content was observed the present study and is congruent with previous literature (Legako et al., 2015b; Hunt et al., 2016). Hunt et al. (2016) evaluated fractioned fatty acid profiles in beef muscles similar to the present study (SV and GM). However, these muscles were graded upper 2/3rd Choice and Select, whereas the present study selected from a broader range of quality grades (fat content). These differences would help explain the present studies deviations from Hunt et al. (2016). Additionally, Legako et al. (2015b) evaluated fatty acids within the *longissimus lumborum*. The metabolism of the present studies muscles would diverge from the *longissimus* (Hergenreder et al., 2017). Aging duration had marginal effects on fatty acid profile which agrees with previous reports (Foraker et al., 2020; Setyabrata et al., 2022). Through fractionation and subsequent gas chromatography, it is difficult to accurately and precisely detect changes in fatty acid profile, especially polar fatty acids, during aging. Additionally, the broad aging treatments applied in the study would fail to capture more subtle changes in lipid profile. More robust methods, such as high-resolution mass spectrometry, may be able to elucidate differences, if any, in lipid metabolism during postmortem aging.

Volatile flavor compounds

Three ketones were influenced by the muscle × aging interaction ($P \leq 0.046$; Table 5). 2-Butanone

Table 4. Least-squares means of fatty acid profile within the neutral lipid fraction from raw ground beef patties varying in USDA quality grade,[1] muscle,[2] and wet-aging duration

	Quality Grade					Muscle					Aging Duration			
Fatty Acid, %	PR	LC	ST	SEM[3]	*P* Value[4]	BF	GM	SV	SEM	*P* Value	21 d	42 d	SEM	*P* Value
Saturated Fatty Acids[5]	45.14	45.39	47.29	1.32	0.198	44.71^{b}	47.34^{a}	45.77^{b}	0.67	<0.001	45.45	46.43	0.53	0.065
10:0	0.06^{a}	0.05^{a}	0.04^{b}	0.01	0.002	0.04^{b}	0.05^{b}	0.06^{a}	0.01	0.003	0.05	0.05	0.004	0.757
12:0	0.07	0.07	0.09	0.02	0.495	0.07	0.08	0.07	0.01	0.801	0.07	0.08	0.02	0.239
14:0	2.98	3.13	3.17	0.23	0.682	3.33^{a}	2.93^{b}	3.01^{b}	0.09	<0.001	3.09	3.09	0.10	0.943
15:0	0.38^{b}	0.46^{a}	0.50^{a}	0.03	<0.001	0.46	0.44	0.44	0.01	0.184	0.45	0.45	0.01	0.668
16:0	25.83	25.41	25.46	0.67	0.748	26.27^{a}	25.72^{a}	24.71^{b}	0.44	0.002	25.39	25.74	0.35	0.314
18:0	14.70^{b}	14.96^{b}	16.71^{a}	0.77	0.018	13.33^{c}	16.08^{b}	16.86^{a}	0.33	<0.001	15.17^{b}	15.74^{a}	0.26	0.033
20:0	0.09^{b}	0.09^{b}	0.10^{a}	0.01	0.031	0.08^{c}	0.11^{a}	0.10^{b}	0.004	<0.001	0.09	0.10	0.003	0.111
Monounsaturated Fatty Acids[6]	52.36	51.63	49.60	1.36	0.113	52.56^{a}	49.79^{b}	51.25^{a}	0.68	<0.001	51.71	50.68	0.54	0.059
14:1	0.68	0.77	0.71	0.07	0.405	0.95^{a}	0.55^{c}	0.66^{b}	0.03	<0.001	0.72	0.71	0.02	0.604
16:1	3.19	3.04	2.97	0.22	0.587	3.98^{a}	2.43^{c}	2.78^{b}	0.15	<0.001	3.09	3.06	0.05	0.699
18:1 *cis 9*	42.98^{a}	40.19^{ab}	38.25^{b}	1.59	0.015	41.01	39.87	40.84	0.90	0.426	40.83	40.12	0.71	0.319
18:1 *trans*	4.62^{b}	6.63^{a}	6.63^{a}	1.55	<0.001	5.57^{b}	6.01^{a}	6.30^{a}	0.22	0.006	6.12	5.80	0.17	0.078
20:1	0.10^{b}	0.16^{ab}	0.21^{a}	0.03	0.007	0.13^{b}	0.19^{a}	0.15^{b}	0.02	0.006	0.15	0.17	0.02	0.194
Polyunsaturated Fatty Acids[7]	2.50^{b}	2.98^{a}	3.11^{a}	0.18	0.002	2.73^{b}	2.88^{a}	2.98^{a}	0.07	0.003	2.84	2.89	0.05	0.426
18:2	1.97^{b}	2.36^{a}	2.48^{a}	0.14	0.002	2.16^{b}	2.28^{a}	2.37^{a}	0.06	<0.001	2.26	2.28	0.05	0.111
20:2	0.02^{a}	0.02^{a}	0.01^{b}	0.004	0.019	0.01^{b}	0.01^{b}	0.04^{a}	0.003	<0.001	0.02	0.02	0.003	0.306
20:3	0.03	0.04	0.03	0.01	0.409	0.03^{b}	0.02^{b}	0.05^{a}	0.005	<0.001	0.04	0.03	0.004	0.268
20:4	0.02^{b}	0.04^{b}	0.06^{a}	0.01	<0.001	0.04^{a}	0.04^{a}	0.03^{b}	0.005	0.009	0.04	0.04	0.004	0.406

[1]USDA Prime (PR), Low Choice (LC), Standard (ST).

[2]*Biceps femoris* (BF), *Gluteus medius* (GM), *Serratus ventralis* (SV).

[3]Largest standard error of the least-squares means.

[4]Observed significance level.

[5]Sum of saturated fatty acids.

[6]Sum of monounsaturated fatty acids.

[7]Sum of polyunsaturated fatty acids.

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

Table 5. Interaction of volatile compounds from ground beef patties varying in muscle and wet-aging duration

	Biceps femoris		*Gluteus medius*		*Serratus ventralis*			
Volatile Compound (ng/g)	21 d	42 d	21 d	42 d	21 d	42 d	SEM[1]	*P* Value[2]
2-Butanone	3.26^{a}	1.20^{ab}	2.10^{ab}	0.99^{ab}	0.17^{b}	3.59^{a}	1.57	0.028
2-Heptanone	0.15^{ab}	0.18^{a}	0.16^{a}	0.15^{ab}	0.10^{b}	0.19^{a}	0.03	0.049

[1]Largest standard error of the least-squares means.

[2]Observed significance level.

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

concentration was greater in patties from 21 d aged BF and 42 d aged SV ($P > 0.05$) compared to patties from 21 d aged SV ($P < 0.05$). Patties from 42 d aged BF, 21 d aged GM, and 42 d aged SV ($P > 0.05$) produced a greater concentration of 2-heptanone compared to 21 d aged SV patties ($P < 0.05$).

A quality grade × aging duration interaction was observed for butanol, decanal, and acetoin ($P \leq 0.048$; Table 6). PR patties aged for 21 d and ST 42 d aged patties ($P > 0.05$) produced a greater concentration of butanol compared to LC patties regardless of age and 21 d aged ST patties ($P < 0.05$). Decanal concentration was the greatest in 21 d aged LC patties compared to 21 d aged PR patties, 42 d aged LC patties, and ST patties, regardless of age ($P < 0.05$). Both 21 d aged PR patties and 21 d aged ST patties produced a greater

Table 6. Interaction of volatile compounds from ground beef patties varying in USDA quality grade and wet-aging duration

	Prime		Low Choice		Standard			
Volatile Compound (ng/g)	21 d	42 d	21 d	42 d	21 d	42 d	SEM[1]	*P* Value[2]
Alcohols								
Butanol	0.13^{b}	0.16^{ab}	0.13^{b}	0.15^{b}	0.08^{b}	0.25^{a}	0.05	0.037
Aldehydes								
Decanal	0.16^{b}	0.37^{ab}	0.56^{a}	0.19^{b}	0.15^{b}	0.17^{b}	0.17	0.010
Ketones								
Acetoin	7.42^{ab}	4.06^{c}	5.26^{bc}	3.44^{c}	8.91^{a}	1.82^{c}	1.86	0.048

[1]Largest standard error of the least-squares means.

[2]Observed significance level.

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

Table 7. Interaction of volatile compounds from ground beef patties varying in USDA quality grade and muscle[1]

	Prime			Low Choice			Standard				
Volatile Compound (ng/g)	BF	GM	SV	BF	GM	SV	BF	GM	SV	SEM[2]	*P* Value[3]
Aldehydes											
Acetaldehyde	2.63^{bc}	3.22^{ab}	2.32^{bc}	2.29^{bc}	2.21^{bc}	1.87^{c}	3.85^{a}	2.14^{bc}	1.48^{c}	0.59	0.041
Ketones											
2-Propanone	5.82^{b}	9.99^{a}	5.02^{b}	5.19^{b}	4.74^{b}	5.20^{b}	6.18^{b}	5.47^{b}	4.39^{b}	1.85	0.026

[1]*Biceps femoris* (BF), *gluteus medius* (GM), *serratus ventralis* (SV).

[2]Largest standard error of the least-squares means.

[3]Observed significance level.

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

concentration of acetoin compared to 42 d aged patties, regardless of quality grade ($P < 0.05$).

Acetaldehyde and 2-propanone were influenced by the quality grade × muscle interaction ($P \leq 0.041$; Table 7). ST BF and PR GM patties produced a greater concentration of acetaldehyde compared to LC and ST SV patties ($P < 0.05$). Moreover, ST BF patties produced a greater concentration of acetaldehyde compared to PR BF and SV patties, LC BF and GM patties, and ST GM patties ($P < 0.05$). PR GM patties produced the greatest concentration of 2-propanone compared to all other treatments ($P < 0.05$).

Main effect results for Maillard reaction and lipid-derived volatile compounds are presented in Tables 8 and 9, respectively. Quality grade did not influence any volatile compounds ($P > 0.05$). Muscle type influenced 5 Maillard reaction products ($P \leq 0.033$). For all pyrazines, BF and GM patties produced greater concentrations compared to SV patties ($P < 0.05$). Dimethyl disulfide concentration was greater in BF patties compared to SV patties ($P < 0.05$). Additionally, BF and GM patties produced a greater concentration of dimethyl sulfide compared to SV patties ($P < 0.05$). No lipid-derived compounds were influenced by muscle ($P > 0.05$). Aging duration influenced 2 Maillard reaction products and 4 lipid-derived volatiles ($P \leq 0.011$). Dimethyl sulfide and methional concentrations were greater in 21 d aged patties compared to 42 d aged patties ($P < 0.05$). Hexanal, 1-heptanol, 1-hexanol, and 1-octen-3-ol concentrations were greater in 42 d aged patties compared to 21 d aged patties ($P < 0.05$).

In cases where aging duration was dependent on either muscle or quality, no clear trends were observed. Ketones were influenced by the muscle × aging duration interaction where only the BF evidenced an increase in ketone production after 42 d of aging. Maillard reaction products are responsible for positive flavor attributes such as beefiness, browned, and roasted (Kerth and Miller, 2015) and consumer liking (Legako et al., 2016). In the present study, quality grade had a minimal influence on Maillard reaction products. Methional, a Strecker aldehyde, was increased in ST patties compared to LC and PR patties. Methional is derived during Strecker degradation of methionine. It could be hypothesized that the decreased fat content of ST product allows for more free water-soluble precursors

Table 8. Least-squares means of Maillard reaction derived volatile compounds from ground beef patties varying in USDA quality grade,[1] muscle,[2] and wet-aging duration

	Quality Grade					Muscle					Aging Duration			
Volatile Compound (ng/g)	PR	LC	ST	SEM[3]	*P* Value[4]	BF	GM	SV	SEM	*P* Value	21 d	42 d	SEM[2]	*P* Value
Pyrazines														
Methylpyrazine	0.42	0.30	0.34	0.11	0.599	0.44[a]	0.39[a]	0.29[b]	0.08	0.019	0.38	0.33	0.06	0.402
2,5-dimethylpyrazine	0.77	0.55	0.67	0.20	0.537	0.83[a]	0.72[a]	0.38[b]	0.13	0.003	0.66	0.63	0.10	0.787
2-Ethyl-3,5-dimethylpyrazine	0.22	0.15	0.18	0.09	0.714	0.28[a]	0.21[a]	0.07[b]	0.07	0.138	0.19	0.18	0.06	0.979
Strecker Aldehydes														
Benzaldehyde	0.44	0.55	0.44	0.12	0.553	0.57	0.47	0.39	0.12	0.272	0.44	0.51	0.09	0.500
Methional	0.06[b]	0.05[b]	0.11[a]	0.02	0.007	0.09[a]	0.08[ab]	0.05[b]	0.02	0.031	0.06[b]	0.09[a]	0.01	0.023
2-Methylbutanal	6.19	4.18	3.46	2.04	0.388	5.97	5.19	2.68	1.75	0.154	3.76	5.47	1.42	0.231
2-Methylpropanal	1.37	1.18	1.08	0.24	0.481	1.35	1.20	1.09	0.21	0.471	1.15	1.27	0.17	0.502
3-Methylbutanal	6.23	6.49	4.17	1.71	0.335	6.32	5.22	5.36	1.62	0.751	5.84	5.42	1.32	0.751
Sulfur-Containing														
Carbon disulfide	51.23	43.28	41.86	9.30	0.557	47.69	44.83	43.86	8.25	0.889	46.28	44.64	6.68	0.807
Dimethyl disulfide	0.11	0.11	0.09	0.04	0.663	0.14[a]	0.11[ab]	0.06[b]	0.03	0.033	0.17	0.09	0.02	0.301
Dimethyl sulfide	0.67	0.55	0.67	0.11	0.453	0.69[a]	0.78[a]	0.41[b]	0.08	< 0.001	0.69[a]	0.56[b]	0.06	0.038

[1]USDA Prime (PR), Low Choice (LC), Standard (ST).

[2]*Biceps femoris* (BF), *gluteus medius* (GM), *serratus ventralis* (SV).

[3]Largest standard error of the least-squares means.

[4]Observed significance level.

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

such as methionine. However, Dinh et al. (2018) reported no differences in methionine content in raw PR, LC, and ST beef *longissimus* aged 21 d. An increase in methional as well as dimethyl sulfide was observed in beef subprimals aged for 42 d compared to 21 d. During postmortem aging of beef, proteolytic activity results in an increase of free amino acids (Koutsidis et al., 2008; Foraker et al., 2020; Vierck et al., 2020; Hernandez et al., 2022). As discussed previously, an increase in methionine and other sulfur-containing amino acids would result in increased methional and dimethyl sulfide concentrations. Muscle had a greater influence on Maillard reaction products compared to quality grade and aging duration. Generally, the SV produced the least Maillard reaction products and the BF produced the most, with the GM being intermediary. Because of the consistency in patty manufacturing and cookery, these differences are likely a result of varying chemical profiles between muscles. As previously discussed, the SV possessed a greater pH compared to GM and BF. The Maillard reaction can be modulated by pH, where more acidic environments are optimal for the Maillard reaction. This could explain the decreased production of Maillard-derived volatiles in the SV. The BF and GM have been classified as "white" muscles, i.e., glycolytic muscle fibers, whereas the SV was classified as intermediate (Kirchofer et al., 2002). The difference in Maillard-derived volatile productions could also be explained by the varying muscle fiber type metabolism, subsequently providing different pools of free amino acids, reducing sugars, and other Maillard reaction contributing metabolites. Li et al. (2023) reported increased differences in Maillard-derived volatiles between beef patties formulated to have high type I fiber type or type II fiber type. Specifically, 3-methylbutanal and acetoin were increased in high type I patties. This increase was attributed to increased leucine, cysteine, and ribose content. Further investigation is required to confirm whether muscles with divergent muscle fiber types possess different concentrations of Maillard reaction substrates.

Despite differences in fatty acid profiles, for both neutral and polar fractions, between quality grades and muscle, minor differences were observed in lipid degradation–derived volatiles. Any differences in lipid-derived volatiles, including quality grade or muscle, were a part of an interaction among themselves or with aging duration. Similar to the Maillard-derived volatiles, these interactions did not evidence a particular trend. The present study is congruent with previous reports of USDA quality grade having minimal influence on lipid-derived volatiles (Mottram and Edwards, 1983;

Table 9. Least-squares means of lipid-derived volatile compounds from ground beef patties varying in USDA quality grade[1], muscle[2], and wet-aging duration

	Quality Grade					Muscle					Aging Duration			
Volatile Compound (ng/g)	PR	LC	ST	SEM[3]	*P* Value[4]	BF	GM	SV	SEM	*P* Value	21 d	42 d	SEM	*P* Value
Aldehydes														
Heptanal	0.62	0.57	0.58	0.08	0.859	0.62	0.57	0.58	0.08	0.686	0.62	0.56	0.07	0.409
Hexanal	3.87	3.67	3.28	0.92	0.806	4.36	3.42	3.03	0.92	0.339	2.18[b]	5.03[a]	0.75	<0.001
Nonanal	0.37	0.28	0.64	0.15	0.051	0.50	0.31	0.47	0.15	0.394	0.33	0.52	0.12	0.123
Octanal	0.34	0.38	0.27	0.09	0.471	0.40	0.35	0.24	0.09	0.201	0.34	0.32	0.08	0.787
Pentanal	0.72	0.79	0.68	0.10	0.539	0.77	0.67	0.75	0.10	0.601	0.71	0.75	0.28	0.588
Undecanal	0.04	0.05	0.05	0.01	0.728	0.04	0.05	0.05	0.01	0.938	0.04	0.05	0.01	0.091
Alcohols														
1-Heptanol	0.12	0.08	0.13	0.03	0.087	0.09	0.14	0.10	0.03	0.222	0.08[b]	0.13[a]	0.02	0.011
1-Hexanol	0.33	0.29	0.42	0.10	0.443	0.29	0.39	0.36	0.08	0.468	0.16[b]	0.54[a]	0.07	<0.001
1-Octen-3-ol	0.68	0.70	0.77	0.07	0.418	0.77	0.72	0.65	0.07	0.209	0.58[b]	0.85[a]	0.06	<0.001
Carboxylic Acids														
Butanoic acid	0.76	0.78	0.82	0.03	0.098	0.79	0.80	0.76	0.02	0.138	0.78	0.79	0.02	0.736
Decanoic acid	0.46	1.72	0.41	1.09	0.390	0.43	1.57	0.59	1.00	0.470	1.18	0.55	0.81	0.444
Heptanoic acid	0.03	0.04	0.04	0.01	0.206	0.04	0.04	0.03	0.01	0.613	0.04	0.04	0.01	0.503
Esters														
Methyl butyrate	0.83	0.51	0.60	0.29	0.538	0.76	0.78	0.41	0.27	0.299	0.64	0.65	0.22	0.992
Methyl octanoate	1.18	1.09	0.87	0.38	0.704	0.83	0.90	1.40	0.38	0.274	1.17	0.93	0.31	0.446
Decane	0.40	0.49	0.24	0.17	0.185	0.39	0.47	0.27	0.14	0.342	0.33	0.43	0.11	0.385
Octane	0.80	0.40	0.44	0.35	0.453	0.43	0.79	0.42	0.34	0.471	0.66	0.43	0.28	0.410
Ketones														
2-Pentanone	0.49	0.48	0.40	0.08	0.418	0.47	0.44	0.46	0.07	0.849	0.50	0.41	0.05	0.126

[1]USDA Prime (PR), Low Choice (LC), Standard (ST).

[2]*Biceps femoris* (BF), *gluteus medius* (GM), *serratus ventralis* (SV).

[3]Largest standard error of the least-squares means.

[4]Observed significance level.

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

Legako et al., 2015a; Hunt et al., 2016; Vierck et al., 2021a). While no differences in volatile concentrations are associated with quality grade, fat content has been suggested to act as a reservoir for lipophilic volatile compounds (Frank et al., 2017). These compounds are then released during mastication, stimulating flavor and aroma release (Frank et al., 2017). Another hypothesis for the lack of concentration differences in beef with varying fat content is the participation of lipid-derived volatiles in the formation of lipid-Maillard interaction products, namely alkylpyrazines and thiols (Whitfield and Mottram, 1992; Mottram, 1998; Dinh et al., 2021). Despite the anaerobic nature of wet-aging, some volatile products of lipid oxidation were increased in 42 d aged samples, specifically, hexanal, 1-hepantol, 1-hexanol, and 1-octen-3-ol. Hexanal is a key secondary product of lipid oxidation and is routinely measured to indicate level of oxidative rancidity (Shahidi and Pegg, 1994). This increase of the aforementioned volatiles is congruent with the increase in cooked malondialdehyde content previously discussed. The oxidative stability of beef decreases during aging and results in decreased color stability (Mancini and Ramanathan, 2014; English et al., 2016). The present study suggests flavor stability is also decreased with extended aging. The reduced oxidative stability would increase lipid degradation during cooking, resulting in increased concentrations of the aforementioned volatiles.

Consumer sensory evaluation

No quality grade × muscle interaction was observed for any consumer sensory attributes or acceptability scores ($P > 0.05$). A quality grade × aging duration interaction was observed for overall acceptability ($P = 0.031$; Table 10) and percentage of patties rated as unsatisfactory ($P = 0.029$). Overall acceptability was the lowest ($P < 0.05$) for LC patties aged for 42 d compared to all other treatment combinations, which were not

Table 10. Interaction of consumer liking,[1] acceptability, and perceived quality of ground beef patties varying in USDA quality grades and wet-aging duration

	Prime		Low Choice		Standard			
Attribute	21 d	42 d	21 d	42 d	21 d	42 d	SEM[2]	*P* Value[3]
Flavor Liking	62.3	61.5	67.2	58.6	60.9	60.9	3.64	0.184
Overall Liking	63.9	62.8	66.9	57.4	60.8	59.8	3.72	0.182
Flavor Acceptability, %	89.8	87.9	92.6	79.6	91.7	90.7	4.13	0.078
Overall Acceptability, %	90.7[a]	87.6[a]	94.4[a]	78.7[b]	88.9[a]	87.9[a]	4.24	0.031
Unsatisfactory, %	10.2[a]	12.0[a]	5.6[b]	23.2[a]	10.2[a]	12.0[a]	4.73	0.029
Everyday Quality, %	47.2	58.3	50.9	37.0	49.1	54.6	7.66	0.058
Better than Everyday Quality, %	31.5	23.2	26.9	25.0	30.6	24.1	6.31	0.756
Premium Quality, %	11.1	6.5	15.7	14.8	10.2	9.3	4.62	0.808

[1]0 = extremely dislike and 100 = extremely like.

[2]Largest standard error of the least-squares means.

[3]Observed significance level.

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

different ($P > 0.05$). LC patties aged for 21 d had the lowest frequency of an unsatisfactory eating experience compared to all other treatment combinations ($P < 0.05$). Remaining sensory attributes were not influenced by the quality grade × aging duration interaction ($P > 0.05$).

A muscle × aging duration interaction was observed for flavor liking ($P = 0.015$; Table 11) and overall liking ($P = 0.028$). Patties from GM aged for 21 d were rated higher for flavor liking compared to GM aged for 42 d and SV aged for 21 and 42 d ($P < 0.05$). Moreover, GM patties aged for 21 d were rated higher for overall liking compared to GM patties aged for 42 d ($P < 0.05$). No other sensory attributes were influenced by the muscle × aging duration interaction ($P > 0.05$).

PC analysis was conducted to visualize the interrelationships between consumer attributes, TBARS, and volatile compounds within the muscle × aging duration interaction. These data accounted for 64.68% of the variation in the data, with PC1 and PC2 accounting for 40.3% and 24.37% of the variation, respectively (Figure 8). SV aged for 21 d negatively loaded on PC1 and separate from other muscle × aging duration treatment combinations. All other variables loaded positively on PC1. Within the PC1 positive loadings, PC2 separated treatments based on aging duration. Muscles that were aged 42 d were associated with TBARS, aldehydes, alcohols, ketones, hydrocarbons, and Strecker aldehydes. Both the GM and BF aged for 21 d were associated with flavor and overall liking as well as Maillard

Table 11. Interaction of consumer liking,[1] acceptability, and perceived quality of ground beef patties varying in muscle and wet-aging duration

	Biceps femoris		*Gluteus medius*		*Serratus ventralis*			
Attribute	21 d	42 d	21 d	42 d	21 d	42 d	SEM[2]	*P* Value[3]
Flavor Liking	63.4[ab]	63.4[ab]	68.7[a]	56.7[b]	59.4[b]	60.9[b]	3.64	0.015
Overall Liking	62.6[ab]	61.5[ab]	68.2[a]	56.1[b]	61.0[ab]	62.3[ab]	3.72	0.028
Flavor Acceptability, %	91.7	91.7	93.5	86.1	88.9	80.6	4.13	0.299
Overall Acceptability, %	89.1	90.7	94.4	85.2	89.8	78.7	4.24	0.103
Unsatisfactory, %	9.3	10.2	5.6	15.7	11.1	21.3	4.73	0.283
Everyday Quality, %	49.1	57.4	47.2	52.8	50.9	39.8	7.66	0.158
Better than Everyday Quality, %	30.6	23.2	31.5	23.2	26.9	25.9	6.31	0.961
Premium Quality, %	11.1	9.3	15.7	8.3	10.2	12.9	4.62	0.240

[1]0 = extremely dislike and 100 = extremely like.

[2]Largest standard error of the least-squares means.

[3]Observed significance level.

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

reaction products and some aldehydes, ketones, carboxylic acids, esters, and hydrocarbons.

In the current study, consumer liking was primarily influenced by muscle and aging duration. While USDA quality grade has been reported to influence consumer liking (Emerson et al., 2013; Legako et al., 2016), the results of the present study do not support the influence of quality grade on flavor liking. This is in line with Nyquist et al. (2018), who reported no muscle (from the chuck and round) × quality grade interactions for any sensory attributes. This would suggest that the palatability of non-middle meat muscles is not reliant on intramuscular fat. Muscle and aging duration were dependent on one another where aging BF and SV did not influence flavor or overall liking. However, flavor and overall liking decreased when the GM was aged for 42 d compared to 21 d. This result contradicts Colle et al. (2015), who reported no differences in flavor liking when aging GM from 2 to 63 d. However, the present study agrees with Colle et al. (2016), who also reported no differences in flavor liking when aging BF from 2 to 63 d. Hernandez et al. (2023) also reported no differences in flavor liking in extended aged *longissimus lumborum*. While not a muscle × aging duration interaction, 42 d aged samples were characterized by increased cooked malondialdehyde and hexanal concentrations. The multivariate data also showed close associations between 42 d aged samples and the aforementioned variables as well as other alcohols and aldehydes associated with off-flavor. As previously discussed, data are accumulating that suggest lipid oxidation is inhibited from progression under vacuum. However, these results were from studies only investigating the *longissimus lumborum* (Watanabe et al., 2015; Foraker et al., 2020; Hernandez et al., 2023) Therefore, muscles such as the GM may not be as oxidatively stable during extended wet-aging and warrant specific aging parameters. Consumers also discriminated against the SV regardless of aging. Within the scope of the study, this can be explained by the decreased concentration of Maillard-derived volatile compounds. For the 21 d SV, this is further supported by the PCA. The Maillard reaction is responsible for the development of desirable flavor aromatics (Kerth and Miller, 2015; Legako et al., 2015a; Li et al., 2021; Vierck et al., 2021a). The classes of volatile compounds associated with consumer liking are responsible for buttery, meaty, and roasted aromas (Kerth and Miller, 2015). However, muscles from the chuck have been suggested to possess increased off-flavor intensity (Meisinger et al., 2006; Calkins and Hodgen, 2007; Wadhwani et al., 2010). It could be speculated that the suggested off-flavors present in chuck muscles could result in decreased consumer liking of the SV. Consumer panels lack the ability to characterize specific flavor aromatics. Therefore, it is difficult to solely attribute the decreased consumer liking to lipid oxidation or other off-flavors.

Conclusion

The present study reports ground muscles from the chuck and sirloin in combination with aging duration have a stronger influence on flavor development compared to USDA quality grade. These results can be attributed to metabolic differences between muscles as well as metabolic changes during postmortem aging. These data also suggest the flavor stability of the GM is decreased during extended aging. Taken together, these data suggest aging recommendations should be muscle-specific in order to maximize beef eating experience.

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