Consumer palatability scores and volatile beef flavor compounds of five USDA quality grades and four muscles

J. F. Legako, J. C. Brooks, T. G. O'Quinn, T. D. J. Hagan, R. Polkinghorne, L. J. Farmer, M. F. Miller

Published Version Information

Citation: Legako, J. F., Brooks, J. C., O'Quinn, T. G., Hagan, T. D. J., Polkinghorne, R., Farmer, L. J., & Miller, M. F. (2015). Consumer palatability scores and volatile beef flavor compounds of five USDA quality grades and four muscles. Meat Science, 100, 291-300.

Digital Object Identifier (DOI): doi:10.1016/j.meatsci.2014.10.026

Publisher's Link: http://www.sciencedirect.com/science/article/pii/S0309174014004744

CONSUMER PALATABILITY SCORES AND VOLATILE BEEF FLAVOR COMPOUNDS OF FIVE USDA QUALITY GRADES AND FOUR MUSCLES

J. F. Legako[a], J. C. Brooks[b], T. G. O'Quinn[c], T. D. J. Hagan[d], R. Polkinghorne[e], L. J. Farmer[d], M. F. Miller[b]

[a] Department of Nutrition, Dietetics & Food Sciences, Utah State University, Logan, UT 84322 USA

[b] Department of Animal & Food Sciences, Texas Tech University, Lubbock, TX 79409 USA

[c] Department of Animal Sciences and Industry, Kansas State University, Manhattan, KS 66506 USA

[d] Agri-Food & Biosciences Institute, Newforge Lane Belfast, Northern Ireland BT9 5PX

[e] Polkinghornes Pty Ltd, 461 Timor Rd, Murrurundi, NSW 2338, Australia

[a] Corresponding Author, Tel.: (435) 797-2114, Fax: (435) 797-2379,

E-mail address: jerrad.legako@usu.edu

Postal address: 8700 Old Main Hill; Utah State University; Logan, UT 84322-8700

Abstract

Proximate data, consumer palatability scores and volatile compounds were investigated for four beef muscles (*Longissimus lumborum*, *Psoas major*, *Semimembranosus* and *Gluteus medius*) and five USDA quality grades (Prime, Upper 2/3 Choice, Low Choice, Select, and Standard). Quality grade did not directly affect consumer scores or volatiles but interactions ($P < 0.05$) between muscle and grade were determined. Consumer scores and volatiles differed ($P < 0.05$) between muscles. Consumers scored *Psoas major* highest for tenderness, juiciness, flavor liking and overall liking, followed by *Longissimus lumborum*, *Gluteus medius*, and *Semimembranosus* ($P <$ 0.05). Principal component analysis revealed clustering of compound classes, formed by related mechanisms. Volatile *n*-aldehydes were inversely related to percent fat. Increases in lipid oxidation compounds was associated with *Gluteus medius* and *Semimembranosus*, while greater quantities of sulfur-containing compounds was associated with *Psoas major*. Relationships between palatability scores and volatile compound classes suggests that differences in the pattern of volatile compounds may play a valuable role in explaining consumer liking.

Keywords: beef; flavor; GC-MS; HS-SPME; Muscle; USDA Quality Grade

1. Introduction

Beef palatability is often believed to be most dependent on tenderness (Miller, Carr, Ramsey, Crockett, & Hoover, 2001; Miller, *et al.*, 1995; Savell, *et al.*, 1987). However, flavor is also considered a primary palatability factor and is shown to be of great importance when tenderness is acceptable (Behrends, *et al*., 2005a, 2005b; Goodson, *et al*., 2002; Killinger, Calkins, Umberger, Feuz, & Eskridge, 2004). Flavor has been identified as the single most important factor in determining consumer acceptability when meat was prepared at home (Huffman, Miller, Hoover, Wu, Brittin, & Ramsey, 1996). Beef flavor is a combination of taste and odor. While taste is generally detected on the tongue as sweet, sour, salty, bitter or other taste sensations such as "umami", odor or aroma is detected in the nose and plays a large role in flavor perception. Numerous volatile compounds have been identified from beef, including: sulfur-containing compounds, furanthiols, disulfides, aldehydes, ketones and other heterocyclic compounds (Cerny & Grosch, 1992; Farmer & Patterson, 1991; Gasser & Grosch, 1988; Mottram, 1991).

Consumers have associated increased flavor desirability with increased intramuscular fat (O'Quinn *et al*., 2012; Smith, Savell, Cross, & Carpenter, 1983). However, laboratory studies have repeatedly found that increased intramuscular fat rarely produces increases in volatile flavor compounds (Cross, Berry, & Wells, 1980; Mottram & Edwards, 1983; Mottram, Edwards, & MacFie, 1982). Evidence from studies on meat products suggests that fat acts as a solvent for volatile compounds, thus delaying flavor release (Chevance, Farmer, Desmond, Novelli, Troy, & Chizzolini, 2000). Documentation of the effect of USDA quality grade among multiple beef muscles upon volatile flavor compounds was not found in the literature.

Research regarding differences in flavor among muscles has focused on flavor intensity and the presence of off-flavors. Calkins and Hodgen (2007) have summarized muscle rankings based on flavor intensity and off-flavors. In most cases flavor intensity and off-flavors were correlated with each other. Volatile compounds associated with lipid oxidation have been reported to vary between muscles of the chuck and round influencing perceived flavor (Hodgen, Cuppett, & Calkins, 2006). Recently a beef flavor lexicon of beef attributes was used to determine differences between top loin, top sirloin, tenderloin, and inside round steaks (Adhikari & Chambers, 2010; Miller, 2010).

To date, no studies have assessed the palatability and volatile profile of multiple beef muscles in various quality grades. The objective of this study was to determine the effects of USDA quality grade and muscle on consumer palatability perception and volatile beef flavor compounds.

2. Materials and Methods

2.1. *Product procurement and preparation*

Boneless striploins [Institutional Meat Purchase Specifications (IMPS) 180, North American Meat Processers Association (NAMP)], tenderloins (IMPS 189, NAMP), inside rounds (IMPS 169, NAMP), and top sirloins (IMPS 184, NAMP) were collected from three ‘A’ maturity (9 to 30 month animals at harvest) carcasses representing each of five USDA quality grades (Prime, Upper 2/3 Choice, Low Choice, Select, and Standard) at a commercial beef processing facility in the Midwest region of the United States. Carcasses were selected by trained individuals who assessed the amount of visual intramuscular fat of the ribeye face at the 12th and 13th rib along with lean color and skeletal ossification (USDA, 1997). Subprimals of the selected carcasses were vacuum packaged and transported to the Gordon W. Davis Meat Laboratory where they were stored at 2 to 4 °C in the absence of light, and aged to 21 days postmortem prior to fabrication. Steak cutting, selection and cooking followed Meat Standards Australia (MSA) protocols (Watson, Gee, Polkinghorne, & Porter, 2008). The muscles, *Longissimus lumborum, Psoas major, Semimembranosus, and Gluteus medius* (from striploin, tenderloin, inside round, and top sirloin subprimals, respectively) were denuded of all epimysium and fat. *Semimembranosus and Gluteus medius* muscles were sectioned parallel with muscle fibers in order to allow steak cutting across the grain. *Longissimus lumborum* and *Psoas major* muscles were cut perpendicular to the length of each muscle having some grain angle, specifically in

Longissimus lumborum steaks. All muscles were cut into 25 mm thick steaks approximately 10 cm x 5 cm in length and width, starting at the anterior end of the muscle or muscle section. The resulting steaks were individually wrapped in plastic, vacuum packed in sets of five, identified with a unique sample code and frozen (-20 ºC). Frozen wrapped steaks were later sorted into predetermined groups of 10 steaks, each being a single steak from 10 of the original sample codes, representing a cooking round and re-vacuum packaged. This re-sorting was determined by MSA protocols and related software routines to produce a six by six latin square presentational order in which six test products were arranged so that each product was cooked and served an equal number of times in each of six presentational orders (serving rounds two to seven) and served before and after each other product an equal number of times. The first cooking and serving round utilized a common presumed mid position “starter” served to all consumers. The five individual steaks from each original sample were placed and served in five different rounds to counter potential order effects.

2.2. *Consumer palatability scores*

Consumer palatability scoring was conducted in accordance with MSA protocols (Watson *et al.*, 2008). Steaks were thawed at 2 to 5 ºC for 24 hours prior to cooking. All steaks were cooked using a Silex clamshell grill (model S-143k, Silex Grills Australia Pty. Ltd., Marrickville, Australia). Plate surface temperature was set at 225 ºC and preheated 45 min prior to panels. Each panel session was conducted using a count up timer and timed schedule. Each session commenced with cooking of a warm up load to stabilize grill recovery temperatures prior to the seven cooking rounds. Loading and unloading of both the warm up and subsequent six test rounds was conducted in accordance with the time schedule as was serving of test samples. During panels steaks were loaded on the grill in seven designated groups (rounds) of 10. The grill surface was scraped, cleaned and greased with non-flavored cooking spray (Pam® Original Non-Stick Cooking Spray, ConAgra Foods, Inc., Omaha, NE, USA) between rounds. Steaks were cooked 5 min with the grill closed, removed at the designated time and allowed to rest for 3 min. During resting three 1.27 cm diameter cores were removed across the center line of selected steaks for volatile analysis by coring through the thickness of steaks perpendicular to cut surfaces in order to produce cores of similar volume (approximately 2.5 cm in length and 1.27 cm in diameter). After the resting period each steak was cut into two pieces (across the cored section), and immediately served to two designated consumers.

Sessions were conducted in evenings by paid consumers (n=278) recruited from Lubbock, TX, USA and the surrounding area. Consumers were recruited from various community and charity groups with the group paid for attendance as a fund raiser rather than paying individuals. Consumers were screened to include only regular beef eaters that preferred “medium doneness.”

Each consumer was assigned to a numbered booth containing a ballot, plastic knife, plastic fork, toothpicks, napkins, a cup of water, an expectorant cup, and between sample palate cleansers (a 10% apple juice, 90% water solution and unsalted crackers). Panelists were verbally instructed to utilize the provided plastic utensils to cut steaks into bite sizes similar to their normal beef consumption habits.

Groups of 20 consumers each evaluated seven steaks, the first a standard “starter”, chosen to be of a mid-range quality, to acclimate consumers, followed by one from each of six product groups encompassing a wide quality range derived from multiple muscles and USDA quality grade. Each steak was rated on a 100-mm continuous line scale for tenderness, juiciness, flavor liking and overall liking. On the scale, zero was verbally anchored as “not tender,” “not juicy,” “dislike flavor extremely,” and “dislike overall extremely.” Conversely, 100 was verbally anchored as "very tender", "very juicy", "like flavor extremely", and "like overall extremely". The MSA "MQ4" score was calculated as a weighted consumer score between one and 100, using the standard MSA weightings of 30% for tenderness, flavor and overall liking and 10% for juiciness.

2.3. *Volatile compound evaluation*

Volatile compound collection and gas chromatography-mass spectrometry (GC-MS) analysis was conducted on selected steaks from those that were grilled and served to consumers during each evening's consumer panel. Samples for volatile collection were collected from the selected steaks, once removed from the grill, by obtaining three 1.27-cm diameter cores from the center line of selected steaks during the resting period and before the remaining steak was cut into two portions and served to two consumers. Each core was then cut again perpendicular to the muscle fibers to enable the six pieces to be placed into a 15 mL clear glass vial (Supelco, Bellefonte, PA, USA; preconditioned in an oven held at 95 ºC). Preheated (60 ºC) vials and screw caps containing a polytetrafluoroethylene septum were then closed. The vial was then placed in a 65 °C water bath (Thermo Scientific, Waltham, MA, USA) and allowed to equilibrate for 5 min. Volatiles were extracted by solid phase microextraction (SPME) using an 85 µm film thickness carboxen polydimethylsiloxane fiber in a manual SPME needle and holder (Supelco, Bellefonte, PA, USA). Following equilibration, a SPME fiber was placed in the headspace above the sample for 10 min. After collection, samples were withdrawn into the SPME needle, capped using an inert GC septum (LB-2, Supelco, Bellefonte, PA, USA) and placed in a glass test tube with a PTFE-lined lid (all preheated in an oven at 95 ºC). The SPME fibers with collected volatiles were held at 2 to 4 ºC for up to a maximum of 24 hours, prior to analysis. Collection and holding was required as multiple volatile samples were collected simultaneously during consumer palatability scoring sessions.

An Agilent 6890 series GC (Agilent Technologies, Santa Clara, CA, USA) equipped with a 5975 MS detector (Agilent Technologies, Santa Clara, CA, USA) was used for separation and detection of volatile compounds. Extracted volatile compounds were desorbed from SPME fibers at the GC-MS inlet at 250 °C in splitless mode. Cryogenic focusing was conducted by placing the front of the GC column into a bed of dry ice (solid CO_2). A loop of the front end of the column (approximately 100 mm), between the injector and the remaining portion of the column, was placed into the dry ice for a period of 5 min prior to injection. The software program was then loaded and prepared to start and the SPME fiber was injected and desorbed for 5 min while the column remained in the dry ice. After 5 min the column was removed from the dry ice and the oven method was started. The SPME fiber remained exposed within the inlet for the first 3 min of the oven method to ensure all volatile compounds had been desorbed.

Compounds were separated using a BPX-5 capillary column (25 m × 0.32 mm, 0.25 µm film thickness; SGE, Austin, TX, USA) with helium as the carrier gas at 1 mL per min. The oven method used included an initial 5 min at 35 ºC, followed by an 8 ºC per min ramp to 220 ºC, then a 20 ºC per min ramp to 290 ºC, and finally a 5 min hold period at 290 ºC. The total run time was 37 min. The inlet was operated in splitless mode for the first 3 min followed by a 10:1 split.

The MS detected ions within 33-500 m/z range in the electron impact mode at 70 eV. Chromatography data was collected in the selective ion monitoring/scan mode (SIM/Scan; Agilent MSD Chemstation D.03.00.611 software, Agilent Technologies, Santa Clara, CA, USA). Ions were selected based on the presence of three primary ions from compounds of interest.

2.4. *Mass spectral identification of volatile compounds*

A solution of *n*-alkanes (C_8-C_{22}, Supelco, Bellefonte, PA, USA; 1 ng/µL) was run each day of analysis and linear retention indices (LRI) were calculated with reference to the *n*-alkanes (Goodner, 2008). The calculated LRI were used to determine retention times of compounds of interest. Volatile compound identity was confirmed by comparison of the ion fragmentation patterns and the LRI with that of the authentic compounds. Three target ions were selected for the comparisons between sample and standard runs with one quantitative ion and two qualifying ions being selected for each compound of interest. A single-point external standard method was used for quantitation. External standard reference compounds (Sigma Aldrich, Saint Louis, MO, USA) were delivered in solutions (1 ng/µl) of pentane (later eluding compounds) or toluene (early eluting compounds) in splitless-mode. Quantitative ion abundances of sample runs were compared with quantitative ion abundances of standard runs of known concentration. Compounds not detected in sample runs were treated as zero

2.5. *Proximate Analysis*

Proximate analysis of raw steaks was conducted by an AOAC official method (2007.04; Anderson, 2007) using a near infrared spectrophotometer (FoodScan, FOSS NIRsystems, Inc., Laurel, MD, USA). Chemical percentages of fat, moisture, protein, and total collagen were determined for each muscle within each USDA quality grade, as described previously (O'Quinn *et al.*, 2011).

2.6. *Statistical analysis*

Statistical analysis was conducted based on a generalized linear mixed model, using the Proc Glimmix procedure of SAS (Version 9.3, Cary, NC). Two-way analysis of variance was used to evaluate the fixed effects of USDA quality grade, beef muscle and their interaction. Steak was the experimental unit. Panel session, serving round, and consumer were each treated as random effects in the model. Differences were considered significant at $P < 0.05$. The CORR procedure of SAS was used to determine Pearson correlation coefficients. Principal component (PC) analysis was performed on volatile compounds using PROC FACTOR of SAS (v.9.3, Cary, NC). Three principal components, PC1, PC2 and PC3 were retained to determine treatment scores and correlation coefficients with consumer palatability scores and proximate data. The treatment PC scores and correlation coefficients were plotted together (x coordinate = PC1; y coordinate = PC2 or PC3 correlation coefficients) to evaluate relationships.

3. Results and Discussion

3.1. *Chemical fat, collagen, moisture, and protein*

Proximate analysis was conducted for steaks from subprimals for which consumer and volatile flavor compound evaluations were obtained (Table 1). It is important to note that the samples for inclusion in this experiment were selected to give clear differences in the chemical fat content of the *Longissimus lumborum* between grades. Therefore, these data do not represent a random selection of samples from these USDA quality grades and are recorded to assist with the explanation of consumer and flavor analyses.

Percent chemical fat, collagen and moisture showed an interaction between USDA quality grade and muscle ($P < 0.001$, 0.01, 0.001, respectively; Table 1). In *Longissimus lumborum* steaks the chemical fat percentages of the various quality grades were similar to previous findings (Emerson, Woerner, Belk, & Tatum, 2013). As quality grade increased, fat content increased while moisture content decreased, as demonstrated in numerous previous studies (Hunt *et al*., 2014; Von Seggern, Calkins, Johnson, Brickler, & Gwartney, 2005; Brackebush, McKeith, Carr, & McLaren, 1991; Romans, Tuma, & Tucker, 1965). The interaction between grade and muscle highlighted the fact that the relationship between grade and fat content differs markedly among muscles. Intramuscular fat levels in *Psoas major*, *Gluteus medius* and *Semimembranosus* follow a similar pattern to the *Longissimus* samples, but the differences were much less distinct, with most difference occurring between Prime and Upper 2/3 Choice compared with the Low Choice, Select and Standard grades. As expected, an opposite pattern of effects was observed for percent moisture content, though the differences between muscles and grades were much smaller. Other researchers have also reported that moisture and fat content of beef muscles vary with quality grade (Hunt *et al.*, 2014; Von Seggern *et al.*, 2005).

There was no interaction for percent protein ($P > 0.05$), but there were differences due to muscles ($P < 0.01$) and grade ($P < 0.05$), similar to Hunt *et al* (2014). As expected, these differences, again small, follow the pattern for the percent moisture and mirror that for percent fat (Table 1). This trend reflects results reported by previous works (Hunt *et al.*, 2014; Brakebusch *et al.*, 1991; Romans *et al.*, 1965).

An interaction was present between grade and muscle for percent collagen ($P < 0.01$), with levels increasing in higher grades of *Longissimus lumborum* but unaffected by grade in *Psoas major*. Prost *et al.* (1975) has previously reported that percent collagen of the *Psoas major* is unaffected by grade. Variation in percent collagen between muscles is well documented (Von Seggern *et al.*, 2005; McKeith, De Vol, Miles, Bechtel, & Carr, 1985; Prost, Pelczynska, & Kotolua, 1975). The effect of quality grade on percent collagen is less clear and often dependent on muscle (Von Seggern *et al.*, 2005), as found in this study.

3.2. *Consumer palatability scores*

Consumer evaluations of tenderness, juiciness, flavor liking, and overall liking of beef steaks from four muscles and five USDA quality grades are displayed in Table 2, along with the composite MQ4 value. The results show significant interactions between muscle and grade ($P <$

0.05) for all attributes except tenderness. Surprisingly, USDA quality grade had no effect (P > 0.05) on consumer tenderness ratings and there was no interaction between muscle and grade (P > 0.05). However, as expected from previous reports (Browning, Huffman, Egbert, & Jungst, 1991; Christensen, Johnson, West, Marchall, & Hargrove, 1991; McKeith *et al.*, 1985), tenderness differed (P < 0.05) between all the muscles (Table 2), with mean scores ranging from 38 for *Semimembranosus* to 89 for *Psoas major*.

Juiciness was determined by consumers to be greatest among *Psoas major* steaks from Prime, Upper 2/3 Choice, Select, and Standard quality grades along with Prime *Longissimus lumborum* steaks (P < 0.05; Table 2). Interestingly, Low Choice *Psoas major* and Low Choice *Semimembranosus* steaks received lower scores than the rest of the quality grades for these muscles, but the same effect was not observed for *Gluteus medius* and *Longissimus lumborum* muscles. Thus, juiciness scores differed between muscles and were generally greater in Prime and Upper 2/3 Choice grades. These are the same grades that had greater percent fat supporting the documented belief that percent fat is related to juiciness (Lorenzen *et al.*, 1999; Lorenzen *et al.*, 2003; Savell, Cross, & Smith, 1986; Smith *et al.*1984). Flavor liking scores followed similar trends (Table 2) to juiciness where an interaction (P < 0.05) for flavor liking was due to lower flavor liking scores within *Psoas major* and *Semimembranosus* Low Choice grade receiving lower scores than expected.

The MSA MQ4 value, as previously described, assessed meat eating quality based on weighted calculations. This value has been shown to predict consumer satisfaction and avoids the difficulty consumers have in distinguishing between attributes (Watson *et al.*, 2008). In this data the MQ4 values followed similar trends as overall liking and flavor liking (Table 2).

Generally, the effect of USDA quality grade on juiciness, flavor liking, overall liking, and MQ4 was found to be dependent on muscle (Table 2). For most muscles, these attributes did not show consistent increases in consumer score with increasing quality grade. Specifically, the *Longissimus lumborum* muscle was the only muscle possessing a linear ranking with quality grade for juiciness, flavor liking, overall liking, and MQ4. This is likely the effect of fat level within the different muscles. The maximum difference in fat content between USDA Prime *Longissimus lumborum* and USDA Standard *Longissimus lumborum* was close to 12% (where samples were selected on percent fat), whereas the range in percent fat was only 5.2% in the *Psoas major*, 5.5% in the *Gluteus medius*, and 4.9% in the *Semimembranosus* (Table 1). Additionally, USDA quality grade did not have an effect ($P > 0.05$) on fat content for muscles other than the *Longissimus lumborum*, especially for the lowest three quality grade treatments (Table 2).

3.3. *Volatile compounds*

A total of 26 volatile compounds representing pathways of cooked beef flavor development (e.g., thermal oxidation of lipids, Maillard reaction) were selected and quantified. Table 3 shows the mean quantities of volatiles collected from different muscles while Table 4 presents the quantities for those volatile compounds which showed a significant interaction ($P < 0.05$). None of the compounds differed ($P > 0.05$) due to quality grade as a first order effect. Some of the interactions were influenced by particularly low quantities detected for one muscle/grade interaction, especially for some *Psoas major* samples.

Five compounds (2,3-butanedione, heptane, 3-hydroxy-2-butanone, octane, and methyl pyrazine) differed ($P < 0.05$) between muscles independent of quality grade (Table 3). The alkanes, heptane and octane, were found in greatest ($P < 0.05$) quantities from *Psoas major* steaks while being similar ($P > 0.05$) to *Gluteus medius* and *Semimembranosus* steaks but differing ($P < 0.05$) from *Longissimus lumborum* steaks (Table 3). Alkanes are formed from the oxidation of long-chain fatty acids (Mottram, 1991). In this study, alkanes did not appear to be related to percent fat.

The ketones, 3-hydroxy-2-butanone and 2,3-butanedone were both present in greatest ($P < 0.05$) abundance in the headspace of *Gluteus medius* and *Semimembranosus* steaks compared with *Longissimus lumborum* and *Psoas major* steaks (Table 3). These compounds can arise from the 2,3-enolisation pathways which form part of the Maillard reaction (Hurrell, 1982). This could arise from elevated levels of reducing sugars and amino acids or from a higher pH, which favors 2,3-enolisation. Other Maillard products are not similarly affected (Table 3) so the role of pH within muscles may be worthy of further investigation.

Methyl pyrazine was found in the greatest ($P < 0.05$) abundance among *Longissimus lumborum* steaks compared with *Psoas major* and *Semimembranosus*, while *Gluteus medius* steaks were intermediate and similar ($P > 0.05$) to all other muscles (Table 3). Similar trends for other pyrazines were not significant ($P > 0.05$; Table 4). Nitrogen-containing pyrazines are known to be some of the final products of the Maillard reaction (Back, 2007). Although they occur at lower abundances, compared with lipid degradation volatile compounds, these compounds have low odor thresholds which contribute roasted flavors (Buttery & Ling, 1997).

Certain aldehydes have been shown to be the result of Strecker degradation of amino acids. Degradation of alanine, isoleucine, leucine, methionine, phenylalanine, and valine leads to the development of acetaldehyde, 2-methylbutanal, 3-methylbutanal, methional, and phenylacetaldehyde (Cerny, 2007). Benzaldehyde, is another volatile compound potentially resulting from the Strecker degradation of the amino acid phenylglycine (MacLeod, & Ames, 1987; Mottram, & Edwards, 1983). However, as phenylglycine is not an amino acid which occurs in muscle, a different mechanism of formation must be responsible in this case. In our study, benzaldehyde was found to be greater (P < 0.05) in *Psoas major, Gluteus medius,* and *Semimembranosus* steaks.

Interactions (P < 0.05) were found between muscle and USDA grade for seven compounds (acetaldehyde, 2-propanone, dimethyl sulfide, hexanal, benzaldehyde, octanal, and nonanal; Table 4). The effect of quality grade on the *n*-aldehydes, octanal, and nonanal, depended on muscle (Table 4). In the case of *Longissimus lumborum* and *Psoas major*, there was a clear and significant increase in quantities detected with a decrease in grade. Interestingly the fat content of these muscles decreased with quality grade (Table 1). Formation of aldehydes occurs in cooked meat through the thermal oxidation of fatty acids such as oleic, linoleic, and linolenic acid (Cerny, 2007). Each of these aldehydes have previously been identified in beef odor (Mottram, 1991).

Among volatile compounds found to have interactions between USDA quality grade and muscle (Table 4), acetaldehyde, 2-propanone and dimethyl sulfide were all found to be greatest among Upper 2/3 Choice *Psoas major* steaks (P < 0.05). Interestingly, Upper 2/3 Choice *Psoas major* steaks received the greatest score for flavor liking by consumers (Table 2). Sulfur-containing compounds, including dimethyl sulfide, contribute to meaty flavor notes (Gasser & Grosch, 1990). The sum of sulfur-containing compounds (dimethyl sulfide, dimethyl disulfide, methanethiol, and methional) were collectively found to be greatest (P < 0.05) among *Psoas major* steaks.

Overall, these data indicate that the pattern of volatile compounds differs between muscles. *Psoas major* was characterized by greater levels of the sulfur-containing thiols and sulfides;

these and other sulfur-containing compounds are known to contribute to the meaty and roasted characteristics of beef flavor (Mottram, 1991). It is of interest that *Psoas major* steaks consistently received the greatest scores for flavor liking though relationships between the attributes may mean that this score was influenced by tenderness (Table 2). This phenomenon has been described as a halo-effect where one favorable attribute influences consumer's perception of other attributes (Roeber, *et al*., 2000). As previously described tenderness is often considered to be the most influential beef palatability attribute and this may have some impact on flavor liking in this study within the notoriously tender *Psoas major* muscle. *Longissimus lumborum* steaks tended to give greater amounts of pyrazines (Table 3), known to contribute to roasted and nutty characteristics (Mottram, 1991), but lower concentrations of benzaldehyde and short chain ketones. *Gluteus medius* and *Semimembranosus* steaks gave high levels of some short chain ketones known to participate in a range of flavor forming reactions and tended to give more *n*-aldehydes, though there was considerable variability between USDA grades (Table 4). These differences would be expected to influence and explain differences in perceived flavor quality between the different muscles.

3.4. *Correlations*

Pearson correlations between proximate data and consumer palatability scores are displayed in Table 5. As expected, moisture was inversely related with chemical fat (r = -0.97; $P < 0.001$). This inverse relationship between moisture and fat content in multiple beef muscles is very similar to previous work, where a similarly highly significant correlation (r = -0.92) was found (Jeremiah, Dugan, Aalhus, & Gibson, 2002).

There is an apparent correlation between increased chemical fat and increased collagen ($P < 0.001$). Previously, accumulation of collagen during animal physiological maturation was documented to impact palatability, specifically tenderness (Berry, Smith, & Carpenter, 1974; Breidenstein, Cooper, Cassens, Evans, & Bray, 1968; Romans *et al.*, 1965). However, in this study similarly young 'A' maturity carcasses were selected for all grades. A weak positive correlation was observed between collagen and juiciness, flavor liking, and overall liking ($P < 0.05$), but not tenderness (Table 5).It is difficult to propose any direct causative link between more collagen and higher consumer scores.

Overall liking was greatly correlated with flavor liking, juiciness and tenderness ($P < 0.001$; Table 5) indicating that consumers find it difficult to differentiate fully between attributes. Percent fat was correlated with overall liking, tenderness, juiciness, and flavor liking ($P < 0.001$), as expected from previous work (McKeith *et al.*, 1985; Tatum, Smith, Berry, Murphey, Williams, & Carpenter, 1980). There was also a tendency for negative correlations of *n*-aldehydes with flavor liking, overall liking, and percent fat (Table 6).

Negative correlations of long chain *n*-aldehydes (octanal and decanal) with percent fat (Table 6) may be due to the retention of volatile compounds by fat, delaying flavor release as described previously (Farmer, Hagan, Oltra, Devlin, & Gordon, 2013; Chevance *et al*., 2000; Chevance & Farmer, 1999). However, this effect was not apparent for other compounds or compound groups, which showed no significant correlations with percent fat ($P > 0.05$; data not tabulated). Instead, these results may indicate a greater potential for oxidation of unsaturated fatty acids of the polar lipid fraction within beef steaks having low total percent fat. Within beef with a lower total fat content, a greater proportion of the fat includes polar lipids (Wood *et al.*, 2008). Polar lipids are known to be more susceptible to oxidation (Mottram, 1998). Previously, volatile compounds associated with lipid oxidation were increased up to 4-fold in response to increased proportions of polyunsaturated fatty acids (Elmore, Mottram, Enser, & Wood, 1999).

3.5. *Principal component analysis*

Principal component analysis (PCA) was conducted in order to explore relationships between multiple volatile compounds and muscles of different quality grades. Volatile compounds were used to determine principal components (PCs). When PCA was conducted for all grade and muscle treatments PC1 explained 39.8%, PC2 explained 29.4%, and PC3 explained 20.8% of the variation associated with volatile compounds (Figures 1 and 2). Plots revealed that PC1 separated Upper 2/3 Choice *Psoas major* from most of the samples on the basis of increased quantities of many of the Maillard products and reduced quantities of lipid oxidation products. Secondly, PC2 tended to separate *Longissimus lumborum* steaks from many of the other muscles and was associated with an overall lack of volatiles. Principle Component 3 separated *Psoas major* steaks of all grades from many of the remaining samples, with the *Psoas major* being associated with greater quantities of sulfur-containing Maillard products.

Volatile compounds segregated into clusters of similar compound classes (Figures 1 and 2). Pyrazines, Strecker aldehydes, and sulfur compounds were found to be positively related with PC1, while lipid oxidation products, aldehydes, ketones, and alkanes were clustered together and negatively related with PC1. Figure 2 revealed that PC3 separated the treatments on the basis of different groups of Maillard products. This collinear divergence of compound groups may make it possible to use related compounds as “markers” for flavor compounds of greater odor significance which are difficult to detect. Most volatile compounds were located on the positive side of PC2 while percent fat was on the negative side, a similar finding was reported in a recent work (Farmer *et al.*, 2013) where lower fat content beef was related with greater quantities of volatile compounds. It was suggested by Farmer *et al.*, (2013) that lower intramuscular fat content leads to increases in volatile compounds, due to the solubility of volatile aroma compounds in lipids, as previously observed in frankfurters (Chevance & Farmer, 1999; Chevance *et al*., 2000).

Longissimus lumborum showed an association with chemical fat content and an absence of volatile compounds compared with other muscles regardless of quality grade (Figure 1). Upper 2/3 Choice *Psoas major*, which diverted from the remaining treatments was associated with groupings of sulfur-containing compounds and Maillard products and was greatly separated from *n*-aldehydes. The data in Table 4 show that this treatment gave unusually (and consistently) high levels of acetaldehyde, 2-propanone and sulfur-containing compounds.

Figure 2 confirms that Maillard products are closely associated with flavor development (Mottram, 1998) and in this study flavor liking. More specifically, sulfur-compounds were greatly associated with flavor liking. This may reflect the importance of these and other sulfur-containing compounds for aspects of beef flavor.

4. Conclusions

The results of this study indicate that there is potential to gain understanding of flavor differences between beef muscles through the analysis of volatile flavor compounds in association with palatability and chemical measurements. Similar to previous studies USDA quality grade affected consumer flavor and overall liking dependent on muscle. Beef muscle type greatly influenced volatile compounds. Some volatile compounds were negatively correlated with percent fat, while others were not related to fat content. Volatile compounds from similar compound classes and from the same pathways of formation behaved, similarly, with Maillard products being most closely related with flavor liking. This clear relationship between palatability scores and volatile compound classes suggests that differences in the pattern of volatile compounds between muscles may play a valuable role in explaining consumer liking.

5. References

Adhikari, K., & Chambers IV, E. (2010). *Differentiation of beef flavor across muscles and quality grades (Phase I)*. Centennial, CO: National Cattlemens' Beef Association.

Anderson, S. (2007). Determination of fat, moisture, and protein in meat and meat products using the FOSS, FoodScan Near-Infrared Spectrophotometer with FOSS Artificial Neural Network Calibration Model and Associated Database: Collaborative study. *Journal of AOAC International*, *90*, 1073-1083.

Back, H. H. (2007). Process flavors. In L. M. L. Nollet (Eds) *Handbook of Meat, Poultry, & Seafood Quality*. (pp 311-326). Ames, Iowa: Blackwell Publishing.

Behrends, J. M., Goodson, K. J., Koohmaraie, M., Shackelford, S. D., Wheeler, T. L., Morgan, W. W., Reagan, J. O., Gwartney, B. L., Wise, J. W., & Savell, J. W. (2005a). Beef customer satisfaction: Factors affecting consumer evaluations of calcium chloride-injected top sirloin steaks when given instructions for preparation. *Journal of Animal Science*, *83*(12), 2869-2875.

Behrends, J. M., Goodson, K. J., Koohmaraie, M., Shackelford, S. D., Wheeler, T. L., Morgan, W. W., Reagan, J. O., Gwartney, B. L., Wise, J. W., & Savell, J. W. (2005b). Beef customer satisfaction: USDA quality grade and marination effects on consumer evaluations of top round steaks. *Journal of Animal Science*, *83*(3), 662-670.

Berry, B. W., Smith, G. C., & Carpenter, Z. L. (1974). Beef carcass maturity indicators and palatability attributes. *Journal of Animal Science, 38*, 507-514.

Brackebusch, S. A., McKeith, F. K., Carr, T. R., & McLaren, D. G. (1991). Relationship between longissimus composition and the composition of the other major muscles of the beef carcass. *Journal of Animal Science 69*, 631-640.

Breidenstein, B. B., Cooper, C. C., Cassens, R. G., Evans, G., & Bray, R. W. (1968). Influence of marbling and maturity on the palatability of beef muscle. 1. Chemical and organoleptic considerations. *Journal of Animal Science*, *27*, 1532-1541.

Browning, M. A., Huffman, D. A., Egbert, W. R., & Jungst, S. B. (1990). Physical and compositional characteristics of beef carcasses selected for leanness. *Journal of Food Science*, *55*, 9-14.

Buttery, R. G., & Ling, L. C. (1997). 2-Ethyl-3,5-dimethylpyrazine and 2-ethyl-3,6-dimethylpyrazine odor thresholds in water solution. *Lebensmittel Wissenschaft und Technologie*, *30*, 109-110.

Calkins, C. R., & Hodgen, J. M. (2007). A fresh look at meat flavor. *Meat Science*, 77, 63-80.

Cerny, C. (2007). Sensory evaluation of beef flavor. In L. M. L. Nollet (Eds) *Handbook of Meat, Poultry, & Seafood Quality*. (pp 311-326). Ames, Iowa: Blackwell Publishing.

Cerny, C., & Grosch, W. (1992). Evaluation of potent odorants in roasted beef by aroma- extract dilution analysis. *Zeitschrift fur Lebensmittel Untersuchung und Forschung*, *194*, 322-325.

Chevance, F. F. V., & Farmer, L. J. (1999). Release of volatile odor compounds from full and low-fat frankfurters. *Journal of Agricultural and Food Chemistry*, *47*, 5161-5168

Chevance, F. F. V., Farmer, L. J., Desmond, E. M., Novelli, E., Troy, D. J., & Chizzolini, R. (2000). Effects of some fat replacers on the release of volatile aroma compounds from low-fat meat products. *Journal of Agricultural and Food Chemistry*, *48*, 3476-3484.

Christensen, K. L., Johnson, D. D., West, R. L., Marshall, T. T., & Hargrove, D. D. (1991). The effect of breed of sire and age at feeding on muscle tenderness in the beef chuck. *Journal of Animal Science*, *69*, 3673-3678.

Cross, H. R., Berry, B. W., & Wells, L. H. (1980). Effects of fat level and source on the chemical, sensory, and cooking properties of ground beef patties. *Journal of Food Science, 45(4)*, 791-794.

Elmore, J. S., Mottram, D. S., Enser, M., & Wood, J. D. (1999). Effect of the polyunsaturated fatty acid composition of beef muscle on the profile of aroma volatiles. *Journal of Agricultural and Food Chemistry, 47(4)*, 1619-1625.

Emerson, M. R., Woerner, D. R., Belk, K. E., & Tatum, J. D. (2013). Effectiveness of USDA instrument-based marbling measurements for categorizing beef carcasses according to differences in longissimus muscle sensory attributes. *Journal of Animal Science, 91*, 1024-1034.

Farmer, L. J., Hagan, T. D. J., Oltra, O. R., Devlin, Y. and Gordon, A. W. (2013). Relating beef aroma compounds to flavour precursors and other measures of quality. *Proceedings of the 10th Wartburg Symposium on Flavor Chemistry and Biology*, April 2013 (in press).

Farmer, L. J., & Patterson, R. L. S. (1991). Compounds contributing to meat flavour. *Food Chemistry*, *40*, 201-205.

Gasser, U., & Grosch, W. (1988). Identification of volatile flavour compounds with high aroma values from cooked beef. *Zeitschrift fur Lebensmittel Untersuchung und Forschung, 186*, 489-494.

Gasser, U., & Grosch, W. (1990). Primary odorants of chicken broth. A comparative study with meat broths from cow and ox. *Zeitschrift fur Lebensmittel Untersuchung und Forschung, 190*, 3-8.

Goodner, K. L. (2008). Practical retention index models of OV-101, DB-1, DB-5, and DB-Wax for flavor and fragrance compounds. *LWT – Food Science and Technology*, *41*, 951-958.

Goodson, K. J., Morgan, W. W., Reagan, J. O., Gwartney, B. L., Courington, S. M., Wise, J. W., & Savell, J. W. (2002). Beef customer satisfaction: factors affecting consumer evaluations of clod steaks. *Journal of Animal Science, 80*(2), 401-408.

Hodge, J. E. (1953). Chemistry of browning reactions in model systems. *Journal of Agricultural and Food Chemistry, 1,* 928-943.

Hodgen, J. M., Cuppett, S. L., & Calkins, C. R. (2006). Identification of off-flavor compounds in beef. In *Proceedings of the American meat science association reciprocal meat conference, Champagne-Urbana, IL.*

Huffman, K. L., Miller, M. F., Hoover, L. C., Wu, C. K., Brittin, H. C., & Ramsey, C. B. (1996). Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. *Journal of Animal Science*, *74*, 91-97.

Hunt, M. R., Garmyn, A. J., O'Quinn, T. G., Corbin, C. H., Legako, J. F., Rathmann, R. J., Brooks, J. C., & Miller, M. F. (2014). Consumer assessment of beef palatability from four beef muscles from USDA Choice and Select graded carcasses. *Meat Science, 98,* 1-8.

Hurrell, R. F. (1982). Maillard reaction in flavour. In I. D. Morton & A. J. Macleod (Eds.). *Food Flavours*. (pp. 399-437). Amsterdam: Elsevier.

Jeremiah, L. E., Dugan, M. E. R., Aalhus, J. L., & Gibson, L. L. (2002). Assessment of the chemical and cooking properties of the major beef muscles and muscle groups. *Meat Science, 65,* 985-992.

Killinger, K. M., Calkins, C. R., Umberger, W. J., Feuz, D. M., & Eskridge, K. M. (2004). Consumer sensory acceptance and value for beef steaks of similar tenderness, but differing in marbling level. *Journal of Animal Science, 82*(11), 3294-3301.

Lorenzen, C. L., Miller, R. K., Taylor, J. F., Neely, T. R., Tatum, J. D., Wise, J. W., Buyck, M. J., Reagan, J. O., & Savell, J. W. (2003). Beef customer satisfaction: Trained sensory panel ratings and Warner-Bratzler shear force values. *Journal of Animal Science, 81*, 143-149.

Lorenzen, C. L., Neely, T. R., Miller, R. K., Tatum, J. D., Wise, J. W., Taylor, J. F., Buyck, M. J., Reagan, J. O., & Savell, J. W. (1999). Beef customer satisfaction: cooking method and degree of doneness effects on the top loin steak. *Journal of Animal Science*, *77*, 637-644.

MacLeod, G., & Ames, J. M. (1987). Effect of water on the production of cooked beef aroma compounds. *Journal of Food Science, 52(1)*, 42-45.

McKeith, F. K., De Vol, D. L., Miles, R. S., Bechtel, P. J., & Carr, T. R. (1985). Chemical and sensory properties of thirteen major beef muscles. *Journal of Food Science*, *50(4)*, 869-872.

Miller, M. F., Carr, M. A., Ramsey, C. B., Crockett, K. L., & Hoover, L. C. (2001). Consumer thresholds for establishing the value of beef tenderness. *Journal of Animal Science, 79*(12), 3062-3068.

Miller, M. F., Hoover, L. C., Cook, K. D., Guerra, A. L., Huffman, K. L., Tinney, K. S., Ramsey, C. B., Brittin, H. C., & Huffman, L. M. (1995). Consumer acceptability of beef steak tenderness in the home and restaurant. *Journal of Food Science*, *60*(5), 963-965.

Miller, R. K. (2010). Differntiation of beef flavor across muscles and quality grades (Phase II). Centennial, CO: National Cattlemens' Beef Association.

Mottram, D. S. (1991). Meat. In H. Maarse (Eds.), *Volatile Compounds in Food and Beverages*. (pp. 107-177). New York: Marcel Dekker, Inc.

Mottram, D. S. (1998). Flavour formation in meat and meat products: a review, *Food Chemistry, 62(4),* 415-424.

Mottram, D. S., & Edwards, R. A. (1983). The role of triglycerides and phospholipids in the aroma of cooked beef. *Journal of the Science of Food and Agriculture, 34(5),* 517-522.

Mottram, D. S., Edwards, R. A., & Macfie, J. H. H. (1982). A comparison of the flavour volatiles from cooked beef and pork meat systems. *Journal of the Science of Food and Agriculture, 33(9),* 934-944.

NAMP. (2010). The meat buyer's guide (6th ed.). North American Meat Processors Association, Reston, VA.

O'Quinn, T. G., J. C. Brooks, R. J. Polkinghorne, A. J. Garmyn, B. J. Johnson, J. D. Starkey, R. J. Rathmann, and M. F. Miller. (2012). Consumer assessment of beef strip loin steaks of varying fat levels. *Journal of Animal Science, 90,* 626-634.

Prost, E., Pelczynska, E., & Kotolua, A. W. (1975) Quality characteristics of bovine meat. I. Content of connective tissues in relation to individual muscles, age and sex of animal and carcass quality grade. *Journal of animal Science, 41,* 534-540.

Roeber, D. L., Cannell, R. C., Belk, K. E., Miller, R. K., Tatum, J. D., & Smith, G. C. (2000). Implant strategies during feeding: impact on carcass grades and consumer acceptability. *Journal of Animal Science, 78*(7), 1867-1874.

Romans, J. R., Tuma, H. J., & Tucker, W. L. (1965). Influence of carcass maturity and marbling on the physical and chemical characteristics of beef 1. Palatability, fiber diameter and proximate analysis. *Journal of Animal Science, 24,* 681-685.

Savell, J. W., Branson, R. E., Cross, H. R., Stiffler, D. M., Wise, J. W., Griffin, D. B., & Smith, G. C. (1987). National consumer retail beef study: palatability evaluations of beef loin steaks that differed in marbling. *Journal of Food Science, 52*(3), 517-519.

Savell, J. W., Cross, H. R., & Smith, G. C. (1986). Percentage of ether extractable fat and moisture content of beef longissimus muscle as related to USDA marbling score, *Journal of Food Science, 51(3)*, 838-839.

Smith, G. C., Savell, J. W., Cross, H. R., & Carpenter, Z. L. (1983). The relationship of USDA quality grade to beef flavor. *Food Technology, 37(5)*, 233-238.

Smith, G. C., Carpenter, Z. L. Cross, H. R. Murphey, C. E. Abraham, H. C. Savell, J. W. Davis, G. W. Berry, B. W. & Parrish Jr, F. C. (1984). Relationship of USDA marbling groups to palatability of cooked beef. *Journal of Food Quality, 7*, 289-308.

Tatum, J. D., Smith, G. C., Berry, B. W., Murphey, C. E., Williams, F. L., & Carpenter, Z. L. (1980). Carcass characteristic, time on feed and cooked beef palatability attributes. *Journal of Animal Science, 50*, 833-840.

USDA. (1997). United States standards for grades of carcass beef. In: A. M. Service (Eds.). United States Department of Agriculture, Washington, DC.

Von Seggern, D. D., Calkings, C. R., Johnson, D. D., Brickler, J. E., & Gwartney, B. L. (2005). Muscle profiling: Characterizing the muscles of the beef chuck and round. *Meat Science, 71*, 39-51.

Watson, R., Gee, A., Polkinghorne, R. & Porter, M. (2008). Consumer assessment of eating quality – development of protocols for Meat Standards Australia (MSA) testing. *Australian Journal of Experimental Agriculture, 48*, 1360-1367.

Wood, J. D., Enser, M., Fisher, A. V., Nute, G. R., Sheard, P. R., Richardson, R. I., Hughes, S. I., & Whittington, F. M. (2008). Fat deposition, fatty acid composition and meat quality: A review, *Meat Science,* 78, 343-358.

Table 1. Proximate Data[1] of raw beef steaks from five USDA Quality Grades and four muscles

		%			
USDA Quality Grade	Muscle	Fat	Collagen	Moisture	Protein
Prime	*Psoas major*	8.1^{b}	1.8^{cde}	69.5^{de}	21.2
Upper 2/3 Choice	*Psoas major*	6.9^{bcd}	1.9^{bcde}	70.3^{cde}	21.4
Low Choice	*Psoas major*	3.8^{defghi}	1.7^{de}	73.1^{abc}	21.7
Select	*Psoas major*	3.5^{efghi}	1.9^{bcd}	72.5^{abc}	22.5
Standard	*Psoas major*	2.9^{fghij}	1.8^{de}	73.1^{abc}	22.1
Prime	*Longissimus lumborum*	13.1^{a}	2.1^{ab}	64.0^{f}	21.7
Upper 2/3 Choice	*Longissimus lumborum*	7.9^{b}	2.0^{abcd}	68.7^{e}	21.9
Low Choice	*Longissimus lumborum*	4.5^{defg}	1.7^{de}	70.4^{cde}	23.2
Select	*Longissimus lumborum*	2.9^{fghi}	1.7^{de}	71.3^{cd}	23.1
Standard	*Longissimus lumborum*	1.3^{ij}	1.6^{e}	73.5^{ab}	23.3
Prime	*Gluteus medius*	7.1^{bc}	2.3^{a}	69.0^{e}	21.7
Upper 2/3 Choice	*Gluteus medius*	4.3^{defgh}	1.7^{de}	71.8^{bc}	21.8
Low Choice	*Gluteus medius*	1.6^{ij}	1.6^{e}	72.4^{abc}	23.3
Select	*Gluteus medius*	2.9^{fghij}	1.9^{bcd}	71.8^{bc}	22.9
Standard	*Gluteus medius*	2.6^{fghij}	1.9^{bcd}	72.3^{abc}	22.9
Prime	*Semimembranosus*	5.6^{cde}	1.9^{bcd}	70.6^{cde}	22.5
Upper 2/3 Choice	*Semimembranosus*	5.0^{cdef}	2.1^{abc}	71.4^{cd}	21.8
Low Choice	*Semimembranosus*	2.0^{hij}	1.8^{cde}	72.8^{abc}	23.2
Select	*Semimembranosus*	2.5^{ghij}	1.9^{bcd}	72.3^{abc}	23.2
Standard	*Semimembranosus*	0.7^{j}	1.6^{e}	74.1^{a}	23.1
Std. Error		1.5	0.2	1.5	0.8
P value		<0.001	0.004	<0.001	0.809
	Psoas Major	5.0	1.8	71.7	21.8^{b}
	Longissimus lumborum	5.9	1.8	69.6	22.7^{a}
	Gluteus medius	3.7	1.9	71.5	22.5^{a}
	Semimembranosus	3.2	1.9	72.2	22.8^{a}
	Std. Error	0.4	0.1	0.4	0.2
	P value	<0.001	0.766	<0.001	0.006
Prime		8.5	2.0	68.3	21.8^{b}
Upper 2/3 Choice		6.0	1.9	70.5	21.7^{b}
Low Choice		2.9	1.7	72.1	22.9^{a}
Select		2.9	1.9	71.9	22.9^{a}
Standard		1.9	1.7	73.2	22.9^{a}
Std. Error		0.5	0.1	0.5	0.2
P value		<0.001	0.019	<0.001	0.028

[abcdefghij] Means within a column lacking a common superscript differ ($P < 0.05$).

[1] Chemical percentages of fat, moisture, protein, and collagen determined of raw steaks by AOAC official method (2007.04; Anderson, 2007)

Table 2. Consumer palatability scores[1] of grilled beef steaks from five USDA Quality Grades and four muscles

USDA Quality Grade	Muscle	Tenderness	Juiciness	Flavor Liking	Overall Liking	MQ4
Prime	*Psoas major*	94.1	85.9[a]	84.8[a]	89.1[a]	89.7[a]
Upper 2/3 Choice	*Psoas major*	90.2	86.3[a]	86.1[a]	88.1[ab]	84.9[abc]
Low Choice	*Psoas major*	81.4	55.5[efg]	67.9[abcde]	67.1[bcd]	71.5[bcde]
Select	*Psoas major*	94.1	73.7[abcd]	84.9[a]	86.3[ab]	87.4[ab]
Standard	*Psoas major*	90.1	81.4[ab]	75.7[ab]	82.7[ab]	82.6[abcd]
Prime	*Longissimus lumborum*	76.6	75.7[abc]	78.4[a]	78.1[ab]	77.9[bcd]
Upper 2/3 Choice	*Longissimus lumborum*	67.9	69.9[bcde]	68.8[abcd]	69.2[bc]	69.8[de]
Low Choice	*Longissimus lumborum*	71.3	67.8[cde]	73.6[abc]	68.4[bc]	70.6[cde]
Select	*Longissimus lumborum*	60.4	59.3[ef]	64.6[bcde]	61.9[cd]	62.3[efg]
Standard	*Longissimus lumborum*	68.2	59.2[ef]	56.4[ef]	58.7[cd]	60.8[efg]
Prime	*Gluteus medius*	54.9	62.5[def]	65.2[bcde]	63.4[cd]	62.7[efg]
Upper 2/3 Choice	*Gluteus medius*	61.2	69.2[bcde]	72.9[abc]	69.5[bc]	67.8[def]
Low Choice	*Gluteus medius*	47.6	60.2[ef]	61.3[bcdef]	58.0[cde]	55.6[efgh]
Select	*Gluteus medius*	51.9	50.4[fgh]	57.2[def]	54.9[cde]	55.4[efgh]
Standard	*Gluteus medius*	48.1	50.8[fgh]	56.6[def]	51.6[def]	52.2[ghi]
Prime	*Semimembranosus*	36.6	62.7[def]	59.7[cdef]	52.1[def]	52.9[fghi]
Upper 2/3 Choice	*Semimembranosus*	33.9	61.6[def]	56.8[def]	41.6[ef]	44.8[hi]
Low Choice	*Semimembranosus*	32.2	38.6[h]	49.4[f]	37.2[f]	39.1[i]
Select	*Semimembranosus*	39.4	55.1[fg]	64.9[bcde]	57.5[cde]	55.6[efgh]
Standard	*Semimembranosus*	42.3	44.3[gh]	52.5[ef]	44.4[ef]	46.2[hi]
Std. Error		7.5	7.1	7.3	7.8	7.0
P value		0.107	0.024	0.032	0.019	0.033
	Psoas major	89.4[a]	76.6	79.9	82.7	83.2
	Longissimus lumborum	69.4[b]	66.4	68.3	67.3	68.3
	Gluteus medius	54.1[c]	58.6	62.6	59.5	58.7
	Semimembranosus	38.4[d]	52.5	56.6	46.6	47.7
	Std. Error	3.7	3.4	3.0	3.1	2.9
	P value	<0.001	<0.001	<0.001	<0.001	<0.001
Prime		68.8	71.7	72.0	70.7	70.8
Upper 2/3 Choice		61.1	71.8	71.2	67.1	66.8
Low Choice		57.8	55.5	63.0	57.7	59.2
Select		63.3	59.6	67.9	65.2	65.2
Standard		63.0	58.9	60.3	59.4	60.4
Std. Error		5.9	3.2	3.8	4.2	4.1
P value		0.735	<0.001	0.135	0.174	0.268

[abcdefghi] Means within a column lacking a common superscript differ ($P < 0.05$).

[1] Consumer rated each steak on a 100-mm continuous line scale for flavor, tenderness, juiciness, and overall liking. On the scale, 0 was verbally anchored as not tender, not juicy, dislike flavor extremely, and dislike overall extremely. Similarly, 100 was verbally anchored as very tender, very juicy, like flavor extremely, and like overall extremely. Meat quality, 4 variables score (MQ4) reflecting a weighted consumer score between 1 and 100 was calculated using standard Meat Standard Australia weightings of 30% for tenderness, flavor and overall liking and 10% for juiciness.

Table 3. Least-squares means of volatile flavor compounds (ng) from grilled beef steaks of four muscles

Volatile compound	Linear Retention Indices	Beef Muscles				Std. Error	*P* value
		Longissimus lumborum	*Psoas major*	*Gluteus medius*	*Semi-membranosus*		
n-Aldehydes							
Acetaldehyde	412	2.52^{b}	6.77^{a}	2.05^{b}	1.59^{b}	0.81	<0.001
Pentanal	697	28.65	33.39	34.84	38.29	9.99	0.859
Hexanal	795	12.24	10.01	13.72	15.18	4.68	0.779
Heptanal	898	0.83	1.09	1.28	1.27	0.16	0.051
Octanal	1002	0.79	1.17	1.11	1.18	0.18	0.188
Nonanal	1107	1.36	1.96	1.94	1.89	0.24	0.103
Decanal	1205	0.22	0.18	0.28	0.23	0.04	0.219
Sum n-Aldehydes		44.16	47.55	53.08	57.48	15.16	0.858
Strecker Aldehydes							
3-Methyl butanal	652	52.43	39.74	41.75	50.49	9.21	0.467
2-Methyl butanal	659	87.38	49.28	71.21	84.45	15.03	0.139
Benzaldehyde	960	0.36^{b}	0.58^{a}	0.54^{a}	0.48^{a}	0.04	<0.001
Phenylacetaldehyde	1045	0.06	0.07	0.07	0.07	0.01	0.711
Sum Strecker aldehydes		139.99	90.44	114.53	136.55	24.81	0.277
Ketones							
2-Propanone	496	2.85^{b}	13.97^{a}	3.78^{b}	4.55^{b}	1.49	<0.001
2,3-Butanedione	560	6.87^{bc}	6.34^{c}	9.45^{ab}	10.53^{a}	1.39	0.033
2-Butanone	597	1.94	2.84	1.92	1.99	0.43	0.235
3-Hydroxy-2-butanone	705	61.44^{b}	65.59^{b}	135.28^{a}	123.33^{a}	13.11	<0.001
Sulfides							
Dimethyl sulfide	519	0.41^{c}	3.03^{a}	1.03^{bc}	1.38^{b}	0.42	<0.001
Dimethyl disulfide	744	0.35	0.52	0.32	0.28	0.07	0.065
Thiols							
Methanethiol	423	0.02	0.04	0.02	0.03	0.01	0.134
Methional	911	0.23	0.28	0.28	0.25	0.04	0.504
Sum Sulfur containing		1.02^{b}	3.81^{a}	1.63^{b}	1.95^{b}	0.44	<0.001
Furans							
2-Pentyl furan	994	0.03	0.06	0.05	0.06	0.02	0.359
Pyrazines							
Methyl pyrazine	833	0.24^{a}	0.12^{b}	0.16^{ab}	0.08^{b}	0.05	0.029
2-5/6-Dimethyl pyrazine	925	0.73	0.35	0.56	0.29	0.18	0.100
Trimethyl pyrazine	1000	0.19	0.91	0.17	0.73	0.05	0.172
2-Ethyl-3,5/6-dimethyl pyrazine	1086	0.09	0.07	0.12	0.06	0.02	0.184
Sum pyrazines		1.25	0.64	1.01	0.52	0.29	0.079
Alkanes	700						
Heptane	800	30.83^{b}	57.63^{a}	40.83^{ab}	42.35^{ab}	7.89	0.034
Octane		1.36^{b}	2.15^{a}	1.77^{ab}	1.71^{ab}	0.23	0.014

^{abc} Means within a row lacking a common superscript differ ($P < 0.05$).

Table 4. Least-squares means of volatile flavor compounds (ng) from grilled beef steaks of five USDA quality grades and four muscles with significant interactions ($P < 0.05$)

USDA Quality Grade	Muscle	Acetaldehyde	2-Propanone	Dimethyl sulfide	Hexanal	Benzaldehyde	Octanal	Nonanal	Sum Sulfur containing
Prime	*Psoas major*	1.46^{c}	5.81^{cd}	0.91^{cd}	5.23^{bcd}	0.26^{e}	0.69^{cd}	1.47^{bcd}	1.04^{ed}
Upper 2/3 Choice	*Psoas major*	18.39^{a}	35.55^{a}	9.44^{a}	4.12^{bcd}	0.91^{a}	0.51^{cd}	1.26^{bcd}	10.59^{a}
Low Choice	*Psoas major*	2.28^{c}	1.92^{cd}	0.58^{cd}	3.91^{cd}	0.55^{bcd}	0.57^{cd}	1.10^{cd}	1.57^{cde}
Select	*Psoas major*	9.43^{b}	15.72^{b}	3.54^{b}	9.66^{bcd}	0.72^{ab}	1.98^{ab}	2.29^{bc}	4.44^{b}
Standard	*Psoas major*	2.28^{c}	10.83^{bc}	0.97^{cd}	27.12^{ab}	0.47^{cde}	2.11^{a}	3.69^{a}	1.39^{de}
Prime	*Longissimus lumborum*	2.90^{c}	4.13^{cd}	0.49^{d}	9.00^{bcd}	0.28^{e}	0.41^{d}	0.72^{d}	1.01^{e}
Upper 2/3 Choice	*Longissimus lumborum*	3.15^{c}	2.32^{cd}	0.19^{d}	10.83^{bcd}	0.33^{de}	0.72^{cd}	1.21^{cd}	0.75^{e}
Low Choice	*Longissimus lumborum*	1.64^{c}	3.00^{cd}	0.38^{d}	10.87^{bcd}	0.34^{de}	0.81^{cd}	1.43^{bcd}	1.01^{e}
Select	*Longissimus lumborum*	2.35^{c}	3.29^{cd}	0.69^{cd}	12.22^{bcd}	0.40^{de}	0.78^{cd}	1.32^{bcd}	1.36^{ed}
Standard	*Longissimus lumborum*	2.56^{c}	1.53^{d}	0.30^{d}	18.28^{abcd}	0.46^{cde}	1.23^{bc}	2.14^{bc}	0.98^{e}
Prime	*Gluteus medius*	1.53^{c}	3.11^{cd}	0.68^{cd}	7.55^{bcd}	0.42^{de}	0.76^{cd}	1.30^{bcd}	0.15^{ed}
Upper 2/3 Choice	*Gluteus medius*	2.29^{c}	9.62^{bc}	2.55^{bc}	13.79^{bcd}	0.39^{de}	0.88^{cd}	1.64^{bcd}	3.00^{bcd}
Low Choice	*Gluteus medius*	3.33^{c}	2.66^{cd}	0.92^{cd}	21.13^{abc}	0.52^{bcd}	1.37^{abc}	2.25^{bc}	1.57^{de}
Select	*Gluteus medius*	1.63^{c}	1.37^{d}	0.45^{d}	16.48^{bcd}	0.82^{a}	1.57^{abc}	2.44^{b}	1.29^{ed}
Standard	*Gluteus medius*	1.46^{c}	2.15^{cd}	0.56^{cd}	9.64^{bcd}	0.58^{bcd}	0.99^{cd}	2.05^{bc}	1.24^{ed}
Prime	*Semimembranosus*	1.77^{c}	3.82^{cd}	0.91^{cd}	25.81^{abc}	0.66^{abc}	1.57^{abc}	2.18^{bc}	1.56^{ed}
Upper 2/3 Choice	*Semimembranosus*	1.81^{c}	1.21^{d}	0.28^{d}	4.64^{bcd}	0.42^{de}	0.73^{cd}	1.33^{bccd}	0.77^{e}
Low Choice	*Semimembranosus*	3.08^{c}	9.73^{bc}	3.49^{b}	7.55^{bcd}	0.39^{de}	1.21^{bc}	2.14^{bc}	4.01^{bc}
Select	*Semimembranosus*	0.27^{c}	2.75^{cd}	0.61^{cd}	35.74^{a}	0.40^{de}	1.55^{abc}	2.37^{bc}	1.17^{ed}
Standard	*Semimembranosus*	1.37^{c}	5.26^{cd}	1.63^{bcd}	2.18^{d}	0.52^{bcd}	0.84^{cd}	1.40^{bcd}	2.22^{bcde}
	Std. Error	1.29	2.75	0.74	7.29	0.08	0.31	0.41	0.72
	P value	<0.001	<0.001	<0.001	0.017	<0.001	0.028	0.037	<0.001

[abcde] Means within a column lacking a common superscript differ ($P < 0.05$).

Table 5. Pearson correlation coefficients (r) of consumer palatability scores[1] and proximate data[2] of grilled beef steaks from five USDA Quality Grades[3] and four muscles[4]

	Overall Liking	Tenderness	Juiciness	Flavor Liking	% Collagen	% Fat	% Moisture
Tenderness	0.79^{***}						
Juiciness	0.75^{***}	0.65^{***}					
Flavor	0.85^{***}	0.61^{***}	0.65^{***}				
% Collagen	0.10^{*}	0.01	0.14^{**}	0.13^{*}			
% Fat	0.27^{***}	0.22^{***}	0.29^{***}	0.27^{***}	0.70^{***}		
% Moisture	-0.23^{***}	-0.16^{***}	-0.24^{***}	-0.23^{***}	-0.68^{***}	-0.97^{***}	
% Protein	-0.28^{***}	-0.25^{***}	-0.29^{***}	-0.26^{***}	-0.57^{***}	-0.64^{***}	0.50^{***}

[1] Consumer rated each steak on a 100-mm continuous line scale for flavor, tenderness, juiciness, and overall liking. On the scale, 0 was verbally anchored as not tender, not juicy, dislike flavor extremely, and dislike overall extremely. Similarly, 100 was verbally anchored as very tender, very juicy, like flavor extremely, and like overall extremely.

[2] Chemical percentages of fat, moisture, protein, and collagen determined of raw steaks by AOAC official method (2007.04; Anderson, 2007).

[3] Beef quality grades included: Prime, Upper 2/3 Choice, Low Choice, Select, and Standard.

[4] Beef muscles included: *Psoas major, Longissimus lumborum, Gluteus medius,* and *Semimembranosus.*

[*] Significant correlation ($P < 0.05$)

[**] Significant correlation ($P < 0.01$)

[***] Significant correlation ($P < 0.001$)

Table 6. Pearson correlation coefficients (r) between *n*-aldehydes, flavor liking[1], overall liking[1] and % fat[2] for grilled beef steaks from five USDA Quality Grades[3] and four muscles[4]

	Flavor liking	Overall liking	% Fat
n-Aldehydes			
Pentanal	-0.15	-0.13	-0.16
Hexanal	-0.17	-0.14	-0.16
Heptanal	-0.18	-0.16	-0.28**
Octanal	-0.19	-0.15	-0.39***
Nonanal	-0.24*	-0.17	-0.41***
Decanal	-0.25*	-0.22*	-0.19
Sum C_5-C_{10} n-Aldehydes	-0.18	-0.15	-0.17

[1] Consumer rated each steak on a 100-mm continuous line scale for flavor liking and overall liking. On the scale, 0 was verbally anchored as dislike flavor extremely, and dislike overall extremely. Similarly, 100 was verbally anchored as like flavor extremely, and like overall extremely.
[2] Chemical percentages of fat, moisture, protein, and collagen determined of raw steaks by AOAC official method (2007.04; Anderson, 2007).
[3] Beef quality grades included: Prime, Upper 2/3 Choice, Low Choice, Select, and Standard.
[4] Beef muscles included: *Psoas major*, *Longissimus lumborum*, *Gluteus medius*, and *Semimembranosus.*
* Significant correlation ($P < 0.05$)
** Significant correlation ($P < 0.01$)
*** Significant correlation ($P < 0.001$)

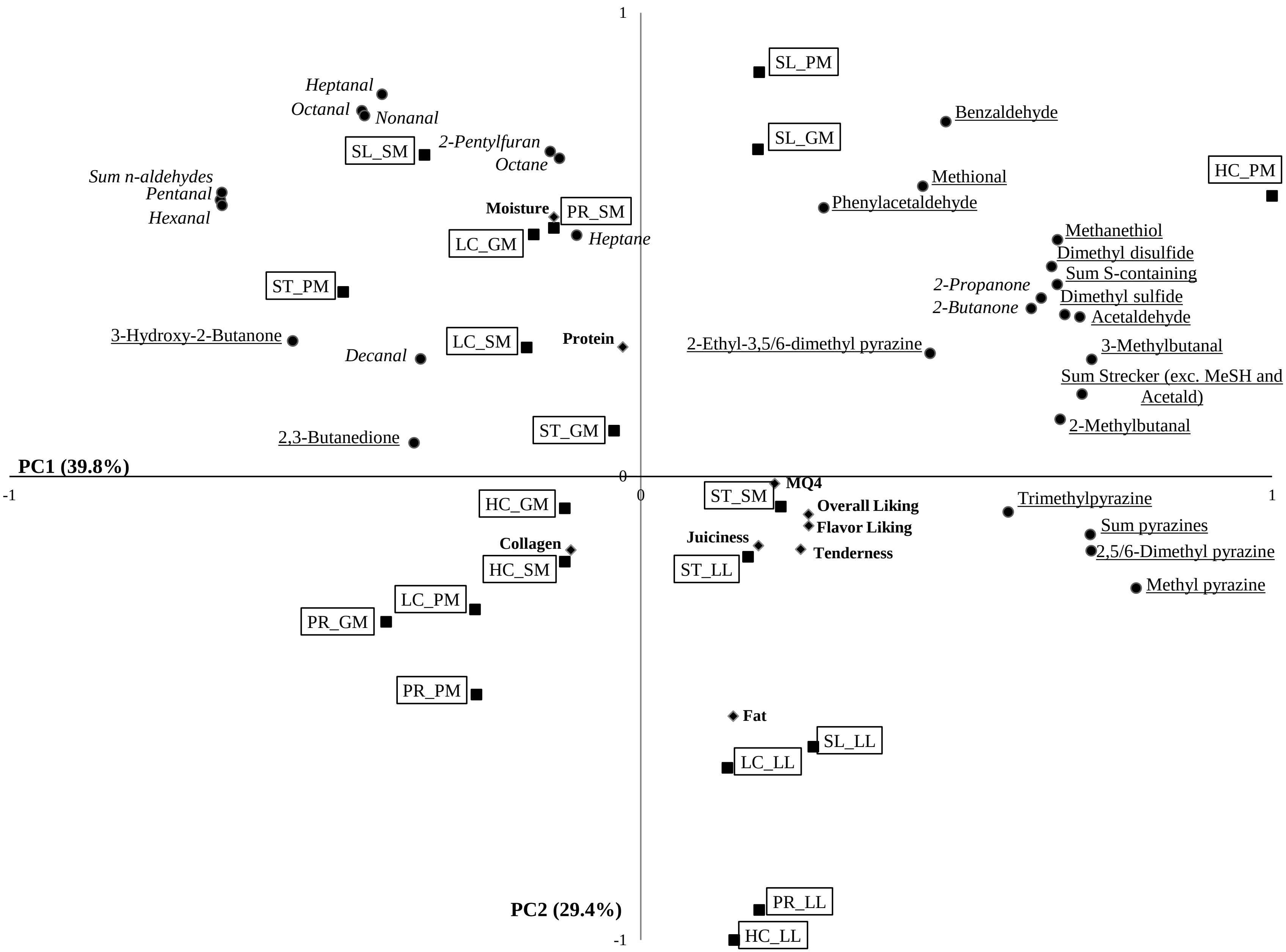

Figure 1. Principal component (PC) analysis for volatile compounds, of five USDA quality grades (Prime = PR, Upper 2/3 Choice = HC, Low Choice = LC, Select = SL, Standard = ST) and four muscles (*Psoas major* = PM, *Longissimus lumborum* = LL, *Gluteus medius* = GM, *Semimembranosus* = SM). Volatile compound groups shown with different formatting: Maillard products and *lipid oxidation products*. **Consumer palatability traits** and **proximate data (%)** were correlated on the same axes.

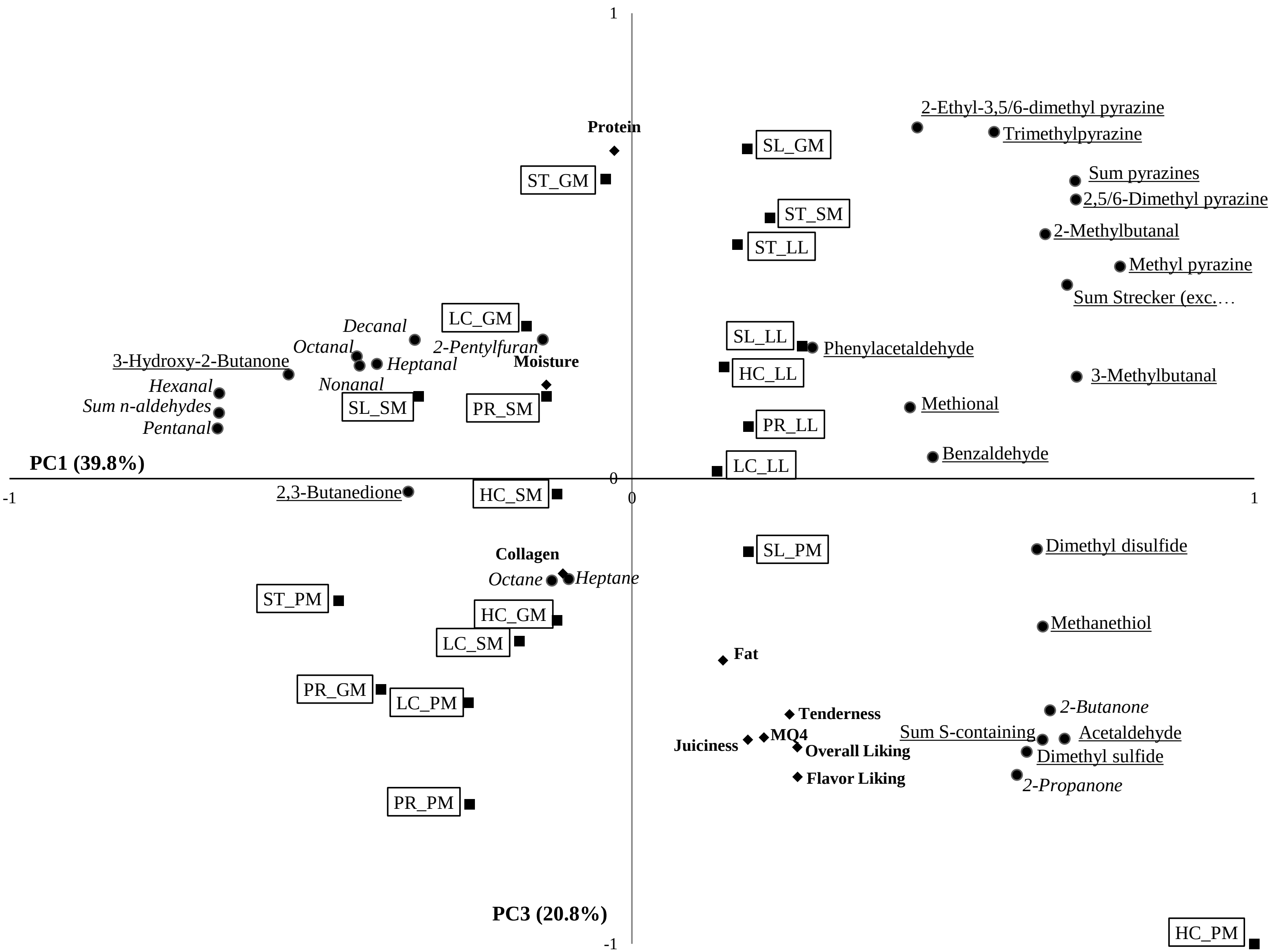

Figure 2. Principal component (PC) analysis for volatile compounds, of five USDA quality grades (Prime = PR, Upper 2/3 Choice = HC, Low Choice = LC, Select = SL, Standard = ST) and four muscles (*Psoas major* = PM, *Longissimus lumborum* = LL, *Gluteus medius* = GM, *Semimembranosus* = SM). Volatile compound groups shown with different formatting: Maillard products and *lipid oxidation products*. **Consumer palatability traits** and **proximate data (%)** were correlated on the same axes.