THESIS

DISCOVERING GROUND BEEF PERFORMANCE THROUGH "PREMIUM GRIND" CONCEPTS

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ABSTRACT

DISCOVERING GROUND BEEF PERFORMANCE THROUGH “PREMIUM GRIND” CONCEPTS

Four independent experiments were conducted to evaluate performance of ground beef from various sources and production techniques. Flavor and texture of 7 different beef products and the effects of dry-aging were evaluated and quantified by descriptive sensory analysis, fatty acid composition, and volatile compound composition. Beef products evaluated included chuck shoulder clods (NAMP 114), chuck boneless short ribs (NAMP 130), whole briskets (NAMP 120), loin tenderloin tips (NAMP 1190C), loin top sirloin caps (NAMP 184D), round sirloin tip knuckles (NAMP 167), and 81/19 chuck sourced trimmings. Fresh (100% un-aged), 100% dry-aged, and 50% fresh/50% dry-aged trimmings were used to evaluate the effects of dry-aging on ground beef performance. Furthermore, the effects of grinder plate size, blend time, and patty-forming technique were evaluated and quantified by descriptive sensory analysis and objective instrument measurement. Additional treatments compared common grocery store practices of grinding bench trimmings versus re-grinding previously ground chubs. Trained panelists evaluated ground beef patties from each treatment for 10 different flavor notes, including beefy/brothy, browned/grilled, buttery/beef fat, bloody/metallic, gamey, earthy/mushroom, nutty/roasted nut, livery, sour/acidic, and bitter, as well as 7 different texture characteristics, including hardness, cohesiveness, tenderness, connective tissue, particle size, moisture content, and beef fat/oily mouthfeel. In addition, samples were analyzed to determine fatty acid composition of raw products and volatile compounds formed during cooking. No single trimming source evaluated in this study outperformed patties comprised of 81/19 chuck sourced trimmings. Notably, briskets and sirloin caps were ranked comparably to 81/19 trimmings in the

desirable flavor attributes of beefy/brothy, browned/grilled, and buttery/beef fat, whereas tenderloin tips were rated lowest in the same desirable flavors. Dry-aged beef samples produced the most complex flavor profile with the highest panel ratings for earthy/mushroom and nutty/roasted nut flavors, and had high scores for browned/grilled flavor.

Grinder plate size and patty-forming technique affected perceived texture differences. Panelists indicated that ground beef patties produced with smaller sized grind plates were softer, more tender, and had a smaller particle size. In agreement, objective measures of texture showed lower peak loads for patties produced with smaller sized grind plates. Patties made with a Formax (Formax F6, equipped with the 2874-6 plate, Mokena, IL) were softer and more cohesive, while patties made with the vacuum stuffer (Model VF50, Handtmann, Germany) equipped with a portioning device were more crumbly but also ranked higher for moisture content and oily mouthfeel. Ground beef patties resulting from the re-ground chubs were perceived to have a greater amount of connective tissue, a larger particle size, greater moisture content, and a greater beef fat/oily mouthfeel. Additionally, objective measures of texture showed greater peak loads for patties from re-ground chubs.

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CHAPTER I

INTRODUCTION

Ground beef has always been one of the most popular beef items sold in retail and foodservice, due to its affordable price and versatility. The economy of recent years coupled with the popularity of premium hamburger chains has increased the demand for ground beef along with prices of beef trimmings. Ground beef is the most popular beef product for consumers preparing meals in their home. In 2008, ground beef was present in 60% of in- home beef servings (NCBA, 2009). Other data show consumers ate more ground beef in 2011 than 2005, also demonstrated by the fact that ground beef represents 63 percent of all beef (by volume) purchased in foodservice (Slagle, 2012). The burger segment in particular is currently the largest menu segment by revenue in the restaurant industry (Technomic, 2012). Fast-casual chain sales increased over 20% from 2010 to 2011. This segment includes chains like Smashburger, which increased sales by 71% in 2011, and Five Guys Burgers, which grew sales 24% in 2011 (Technomic, 2012).

The 2011 National Beef Quality Audit said that eating satisfaction was one of the most important issues according to foodservice and retail businesses (Igo, et al., 2013). Burger consumers agree, saying that the quality and taste of the meat block itself is by far the most important part of the burger (Technomic, 2012).

The high value of beef trimmings has motivated major beef packers to merchandise a larger proportion of the carcass as beef trimmings for grinding operations. Additionally, the success of premium hamburger chains has increased demand for specialty blends as well as increased utilization of whole muscle cuts as grindable items. Many restaurant chains and mail-

order, online meat businesses advertise specialty ground beef blends of whole muscle cuts or sub-primals, including briskets, short ribs, and chuck clods among others. Additionally, these same businesses are marketing dry- and wet-aged ground beef from sub-primal sources. In all of these instances, ground beef and hamburgers sell for a price that rivals premium steaks from the same company. Although numerous restaurant chains are marketing gourmet burgers, their ground beef blends and formulations remain proprietary. Little published scientific research exists to back up these marketing claims.

Beef industry experts agree that ground beef performance is highly complex and not much research has been dedicated to it in recent years. Overall ground beef performance includes flavor and texture. Flavor in ground beef is influenced by fat content, fatty acid composition, volatile composition, muscle type or location, post-mortem aging, and connective tissue presence. Ground beef texture is affected by grinder plate size, patty-forming technique, mixing time, muscle type, fat percentage, and chub packaging verses fresh grinds.

Flavor and texture of individual muscles has been documented by Gruber et al. (2006) and Seggern et al. (2005), among others, but little published research exists documenting flavor and texture differences of individual muscles in ground form. Results from a beef flavor study conducted at Colorado State University with Beef Check-off funds indicate that dry-aging beef sources contributes to beef flavor desirability and increased ratings for beefy/brothy, browned/grilled, buttery/beef fat, and nutty/roasted nut flavors (O'Quinn, 2012). Additional research at Colorado State University (unpublished) has shown the potential ability of a texture analyzer instrument to find quantitative texture differences in ground beef blends.

A better understanding of the factors influencing the performance of ground beef products as well as the development of industry standards that could be utilized to develop

premium ground beef specifications for flavor and texture could greatly contribute the demand for ground beef products and the profitability of the beef industry. This research will assist in determining the validity of various production and premium ground beef marketing claims. The objectives of the current study were to evaluate the flavor effects of individual muscles as grind sources and dry-aging techniques. Objectives also included evaluating the effects of grinder plate size, blend time, patty-forming technique, and chub packaging verses fresh grinds on ground beef texture.

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CHAPTER II

REVIEW OF LITERATURE

Flavor

The flavor of food is complex and is a challenge to fully explain because it involves multiple sensory systems. However, most agree that flavor perception involves three sensory systems: gustatory, olfactory, and trigeminal (Civille & Szczesniak, 1973; Farmer, 1994; Idolo Imafidon & Spanier, 1994b). The gustatory system is more commonly known as the taste sensations perceived in the mouth, which are non-volatile compounds (Farmer, 1994). This includes the five basic tastes of sweet, salty, sour, bitter, and umami.

The olfactory system is comprised of odors and aromas perceived in the nose and throat (Farmer, 1994). In this system, volatile compounds stimulate receptors located in the nose (orthonasal olfaction) and/or the mouth through the nasopharynx (retronasal olfaction) (Auvray & Spence, 2008; Farmer, 1994). Odors have a unique ability to change the way a taste is perceived, and in fact the senses of taste and smell are often confused. Auvray and Spence (2008) looked at this confusion and found that people tend to have a poor ability to label odors and discriminate between them, often attributing to taste what actually belongs to the sense of smell, or describing a smell with taste adjectives (e.g. the odor of vanilla is often reported as smelling sweet, although ‘sweet’ is a taste, not a smell). This confusion is realized when people are asked to block their nose while tasting a food, reporting that they lose their sense of taste. When in fact, much of the taste of food actually originates from the nose and the interactions between smell and taste (Auvray & Spence, 2008). Odors also have the ability to modify taste qualities. When “sweet” odors, which possess no taste, are added to a solution, participants

generally perceive increased sweetness (Auvray & Spence, 2008). Similarly, the identification of odors is confused when they are presented with an inappropriate color (e.g. when strawberry odor is paired with a blue color) (Auvray & Spence, 2008).

The third sensory system involved in flavor perception is the trigeminal system. The trigeminal system is determined by nerve endings in the eyes, nose, and mouth and is stimulated by temperature, acridness, or pungency (Idolo Imafidon & Spanier, 1994b). In addition to the trigeminal system, there are mouthfeel sensations evoked by any food. The mouth and tongue are sensitive to touch, including size, shape, and density, all of which are components of texture. Although texture is separate from flavor and will be discussed later, it is the combination of all of these factors leads to overall flavor perception. Overall flavor perception is a combination of sensory observations, including taste, smell, temperature, and touch, as well as visual clues (Auvray & Spence, 2008; Civille & Szczesniak, 1973).

Beef Flavor Development

Considerable research has been conducted in an attempt to understand beef flavor and how the flavor of beef is developed. However, most can agree that a wide variety of attributes influence the flavor of meat and no single attributes or group of attributes can explain it simply (Adhikari, et al., 2011; Fereidoon Shahidi, Rubin, D'Souza, Teranishi, & Buttery, 1986). Though, it is accepted that beef flavor is thermally derived, because uncooked beef has little to no aroma and a bloody taste (Donald S. Mottram, 1998; F. Shahidi, 1994). During the cooking process, a series of thermal-induced chemical reactions occur, resulting in numerous reaction products (Farmer, 1994; Donald S. Mottram, 1998). These products can be generally attributed to two major reactions: the Maillard Reaction and lipid degradation. The products from these two reaction interact with each other to produce compounds responsible for the characteristic flavor

of beef (Idolo Imafidon & Spanier, 1994b). These compounds and the resulting flavors can be altered or intensified by different cooking methods and endpoint temperatures (Idolo Imafidon & Spanier, 1994b). The compounds derived during the cooking process can be non-volatile compounds with taste properties, or volatile compounds with odor properties (Idolo Imafidon & Spanier, 1994b). It is the volatile compounds, which are responsible for both pleasant aromas and off-flavor odors, that are believed to contribute most to the characteristic flavor of beef (Calkins & Hodgen, 2007; Donald S. Mottram, 1998).

Effect of Volatile Compounds on Beef Flavor

Numerous researchers have studied odors and aromas in cooked beef and the volatile compounds causing them. However, much is still unknown regarding the exact chemistry and the exact compounds causing the characteristic flavors of meat (Idolo Imafidon & Spanier, 1994b; Fereidoon Shahidi, et al., 1986). Over 1000 volatile compounds have been identified in meat, and the exact combination and contribution is not known (Idolo Imafidon & Spanier, 1994b; Donald S. Mottram, 1998). It is believed by scientists that a relatively small portion of the volatiles present actually contributes to the characteristic aroma and that a compound's individual contribution depends on its concentration and odor threshold (Farmer, 1994; Ventanas, Mustonen, Puolanne, & Tuorila, 2010). Researchers believe there are at least 17 compounds which specifically contribute to the aroma of cooked beef, and 7 compounds which are unique to beef (Brewer, 2007; Idolo Imafidon & Spanier, 1994a; Ramarathnam, Rubin, & Diosady, 1993). These include bis(2-methyl-3-furyl)disulfide, methional, 4-ethyl-1-methylhexane, 1,1,3-trimethylcyclohexane, alpha-pinene, 4-ethyl-1,2-dimethylbenzene, and 3,6-dimethylundecane (Brewer, 2007; Idolo Imafidon & Spanier, 1994a; Ramarathnam, et al., 1993). However, it becomes difficult to compare results from one study to another because there is little

recurrence in results reported and varying protocols (e.g. different cuts of meat used, varying cooking methods and endpoint temperatures, different isolation procedures, etc.) (Fereidoon Shahidi, et al., 1986). Despite all that is unknown, it is known how volatile compounds are formed during the cooking process: through lipid oxidation and through the Maillard Reaction (Farmer, 1994; Idolo Imafidon & Spanier, 1994b; Donald S. Mottram, 1998; Ventanas, et al., 2010).

Lipid oxidation during the cooking process is a major contributor to the formation of volatile compounds. The lipid content of beef has a major impact on the profile of flavors and their perceived intensity (Druaux & Voilley, 1997). Researchers have also found that the volatiles originating from the lipid portion of meat are those responsible for the species-specific flavor (G. MacLeod, 1994; F. Shahidi, 1994). Many researchers also agree that the lipid-derived volatiles are highly influenced by the animal's diet (J. Stephen Elmore, Mottram, Enser, & Wood, 1999). Fatty acids, mainly the poly-unsaturated fatty acids (PUFA) are oxidized in the presence of heat, which breaks down lipids and produces volatile compounds (Calkins & Hodgen, 2007; Farmer, 1994). In particular, the phospholipid portion of lean tissue contains the highest proportion of PUFA, which undergo auto-oxidation more quickly than saturated fatty acids (SFA) (J. Stephen Elmore, et al., 1999; Donald S. Mottram, 1998). Aldehydes are the most dominant products derived from lipid oxidation, followed by ketones, alcohols, and hydrocarbons (J. Stephen Elmore, et al., 1999). Aldehydes in particular have low odor thresholds so they have a large effect on aroma and flavor (Elmore et al., 1999).

A few studies have looked at volatiles of ground beef in regards to lipid content, with varying results. Cross et al. found no differences in ground beef flavor intensity regardless of fat content, which ranged from 16-28% (1980). On the other hand, El-Magoli et al. found that a

higher fat content (ranging 11-22%) in ground beef also resulted in higher levels of 2-butanone, 2-pentanone, and 3-hydroxy-2 butanone (1996). A third study looked at ground beef from Wagyu cattle verses ground beef from dairy cattle, and found that Wagyu cattle produced higher levels of overall volatiles, epecially ketones and lactones, whereas dairy cattle produced higher levels of aldehydes and alcohols (Sato, et al., 1995).

The Maillard Reaction is the second major source of volatile compounds formed during the cooking process. The Maillard Reaction occurs when an amino compound (NH_3 from protein) and a carbonyl group of a reducing sugar react together to form Maillard Reaction products (Brewer, 2007; D. S. Mottram, 1993). These resulting products are in part responsible for the formation of meat flavor (Idolo Imafidon & Spanier, 1994a). This reaction between 1 amino acid and 1 sugar will yield hundreds of volatile compounds (Farmer, 1994; Farmer & Patterson, 1991). The amino acid determines the odor or aroma, while the sugar defines the rate of the reaction. The initial reaction results in an aldehyde and an aminoketone, which form furfurals, furanones, hydroxyketones, and dicarbonyl compounds upon further rearrangement and dehydration (Brewer, 2007; Calkins & Hodgen, 2007).

One class of compounds predominant in cooked meat is sulfur-containing compounds (Donald S. Mottram, 1998). Sulfur-containing compounds have been found to be the most powerful aroma volatile compounds (F. Shahidi, 1994). These sulfur-containing compounds have a very low odor threshold which makes them potent at small levels. As a result, low levels of sulfur-containing compounds have meaty aromas, while high levels have strong, objectionable, sulfurous odors (Hogan, 2002; D. S. Mottram, 1993; Donald S. Mottram, 1998; F. Shahidi, 1994). Sulfur-containing compounds, along with carbonyl-containing compounds are most often associated with the meaty aroma derived from the lean portion of beef (Hogan, 2002).

Furthermore, sulfur-containing compounds can react with other Maillard Reaction products as well as lipid oxidation products to produce other flavor compounds. Degraded sulfur-containing compounds react with amino acids which produce pyrazines, oxazoles, thiophenes, thiazoles (Brewer, 2007; Glesni MacLeod & Ames, 1986; Donald S. Mottram, 1998). These heterocyclic compounds, including pyrazines, thiazoles, and oxazoles, have been associated with roasted beef flavors (Donald S. Mottram, 1998). Pyrazines in particular have been associated with nutty aromas and have been the predominant class of volatiles found in well-done, grilled beef (Hogan, 2002; D. S. Mottram, 1993; Donald S. Mottram, 1998). Moreover, the heterocyclic compounds formed in the Maillard Reaction, can react with products from lipid oxidation to produce aroma volatiles. Researchers have found that aldehydes from lipid oxidation react with Maillard Reaction heterocyclic compounds to form thiazoles, among other volatiles (Donald S. Mottram, 1998). Much of the flavor and aroma volatiles associated with cooked meat is believed to result from these secondary interactions.

Effect of Fatty Acid Composition on Beef Flavor

The role of fatty acid composition in beef flavor has been the subject of multiple studies. Oleic acid (C18:1c9) commonly represents about one third of the total fatty acid content in beef so is an important factor in beef flavor (Rule, Broughton, Shellito, & Maiorano, 2002). In fact, oleic acid is known as the mono-unsaturated fatty acid (MUFA) with the most beneficial effect on beef flavor desirability (Dryden & Marchello, 1970; Garmyn, et al., 2011; Westerling & Hedrick, 1979). In a study evaluating the role of fatty acids on the palatability of LM steaks, oleic acid was highly correlated to beef flavor (r=0.66) (Dryden & Maechello, 1970). However, when this study combined results from LM, *M. triceps brachii*, and *M. semimembranosus*, no significant differences were found for any muscle for any of the fatty acids analyzed (Dryden &

Maechello, 1970). In regards to oleic acid, another study a few years later found similar results. Researchers found that oleic acid and total unsaturated fatty acid (UFA) content were positively correlated with beef flavor (Westerling & Hedrick, 1979). In the same study, C16:0 (palmitic), C18:0 (stearic), C18:2 (linoleic), and total saturated fatty acid (SFA) content were negatively correlated with beef flavor (Westerling & Hedrick, 1979).

Another recent study jointly conducted at Oklahoma State University and Iowa State University looked at relationships between LM sensory characteristics and fatty acid profiles (Garmyn, et al., 2011). This study found C14:0, C16:0, C16:1, C17:0, C18:1 *cis*-9, C18:1 *trans*-10/11, C18:1 *trans*-15, and total SFA and monounsaturated fatty acid (MUFA) content were positively correlated with beef flavor (Garmyn, et al., 2011). Moreover, C18:2, C20:4, total PUFA content, n-3 fatty acids, and n-6 fatty acids were negatively correlated with beef flavor (Garmyn, et al., 2011). This study also found C17:0, C18:0, C18:1 *trans*-15, and C18:2 positively correlated with fishy flavor, and C18:1 *trans*-10/11 positively correlated with livery/metallic flavor (Garmyn, et al., 2011). Multiple other studies agree with these results with regards to positive and negative correlations between specific fatty acids and beef flavor desirability (Baublits, et al., 2009; Dryden & Marchello, 1970; Sexten, et al., 2012)

There are also numerous studies which focus on the fatty acid composition of LM under different feeding conditions or different breeds of cattle. The same fatty acids which had a negative impact on flavor were more prevalent in grass-fed cattle, whereas the fatty acids which had a positive impact on flavor were more prevalent in grain-fed cattle (Melton, Amiri, Davis, & Backus, 1982; Melton, Black, Davis, & Backus, 1982; Westerling & Hedrick, 1979). This was confirmed by a more recent study by Elmore, who found that concentrate-fed beef contained

higher levels of oleic and linoleic and lower levels of linolenic than grass-fed beef (J. S. Elmore, et al., 2004).

On the other hand, there is not a lot of present literature which discuss differences in fatty acid composition of different muscles (Sexten, et al., 2012). However, the fatty acid profile of different muscles of the beef carcass have been recently updated and reported in the USDA's Nutrient Database for Standard Reference (U.S. Department of Agriculture, 2012). Of the six muscles being evaluated in this study, five have recent data reported: Beef chuck, short ribs boneless (NAMP 130A), beef chuck, shoulder clods (NAMP 114), beef briskets (NAMP 120), beef loin, top sirloin caps (NAMP 184D), and beef round, knuckles (NAMP 167). Overall beef short ribs and beef briskets have more total fat than the other cuts (U.S. Department of Agriculture, 2012). Compared to the other muscles chosen, on a percentage of total SFA basis, beef short ribs have a lower proportion of palmitic acid and higher proportion of stearic acid, indicating that off-flavors may be present (U.S. Department of Agriculture, 2012). Beef loin, top sirloin caps also have a high proportion of stearic acid as a percentage of total SFA, which may indicate objectionable flavors (U.S. Department of Agriculture, 2012). Of the 5 muscles, beef briskets displayed the highest proportion of 14:0, a high proportion of C16:0, and a low proportion of C18:0 (U.S. Department of Agriculture, 2012).

Although there are not many research studies focused on fatty acid composition of muscles across the beef carcass, there are a few studies which compare fatty acid composition of LM to one or two other muscles, often the semitendinosus (ST), in order to compare fatty acids across muscle types. Schreurs (2008) stated that muscle type accounts for the largest proportion of variation in meat quality characteristics. Studies by Alasnier (1996) and Enser (1998) both state that lipid content is higher in red, oxidative, type I muscle fibers. This is important because

others have found that between different muscles, lipid content had a strong influence on panel ratings for desirable flavor (Dryden & Marchello, 1970). Rhee (1988) looked at the psoas major muscle (PM), a muscle with high proportion of oxidative, type I muscle fibers, compared to ST. Results from this study showed PM possessed higher levels of stearic acid (C18:0), higher levels of MUFA, and a trend of higher linoleic acid (C18:2) than ST. Alfaia (2007) looked at muscle type differences in veal and found that muscles higher in type I, like LM, exhibited greater proportions of lauric acid (C12:0) and stearic acid (C18:0), which agrees with Rhee's study. Alfaia also found muscles higher in type II, like ST, exhibited greater proportions of MUFAs, particularly palmitoleic (C16:1c9) and C18:1c11. A recent study conducted at Oklahoma State University found results agreeing that LM (type I) displayed higher levels of lauric and stearic acids, as well as higher levels of capric acid (C10:0) and palmitic acid (C16:0) (Sexten, et al., 2012). This same study found ST (type II) to contain higher proportions of pentadecanoic acid (C15:0) and MUFA including myristoleic (C14:1), palmitoleic (C16:1c9), hepadecanoic (C17:1), and oleic (C18:1c9) acids. This research can potentially be used to explain differences in fatty acid composition of other muscles high in type I or type II muscle fibers.

Effect of Aging on Beef Flavor

Aging of beef is a widely accepted process in which beef is stored at refrigerated temperatures to enhance the eating characteristics. It is generally recognized that the aging process increases tenderness in beef, but disagreement exists about the effect of aging on other palatability characteristics including flavor (Campbell, Hunt, Levis, & Chambers, 2001; Idolo Imafidon & Spanier, 1994b; Laster, et al., 2008; Sitz, Calkins, Feuz, Umberger, & Eskridge, 2006; Smith, et al., 2008; Warren & Kastner, 1992). Multiple survey results have shown that among American consumers, aging is generally considered a positive term, whether they

understand the process or not (Laster, et al., 2008; Smith, et al., 2008). There are two methods of aging commonly used in the beef industry, wet aging and dry aging.

Wet aging involves storing the product in vacuum sealed, non-permeable packages at refrigerated temperatures (Campbell, et al., 2001; Sitz, et al., 2006; Warren & Kastner, 1992). Wet aging is currently the most commonly used method of aging in the United States (Laster, et al., 2008; Smith, et al., 2008). Dry aging refers to storing product unpackaged in a controlled humidity and temperature setting (Campbell, et al., 2001; Smith, et al., 2008; Warren & Kastner, 1992). Dry aging can be utilized for entire carcasses or sub-primal cuts (Sitz, et al., 2006). Dry aging is often perceived as a premium product in the marketplace, commanding consumer willingness-to-pay a higher price (Laster, et al., 2008). Recently, all levels of foodservice have capitalized on this willingness-to-pay, high perceived value of dry-aged beef and have marketed products ranging from whole muscle cuts to ground beef burgers (Laster, et al., 2008).

Significant research has been published comparing dry-aging versus wet-aging as well as un-aged product, but results have varied. Wet aging generally always results in significantly higher saleable yields for all cuts compared to dry-aging (Laster, et al., 2008; Smith, et al., 2008; Warren & Kastner, 1992). Additionally, aging itself significantly affects Warner-Bratzler shear force values, but when aging time period is held constant, between aging methods there is no difference on WBSF (Smith, et al., 2008). Multiple studies have reported no significant differences between wet and dry aging for flavor like, beef flavor, juiciness, and overall acceptability (Laster, et al., 2008; Sitz, et al., 2006; Smith, et al., 2008). In these panels, consumers could not tell the difference between dry-aged and wet-aged, although both received high ratings for overall desirability. This could suggest that average consumers are not able to differentiate flavor characteristics associated with dry-aged beef, or perhaps there is no true

difference in flavor characteristics between aging methods. On the other hand, some studies have found significant differences between aging methods. In consumer panels conducted in Chicago and Denver, *Prime* wet-aged strip steaks were rated significantly higher than *Prime* dry-aged steaks (Sitz, et al., 2006). Another study reported dry-aged steaks resulted in higher beefy and brown/roasted sensory attributes than both wet-aged and un-aged samples (Warren & Kastner, 1992). This same study found higher bloody/serumy sensory values in wet-aged samples than both dry-aged and un-aged (Warren & Kastner, 1992). Campbell, et al. (2001) conducted an extensive study on the effects of dry-aging on beef flavor, evaluating Certified Angus Beef brand striploins and shortloins. The samples were first vacuum packaged for 7-14 days followed by a dry-aging period of 0-21 days. Campbell, et al. (2001) found that with at least 14 days of dry-aging, both brown/roasted flavor and aged-beef flavor intensity increased significantly over non-aged samples. This study also found that increasing dry-aging time also increased juiciness ratings by trained panelists (Savell, 2008). A different study looked at glutamic acid in meat and found that glutamic acid content more than doubled during the first 7 days of aging (Bauer, 1983). It is generally accepted that glutamic acid is the precursor to umami or the savory taste found in meat, so if glutamic acid increases then it can be inferred that beefy/brothy flavor notes would also increase (Maga, 1994).

Another common theory related to aging methods is that aging to a certain point increases positive flavor notes, but that after a certain point undesirable flavor notes will arise. However the number of days resulting in this peak aging point is not agreed upon. Smith et al. believed that this point occurred at 21 days; steaks aged for 21 days resulted in the highest levels of beef flavor and beyond 21 days resulted in decreased beef flavor (2008). Spanier et al. found during a 14-day post-mortem aging period, there was a gradual decline in beefy, brothy,

browned/caramel, and sweet flavor notes, and then a gradual increase in undesirable flavor notes, including painty, cardboard, bitter, and sour (1997). Clearly, more research should be conducted to agree upon whether aging methods have an effect on beef flavor, or to what point beef should be aged for maximum desired flavor.

Effect of Muscle Differences on Beef Flavor

Many restaurant chains who are currently marketing "gourmet burgers" strongly believe in their own "specialty grinds" which often include chucks, briskets, short ribs, even tenderloin tips. While numerous studies have been published regarding the differences in eating characteristics between different muscles, each has different results than the next. Moreover, most published research has looked at whole muscles, not ground or in patty form. Most of the published research has focused on tenderness differences between muscles, because there is much more variation in tenderness than flavor between muscles (Calkins & Hodgen, 2007; M. S. Rhee, Wheeler, Shackelford, & Koohmaraie, 2004).

Tables 2.1 and 2.2 summarize muscle rankings from multiple studies for juiciness and beef flavor intensity. For the purposes of this review, only muscles to be evaluated in the current study are included. Although the results are varied, it could be argued that the *M. psoas major* ranks consistently high while *M. deep pectoral* and *M. rectus femoris* rank consistently low in juiciness and beef flavor intensity sensory attributes. It should also be noted that not all studies reported significant differences and those that did varied in α level. Yancey et al. (2005) conducted a study which found *M. psoas major* possessed a more intense beef flavor than *M. rectus femoris*. A similar study conducted by Stetzer (2008) found the same results but also that *M. rectus femoris* exhibited less off-flavors than *M. psoas major*. Kukowski (2004) looked at a

few other muscles and found that *M. triceps brachii* was rated more flavorful than LM, *M. serratus ventralis*, and *M. complexus.* Research conducted by the National Cattlemen's Beef Association also found that *M. vastus lateralis* and *M. psoas major* exhibited the highest livery off-flavors compared to other muscles (Brewer, 2007).

One study did look at the effects of fat source in ground beef, comparing short ribs (*M. serratus ventralis*) and brisket (*M. deep pectoral*) (Cross, et al., 1980). The sensory results from this study found no significant differences between fat sources, as well as no differences in proximate fat or moisture levels (Cross, et al., 1980).

Most studies comparing palatability and flavor traits between muscles have utilized whole muscle cuts, whereas the current study will use ground samples, which could have an impact on flavor perception. If the texture of a sample becomes unsatisfactory, it could impact a panelist's perception of flavor. Furthermore, while whole muscle tenderness is not a factor in the current study, the portion of tenderness derived from connective tissue in a muscle cut could translate to connective tissue present in a ground sample. Seggern (2005) conducted a study at the University of Nebraska, evaluating performance attributes of muscles from the chuck and round. This study found significant differences in collagen content between muscles, which could translate to connective tissue detectible in a ground product.

It is difficult to completely rank muscles across all palatability traits; however muscles chosen for this study were intended to represent whole muscles that could be potentially used in premium ground beef operations.

Evaluation of Texture in Meat Products

Texture is a very broad subject, but in the Encyclopedia of Food Sciences and Nutrition, M.C. Bourne defines it as "the group of physical characteristics that arise from the structural elements of the food, are sensed primarily by the feeling of touch, are related to the deformation, disintegration, and flow of the food under a force, and are measured objectively by functions of mass, time, and length" (Bourne & Szczesniak, 2003). Texture, as opposed to taste, odor, and color, has no specific receptors (Bourne & Szczesniak, 2003). It is a multi-sensory observation of the structure of a food (Bourne & Szczesniak, 2003; Civille & Szczesniak, 1973). Consumers recognize texture as an important characteristic that contributes to the satisfaction of chewing and the pleasure of eating (Bourne & Szczesniak, 2003). In 1973, researchers recognized the need for standard protocols and sensory descriptors to evaluate the texture of food (Civille & Szczesniak). Texture characteristics were categorized into three groups: mechanical, geometrical, and other characteristics. Mechanical characteristics are those involving the reaction of foods to stress, including hardness, tenderness, cohesiveness, viscosity, and springiness. Geometrical characteristics are those involving the arrangement of the physical constituents of a food, including particle size, shape, and orientation. Other texture characteristics involve the moisture and fat content and their release (Civille & Szczesniak, 1973). When objectively evaluating the texture of a food, most often a combination of sensory panels and instrument evaluation is utilized.

Sensory evaluation is important in evaluating the texture of meat products because if the texture properties of a product are not correct, the product will almost always fail (Chambers Iv, 1994). While intact muscle cuts can be evaluated with just a few descriptive terms, processed meats, including ground beef, entail a more extensive list of texture traits in order to evaluate and

characterize them (Claus, 1995). The simplest texture evaluations, including those evaluations for whole muscle cuts, usually include descriptors of tenderness and juiciness (Claus, 1995). More extensive texture evaluations have included sensory descriptors of hardness, cohesiveness (crumbly to dense), tenderness, particle size and shape (gritty, grainy, course), moisture content, and fat flavor/oily mouthfeel (Bourne & Szczesniak, 2003; Civille & Szczesniak, 1973; Szczesniak, 1986). Other sensory descriptors found in literature on ground beef texture include initial and sustained juiciness, moisture release, sustained moisture, firmness, sustained cohesiveness, cohesiveness of mass, appearance, density, texture, and overall texture acceptability (Berry & Leddy, 1984; Bourne & Szczesniak, 2003; Civille & Szczesniak, 1973; Huffman & Egbert, 1990; Suman & Sharma, 2003; Szczesniak, 1986; Troutt, et al., 1992).

Although sensory evaluation produces valuable results, objective measurement through instrument use is always desired in addition. To be successful, any instrumental measurement must correlate highly with the sensory evaluation (Bourne & Szczesniak, 2003; Civille & Szczesniak, 1973; Claus, 1995). Many texture evaluation instruments have been described in literature and hundreds of instruments are available commercially (Bourne & Szczesniak, 2003). The main differences between testing equipment usually include the structure of the test cell and the type of force applied to the sample (e.g. cutting, puncturing, compression, extrusion, etc.) (Bourne & Szczesniak, 2003). Numerous texture instruments are described in literature, including but not limited to: L.E.E.-Kramer Shear Press; Allo-Kramer Shear; Modified, straight-edged and "V" shaped WB Shear; Armour Tenderometer; Christel Texturemeter; Slice Tenderness Evaluator; U.S. Army Meat Penetrometer; Lehmann Dexometer; Volodkevich Bite Tenderometer; M.I.T. Denture Tenderometer; General Foods Texturometer (Berry & Leddy, 1984; Bourne & Szczesniak, 2003; Claus, 1995; Hollender & Kropf, 1994; Suman & Sharma,

2003; Troutt, et al., 1992). Additionally, many studies use attachments to the Instron Machine to evaluate texture in ground beef (Cross, Stanfield, & Franks, 1978). It becomes difficult to compare studies when so many different instruments are used to measure texture. Additionally, repeatability is difficult because exact machine settings are rarely reported in published results. Current texture instruments produce single measurements that may or may not relate to what is perceived by the person consuming the product (Hollender & Kropf, 1994). In fact, Szczezniak, who has published numerous papers and book chapters regarding evaluation of texture in foods, believes that no device can simulate well enough the process of mastication that a food is subjected to (1986). Despite widespread use and the wealth of information and instruments available to evaluate texture, there is not a single method available that can appropriately evaluate texture across all meat products (Bourne & Szczesniak, 2003; Claus, 1995). Moreover, there isn't a standard method which is generally accepted across the meat science industry, similar to the way Warner-Bratzler and Slice Shear Force methods are generally recognized. With the rise of premium hamburger restaurant chains combined with the popularity and economic feasibility of cooking with ground beef, opportunities exist for developing standards and an industry-wide method of evaluating texture.

As you can see, research on the texture of meat products is not a new development. As far back as 1907, instruments were used to test the tenderness of meat (Cross, et al., 1978). However, the vast majority of the research conducted on texture up to this point has been in regards to tenderness of whole muscle cuts. Few researchers have studied texture in ground beef, and of those that have, many have looked at the effects of varying fat levels on palatability (Berry & Leddy, 1984; Cross, et al., 1980; Huffman & Egbert, 1990; Suman & Sharma, 2003; Troutt, et al., 1992). Relating to the effect of particle size on ground beef texture, a couple

studies have been found. One study reported no differences in a trained sensory panel among ground beef manufactured with different sized grinding plates (Huffman & Egbert, 1990). However the same researchers in a different study found increased tenderness and desirability when beef was ground through a larger plate (Egbert, Huffman, Chen, & Dylewski, 1991). A study on texture in ground chicken agreed with these results, finding increased texture acceptability ratings with larger grind plate sizes (Elsner, Resurreccion, & McWatters, 1997). Yet another study reported the opposite: significantly higher sensory ratings for juiciness, texture, and overall acceptability in ground buffalo patties manufactured with a smaller plate (Suman & Sharma, 2003). These differing results show a need for more research in order to determine not only the effect of ground beef particle size, but other texture characteristics as well.

Table 2.1. Ranking of muscles[a] for juiciness from various published studies

Study Rank[b]	(McKeith, Vol, Miles, Bechtel, & Carr, 1985)	(Carmack, Kastner, Dikeman, Schwenke, & García Zepeda, 1995)	(Jeremiah, Gibson, Aalhus, & Dugan, 2003)	(M. S. Rhee, et al., 2004)
1	BF	SV	SV	BF
2	TB	PM	PM	PM
3	RF	TB	BF	TB
4	PM	RF	VL	RF
5	DP	BF	DP	
6			TB	
7			RF	

[a] PM = *M. psoas major*; TB = *M. triceps brachii*; RF = *M. rectus femoris*; VL = *M. vastus lateralis*; BF = *M. biceps femoris*; SV = *M. serratus ventralis*; DP = *M. deep pectoral*.

[b] Samples are ordered from the most juicy to least juicy.

Table 2.2. Ranking of muscles[a] for beef flavor intensity from various published studies

Study Rank[b]	(McKeith, et al., 1985)	(Carmack, et al., 1995)	(Brickler, 2000)	(Jeremiah, et al., 2003)	(M. S. Rhee, et al., 2004)
1	PM	BF	SV	BF	BF
2	RF	PM	TB	SV	TB
3	BF	TB	VL	PM	RF
4	TB	RF	BF	TB	PM
5	DP	SV	RF	DP	
6				VL	
7				RF	

[a] PM = *M. psoas major*; TB = *M. triceps brachii*; RF = *M. rectus femoris*; VL = *M. vastus lateralis*; BF = *M. biceps femoris*; SV = *M. serratus ventralis*; DP = *M. deep pectoral*.

[b] Samples are ordered from the most intense beef flavor to least (bland).

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CHAPTER III

THE EFFECTS OF MUSCLE AND DRY-AGING ON GROUND BEEF FLAVOR AND TEXTURE

INTRODUCTION

Ground beef is one of the most popular beef items sold in retail and foodservice, due to its affordable price and versatility (NCBA, 2009; Slagle, 2012). The economy of recent years coupled with the popularity of premium hamburger chains has exponentially increased the demand for ground beef along with prices of beef trimmings. The 2011 National Beef Quality Audit identified that eating satisfaction was one of the most important issues for foodservice and retail (Igo, et al., 2013). Burger consumers agree, saying that the quality and taste of the meat block itself is by far the most important attribute of the burger (Technomic, 2012).

The high value of beef trimmings has motivated major beef packers to merchandise a larger proportion of the carcass as beef trimmings for grinding operations. Additionally, the success of premium hamburger chains has increased demand for specialty blends as well as increased utilization of whole muscle cuts as grindable items. Many restaurant chains and mail-order, online meat businesses advertise specialty ground beef blends of whole muscle cuts or sub-primals, including briskets, short ribs, and chuck clods among others. Additionally, some of these businesses are marketing dry- and wet-aged ground beef from sub-primal sources. In each instance, ground beef and hamburgers sell for prices that rival premium steaks from the same company. Although numerous restaurant chains are marketing gourmet burgers, their ground beef blends and formulations remain proprietary. Little to no published scientific research exists to justify these marketing claims.

Beef industry experts agree that ground beef performance is highly complex and not much research has been dedicated to it in recent years. Overall, ground beef performance includes flavor, texture, and color factors. Perceived flavor in ground beef may be influenced by fat content, fatty acid composition, volatile composition, muscle type or location, post-mortem aging, and connective tissue presence.

Flavor and texture/tenderness of individual muscles have been documented by Gruber et al. (2006) and Seggern et al. (2005), among others, but little published research exists documenting flavor and texture differences of individual muscles in ground form. Results from a beef flavor study conducted at Colorado State University with Beef Check-off funds indicated that dry-aging of beef contributes to beef flavor desirability and increased ratings for beefy/brothy, browned/grilled, buttery/beef fat, and nutty/roasted nut flavors (O'Quinn, 2012).

A better understanding of the factors influencing the performance of ground beef products as well as the development of industry standards that could be utilized to develop premium ground beef specifications for flavor and texture could greatly contribute the demand for ground beef products and the profitability of the beef industry. This research will assist in determining the validity of various production and premium ground beef marketing claims. The objectives of the current study were to evaluate the effects of trimming source (individual muscles) and dry-aging techniques on ground beef flavor and texture.

MATERIALS AND METHODS

Two independent experiments were conducted to address the objectives of the study. Experiment 1 was conducted to determine the effects of trimmings source on ground beef flavor and texture, while Experiment 2 compared blends with varying levels of dry-aged beef (Table 3.1).

Experimental Treatments and Sample Preparation

Experiment 1. Beef sub-primals representing 7 different whole muscle grind sources were purchased for use in the study. Details describing the 7 experimental treatments are provided in Table 3.1. Treatments were specifically chosen to represent beef sub-primals that are commonly ground and merchandised as “gourmet burgers”.

Beef chuck, shoulder clods (shoulder clods; NAMP 114), beef chuck, boneless short ribs (short ribs; NAMP 130A), beef briskets (briskets; NAMP 120), beef loin, top sirloin caps (sirloin caps; NAMP 184D), beef round, sirloin tip knuckles (knuckles; NAMP 167) were selected by Colorado State University (CSU) personnel from a commercial processing facility in Northern Colorado to represent treatments 1-5. Beef cuts were transported, under refrigeration (2°C), to the Colorado State University (CSU) Meat Laboratory, where they were vacuum packaged and wet-aged (stored in vacuum-sealed packages in the absence of light at 2-4°C) for 10 days. Samples were checked daily throughout the wet-aging period to ensure that vacuum seals were maintained on all packages. All beef products were obtained from carcasses graded Low Choice (Small marbling score).

Beef loin, tenderloin tips (tenderloins; NAMP 1190C) were purchased from a commercial meat purveyor in Northeast Texas to represent treatment 6. Tenderloin tips were wet-aged for 10 days at the CSU Meat Laboratory using procedures previously described. Chuck sourced

trimmings (81% lean/19% fat) were obtained from a commercial processing facility in Northern Colorado, to represent treatment 7.

On day 3 of the post-mortem aging period, in an attempt to standardize fat percentage, sub-primals intended for use in treatments 1 through 6 were unpackaged and separated into lean and external fat portions. Then, lean and fat portions were cut into cubes of a standard size equal to or smaller than 12.9 square centimeters. Within each treatment, 5 batches (replicates; 13.6kg each) were created by randomly assigning an equal number of sub-primals to each batch. Using crude fat estimates for each cut from the USDA Nutrient Database Standard Reference (U.S. Department of Agriculture, 2012), batches were formulated to contain 15% fat using the Pearson square formula. Each batch of each treatment was re-packaged in vacuum-sealed bags and continued the wet-aging process stated above.

Experiment 2. In order to evaluate the effects of dry-aging techniques on ground beef flavor and performance, beef chuck, shoulder clods (shoulder clods; NAMP 114), were purchased from a commercial processing facility in Northern Colorado and transported, under refrigeration (2°C), to the CSU Meat Laboratory. Upon arrival, the samples were wet-aged for 21 days (stored in vacuum-sealed packages in the absence of light at 2-4°C). Following the 21-day wet-aging period, samples were transported to a commercial dry-aging facility where they were dry-aged, without protective packaging at 2°C, for an additional 21 days. To build a comparison with the dry-aged samples, additional shoulder clods were obtained from the same processing facility in plastic lined combos and ground within 4 days postmortem. These samples represented treatments 8, 9, and 10, as described in Table 3.1. Immediately prior to grinding, shoulder clods were trimmed to remove exterior fat and cut into cubes of a standard size equal to or smaller than 12.9 square centimeters. Within each treatment, 5 batches (replicates; 13.6kg each) were created

by randomly assigning an equal number of sub-primals to each batch. Using crude fat estimates for each cut from the USDA Nutrient Database Standard Reference (U.S. Department of Agriculture, 2012), batches were formulated to contain 15% fat using the Pearson square formula.

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

Objective Color Analysis

Experiment 1&2. Following patty-forming but before blast freezing, objective color measurements were attained from patties (n=9) from the beginning, middle and end of each batch within each treatment. Measurements were taken using a portable spectrophotometer

equipped with a 6 mm measurement port (Miniscan Model 4500S, Hunter Laboratories, Reston, VA). Final color values for each sample were recorded as the mean of 3 individual L*, a*, and b* values from each patty.

Descriptive Sensory Analysis

Experiment 1&2. Sensory analysis was conducted at Colorado State University. Prior to evaluating samples included in the finding of this study, panelists were introduced to standard beef flavor characteristics using the lexicon developed by Adhikari, et al. (2011) and trained to objectively quantify the presence/absence of each flavor using an unstructured 10 cm line scale.

Samples designated for sensory analysis were randomly assigned to sensory sessions so that all treatments were represented in each panel. For Experiment 1, two panel sessions were conducted each day with 10-11 samples per session, so that 3 full replicates representing all 7 treatments were evaluated in 1 day. For Experiment 2, one panel session was conducted each day with 9 samples per session, so that 3 full replicates representing all 3 treatments were evaluated in 1 day. Samples were thawed for 12-24 hours at 2°C before each sensory session. All samples were cooked on griddle pans (Cephalon Contemporary Non-Stick 11" Square Griddle, sold at Bed Bath and Beyond) over open gas burners (Southbend 4602DD-2TR, Fuquay-Varina, NC). Pans were heated for 20 minutes prior to cooking samples. During cooking, samples were turned once, halfway through, and cooked to an internal temperature of 71°C monitored by a Type K Thermocouple Thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation, Middlefield, CT). Following cooking, patties were cut into 8 wedge-shaped, equally sized portions and held in a warming oven for no more than 15 minutes before being served to the panel.

During sessions, panelists were seated in individual cubicles in a dark room. Samples were served under red incandescent light to mask color variation among samples. Panelists were supplied with distilled water, apple juice, and unsalted saltine crackers, which were used for palate cleansing between samples. Panelists evaluated each sample for 10 different flavor notes, including beefy/brothy, browned/grilled, buttery/beef fat, bloody/metallic, gamey, earthy/mushroom, nutty/roasted nut, livery, sour/acidic, and bitter. Panelists also evaluated 7 different texture characteristics, including hardness, cohesiveness, tenderness, connective tissue, particle size, moisture content, and beef fat/oily mouthfeel. Each sensory attribute was rated on a 10-cm, unstructured line scale with 0-cm anchored at very low intensity for all flavors and 10-cm anchored at very high intensity for all flavors. An example of the sensory ballot utilized is presented in Figure 8. After each panel session, individual panelist's ratings were averaged to obtain a single panel rating for each sensory attribute of each sample.

Proximate Analysis

Experiment 1&2. Three patties from each batch within each treatment were broken into smaller pieces, submerged in liquid nitrogen, and homogenized into a fine powder using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc., Ridgeland, MS). After homogenization, samples were placed in Whirl-Pak bags (Nasco, Ft. Atkinson, WI), individually labeled, and stored at -80°C until further analysis.

Total lipid analysis was conducted by the extraction of 1g of each sample using the methods described by Folch, Lees, and Sloane Stanley (1957) and Bligh and Dyer (1959). After extraction, the lipid-containing portion was dried under N_2 gas and placed into a 100°C drying oven for 3 hours. Samples were then cooled to room temperature (22°C) in a desiccator. Once the samples were cooled, samples were weighed and percentage lipid was reported on a wet-

weight basis. The total percentage of sample weight comprised of lipid was calculated by dividing the final weight of the remaining sample by the initial sample weight and multiplying by 100.

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

Crude protein was determined using the method indicated by the AOAC (2005). A conversion factor of 6.25 was used to determine crude protein (Merrill & Watt, 1973).

Ash was analyzed using the ashing method specified by the AOAC (2005). For each sample, approximately 1 g was weighed into a dry crucible. Crucibles were then set in a Thermolyne box furnace (Thermo Fisher Scientific, Pittsburgh, PA) which was set at 600°C for 24 hours. After removal from the incinerator, samples were cooled to room temperature (22°C) in a desiccator. Samples were then re-weighed to obtain the ash percentage. The total percentage of ash was determined by dividing the sample weight in the crucible post-incineration by the initial weight and multiplying by 100.

Fatty Acid Analysis

Experiment 1&2. To measure long- and short-chain fatty acids, total lipid was extracted from 1g of homogenized sample as described in the process above. Saponification and methylation were achieved using the methods of Park and Goins (1994) and Phillips, et al. (2010). Fatty acids were derived to methyl esters (FAME) and analyzed via gas chromatography.

Samples were analyzed using a Hewlett Packard (Avondale, PA) Model 6890 series II gas chromatograph (GC) fixed with a series 7683 injector and flame ionization detector. The GC was equipped with a 100-m x 0.25-mm (i.d.) fused silica capillary column (SP-2560 Supelco Inc., Bellefonte, PA). Helium was used as the carrier gas with a flow rate of 2.0 mL/min. Column oven temperature increased from 40°C to 150°C at a rate of 8°C/min, held for 20min at 150°C, and then increased from 150°C to 160°C at 0.5°C/min and from 160°C to 190°C at 0.2°C/min. The detector was maintained at 300°C and the inlet at 250°C throughout the run. Individual FAME were quantified as a percentage of the total amount of FAME identified. Fatty acid standards were obtained from Nu-Check Prep (Elysian, MN). Results were reported in units of grams fatty acid per 100g original sample.

Volatile Analysis

Experiment 1&2. Frozen samples were transported to Texas Tech University Meat Laboratory for volatile compound analysis according to methods established at the university (J. Legako, 2013; J. F. Legako, 2011). Patties (n=1) from each batch within each treatment were thawed and cooked according to the same method as previously described in sensory analysis. Immediately after cooking, 3 cores (1.3-cm in diameter) were collected from each sample using a Warner-Bratzler coring tool. A 3.5g (±0.1g) sample from the cores was weighed and placed into a 15mL clear glass vial (Supelco, Bellefonte, PA) and closed with a screw cap. Each vial was submerged up to the neck in a 65°C water bath (Thermo Scientific, Waltham, MA) and allowed to equilibrate for 5 minutes. After equilibration period, an 85-µm film thickness carboxen polydimethylsiloxane solid phase microextraction (SPME) fiber was used to extract the volatile compounds. The SPME fiber, contained in a manual SPME needle and holder (Supelco, Bellefonte, PA), was exposed to the headspace in the vial above the sample for 10 minutes. After

10 minutes of extraction, the SPME fiber was retracted into the needle and capped with a GC septum to prevent contamination from volatiles present in the atmosphere. Samples were held for no more than 3 hours before injection into the GC.

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

Ions within 33-500 m/z range were detected by the MS in the electron impact mode at 70 eV. Chromatography data was collected in the selective ion monitoring/scan mode (SIM/Scan; Agilent MSD Chemstation D.03.00.611 software, Agilent Technologies, Santa Clara, CA). Three primary ions from compounds of interest were selected and used for identification, detection and in run measurement. An alkane standard mix (C8-C22; Supelco, Bellefonte, PA) was used to calculate expected linear retention indexes (LRI) for compounds of interest. Lastly, volatile compound identities were validated by authentic external standards, in addition to the MS library. Quantitative estimates of compounds of interest were conducted by an external standard method (J. Legako, 2013; J. F. Legako, 2011).

Texture Analysis

Experiment 1. Textural differences of raw ground beef patties (n=3) from each batch of Treatments 1-7 were objectively quantified using an analyzer (CT3 50K Texture Analyzer;

Brookfield Engineering Laboratories). Samples were randomized and thawed to 0-5°C prior to analysis. For each sample, a 3.8-cm x 3.8-cm square piece was cut from the middle of the patty and placed in the CT3 Texture Analyzer equipped with the Fixture Base Table (TA-BT-KIT, Brookfield Engineering Laboratories) and the Ottawa Cell (TA-OC, Brookfield Engineering Laboratories). A Compression test was run with the following test parameters: target type = distance; target value = 57.0-mm; hold time = 0-s; trigger load = 0-kg; test speed = 300-mm/min; cycle count = 1. Results were reported as a measure of hardness, or the maximum load value (kg) of the compression cycle. Results from each sample within each batch were averaged in order to obtain a single measurement for each batch within each treatment.

Statistical Methods

All analyses were conducted using statistical procedures of SAS (SAS 9.3, Cary, NC). Treatment comparisons were tested for significance using generalized linear model procedures (PROC GLM). Least squares means were calculated for each flavor and texture characteristic across treatments, with differences determined at $\alpha = 0.05$. To account for variations in lipid content, percent lipid was tested as a covariate in each model. In cases where the covariate was significant (buttery/beef fat, cohesiveness, and beef fat/oily mouthfeel), the covariate was included in the model statement. In these models, tests for unequal slopes were not significant, indicating that the covariate was appropriately used. When percent lipid as a covariate was not significant it was removed from the model. Additionally, Pearson correlation coefficients were calculated to show relationships between sensory attributes, fatty acid composition, and volatile compound composition. Examples of the SAS code utilized are presented in Figure 9.

Principle component analysis (PCA) was performed using sensory panel flavor ratings for all three aging treatments. The PC1 and PC2 were then correlated with volatile flavor

compounds. Aging treatments, flavor traits, and volatile compounds were correlated with PC1 (x-axis), PC2 (y-axis), and plotted to determine relationships, as shown in Figure 7.

RESULTS AND DISCUSSION

Proximate Composition and Relationship to Sensory Attributes

Experiment 1. Least squares means for percentages of lipid, moisture, protein, and ash for all of the treatments are summarized in Table 3.2. Sirloin caps and trimmings contained the highest lipid content (19.2-19.5%), while brisket and knuckles contained the lowest percent lipid (12.0-13.7%). During formulation of treatments 1-6 in Experiment 1, each batch was formulated to contain approximately 15-20% fat utilizing the Pearson square formula and the USDA Nutrient Database Standard Reference (U.S. Department of Agriculture, 2012). However, not all cuts in the database have updated nutrient content information, which could have been the reason why treatments differed in percent lipid, particularly for brisket and knuckles, which were lower than desired. Due to the differences in lipid content in Experiment 1, percent lipid was used as a covariate (when significant at $P<0.05$) in the models for determining sensory results. Treatments across all experiments also differed in percent moisture ($P<0.0001$). Percent moisture was inversely related to percent lipid ($r = -0.89$). In Experiment 1, treatments varied in moisture, ranging from 60.59% to 66.99%, based on the same variation as identified in percent lipid. Protein percent was also inversely correlated to percent lipid ($r = -0.69$), and varied among treatments ($P<0.0001$). Treatments formulated with less fat resulted in a greater lean proportion and therefore resulted in a higher percent protein. Between muscle sources, no significant differences were present in percent ash.

Experiment 2. Least squares means for percentages of lipid, moisture, protein, and ash for Experiment 2 are summarized in Table 3.2.Percent lipid did not differ significantly between aging treatments. This was likely due to the fact that all three treatments were from the same muscle source (shoulder clods) so the formulations were consistent. Dry-aged and 50-50 mix

samples exhibited less moisture (62.26% and 63.79%, respectively) than fresh samples (66.07%). Sitz et al. (2006) found similar results, reporting that dry-aged strip loins contained less moisture than comparable wet-aged strip loins. In Experiment 2, protein was also increased significantly in dry-aged samples compared to the fresh samples. This could have been caused by the decreased moisture in these treatments, which would result in the protein content appearing more concentrated (Wahrmund-Wyle, Harris, & Savell, 2000). Percent ash differed ($P<0.001$) among treatments but the difference between the highest (dry-aged) and lowest (fresh) means was less than 0.3%.

Experiment 1&2. Pearson correlation coefficients presented in Table 3.3 show relationships between proximate analysis results and flavor characteristics as identified in sensory panels across all treatments. As expected, percent lipid was most strongly correlated with the buttery/beef fat flavor note (r=0.66). Moderate but significant negative correlations also existed between percent lipid and gamey (r= -0.36) as well as livery (r= -0.34). Percent protein was positively correlated with the earthy/mushroom flavor note (r=0.61) and nutty/roasted nut (r=0.60). A significant correlation also existed between percent protein and buttery/beef fat (r= -0.48), which matches the negative correlation seen between percent protein and percent lipid. Additionally, percent moisture was inversely related to buttery/beef fat (r= -0.62) which agrees with the negative correlation found between percent moisture and percent lipid (r= -0.89). Other weak but significant correlations between percent moisture and various sensory traits are reported in Table 3.3. It is also important to note that percent ash was positively related to earthy/mushroom (r=0.50) as well as nutty/roasted nut (r=0.51). Dry-aged beef samples (T10) contained higher percentages of ash due to decreased moisture content and also were ranked higher for these flavor attributes.

Flavor and Texture Differences as Quantified by Trained Sensory Panels

Experiment 1. Demand for specialty blends and trimmings has motivated commercial ground beef processors to merchandise whole-muscle cuts in gourmet burger grinds. Six muscles and 81/19 trimmings, as outlined in Table 3.1, were chosen to represent cuts that might be used in specialty grinds. Objective and subjective tests of flavor and texture revealed numerous differences. Beef flavor and texture characteristics of ground beef patties representing the 7 beef product sources are summarized in Figure 1 and Tables 3.4 and 3.5.

Chuck sourced trimmings (81/19) were utilized as an industry standard to compare against other muscle sources, and proved to be a favorable source of lean trimmings for ground beef blends. Trimmings ranked as among the highest in beefy/brothy, browned/grilled, buttery/beef fat, and nutty/roasted nut. Trimmings also displayed a low incidence of off-flavors. Patties comprised of chuck sourced trimmings were not outperformed by any of the other muscle sources evaluated. However, for texture characteristics, trimmings ranked highest in particle size and connective tissue, indicating that the chuck sourced trimmings may have contained more .connective tissue than the whole muscle treatments. Objective texture measurement of peak load also showed trimmings to be substantially higher than other samples, which corresponds with the sensory ratings for connective tissue and particle size.

Ground beef patties from sirloin caps and brisket also performed very well and were comparable to the trimmings. Both treatments were rated among the highest for beefy/brothy, browned/grilled and buttery/beef fat flavors, as well as very low in negative off-flavors, including bloody/metallic, gamey, livery, sour/acidic, and bitter. Sirloin caps also were rated comparable with trimmings in nutty/roasted nut flavor. Furthermore, sirloin caps were identified as one of the highest in perceived moisture content. Nonetheless, brisket was ranked high in

hardness and low in tenderness, indicating that samples were tougher. Despite the fact that sensory panel scores did not denote a difference in perceived connective tissue, brisket samples were identified as having a larger particle size or more intact muscle pieces. Overall, ground beef patties made from sirloin caps and brisket exhibited positive flavor attributes and were very comparable to chuck sourced trimmings.

Tenderloin performed poorly in flavor and texture characteristics compared to the other treatments. Tenderloin was ranked absolute lowest in beefy/brothy, browned/grilled, and buttery/beef fat. Tenderloin undoubtedly ranked highest in sour/acidic flavor notes. Due to the fact that raw product for this treatment was procured from a further processor, it had been exposed to wet-aging conditions for a longer period than other treatments. Flavor profiles of beef that has been exposed to extended wet-aging is an area that does not have significant published research, but a few recent studies found sour, undesirable flavors in beef that had been wet-aged for extended periods (Jeremiah & Gibson, 2003; O'Quinn, 2012; Yancey, Dikeman, Hachmeister, Chambers, & Milliken, 2005). The strong sour/acidic flavor of tenderloin samples was likely associated with growth of lactic acid bacteria during the wet-aging period (Seideman, Vanderzant, Smith, Hanna, & Carpenter, 1976). Additionally, muscles like tenderloin often exhibit livery and other off-flavors usually due to higher levels of heme iron and/or myoglobin (Yancey, et al., 2006). Furthermore, tenderloins have been shown to possess a less intense beef flavor compared to other muscles (M. S. Rhee, Wheeler, Shackelford, & Koohmaraie, 2004). Also in the current study, tenderloins were ranked lowest in hardness, cohesiveness, particle size, and beef fat/oily mouthfeel, as well as ranked highest for tenderness. It is generally accepted that the tenderloin is one of the most tender muscles in the entire carcass, which these results agree with (M. S. Rhee, et al., 2004; Shackelford, Wheeler, & Koohmaraie, 1995). These substantial

texture differences indicate that tenderloins become mushy, soft, and grainy when incorporated into a grind.

Shoulder clods, short ribs, and knuckles were rated about neither exceptionally high or low for sensory traits compared to other treatments. Short ribs were ranked highest in cohesiveness, perceived as denser and less crumbly than other treatments. Additionally, color a* values were highest for short ribs (not reported in tabular form), indicating that samples from this blend were more red than others. Knuckles were in fact ranked highest in gamey off-flavors. Current data suggests that neither shoulder clods, short ribs, nor knuckles performed as well as chuck sourced trimmings in ground beef blends.

Experiment 2. Three blends of beef, chuck, shoulder clods were used to evaluate the effects of dry-aging techniques on ground beef flavor. Treatments were blended to represent 100% fresh, 50-50 mix, and 100% dry-aged. As more dry-aged beef was added to the grind numerous flavor and textural characteristics increased or decreased, producing results exhibited in Tables 3.6, 3.7 and Figure 3.

Increasing dry aged beef resulted in increased ratings for browned/grilled, earthy/mushroom, and nutty/roasted nut flavors. However, increasing dry-aged beef also resulted in sour/acidic and bitter off-flavors. O'Quinn (2012) found similar results; dry-aged samples were rated higher for browned/grilled flavors and trended higher for earthy/mushroom and nutty/roasted nut flavors. The same study also found an increased incidence of livery off-flavors in dry-aged samples. It is interesting to note that patties from the 50-50 mix treatment were rated highest for buttery/beef fat flavors. These data suggests that a premium grind of 100% dry-aged beef would produce positive flavor notes and perhaps a more intense overall flavor, but off-flavors would also be present. It can be suggested then, that a grind with a combination of fresh

and dry-aged product would benefit from the intensified, dry-aged beef flavors with less incidence of negative off-flavors.

Additionally, panelists ranked samples in this experiment for texture characteristics. As more dry-aged beef was added to the grind, panelist ratings increased for hardness and decreased for tenderness. This shows that dry-aged beef samples were harder and tougher than fresh samples, which is plausible based on the fabrication methods. In order to standardize the batch fabrication process, the lean portion of the dry-aged shoulder clods was cubed and ground without trimming the hard, external surface that occurs with standard dry-aging processes. The hard, external surfaces were incorporated into the grind and likely contributed to the increased rankings for hardness and toughness.

Furthermore, color results (not reported in tabular form) show higher L* values and lower a* values for dry-aged samples, indicating that dry-aged samples were lighter in color and less red. Fresh samples had highest a* values, meaning those samples were more red compared to other treatments.

Relationships between Fatty Acid Composition and Sensory Attributes

Results of statistical analysis for least squares means of fatty acid composition among treatments for Experiment 1 and 2 are presented in Tables 3.8, 3.10 and Figures 2, 4 and 5. Additionally, Pearson correlation coefficients between fatty acids and sensory characteristics for Experiments 1 and 2 are presented in Tables 3.9 and 3.11.

Experiment 1. Differences between muscle sources existed for every saturated fatty acid (SFA) analyzed, and many strong correlations exist between SFAs and sensory flavor attributes. Shoulder clods possessed the highest proportion of C12:0, C14:0, and C16:0, which were not strongly correlated to any flavor notes in this study. However, others have found these fatty acids

positively correlated with beefy/brothy flavors and higher in muscles with greater Type I muscle fibers (Alfaia, et al., 2007; Baublits, et al., 2009; Dryden & Marchello, 1970; Garmyn, et al., 2011; Sexten, et al., 2012). Knuckles had the highest proportion of C15:0 while tenderloins displayed the lowest proportion. In the current study, C15:0 was positively correlated with beefy/brothy, browned/grilled, and nutty/roasted nut while negatively correlated with sour/acidic. However, several studies have found C15:0 to be negatively correlated with beefy and buttery while positively correlated with bloody/metallic (Baublits, et al., 2009; Dryden & Marchello, 1970; O'Quinn, 2012). C17:0 was present in highest proportion in sirloin caps and lowest proportion in shoulder clods and tenderloins. In this study, C17:0 was positively correlated with beefy/brothy and inversely related to livery and bloody/metallic. Although, other studies have found the opposite; C17:0 was inversely related to beefy, browned, buttery flavors (Baublits, et al., 2009; Garmyn, et al., 2011; O'Quinn, 2012). The last SFA identified in this study was C18:0, stearic acid, which was unquestionably highest in tenderloins and lowest in shoulder clods and briskets. Stearic acid is typically positively associated with grassy, gamey, livery, sour/acidic, and fishy off-flavors and negatively associated with beefy, browned, buttery, desirable flavors (Dryden & Marchello, 1970; O'Quinn, 2012). Among studies that evaluated fatty acids across different muscles, tenderloins possessed the greatest amount of stearic acid along with other Type I muscles (Alfaia, et al., 2007; K. S. Rhee, Ziprin, Ordonez, & Bohac, 1988; Sexten, et al., 2012). Results from Experiment 1 agreed with all previous studies, in that stearic acid was strongly negatively correlated with beefy/brothy (r=-0.71), browned/grilled (r=-0.57) and buttery/beef fat, while being strongly positively correlated with sour/acidic (r=0.86) and gamey. The high levels of stearic acid in tenderloins can be explained in part by the fact that tenderloins

are a predominantly Type I muscle, coupled with the fact that tenderloins were wet aged for an extended period of time, building up sour/acidic flavors.

Differences between muscle sources also existed for many monounsaturated fatty acids (MUFA) analyzed. Recent literature generally agrees that MUFAs have a positive effect on beef flavor (Larick & Turner, 1990; O'Quinn, 2012). Additionally, O'Quinn (2012) found that MUFAs were positively correlated to lipid content. Shoulder clods and briskets possessed the highest percentages of C14:1, myristoleic acid, while knuckles and tenderloins were lowest. C14:1 was correlated with beefy/brothy, browned/grilled, and bloody/metallic, as well as inversely related to sour/acidic (r=-0.64). Shoulder clods, brisket, and sirloin caps all displayed the highest percent C16:1c9, palmitoleic acid, while short ribs and tenderloins were lowest. C16:1c9 was positively correlated with beefy/brothy, browned/grilled, and bloody/metallic as well as negatively correlated with sour/acidic. This agrees with previous studies, which have found a positive association between C16:1c9 and beefy/beef fat flavors (Baublits, et al., 2009; Dryden & Marchello, 1970; Garmyn, et al., 2011). Studies have also found that muscles with a high proportion of Type II muscle fibers have higher levels of C16:1c9, which agrees with this study in that tenderloins exhibited the lowest levels compared to the other muscle sources (Alfaia, et al., 2007; Sexten, et al., 2012). C17:1 was present in highest proportion in brisket and substantially lowest in tenderloins. C17:1 was highly correlated with beefy/brothy (r=0.74), browned/grilled (r=0.57), and significantly inversely related to sour/acidic (r=-0.73). However it is difficult to compare this result because little research exits evaluating C17:1.

Oleic acid, C18:1c9, accounts for about 1/3 of the total fatty acid content in beef, and is well-known as the MUFA with the most beneficial effect on beef flavor desirability (Dryden & Marchello, 1970; Garmyn, et al., 2011; Rule, Broughton, Shellito, & Maiorano, 2002; Westerling

& Hedrick, 1979). Treatments 1-5 all exhibited high proportions of oleic acid, with brisket highest, whereas tenderloins unquestionably showed the lowest proportion of oleic acid. In this study, oleic acid was correlated with beefy/brothy (r=0.61) and browned/grilled, as well as negatively correlated with sour/acidic (r=-0.71). This agrees with previous researchers who found oleic acid to be positively correlated with beefy/brothy, browned/grilled, and buttery/beef fat flavors (Dryden & Marchello, 1970; Garmyn, et al., 2011; O'Quinn, 2012).

Polyunsaturated fatty acids (PUFA) did not differ much between treatments with the exception of C18:2 total, linoleic acid. Sexten (2012) also found no differences between muscles in PUFAs. O'Quinn (2012) and Garmyn (2011) found linoleic acid to have a negative effect on beef flavor. However the results of this study show the opposite; linoleic acid was correlated with beefy/brothy and browned/grilled and negatively correlated to sour/acidic. C18:2 total was found in greatest concentration in samples of brisket and least concentrations in tenderloins and short ribs.

Overall, data in Table 3.9 suggests that positive beef flavor characteristics were associated with an increased percent of monounsaturated fatty acids, while negative off-flavors were associated with an increased percent of saturated fatty acids. MFA's, including C14:1, C16:1c9, C17:1, C18:1t (total), and C18:1c9, were generally positively related to beefy/brothy and browned/grilled flavors and negatively associated with off-flavors such as sour/acidic. Saturated fatty acids, particularly C18:0, were associated with negative off-flavors, including sour/acidic and gamey. Other lesser researched SFA's including C15:0 and C17:0 were associated with more positive beef flavors. Beef flavor attributes were not strongly associated positively or negatively with PUFA's, and few treatment differences existed. Across muscle source treatments, shoulder clods, brisket, and sirloin caps generally contained the highest

percentages of fatty acids associated with positive beef flavors, whereas tenderloins contained the highest percentages of fatty acids associated with negative off-flavors.

Experiment 2. Data in Tables 3.10 and 3.11 show numerous differences ($P<0.05$) in percentages of many fatty acids and the relationship of those fatty acids to sensory results. Experimental design of the three aging treatments allowed for an unique evaluation of fatty acids as increasing levels of dry-aged beef (0%, 50%, 100%) were added to the ground beef blend. Results for individual fatty acids show a stepwise increase or decrease as percentage of dry-aged beef in the blend increased, illustrated in Figures 4 and 5.

Amount of saturated fatty acids (SFA) generally decreased as dry-aged beef increased (C12:0, C14:0, C15:0, C16:0) with the exception of C18:0. Lauric acid (C12:0), Myristic acid (C14:0), pentadecanoic acid (C15:0), and palmitic acid (C16:0) all decrease ($P<0.05$) from fresh to dry-aged. These SFAs are all negatively correlated with browned/grilled, earthy/mushroom and nutty/roasted nut, indicating that the dry-aged samples had a lower proportion of these fatty acids but were ranked higher for the positive beef flavor attributes. Stearic acid (C18:0) was the only SFA which did not follow the trend of the other SFAs. Stearic acid increased from fresh to dry-aged and was positively correlated with browned/grilled, earthy/mushroom, nutty/roasted nut, sour/acidic, and bitter. This appears to be the opposite of published literature, which generally agrees that increasing C18:0 has a negative effect on beef flavor. However, most published literature which reports negative associations between C18:0 and beef flavor desirability were studies which included grass-fed beef samples. When looking at data tables from O'Quinn (2012) and comparing Premium Choice samples wet aged 14 days to Premium Choice samples wet aged 17 days followed by 30 days dry-age, the same trends were seen as in the current study.

Percentages of all monounsaturated fatty acids decreased from fresh to dry-aged with the exception of C18:1 trans fatty acid isomers. Myristoleic acid (C14:1), palmitoleic acid (C16:1), hepadecanoic acid (C17:1), and oleic acid (C18:1c9) all decrease from fresh to dry-aged. These MUFAs are inversely related to browned/grilled, earthy/mushroom, nutty/roasted nut, sour/acidic, and bitter flavor notes. Again, data from O'Quinn's research (2012) shows similar trends. It appears that incorporating dry-aged beef into grinds results in decreased proportions of MUFAs but increased positive ratings for flavor characteristics.

Polyunsaturated fatty acids did not differ between treatments, with the exception of C18:2 total. Linoleic acid (C18:2 total) decreased from fresh to 50/50 mix to dry-aged. This PUFA is negatively correlated with browned/grilled, earthy/mushroom, nutty/roasted nut, sour/acidic, and bitter flavors. This trend is also seen in O'Quinn's data for this PUFA (2012). Polyunsaturated fatty acids are the most unstable fatty acids and therefore oxidize more quickly than other fatty acids (Elmore, Mottram, Enser, & Wood, 1999; Mottram, 1998). It is likely that the PUFAs present in fresh shoulder clods oxidized during the dry-aging process.

Overall, reported results for fatty acid composition differences in aging treatments disagree with commonly cited literature (Baublits, et al., 2009; Dryden & Marchello, 1970; Garmyn, et al., 2011; Larick & Turner, 1990; Westerling & Hedrick, 1979). However, these results do generally match results seen in another study evaluating fatty acid composition in dry-aged beef samples (O'Quinn, 2012). Moreover, it is important to realize that the vast majority of published research looked at fatty acid composition in fresh beef from cattle finished on grass compared to cattle fed concentrate diets. Little research exists that reports fatty acid composition in dry-aged beef. It appears that dry-aged beef samples show opposite relationships than those generally seen between fatty acids and positive/negative beef flavor notes.

Relationships between Volatile Compounds and Sensory Attributes

Experiment 1. Forty different volatiles were isolated from the headspace of cooked ground beef patties. Previous research has identified these volatile compounds present in cooked beef and formed through either lipid oxidation or the Maillard reaction (Mottram, 1998; Fereidoon Shahidi, Rubin, D'Souza, Teranishi, & Buttery, 1986). Least squares mean concentrations of volatiles by treatment are presented in Table 3.12. Pearson correlation coefficients showing relationships between volatile concentrations and beef flavor attributes are summarized in Table 3.13. Of the 40 volatiles identified, the volatiles showing meaningful differences between treatments and relationships to sensory attributes were mainly aldehydes, ketones, alcohols, and sulfur-containing compounds.

Hexanal, methional, and 3-methyl butanal are all aldehydes which presented notable differences between muscle sources. Hexanal is a short-chain carbonyl that results from lipid oxidation. It has been shown to be correlated with positive or negative flavor notes, and there seems to be a threshold of acceptability before becoming abundant and offensive (Brewer, 2007; Maruri & Larick, 1992; Stetzer, Cadwallader, Singh, McKeith, & Brewer, 2008). In the current study, hexanal is abundant in PM tenderloins and associated with sour flavors. It is negatively correlated with beefy/brothy and earthy/mushroom flavors in this study. It appears that the concentration of hexanal in tenderloins exceeded the threshold of acceptability and was associated with negative off-flavors. Methional was present in highest concentration in chuck sourced trimmings and was positively correlated with buttery/beef fat and nutty/roasted nut flavors. Methional is a strecker aldehyde that has been shown to provide a meaty aroma. It is also one of the seven compounds unique to beef (Brewer, 2007). 3-Methyl butanal is also a strecker aldehyde that results from degradation of amino acids (Elmore, et al., 1999). It perhaps follows

the same trend as hexanal in that it is acceptable until a certain point where it becomes too concentrated and is associated with off-flavors. Previous research has 3-methyl butanal correlated with browned, buttery, nutty, and sweet flavors as well as present in coffee, hazelnuts, chocolate, bread crust, and cheddar cheese (Burdack-Freitag & Schieberle, 2012; Larick & Turner, 1990; O'Quinn, 2012; Whetstine, Drake, Broadbent, & McMahon, 2006; Zehentbauer & Grosch, 1998). The current data shows 3-methyl butanal to be at an unacceptable level in tenderloins, and is associated with sour off-flavors.

2-Propanone, 2-3-butanedione, and 3-hydroxy-2-butanone are three ketones which presented important differences between treatments 1-7. 2-Propanone, also referred to as acetone, was highest in sirloin caps and undoubtedly lowest in tenderloins. It seems to have a definite beneficial effect on beef aroma, as it was positively correlated with beefy/brothy and inversely related to sour/acidic. However a few other published studies show 2-propanone to be associated with negative flavor characteristics (Gorraiz, Beriain, Chasco, & Insausti, 2002; Larick & Turner, 1990). 2-3-Butanedione and 3-hydroxy-2-butanone develop during the Maillard reaction and have been known to impart buttery, beefy, positive flavors (Brewer, 2007; El-Magoli, Laroia, & Hansen, 1996; Hirai, Herz, Pokorny, & Chang, 1973; Peterson, Izzo, Jungermann, & Chang, 1975). One recent study at Colorado State University found these volatile compounds to be the two most highly correlated with overall flavor desirability (O'Quinn, 2012). Both of these compounds were found in highest abundance in sirloin caps in this data, which makes sense because sirloin caps ranked among the highest in beefy/brothy, browned/grilled flavors, and nutty/roasted nut flavor notes.

Sulfur-containing compounds, particularly dimethyl sulfide and dimethyl disulfide, were detected in differing concentrations between treatments ($P<0.05$). Sulfur-containing compounds

are often known as the most powerful aroma volatiles because they have such a low odor threshold (F. Shahidi, 1994). Low levels of these compounds can have a meaty aroma, but high levels have strong, objectionable aromas (Mottram, 1993, 1998; F. Shahidi, 1994). Sulfur-containing compounds are produced out of the Maillard reaction (Hogan, 2002; Mottram, 1993). The current data shows highest concentrations of dimethyl sulfide in knuckles and highest levels of dimethyl disulfide in knuckles and tenderloins. Dimethyl sulfide was strongly correlated with gamey off-flavors, while dimethyl disulfide was negatively related to buttery/beef fat flavors. Previous studies reported positive associations between dimethyl sulfide and off-flavors as well as negative correlations to flavor desirability, browned, buttery, nutty, and sweet flavors (Larick & Turner, 1990; O'Quinn, 2012).

1-Octen-3-ol, also referred to as octenol, showed notable differences across treatments. Sirloin cap samples possessed octenol in the highest concentrations. Octenol is formed during the oxidation of linoleic acid, and is commonly associated with roasted beef and mushroom flavor notes, while negatively related to gamey and other off-flavors (Brewer, 2007; Calkins & Hodgen, 2007; Maruri & Larick, 1992; Ventanas, Mustonen, Puolanne, & Tuorila, 2010).

Acetic acid and 1-hexanol were both strongly associated with negative off-flavors in this study. Acetic acid was unquestionably highest in tenderloin samples and highly correlated (r=0.91) to sour/acidic flavors, coupled with negative correlations to beefy/brothy (r=-0.73), browned/grilled (r=-0.52), and buttery/beef fat (r=-0.62). Acetic acid is a carboxylic acid that is found in organic acids and typically imparts a sour flavor (Brewer, 2007). 1-Hexanol was also very strongly correlated to sour/acidic (r=0.95) flavors and negatively correlated with beefy/brothy (r=-0.80), browned/grilled (r=-0.60), and buttery/beef fat (r=-0.62). 1-Hexanol is an alcohol that results from lipid oxidation (Brewer, 2007).

Experiment 2. Forty different volatiles were isolated from the headspace of cooked ground beef patties representing 3 different aging treatments. Least squares mean concentrations of volatiles by treatment are presented in Table 3.14. Pearson correlation coefficients showing relationships between volatile concentrations and beef flavor attributes are summarized in Table 3.15. Of the 40 volatiles identified, 12 showed significant differences between aging treatments, as illustrated in Figure 7. Principle component analysis (PCA) was performed using sensory panel flavor ratings for all three aging treatments. Aging treatments, flavor traits, and volatile compounds were correlated with PC1 (x-axis), PC2 (y-axis), and plotted together to determine relationships, as shown in Figure 8.

The majority of the volatiles identified with aging treatment differences were aldehydes and ketones, which are the most dominant products from the lipid oxidation portion of the cooking process (Elmore, et al., 1999). Aldehydes in particular have a low odor threshold, so a small concentration can have a large effect on aroma and flavor (Elmore, et al., 1999). Hexanal, pentanal, 3-methyl butanal, and 2-methyl butanal were the aldehydes identified with significant differences between aging treatments. Hexanal and pentanal are primarily the result of lipid oxidation; they are both short-chain carbonyls that are often related to off-flavors, as observed in multiple studies (Brewer, 2007; Maruri & Larick, 1992; Stetzer, et al., 2008). However, there seems to be a threshold of acceptability before they become too abundant, because O'Quinn et al. (2012) found them (specifically pentanal) to be correlated with buttery/beef fat and sweet flavors as well as overall desirability. In this study, hexanal and pentanal were positively correlated to beefy/brothy, browned/grilled, and earthy/mushroom, but also correlated to livery and bitter off-flavors, which supports the idea of a threshold of acceptability.

The other 2 aldehydes present in increased concentrations in dry-aged samples were 3-methyl butanal, and 2-methyl butanal. The present data shows these compounds associated with browned/grilled and earthy/mushroom flavors but also livery off-flavors. 3-methyl butanal, and 2-methyl butanal are strecker aldehydes that result from the degredation of amino acids (Elmore, et al., 1999). O'Quinn (2012) also found these a higher prevalence of these compounds in dry-aged beef, associated with browned, nutty, and sweet flavors. Studies of volatile compounds outside of beef have found these compounds present in chocolate, hazelnuts, French bread crust, cheddar cheese, and coffee (Burdack-Freitag & Schieberle, 2012; Whetstine, et al., 2006; Zehentbauer & Grosch, 1998).

The other dominant class of volatiles present in increased amounts in dry-aged samples were ketones, particularly 2-propanone, 2-heptanone, 2,3-butanedione, and 3-hydroxy-2-butanone. 2-Propanone was positively correlated to browned/grilled, earthy/mushroom, and nutty/roasted nut. This disagrees with previous studies, which found 2-propanone associated with sour and bloody/metallic (Larick & Turner, 1990; O'Quinn, 2012). 2-Heptanone was higher in dry-aged samples and associated with beefy/brothy, browned/grilled, earthy/mushroom, and nutty/roasted nut in conjunction with a negative correlation to bloody/metallic. Published research doesn't discuss this compound in great detail, but it is believed to derive from lipid oxidation. 3-hydroxy-2-butanone and 2,3-Butanedione were both present in significantly higher concentrations in dry-aged ground beef patties. 3-Hydroxy-2-butanone was positively correlated to browned/grilled, earthy/mushroom, and nutty/roasted nut flavors, while 2,3-Butanedione was positively correlated to earthy/mushroom as well as sour/acidic off-flavors. These two compounds, also referred to as acetoin and diacetyl, mainly develop from the Maillard reaction, but could also develop from the oxidation of lipids. They have been the compounds most

positively associated with overall flavor desirability, and often impart buttery, positive flavor notes (Brewer, 2007; El-Magoli, et al., 1996; Hirai, et al., 1973; O'Quinn, 2012; Peterson, et al., 1975). These two compounds are also often used in artificial butter flavorings (O'Quinn, 2012).

The other volatile compounds which showed significant differences between aging treatments included 1-hexanol, methional, and 2-pentylfuran. 1-Hexanol was positively associated with beefy/brothy, earthy/mushroom, and nutty/roasted nut flavors, but also bitter and sour/acidic off-flavors. This compound primarily results from lipid oxidation and may be linked back to linoleic acid (Elmore, et al., 1999). Methional is a strecker aldehyde that is a direct result of the degradation of the amino acid methionine. It is the first in a series of sulphur-containing compounds produced from methionine. It has been shown to produce a meaty aroma and is one of seven compounds specific to cooked beef (Brewer, 2007). It was detected in higher concentrations in fresh samples than dry-aged samples, which may be because a greater amount of methionine was intact in the fresh sample and available to produce methional. 2-Pentylfuran was correlated with beefy/brothy in this study and is generally recognized as a heterocyclic compound created through the Maillard reaction (Brewer, 2007; Elmore, et al., 1999).

Principle component analysis (PCA) was conducted using sensory panel ratings for beef flavor attributes. Principle Components 1 and 2 explained 68.3% and 31.7% of variances, respectively. PC1 and PC2 were then correlated with treatment scores, sensory attributes, and volatile compounds and plotted together, as shown in Figure 8, to show relationships. Samples comprised of 100% fresh beef were most closely related to metallic flavors and the volatiles methional and carbon disulfide. 50-50 mix samples were closely related to buttery flavors. Samples comprised of 100% dry aged beef were most closely related to browned/grilled, nutty/roasted nut, earthy/mushroom, livery, sour, and bitter flavors. Dry-aged beef samples were

also closely related to numerous volatiles, including the aldehydes and ketones previously discussed. The PCA plot serves as a visual representation of the relationships between treatments, sensory attributes, and volatile compounds.

Relationships between Volatile Compounds and Fatty Acid Composition

Experiments 1&2. Pearson correlation coefficients between volatile compounds and fatty acid composition are presented in Table 3.16. When all samples across all treatments in Experiment 1 and 2 were combined to look at relationships between volatile compounds and fatty acids, some notable associations existed. Multiple aldehydes, including 3-methyl butanal, 1-octene, hexanal, and 1-hexanol, were all negatively correlated with the monounsaturated fatty acids, in particular C14:1, C16:1c9, C17:1, and C18:1c9. At the same time, all four of these aldehydes were positively correlated with stearic acid (C18:0). A few ketones, in particular 2-propanone, and 2-heptanone, appear to be negatively associated with saturated fatty acids C14:0 and C16:0, while being positively correlated to C18:1t (total). The sulfur-containing compound dimethyl sulfide was positively related to C15:0, a relationship also seen in O'Quinn's data (2012). Furthermore, acetic acid, which was highly related to sour/acidic off-flavors, was positively correlated with C18:0 and negatively correlated with MUFAs C14:1, C16:1c9, C17:1, C18:1c9, and PUFA C18:2 total.

Conclusions

Experiment 1. No single trimming source evaluated in this study outperformed patties comprised of 81/19 chuck sourced trimmings. Notably, briskets and sirloin caps were ranked comparably to 81/19 trimmings in the desirable flavor attributes of beefy/brothy, browned/grilled, and buttery/beef fat, whereas tenderloin tips were rated lowest in the same desirable flavors. Tenderloins were rated lowest in beefy/brothy, browned/grilled, and

buttery/beef fat, as well as highest in sour/acidic off-flavors. Tenderloins were also the softest, least cohesive, and perceived to have the smallest particle size. Panelists did not detect many differences among other muscle source treatments. Monounsaturated fatty acids were generally positively associated with beefy/brothy and browned/grilled flavor attributes, while increased saturated fatty acids, in particular C18:0, were associated with incidence of off-flavors, including sour/acidic and gamey. 2-Propanone, 2-3-butanedione, 3-hydroxy-2-butanedione, and 1-octen-3-ol were most prevalent in sirloin caps and associated with beefy/brothy flavors. Hexanal,1-hexanol, and acetic acid were most prevalent in tenderloins, and associated with sour/acidic off-flavors.

Experiment 2. Dry-aged beef samples produced the most complex flavor profile with the highest panel ratings for earthy/mushroom and nutty/roasted nut flavors, and had high scores for browned/grilled flavor. However, panelists also detected some incidence of sour/acidic and bitter off-flavors in dry-aged ground beef samples. Relationships between sensory flavor characteristics and fatty acid composition show opposite results of commonly cited literature, in that beef flavor notes such as browned/grilled, nutty/roasted nut, and earthy/mushroom were associated with increased proportions of C18:0 and decreased proportions of monounsaturated fatty acids including C14:1, C16:1, C17:1, C18:1c9. Aldehydes, including hexanal, pentanal, 3-methyl-butanal, and 2-methyl-butanal were prevalent in dry-aged samples and associated with browned/grilled and earthy/mushroom flavors. Ketones such as 2-propanone, 2-heptanone, 3-hydroxy-2-butanedione, and 2,3-butanedione were present in increased concentrations in dry-aged samples and positively associated with browned/grilled, nutty/roasted nut, and earthy/mushroom flavors. This study demonstrates an increased flavor intensity of dry-aged beef and shows the fatty acid and volatile compounds associated with those flavors in dry-aged beef.

Table 3.1. Description of experimental treatments

Trt. #	Description[1]	Product Age (from box date)
Experiment 1		
1	Shoulder Clods	10
2	Short Ribs	10
3	Briskets	10
4	Top Sirloin Caps	10
5	Knuckles	10
6	Tenderloins	15
7	Trimmings (81/19)	6
Experiment 2		
8	100% Fresh Shoulder Clods	1
9	50% Fresh, 50% Dry Aged	--
10	100% Dry Aged Shoulder Clods	21wet/ 21dry

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

Table 3.2. Least squares means for percentage lipid, protein, moisture, and ash as determined by proximate analysis of raw samples representing 10 treatments

Treatment[1]	Lipid, %	Protein, %	Moisture, %	Ash, %
Experiment 1				
Shoulder Clods	14.20[bcd]	17.79 [bc]	65.74 [ab]	0.81
Short Ribs	17.12[ab]	17.06 [bc]	63.33 [bc]	0.72
Briskets	13.72[cd]	18.35 [ab]	65.20 [ab]	0.86
Top Sirloin Caps	19.18[a]	16.55 [c]	60.59 [c]	0.76
Knuckles	12.04[d]	19.39 [a]	66.99 [a]	0.88
Tenderloins	15.35[bc]	18.03 [abc]	64.67 [ab]	0.82
Trimmings (81/19)	19.52[a]	16.75[c]	60.75 [c]	0.74
SEM	0.73	0.33	0.70	0.04
P-value	<.0001	<.0001	<.0001	0.12
Experiment 2				
Fresh	13.38	18.45 [b]	66.07 [a]	0.91 [b]
50-50	14.13	19.50 [b]	63.79 [b]	0.95 [b]
Dry-Aged	13.68	21.15 [a]	62.26 [c]	1.07 [a]
SEM	0.25	0.37	0.03	0.03
P-value	0.1482	0.0008	<.0001	0.0129

[abcdefgh] Least squares means in the same column lacking a common superscript differ (P<0.05)

[1] Treatments: shoulder clods (beef chuck, shoulder clods; NAMP 114); short ribs (beef chuck, boneless short ribs; NAMP 130A); briskets (beef briskets; NAMP 120); sirloin caps (beef loin, top sirloin caps; NAMP 184D); knuckles (beef round, sirloin tip knuckles; NAMP 167); tenderloins (beef loin, tenderloin tips; NAMP 1190C); trimmings (chuck sourced trimmings 81% lean/19% fat); fresh (100% fresh); 50-50 (50% fresh, 50% dry-aged); dry-aged (100% dry-aged)

Table 3.3. Pearson correlation coefficients between sensory attributes and proximate composition of ground beef

Sensory Trait	Lipid, %	Protein, %	Moisture, %	Ash, %
Hardness	0.12	0.09	-0.26*	-0.02
Cohesiveness	0.01	0.05	0.00	0.05
Tenderness	0.11	-0.10	-0.07	-0.08
Connective Tissue	0.15	-0.07	-0.17	-0.06
Particle Size	0.15	-0.11	-0.19*	-0.14
Moisture Content	0.20*	-0.24*	-0.17	-0.14
Beef Fat/Oily Mouthfeel	0.33*	-0.31*	-0.34*	-0.18
Beefy/Brothy	0.29*	-0.11	-0.38*	-0.07
Browned/Grilled	0.25	0.14	-0.43*	0.12
Buttery/Beef Fat	0.66*	-0.48*	-0.62*	-0.29*
Bloody/Metallic	-0.28*	-0.09	0.40*	-0.10
Gamey	-0.36*	0.18	0.38*	0.12
Earthy/Mushroom	-0.26*	0.61*	-0.13	0.50*
Nutty/Roasted Nut	-0.08	0.60*	-0.34*	0.51*
Livery	-0.34*	0.19	0.34*	0.05
Sour/Acidic	-0.04	0.00	0.12	0.00
Bitter	-0.06	0.30*	-0.12	0.19

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

Table 3.4. Sensory panel ratings[1] for beef flavor attributes of ground beef samples representing 7 muscle source treatments

Treatment[2]	Beefy/ Brothy	Browned / Grilled	Buttery/ Beef Fat	Bloody/ Metallic	Gamey	Earthy/ Mushroom	Nutty/ Roasted Nut	Livery	Sour/ Acidic	Bitter
Shoulder clods	6.61^{c}	6.64^{b}	6.25^{ab}	0.21	0.09^{b}	0.42	0.26^{bc}	0.34^{ab}	0.14^{b}	0.10
Short ribs	6.72^{bc}	6.48^{b}	6.10^{b}	0.07	0.02^{b}	0.34	0.31^{b}	0.16^{abc}	0.19^{b}	0.21
Brisket	6.85^{ab}	6.65^{b}	6.12^{ab}	0.20	0.03^{b}	0.27	0.26^{bc}	0.01^{c}	0.29^{b}	0.09
Sirloin caps	7.02^{a}	7.03^{a}	6.18^{ab}	0.05	0.04^{b}	0.20	0.38^{ab}	0.00^{c}	0.15^{b}	0.17
Knuckles	6.69^{bc}	6.76^{ab}	6.00^{b}	0.21	0.19^{a}	0.30	0.31^{b}	0.36^{a}	0.16^{b}	0.20
Tenderloins	6.04^{d}	6.09^{c}	5.38^{c}	0.03	0.01^{b}	0.09	0.08^{c}	0.11^{bc}	3.29^{a}	0.51
81/19 Trim	6.80^{abc}	7.04^{a}	6.58^{a}	0.12	0.00^{b}	0.33	0.51^{a}	0.00^{c}	0.01^{b}	0.28
SEM	0.08	0.13	0.10	0.07	0.04	0.07	0.08	0.06	0.08	0.11
P-value	<0.0001	0.000	<0.0001	0.190	0.002	0.169	0.004	0.011	<0.0001	0.374

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

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

[abc] Least squares means in the same column lacking a common superscript differ (P<0.05)

Table 3.5. Sensory panel ratings[1] and objective measurements for beef texture of ground beef samples representing 7 muscle source treatments

Treatment[2]	Hardness	Cohesiveness	Tenderness	Connective Tissue	Particle Size	Moisture Content	Beef Fat/Oily Mouthfeel	Peak Load (kg)
Shoulder clods	4.58^{b}	5.75^{ab}	6.11^{bc}	0.47^{bcd}	4.96^{bc}	5.74^{bc}	6.24^{a}	15.99^{bc}
Short ribs	4.49^{b}	6.28^{a}	5.90^{bc}	0.45^{cd}	4.66^{cd}	5.74^{bc}	6.06^{a}	16.79^{bc}
Brisket	5.25^{a}	5.76^{ab}	4.90^{e}	0.61^{bc}	5.34^{b}	5.79^{bc}	6.16^{a}	13.11^{c}
Sirloin caps	4.43^{b}	5.75^{b}	6.30^{b}	0.37^{cd}	4.35^{d}	6.28^{a}	6.20^{a}	16.77^{bc}
Knuckles	5.48^{a}	5.46^{b}	5.27^{de}	0.77^{b}	4.94^{bcd}	5.27^{d}	5.97^{ab}	16.47^{bc}
Tenderloins	3.65^{c}	4.48^{c}	6.90^{a}	0.19^{d}	3.37^{e}	5.62^{c}	5.66^{b}	18.73^{b}
81/19 Trim	5.34^{a}	6.07^{ab}	5.75^{cd}	1.88^{a}	6.02^{a}	5.96^{ab}	6.45^{a}	25.37^{a}
SEM	0.21	0.17	0.15	0.09	0.18	0.14	0.11	1.26
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001

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

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

[abcde] Least squares means in the same column lacking a common superscript differ (P<0.05)

Table 3.6. Sensory panel ratings[1] for beef flavor attributes of ground beef samples representing 3 aging treatments

Treatment[2]	Beefy/ Brothy	Browned/ Grilled	Buttery/ Beef Fat	Bloody/ Metallic	Gamey	Earthy/ Mushroom	Nutty/ Roasted Nut	Livery	Sour/ Acidic	Bitter
Fresh	6.49	6.28^{a}	5.86^{ab}	0.09	0.04	0.23^{a}	0.17^{a}	0.03	0.05^{a}	0.07^{a}
50-50	6.75	6.72^{ab}	6.12^{a}	0.00	0.00	1.07^{b}	0.94^{b}	0.05	0.11^{a}	0.37^{ab}
Dry Aged	6.68	7.00^{b}	5.70^{b}	0.03	0.04	1.72^{c}	1.53^{c}	0.13	0.42^{b}	0.61^{b}
SEM	0.08	0.13	0.08	0.03	0.02	0.12	0.11	0.04	0.09	0.11
P-value	0.054	0.001	0.003	0.086	0.322	<0.0001	<0.0001	0.147	0.011	0.005

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

[2] Treatments: fresh (100% fresh); 50-50 (50% fresh, 50% dry-aged); dry-aged (100% dry-aged)

[abc] Least squares means in the same column lacking a common superscript differ (P<0.05)

Table 3.7. Sensory panel ratings[1] for beef texture attributes of ground beef samples representing 3 aging treatments

Treatment[2]	Hardness	Cohesiveness	Tenderness	Connective Tissue	Particle Size	Moisture Content	Beef Fat/ Oily Mouthfeel
Fresh	4.05[a]	5.80	6.41[a]	0.56	4.42	5.49	5.82[ab]
50-50	4.83[b]	5.93	6.10[ab]	1.00	4.87	5.53	6.03[a]
Dry Aged	5.62[c]	5.98	5.79[b]	0.55	4.80	5.29	5.64[b]
SEM	0.21	0.13	0.13	0.17	0.15	0.15	0.10
P-value	<0.0001	0.580	0.006	0.113	0.092	0.469	0.035

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

[2] Treatments: fresh (100% fresh); 50-50 (50% fresh, 50% dry-aged); dry-aged (100% dry-aged)

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

Table 3.8. Concentrations[1] of identified fatty acids in ground beef samples representing 7 muscle source treatments

	Treatment[2]								
Fatty Acid	Shoulder clods	Short ribs	Brisket	Sirloin caps	Knuckles	Tenderloin	Trimmings	SEM	P-value
C10:0	0.07	0.06	0.08	0.06	0.05	0.06	0.07	0.007	0.226
C12:0	0.11^{a}	0.08^{bc}	0.10^{ab}	0.08^{c}	0.09^{abc}	0.09^{abc}	0.09^{abc}	0.005	0.004
C12:1	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.003	0.277
C14:0	3.66^{a}	3.15^{e}	3.39^{bcd}	3.28^{de}	3.58^{ab}	3.34^{cde}	3.53^{abc}	0.053	<.0001
C14:1	1.09^{a}	0.55^{c}	0.98^{a}	0.74^{b}	0.76^{b}	0.35^{d}	0.66^{bc}	0.029	<.0001
C15:0	0.62^{bc}	0.61^{bc}	0.63^{bc}	0.64^{abc}	0.69^{a}	0.59^{c}	0.67^{ab}	0.013	0.000
C15:1	0.05	0.04	0.05	0.04	0.04	0.02	0.06	0.007	0.061
C16:0	26.88^{a}	25.36^{bc}	25.16^{c}	26.10^{abc}	26.06^{abc}	25.85^{abc}	26.48^{ab}	0.293	0.004
C16:1c9	4.05^{a}	2.75^{c}	3.86^{a}	3.08^{bc}	3.64^{a}	2.02^{d}	3.18^{b}	0.096	<.0001
C17:0	1.37^{d}	1.77^{ab}	1.65^{bc}	1.88^{a}	1.62^{bc}	1.54^{cd}	1.65^{bc}	0.046	<.0001
C17:1	0.92^{b}	0.87^{b}	1.16^{a}	1.01^{ab}	1.03^{ab}	0.52^{c}	0.85^{b}	0.042	<.0001
C18:0	13.17^{cd}	17.21^{b}	12.20^{d}	14.28^{c}	13.94^{c}	23.75^{a}	16.18^{b}	0.359	<.0001
C18:1 t (total)	1.99^{c}	3.56^{ab}	3.48^{ab}	4.01^{a}	2.94^{bc}	3.11^{ab}	3.53^{ab}	0.217	<.0001
C18:1c9	33.74^{a}	32.58^{ab}	35.03^{a}	32.82^{ab}	33.60^{a}	26.88^{c}	30.10^{b}	0.663	<.0001
C18:2 total	1.95^{b}	1.65^{c}	2.29^{a}	1.81^{bc}	1.98^{b}	1.31^{d}	1.72^{bc}	0.058	<.0001
C18:2t[3]	0.53	0.48	0.58	0.45	0.59	0.56	0.49	0.056	0.512
C18:3 gamma/delta	0.73^{ab}	0.74^{ab}	0.59^{ab}	0.57^{ab}	0.94^{a}	0.96^{a}	0.45^{b}	0.104	0.011
C18:3 n-3	0.16	0.22	0.11	0.19	0.11	0.20	0.18	0.043	0.469
C20:1c11	0.22^{ab}	0.20^{ab}	0.27^{a}	0.20^{ab}	0.19^{ab}	0.16^{b}	0.21^{ab}	0.019	0.031
C20:2	0.71	0.75	0.69	0.87	0.37	0.39	0.95	0.143	0.057

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

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

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

[abcde]Least squares means in the same row lacking a common superscript differ (P<0.05)

Table 3.9. Pearson correlation coefficients showing relationships between fatty acid concentrations and sensory flavor attributes for 7 muscle source treatments

	Flavor Attribute									
Fatty Acid	Beefy/ Brothy	Browned/ Grilled	Buttery/ Beef Fat	Bloody/ Metallic	Gamey	Earthy/ Mushroom	Nutty/ Roasted Nut	Livery	Sour/ Acidic	Bitter
C10:0	-0.09	-0.22	-0.07	-0.11	-0.28	0.06	-0.12	0.01	-0.05	-0.07
C12:0	-0.16	-0.22	-0.22	0.25	0.01	0.22	-0.19	0.32	-0.12	-0.19
C12:1	-0.01	-0.08	-0.12	-0.08	0.00	-0.02	0.02	0.27	-0.20	-0.21
C14:0	0.00	0.18	0.01	0.16	0.27	0.24	0.15	0.26	-0.18	-0.05
C14:1	0.45*	0.36*	0.24	0.45*	0.30	0.36*	0.13	0.23	-0.64*	-0.36*
C15:0	0.42*	0.43*	0.20	-0.03	0.34*	0.04	0.38*	0.02	-0.44*	-0.09
C15:1	0.24	0.08	0.41*	-0.06	-0.31	0.28	0.20	-0.12	-0.40*	-0.30
C16:0	-0.09	0.05	0.18	-0.05	-0.01	0.22	0.10	0.14	-0.09	-0.05
C16:1c9	0.51*	0.47*	0.28	0.55*	0.39*	0.36*	0.24	0.23	-0.71*	-0.34*
C17:0	0.48*	0.30	0.26	-0.42*	-0.09	-0.30	0.25	-0.51*	-0.21	0.09
C17:1	0.74*	0.57*	0.32	0.36*	0.35*	0.13	0.31	-0.09	-0.74*	-0.31
C18:0	-0.71*	-0.57*	-0.41*	-0.43*	-0.34*	-0.31	-0.34*	-0.09	0.86*	0.40*
C18:1 t (total)	0.40*	0.31	0.21	-0.39*	-0.21	-0.30	0.30	-0.45*	-0.07	0.13
C18:1c9	0.61*	0.42*	0.22	0.50*	0.41*	0.20	0.15	0.11	-0.71*	-0.36*
C18:2 total	0.57*	0.44*	0.20	0.48*	0.35*	0.21	0.16	0.06	-0.64*	-0.31
C18:2t[4]	-0.25	-0.18	-0.27	0.32	0.07	0.15	-0.05	0.30	0.13	-0.12
C18:3 gamma/delta	-0.33	-0.19	-0.45*	0.19	0.39*	-0.21	-0.34*	0.40*	0.35*	0.09
C18:3 n-3	-0.14	-0.19	0.01	-0.12	-0.24	0.27	-0.22	0.08	0.11	0.16
C20:1c11	0.36*	0.27	0.16	0.08	-0.05	0.07	0.19	-0.11	-0.34*	-0.18
C20:2	0.19	0.10	0.46*	-0.15	-0.38*	0.08	0.23	-0.29	-0.32	-0.09

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

Table 3.10. Concentrations[1] of identified fatty acids in ground beef samples representing 3 aging treatments

	Treatment[2]				
Fatty Acid	Fresh	50-50	Dry-Aged	SEM	P-value
C10:0	0.05	0.05	0.05	0.00	0.242
C12:0	0.08[a]	0.08[ab]	0.07[b]	0.00	0.034
C12:1	0.03	0.03	0.03	0.00	0.621
C14:0	3.44[a]	3.23[b]	3.04[c]	0.05	0.0003
C14:1	0.90[a]	0.83[a]	0.66[b]	0.03	0.0003
C15:0	0.65[a]	0.64[a]	0.59[b]	0.01	0.001
C15:1	0.01	0.02	0.01	0.01	0.624
C16:0	26.48[a]	25.13[b]	24.30[b]	0.25	0.0002
C16:1c9	3.75[a]	3.47[b]	2.82[c]	0.07	<.0001
C17:0	1.58	1.62	1.56	0.04	0.653
C17:1	1.08[a]	1.02[a]	0.83[b]	0.02	<.0001
C18:0	13.55[c]	14.63[b]	17.17[a]	0.16	<.0001
C18:1 t (total)	2.76[b]	4.11[a]	4.60[a]	0.30	0.003
C18:1c9	35.67[a]	34.29[ab]	33.70[b]	0.41	0.015
C18:2 total	2.07[a]	1.98[b]	1.71[c]	0.02	<.0001
C18:2t[3]	0.46	0.45	0.45	0.05	0.999
C18:3 gamma/delta	1.16[ab]	0.94[b]	1.25[a]	0.08	0.043
C18:3 n-3	0.30	0.35	0.37	0.04	0.538
C20:1c11	0.19	0.14	0.16	0.04	0.696
C20:2	0.41	0.45	0.29	0.06	0.190

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

[2] Treatments: fresh (100% fresh); 50-50 (50% fresh, 50% dry-aged); dry-aged (100% dry-aged)

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

[abc]Least squares means in the same row lacking a common superscript differ (P<0.05)

Table 3.11. Pearson correlation coefficients showing relationships between fatty acid concentrations and sensory flavor attributes for 3 aging treatments

	Flavor Attribute									
Fatty Acid	Beefy/ Brothy	Browned/ Grilled	Buttery/ Beef Fat	Bloody/ Metallic	Gamey	Earthy/ Mushroom	Nutty/ Roasted Nut	Livery	Sour/ Acidic	Bitter
C10:0	-0.57*	-0.62*	0.08	0.26	-0.46	-0.44	-0.39	-0.41	-0.38	-0.23
C12:0	0.04	-0.25	0.37	-0.14	-0.01	-0.64*	-0.53*	-0.22	-0.28	-0.30
C12:1	-0.10	0.12	-0.06	-0.47	-0.36	0.14	0.22	-0.06	-0.26	0.32
C14:0	-0.48	-0.68*	0.22	0.42	-0.25	-0.86*	-0.85*	-0.45	-0.45	-0.54*
C14:1	-0.38	-0.64*	0.44	0.30	-0.09	-0.85*	-0.80*	-0.47	-0.59*	-0.52*
C15:0	-0.15	-0.43	0.46	0.09	-0.20	-0.75*	-0.66*	-0.50	-0.46	-0.42
C15:1	0.29	-0.13	0.14	-0.26	-0.46	-0.03	0.00	0.16	-0.09	0.20
C16:0	-0.50	-0.71*	0.19	0.36	-0.16	-0.89*	-0.87*	-0.34	-0.51	-0.50
C16:1c9	-0.37	-0.66*	0.44	0.31	-0.05	-0.91*	-0.85*	-0.47	-0.61*	-0.59*
C17:0	0.32	0.22	0.00	-0.05	-0.16	0.04	0.05	-0.01	0.13	0.04
C17:1	-0.16	-0.45	0.41	0.21	0.01	-0.79*	-0.72*	-0.41	-0.54*	-0.53*
C18:0	0.35	0.66*	-0.44	-0.33	0.04	0.89*	0.87*	0.46	0.60*	0.64*
C18:1 t (total)	0.46	0.62*	-0.21	-0.20	-0.05	0.84*	0.75*	0.29	0.59*	0.46
C18:1c9	-0.41	-0.46	0.28	0.17	0.36	-0.70*	-0.62*	-0.25	-0.56*	-0.49
C18:2 total	-0.28	-0.55*	0.44	0.20	-0.02	-0.88*	-0.80*	-0.43	-0.67*	-0.57*
C18:2t[4]	-0.07	0.05	-0.16	-0.04	-0.20	0.16	0.07	-0.23	-0.10	-0.24
C18:3 gamma/delta	-0.27	0.19	-0.31	0.33	0.67*	0.16	0.16	-0.07	0.32	-0.13
C18:3 n-3	0.33	0.19	0.12	-0.37	-0.07	0.23	0.10	0.14	0.32	0.19
C20:1c11	-0.11	-0.38	-0.13	0.56*	0.36	-0.03	-0.25	-0.08	0.31	-0.60*
C20:2	-0.06	-0.40	0.15	-0.15	-0.59*	-0.32	-0.38	0.18	-0.45	0.00

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

Table 3.12. Concentrations of identified volatiles from cooked ground beef samples representing 7 muscle source treatments

Volatile (ng/g)	Treatment[1] Shoulder clods	Short ribs	Brisket	Sirloin caps	Knuckles	Tender-loin	Trimmings	SEM	P-value
Acetaldehyde	0.77^{ab}	0.43^{b}	0.68^{ab}	1.08^{a}	0.81^{ab}	0.52^{ab}	0.62^{ab}	0.13	0.047
Methanethiol	0.00^{ab}	0.00^{b}	0.00^{ab}	0.01^{a}	0.01^{ab}	0.01^{a}	0.00^{ab}	0.00	0.005
2-Propanone	12.19^{bc}	19.17^{ab}	13.53^{abc}	22.38^{a}	17.39^{abc}	8.02^{c}	10.40^{bc}	2.24	0.001
Dimethyl sulfide	0.69^{b}	0.44^{b}	0.86^{b}	0.79^{b}	2.03^{a}	0.31^{b}	0.34^{b}	0.18	<0.0001
Carbon disulfide	0.33	0.13	0.08	0.16	0.68	0.20	0.11	0.22	0.523
Isobutanal	0.06	0.05	0.07	0.09	0.10	0.05	0.06	0.01	0.044
2,3-Butanedione	0.46^{ab}	0.05^{c}	0.22^{bc}	0.61^{a}	0.42^{ab}	0.07^{c}	0.23^{bc}	0.07	<0.0001
2-Butanone	0.70	0.78	0.74	0.92	1.19	0.68	0.62	0.14	0.107
Acetic acid	3.72^{b}	3.83^{b}	2.19^{b}	5.18^{b}	4.27^{b}	21.93^{a}	2.99^{b}	1.30	<0.0001
3-Methyl butanal	1.04^{b}	0.65^{b}	1.04^{b}	1.86^{b}	2.06^{b}	6.20^{a}	0.92^{b}	0.64	<0.0001
2-Methyl butanal	0.57^{ab}	0.30^{b}	0.75^{ab}	1.34^{a}	1.30^{a}	0.78^{ab}	0.67^{ab}	0.21	0.018
Pentanal	0.23	0.18	0.25	0.26	0.20	0.28	0.23	0.03	0.495
3-Hydroxy-2-butanone	4.05^{b}	0.51^{c}	2.79^{bc}	7.37^{a}	4.33^{ab}	0.17^{c}	1.88^{bc}	0.72	<0.0001
Dimethyl disulfide	0.02^{ab}	0.01^{b}	0.03^{ab}	0.03^{ab}	0.05^{a}	0.04^{a}	0.02^{ab}	0.01	0.006
Butanoic acid	0.25^{b}	0.17^{b}	0.15^{b}	0.39^{ab}	0.74^{ab}	0.86^{a}	0.14^{b}	0.13	0.002
1-Octene	0.15^{ab}	0.11^{b}	0.11^{b}	0.12^{b}	0.11^{b}	0.25^{a}	0.09^{b}	0.03	0.002
Octane	0.49	0.30	0.72	0.33	0.27	0.52	0.43	0.16	0.467
Hexanal	0.58^{bc}	0.40^{c}	0.79^{bc}	0.97^{b}	0.55^{bc}	1.54^{a}	0.73^{bc}	0.12	<0.0001
Methyl pyrazine	0.06	0.04	0.07	0.09	0.08	0.04	0.07	0.01	0.110
1-Hexanol	0.04^{b}	0.04^{b}	0.04^{b}	0.04^{b}	0.05^{b}	0.24^{a}	0.03^{b}	0.01	<0.0001
2-Heptanone	0.02	0.02	0.02	0.03	0.02	0.03	0.02	0.00	0.023
Heptanal	0.11	0.06	0.16	0.08	0.06	0.12	0.10	0.03	0.332
Methional	0.02^{b}	0.03^{b}	0.02^{b}	0.03^{b}	0.02^{b}	0.02^{b}	0.04^{a}	0.00	<0.0001
2,5-dimethylpyrazine	0.09^{ab}	0.06^{ab}	0.10^{ab}	0.13^{a}	0.12^{ab}	0.05^{b}	0.09^{ab}	0.02	0.013
Hexanoic acid	0.09	0.06	0.12	0.11	0.08	0.16	0.07	0.03	0.128
1-Heptanol	0.04	0.03	0.05	0.04	0.04	0.06	0.03	0.01	0.132
Benzaldehyde	0.08	0.04	0.07	0.06	0.09	0.09	0.05	0.01	0.124
1-Octen-3-ol	0.03^{bc}	0.03^{c}	0.04^{abc}	0.06^{a}	0.03^{bc}	0.05^{ab}	0.03^{bc}	0.00	0.001
2-Pentylfuran	0.00^{ab}	0.00^{b}	0.01^{a}	0.00^{ab}	0.00^{ab}	0.01^{ab}	0.00^{ab}	0.00	0.036
Octanal	0.08	0.04	0.15	0.05	0.04	0.10	0.07	0.04	0.452
Trimethylpyrazine	0.03	0.02	0.03	0.04	0.04	0.01	0.04	0.01	0.047

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

[abcd] Least squares means in the same row lacking a common superscript differ (P<0.05)

Table 3.13. Pearson correlation coefficients representing 7 muscle sources showing relationships between beef sensory attributes and concentrations of volatile compounds

	Beefy/ Brothy	Browned / Grilled	Buttery/ Beef Fat	Gamey	Earthy/ Mushroom	Nutty/ Roasted Nut	Livery	Sour/ Acidic	Bitter
Acetaldehyde	0.32	0.13	0.03	0.14	0.08	0.24	0.00	-0.21	-0.17
Methanethiol	-0.26	-0.22	-0.40*	-0.03	-0.26	-0.13	0.02	0.51*	-0.04
2-Propanone	0.40*	0.16	0.08	0.16	0.10	0.23	-0.11	-0.41*	-0.21
Dimethyl sulfide	0.15	0.09	-0.27	0.66*	0.13	0.00	0.24	-0.28	-0.11
Carbon disulfide	-0.09	-0.08	-0.14	-0.04	0.13	-0.10	0.24	-0.06	-0.12
Isobutanal	0.13	0.07	-0.17	0.32	0.11	0.06	0.02	-0.20	-0.16
2,3-Butanedione	0.37*	0.34*	0.07	0.35*	0.06	0.22	0.13	-0.39*	-0.20
2-Butanone	0.13	-0.09	-0.24	0.28	0.11	0.06	0.15	-0.12	-0.22
Acetic acid	-0.73*	-0.52*	-0.62*	-0.21	-0.31	-0.43*	0.06	0.91*	0.37*
3-Methyl butanal	-0.60*	-0.38*	-0.56*	-0.06	-0.26	-0.39*	-0.02	0.74*	0.40*
2-Methyl butanal	0.04	0.09	-0.24	0.35*	0.05	-0.04	-0.01	-0.02	-0.02
Pentanal	-0.21	-0.10	-0.14	-0.28	-0.15	0.06	-0.17	0.29	-0.04
3-Hydroxy-2-butanone	0.44*	0.35*	0.09	0.24	0.06	0.18	0.06	-0.44*	-0.27
Dimethyl disulfide	-0.39*	-0.27	-0.53*	0.23	-0.20	-0.22	0.17	0.39*	-0.14
Butanoic acid	-0.45*	-0.27	-0.60*	0.31	-0.05	-0.23	0.22	0.51*	0.24
1-Octene	-0.54*	-0.38*	-0.56*	-0.19	-0.27	-0.38*	0.07	0.69*	0.17
Octane	0.00	-0.01	-0.03	-0.05	0.01	-0.07	-0.20	0.16	-0.10
Hexanal	-0.47*	-0.27	-0.31	-0.26	-0.42*	-0.22	-0.27	0.71*	0.39*
Methyl pyrazine	0.26	0.23	0.03	0.18	0.14	0.19	0.02	-0.27	-0.23
1-Hexanol	-0.80*	-0.60*	-0.62*	-0.19	-0.37*	-0.48*	0.02	0.95*	0.25
Methional	0.30	0.45*	0.57*	-0.15	0.06	0.65*	-0.25	-0.20	0.24
2,5-dimethylpyrazine	0.39*	0.33	0.05	0.31	0.18	0.16	0.09	-0.37*	-0.14
Hexanoic acid	-0.27	-0.15	-0.26	-0.16	-0.08	-0.19	0.02	0.46*	0.14
1-Heptanol	-0.30	-0.22	-0.34*	-0.09	0.00	-0.24	0.16	0.45*	0.15
1-Octen-3-ol	-0.04	-0.01	-0.08	-0.13	-0.32	0.11	-0.35*	0.36*	0.19
2-Pentylfuran	-0.02	-0.01	0.01	-0.07	-0.05	-0.15	-0.12	0.21	0.04
Trimethylpyrazine	0.42*	0.37*	0.13	0.31	0.25	0.19	0.12	-0.36*	-0.07
3-Ethyl-2,5-dimethylpyrazine	0.39*	0.32	0.08	0.28	0.30	0.10	0.24	-0.33	-0.07
2-Ethyl-3,5-dimethylpyrazine	0.38*	0.35*	0.11	0.33*	0.17	0.04	0.05	-0.23	0.03

* Correlation coefficient differs from 0 (P<0.05)

Table 3.14. Concentrations of identified volatiles from cooked ground beef samples representing 3 aging treatments

	Treatment[1]				
Volatile (ng/g)	Fresh	50-50	Dry-Aged	SEM	P-value
Acetaldehyde	0.59	0.65	0.46	0.08	0.289
Methanethiol	0.00	0.01	0.01	0.00	0.080
2-Propanone	14.15[a]	16.29[a]	32.01[b]	3.40	0.006
Dimethyl sulfide	0.74	0.61	0.82	0.11	0.400
Carbon disulfide	0.15	0.10	0.11	0.03	0.481
Isobutanal	0.05	0.08	0.18	0.03	0.051
2,3-Butanedione	0.40[a]	0.54[ab]	0.91[b]	0.13	0.046
2-Butanone	0.82	1.71	1.77	0.28	0.057
Acetic acid	2.75	3.61	3.01	0.54	0.532
3-Methyl butanal	0.74[a]	1.57[ab]	3.47[b]	0.59	0.020
2-Methyl butanal	0.47[a]	1.15[ab]	2.95[b]	0.59	0.031
Pentanal	0.16[a]	0.28[ab]	0.33[b]	0.04	0.050
3-Hydroxy-2-butanone	5.26[a]	7.45[a]	10.76[b]	0.74	0.001
Dimethyl disulfide	0.02	0.03	0.07	0.01	0.074
Butanoic acid	0.22	0.29	0.22	0.05	0.473
1-Octene	0.05	0.08	0.09	0.02	0.212
Octane	0.22[a]	0.43[b]	0.40[b]	0.04	0.004
Hexanal	0.56[a]	0.97[ab]	1.37[b]	0.16	0.012
Methyl pyrazine	0.08	0.10	0.14	0.02	0.181
1-Hexanol	0.04[a]	0.07[b]	0.10[b]	0.01	0.0001
2-Heptanone	0.02[a]	0.04[ab]	0.05[b]	0.01	0.011
Heptanal	0.06	0.11	0.11	0.02	0.069
Methional	0.03[a]	0.02[ab]	0.02[b]	0.00	0.024
2,5-dimethylpyrazine	0.13	0.14	0.18	0.03	0.446
Hexanoic acid	0.07	0.11	0.09	0.01	0.164
1-Heptanol	0.04	0.05	0.04	0.00	0.195
Benzaldehyde	0.07	0.10	0.08	0.01	0.266
1-Octen-3-ol	0.03	0.05	0.04	0.00	0.088
2-Pentylfuran	0.00[a]	0.01[b]	0.01[b]	0.00	0.001
Octanal	0.05	0.08	0.06	0.01	0.213
Trimethylpyrazine	0.04	0.05	0.06	0.01	0.488
Phenylacetaldehyde	0.00	0.01	0.00	0.00	0.224
Heptanoic acid	0.05	0.06	0.05	0.00	0.193
3-Ethyl-2,5-dimethylpyrazine	0.02	0.03	0.03	0.00	0.757
2-Ethyl-3,5-dimethylpyrazine	0.05	0.05	0.05	0.01	0.793
Nonanal	0.27	0.56	0.23	0.14	0.239
Octanoic acid	0.05	0.06	0.05	0.00	0.520
Decanal	0.02	0.04	0.01	0.01	0.212
Nonanoic acid	0.10	0.18	0.09	0.03	0.100
Decanoic acid	0.09	0.10	0.09	0.01	0.091

[1] Treatments: fresh (100% fresh); 50-50 (50% fresh, 50% dry-aged); dry-aged (100% dry-aged)

[abc] Least squares means in the same row lacking a common superscript differ (P<0.05)

Table 3.15. Pearson correlation coefficients representing 3 aging treatments showing relationships between beef sensory attributes and concentrations of volatile compounds

	Beefy/ Brothy	Browned / Grilled	Buttery/ Beef Fat	Bloody/ Metallic	Gamey	Earthy/ Mushroom	Nutty/ Roasted Nut	Livery	Sour/ Acidic	Bitter
Acetaldehyde	0.33	-0.35	0.21	-0.25	0.04	-0.22	-0.10	0.18	-0.30	-0.05
Methanethiol	0.19	0.47	-0.21	0.34	-0.10	0.60*	0.13	0.28	0.43	0.55*
2-Propanone	0.26	0.38	-0.34	0.68*	-0.50	0.63*	0.35	0.42	0.64*	0.43
Dimethyl sulfide	0.21	0.00	-0.08	0.36	-0.61*	0.11	0.26	0.33	0.12	0.16
Carbon disulfide	-0.01	-0.14	-0.25	-0.13	0.09	-0.33	-0.02	0.00	-0.31	-0.12
Isobutanal	0.41	0.44	-0.36	0.61*	-0.36	0.55*	0.58*	0.65*	0.48	0.46
2,3-Butanedione	0.35	0.35	0.02	0.22	-0.15	0.59*	0.09	0.27	0.38	0.84*
2-Butanone	0.48	0.34	-0.49	0.49	-0.09	0.59*	0.25	0.47	0.53*	0.23
Acetic acid	0.40	-0.21	0.09	-0.20	0.17	0.17	-0.17	-0.11	0.08	0.24
3-Methyl butanal	0.41	0.52*	-0.41	0.63*	-0.34	0.63*	0.52*	0.65*	0.56*	0.49
2-Methyl butanal	0.43	0.51	-0.39	0.63*	-0.33	0.57*	0.56*	0.67*	0.52*	0.47
Pentanal	0.67*	0.55*	-0.52*	0.57*	-0.18	0.54*	0.28	0.62*	0.49	0.49
3-Hydroxy-2-butanone	0.36	0.61*	-0.42	0.62*	-0.37	0.87*	0.17	0.53*	0.72*	0.60*
Dimethyl disulfide	0.30	0.43	-0.30	0.54*	-0.30	0.53*	0.57*	0.57*	0.40	0.56*
Butanoic acid	0.35	-0.48	0.21	-0.41	0.43	0.05	-0.14	-0.31	-0.14	0.29
1-Octene	0.29	-0.15	0.01	-0.06	0.14	0.55*	-0.16	0.00	0.27	0.55*
Octane	0.74*	0.62*	-0.76*	0.59*	0.21	0.51	0.10	0.55*	0.56*	0.17
Hexanal	0.57*	0.63*	-0.47	0.61*	-0.26	0.61*	0.27	0.65*	0.60*	0.54*
Methyl pyrazine	0.53*	0.39	-0.34	0.46	-0.16	0.41	0.53*	0.62*	0.27	0.58*
1-Hexanol	0.63*	0.66*	-0.47	0.61*	-0.08	0.79*	0.14	0.56*	0.71*	0.65*
2-Heptanone	0.60*	0.62*	-0.56*	0.65*	-0.06	0.66*	0.32	0.62*	0.60*	0.45
Heptanal	0.40	0.73*	-0.58*	0.33	0.22	0.36	-0.29	0.38	0.45	0.03
Methional	-0.57*	-0.45	0.56*	-0.58*	0.18	-0.59*	-0.16	-0.56*	-0.63*	-0.29
2,5-dimethylpyrazine	0.41	0.32	-0.28	0.28	-0.04	0.26	0.51	0.50	0.10	0.52*
Hexanoic acid	0.23	-0.05	0.06	-0.26	0.51*	0.22	-0.52*	-0.36	0.12	0.29
1-Heptanol	0.27	0.45	-0.18	0.06	0.36	0.34	-0.42	0.00	0.32	0.25
Benzaldehyde	0.00	0.09	-0.17	-0.04	0.52*	0.11	-0.13	-0.14	-0.01	-0.04
2-Pentylfuran	0.60*	0.42	-0.52*	0.40	0.36	0.44	-0.24	0.21	0.44	0.22
Octanal	0.14	0.39	-0.39	0.00	0.56*	-0.03	-0.43	-0.02	0.07	-0.17
Phenylacetaldehyde	0.32	0.09	-0.11	0.00	0.67*	-0.08	-0.31	-0.17	-0.07	0.12
Heptanoic acid	0.16	0.30	-0.12	-0.11	0.52*	0.02	-0.45	-0.05	0.00	-0.13
3-Ethyl-2,5-dimethylpyrazine	0.28	0.30	-0.30	0.28	0.13	0.22	0.59*	0.33	0.10	0.31
Nonanal	-0.05	0.14	-0.29	-0.03	0.58*	-0.13	-0.26	-0.23	0.00	-0.28

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

Table 3.16. Pearson correlation coefficients showing relationships between fatty acids and volatile compounds

	C10:0	C12:0	C12:1	C14:0	C14:1	C15:0	C16:0	C16:1 c9	C17:1	C18:0	C18:1 t(total)	C18:1 c9	C18:2 total	C18:2t[4]	C18:3 gamma/ delta	C18:3 n-3	C20:2
Acetaldehyde	-0.12	0.02	-0.02	0.20	0.21	0.30*	0.09	0.21	0.30*	-0.28*	0.08	0.08	0.21	0.13	-0.30*	-0.24	0.01
Methanethiol	-0.21	-0.21	-0.03	-0.11	-0.24	-0.03	-0.16	-0.27	-0.18	0.28	0.21	-0.25	-0.23	0.15	-0.14	0.12	-0.24
2-Propanone	-0.27	-0.34*	-0.13	-0.43*	-0.05	-0.07	-0.38*	-0.09	0.11	-0.10	0.43*	0.26	0.00	-0.08	0.27	0.24	-0.14
Dimethyl sulfide	-0.12	0.21	0.12	0.27	0.23	0.41*	0.02	0.30*	0.32*	-0.35*	-0.10	0.28	0.32*	0.26	-0.10	0.08	-0.19
Carbon disulfide	-0.20	0.07	-0.11	0.11	0.02	0.00	0.05	0.06	-0.01	-0.05	-0.22	0.01	0.02	0.45*	-0.12	0.03	-0.04
Isobutanal	-0.22	-0.15	-0.07	-0.31*	-0.04	-0.08	-0.38*	-0.06	0.01	-0.03	0.35*	0.14	-0.01	0.03	0.18	0.26	-0.21
2,3-Butanedione	-0.26	-0.22	-0.02	-0.14	0.23	0.15	-0.18	0.14	0.20	-0.24	0.35*	0.29*	0.13	-0.24	0.30*	0.24	-0.22
2-Butanone	-0.38*	-0.32*	-0.01	-0.40*	-0.02	-0.04	-0.43*	-0.03	0.07	-0.04	0.39*	0.22	0.03	-0.07	0.23	0.35*	-0.28*
Acetic acid	0.05	-0.03	-0.06	-0.04	-0.59*	-0.29*	0.02	-0.62*	-0.67*	0.77*	-0.05	-0.69*	-0.62*	0.19	-0.06	0.11	-0.20
3-Methyl butanal	-0.11	-0.03	-0.05	-0.18	-0.51*	-0.33*	-0.17	-0.56*	-0.58*	0.64*	0.09	-0.49*	-0.54*	0.23	0.01	0.27	-0.30*
2-Methyl butanal	-0.25	-0.19	-0.10	-0.35*	-0.09	-0.14	-0.39*	-0.13	-0.07	0.05	0.37*	0.09	-0.08	-0.04	0.26	0.31*	-0.24
Pentanal	-0.17	-0.11	-0.06	-0.15	-0.13	-0.14	-0.23	-0.20	-0.15	0.18	0.29*	-0.17	-0.14	0.00	0.16	-0.03	-0.06
3-Hydroxy-2-butanone	-0.25	-0.29*	-0.07	-0.33*	0.27	0.01	-0.29*	0.18	0.26	-0.30*	0.39*	0.44*	0.22	-0.22	0.44*	0.33*	-0.25
Dimethyl disulfide	-0.28*	-0.11	-0.03	-0.23	-0.21	-0.11	-0.32*	-0.21	-0.17	0.20	0.24	-0.06	-0.17	0.15	0.06	0.36*	-0.34*
Butanoic acid	0.01	0.11	0.10	0.14	-0.32*	0.04	0.11	-0.29*	-0.38*	0.39*	-0.12	-0.39*	-0.34*	0.25	-0.05	0.13	-0.21
1-Octene	0.04	0.12	0.02	0.12	-0.32*	-0.26	0.03	-0.38*	-0.46*	0.49*	-0.11	-0.50*	-0.39*	0.22	-0.12	-0.04	-0.08
Hexanal	-0.19	-0.29*	-0.22	-0.31*	-0.42*	-0.35*	-0.26	-0.51*	-0.44*	0.54*	0.32*	-0.40*	-0.41*	-0.12	0.18	0.14	-0.15
Methyl pyrazine	-0.14	-0.11	0.01	-0.24	0.07	0.11	-0.22	0.04	0.14	-0.15	0.33*	0.22	0.09	-0.11	0.33*	0.17	-0.12
1-Hexanol	-0.09	-0.11	-0.12	-0.21	-0.62*	-0.39*	-0.14	-0.69*	-0.71*	0.82*	0.07	-0.64*	-0.64*	0.14	0.06	0.24	-0.30*
2-Heptanone	-0.26	-0.36*	-0.15	-0.47*	-0.10	-0.19	-0.45*	-0.18	-0.07	0.12	0.52*	0.04	-0.08	-0.24	0.31*	0.30*	-0.28
2,5-dimethylpyrazine	-0.14	-0.10	0.03	-0.17	0.22	0.23	-0.16	0.19	0.29*	-0.30*	0.25	0.37*	0.24	-0.15	0.32*	0.21	-0.17
Hexanoic acid	0.04	-0.07	-0.15	0.00	-0.08	-0.11	-0.08	-0.17	-0.16	0.23	0.12	-0.29*	-0.07	0.03	0.03	-0.03	-0.11
1-Octen-3-ol	-0.11	-0.39*	-0.32*	-0.25	-0.17	-0.20	-0.09	-0.26	-0.10	0.20	0.31*	-0.17	-0.16	-0.28*	0.08	-0.10	0.06
2-Pentylfuran	-0.09	-0.20	-0.19	-0.23	0.11	-0.23	-0.28	0.03	0.03	0.01	0.31*	0.04	0.13	-0.28*	0.24	0.10	-0.11
Trimethylpyrazine	-0.18	-0.13	0.01	-0.11	0.25	0.24	-0.12	0.23	0.28*	-0.31*	0.25	0.35*	0.25	-0.24	0.30*	0.22	-0.18
3-Ethyl-2,5-dimethylpyrazine	-0.18	-0.09	0.06	-0.10	0.26	0.22	-0.13	0.23	0.25	-0.29*	0.19	0.33*	0.23	-0.19	0.33*	0.25	-0.19
2-Ethyl-3,5-dimethylpyrazine	-0.18	-0.14	-0.01	0.01	0.34*	0.26	-0.05	0.32*	0.36*	-0.34*	0.17	0.35*	0.35*	-0.32*	0.14	0.18	-0.20

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

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CHAPTER IV

THE EFFECTS OF GRIND PLATE SIZE, BLEND TIME, PATTY-FORMING EQUIPMENT, AND PACKAGING TYPE ON GROUND BEEF TEXTURE

INTRODUCTION

The recent high value of beef trimmings has motivated major beef packers to merchandise a larger proportion of the carcass as beef trimmings for grinding operations. Additionally, the success of premium hamburger chains has increased demand for specialty blends. Although numerous restaurant chains are marketing gourmet burgers, their ground beef blends and formulations remain proprietary. Very little published research exists to support the use of specific ground beef trimmings sources and marketing claims.

Beef industry experts agree that ground beef performance is highly complex and not much research has been dedicated to it in recent years. Overall ground beef performance includes beef flavor and texture. Ground beef texture can be affected by grinder plate size, patty-forming technique, mixing time, muscle type, fat percentage, and chub packaging verses fresh grinds.

Flavor and texture of individual muscles has been documented by Gruber et al. (2006) and Seggern et al. (2005), among others, but little published research exists documenting flavor and texture differences of individual muscles in ground form.

A better understanding of the factors influencing the performance of ground beef products as well as the development of industry standards that could be utilized to develop premium ground beef specifications for flavor and texture could greatly contribute the demand for ground beef products and the profitability of the beef industry. This research will assist in determining the validity of various production and premium ground beef marketing claims. The

objectives of the current study are to evaluate the texture effects of grinder plate size, blend time, patty-forming technique, and chub packaging verses fresh grinds.

MATERIALS AND METHODS

Two independent experiments were conducted to address the objectives of the study. Experiment 1, as outlined in Table 4.1, was a factorial comparison of two grind plate sizes, three mixing times, and two patty-forming devices. Experiment 2, as outlined in Table 4.1, was a comparison designed to imitate common retail practices, which could include either fresh, ground bench trimmings, or previously-ground, chub-packaged ground beef which was re-ground.

Experimental Treatments and Sample Preparation

Experiment 1. In order to quantify textural differences between ground beef patties and develop standards for ground beef texture, a factorial design was created to evaluate grind plate diameter, blend/mix time, and patty-forming device. Two common grinder plate sizes, 3.175mm and 1.588mm, were evaluated, as well as 2 patty-forming devices. A Formax machine (Formax F6, equipped with the 2874-6 plate, Mokena, IL) and a vacuum stuffer (Model VF50, Handtmann, Germany) equipped with a portioning device were used to create patties. Both of these patty-forming techniques are commonly used in commercial ground beef operations. Additionally, 3 blend times were used to evaluate the texture of product.

To serve as the trimming source for these treatments, chuck sourced trimmings (81% lean, 19% fat) were obtained from a commercial processing facility in Northern Colorado and ground within 5 days of box date. All product was transported, under refrigeration (2°C), to a research and development pilot plant in Northern Colorado. Trimmings were randomly allocated to 5 batches (replicates; 13.6kg each) within Treatments 1-12, as outlined in Table 4.1. All pieces were cut into cubes of a standard size equal to or smaller than 12.903 square centimeters before grinding.

Each batch of each treatment was then ground using a meat grinder (Biro, Model 7552 L04, Marblehead, OH) equipped with a coarse grinding plate (1.27cm). After grinding, each batch was mixed for 1.5- 4.5 minutes, as specified in Table 4.1 for each treatment in a double action mixer (Blentech, Model DM-10028-PVS, Rohnert Park, CA). During the first 1.5 minutes of mixing, CO_2 was continuously added to the mixer. This was done to simulate CO_2 chilling processes that are commonly used in commercial grinding operations. Following mixing, batches were ground a second time using the same grinder equipped with a fine grinding plate (3.175mm or 1.588mm as specified for each treatment in Table 4.1). Each batch was then formed into patties weighing 151 grams using either a Formax (Formax F6, equipped with the 2874-6 plate, Mokena, IL) or a vacuum stuffer (Model VF50, Handtmann, Germany) equipped with a portioning. Each piece of equipment was rinsed in between treatments, with the exception of the patty-forming devices which were cleared in between batches. Patties from each batch were separated and held in a CO_2 blast freezer (Martin-Baron Inc., MBI 1-18-0002-19, Irwindale, CA) for no longer than 5 hours. Patties from each batch were randomly sorted, vacuum packaged, and placed in frozen storage (-20°C) for further analysis.

Experiment 2. In order to evaluate performance and texture differences between freshly ground bench trimmings and previously ground and chub packaged ground beef, beef chuck, shoulder clods (NAMP 114) were purchased from commercial processing facilities in Northern Colorado and ground within 1 day of box date. These sub-primals, representing treatment 13 as outlined in Table 4.1, were ground and processed according to the process stated above, including a coarse grind (1.27cm), mix (3 minutes), fine grind (3.175mm), and patty-forming (Formax F6, equipped with the 2874-6 plate, Mokena, IL). To mimic common retail practices, 4.54 kg (10 lb.) chubs of 81/19 finely ground (3.175mm) beef were purchased from a

commercial grinding facility in Northern Colorado. Representing treatment 14 as described in Table 4.1, three chubs randomly allocated to each batch were processed the same as T13, with the exception of the initial coarse grind. The previously ground chubs were placed straight in the mixer, skipping the coarse grind step, but otherwise followed the same procedures, including patty-forming.

Objective Color Analysis

Experiment 2. Following patty-forming but before blast freezing, objective color measurements were attained from patties (n=9) from each batch within each treatment. Patties measured were randomly selected to represent the beginning, middle and end of each batch. Measurements were taken using a portable spectrophotometer equipped with a 6 mm measurement port (Miniscan Model 4500S, Hunter Laboratories, Reston, VA). Final color values for each sample were reported as the mean of 3 individual L*, a*, and b* readings.

Descriptive Sensory Analysis

Experiment 1&2. Sensory analysis was conducted at Colorado State University. Prior to evaluating samples included in the finding of this study, panelists were introduced to standard beef flavor characteristics using the lexicon developed by Adhikari, et al. (2011) and trained to objectively quantify the presence/absence of each flavor using an unstructured 10 cm line scale.

Samples designated for sensory analysis were randomly assigned to sensory sessions so that all treatments were represented in each session. For Experiment 1, two sessions were served each day with 12 samples per session, so that 1 full replicates representing all 12 treatments was served each day. For Experiment 2, one panel was served each day with 10 samples per session, so that 5 full replicates representing the 2 treatments was served each day. Samples were thawed for 12-24 hours at 2°C before each sensory session. For Experiment 1, patties from Treatments

7-12 were pressed using a patty press to standardize patty thickness with samples from Treatments 1-6. All samples were cooked on griddle pans with non-stick coating (Cephalon Contemporary Non-Stick 11" Square Griddle, sold at Bed Bath and Beyond) over open gas burners (Southbend 4602DD-2TR, Fuquay-Varina, NC). Pans were heated for 20 minutes prior to cooking samples. During cooking, samples were turned once, halfway through, and cooked to an internal temperature of 71°C monitored by a Type K Thermocouple Thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation, Middlefield, CT). Following cooking, patties were cut into 8 wedge-shaped, equal-sized portions and held in a warming oven before being served to the panelists.

During sessions, panelists were seated in individual cubicles in a dark room. Samples were served under red incandescent light to mask color variation among samples. Panelists were supplied with distilled water, apple juice, and unsalted saltine crackers, which were used for palate cleansing in between samples. Panelists evaluated 7 different texture characteristics, including hardness, cohesiveness, tenderness, connective tissue, particle size, moisture content, and beef fat/oily mouthfeel. Each sensory attribute was rated on a 10-cm, unstructured line scale with 0-cm anchored at very low intensity for all characteristics and 10-cm anchored at very high intensity for all characteristics. An example of the sensory ballot utilized is presented in Figure 8. After each panel session, individual panelist's ratings were averaged to obtain a single panel rating for each sensory attribute of each sample.

Texture Analysis

Experiment 1&2. Textural differences of raw ground beef patties (n=3) from each batch of all treatments were quantified using an objective texture analyzer (CT3 50K Texture Analyzer; Brookfield Engineering Laboratories). Samples were randomized and thawed to 0-5°C

prior to analysis. For each sample, a 3.8-cm x 3.8-cm square piece was cut from the middle of the patty and placed in the CT3 Texture Analyzer equipped with the Fixture Base Table (TA-BT-KIT, Brookfield Engineering Laboratories) and the Ottawa Cell (TA-OC, Brookfield Engineering Laboratories). For experiment 1, patties from treatments 7-12 were pressed using a patty press to standardize patty thickness with samples from treatments 1-6. A compression test was run with the following test parameters: target type = distance; target value = 57.0-mm; hold time = 0-s; trigger load = 0-kg; test speed = 300-mm/min; cycle count = 1. Results were reported as a measure of hardness, or the maximum load value (kg) of the compression cycle. Results from each sample within each batch were averaged in order to obtain a single measurement for each batch within each treatment.

Proximate Analysis

Experiment 1&2. Three patties from each batch within each treatment were broken into smaller pieces, submerged in liquid nitrogen, and homogenized into a fine powder using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc., Ridgeland, MS). After homogenization, samples were placed in Whirl-Pak bags (Nasco, Ft. Atkinson, WI), individually labeled, and stored at -80°C until further analysis.

Total lipid analysis was conducted by the extraction of 1g of each sample using the methods described by Folch, Lees, and Sloane Stanley (1957) and Bligh and Dyer (1959). After extraction, the lipid-containing portion was dried under N_2 gas and placed into a 100°C drying oven for 3 hours. Samples were then cooled to room temperature (22°C) in a desiccator. Once the samples were cooled, samples were weighed and the percentage lipid was reported on a wet-weight basis. The total percentage of sample weight comprised of lipid was calculated by

dividing the final weight of the remaining sample by the initial sample weight and multiplying by 100.

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

Crude protein was determined using the method indicated by the AOAC (2005). A conversion factor of 6.25 was used to determine crude protein (Merrill & Watt, 1973).

Ash was analyzed using the ashing method specified by the AOAC (2005). For each sample, approximately 1 g was weighed into a dry crucible. Crucibles were then set in a Thermolyne box furnace (Thermo Fisher Scientific, Pittsburgh, PA) which was set at 600°C for 24 hours. After removal from the incinerator, samples were cooled to room temperature (22°C) in a desiccator. Samples were then re-weighed to obtain the ash percentage. The total percentage of ash was determined by dividing the sample weight in the crucible post-incineration by the initial weight and multiplying by 100.

Statistical Methods

All analyses were conducted using statistical procedures of SAS 9.3 (SAS Inst. Inc., Cary, NC). Treatment comparisons were tested for significance using generalized linear model procedures (PROC GLM). Experiment 1 was designed to be analyzed as a 3x2x2 factorial. Interactions were reported but not significant at $\alpha = 0.05$, so only main effects were discussed. For experiment 2, least squares means were calculated for each texture characteristic across

treatments, with differences determined at $\alpha = 0.05$. To account for variations in lipid content, percent lipid was tested as a covariate in each model. However, percent lipid as a covariate was not significant in any model and therefore removed from all models. Additionally, Pearson correlation coefficients were calculated to show relationships between sensory attributes and objective texture measurements. Examples of the SAS code utilized are presented in Figure 9.

RESULTS AND DISCUSSION

Proximate Composition and Relationship to Sensory Attributes

Experiment 1. No differences existed for treatments in Experiment 1, since all batches of all treatments were fabricated from a common source of trimmings. Average percent lipid across treatments in Experiment 1 ranged from 16.08% to 20.46% with a mean of 18.31% (not reported in tabular form).

Experiment 2. Least squares means for percentages of lipid, moisture, protein, and ash for Experiment 2 are summarized in Table 4.2.Treatments differed ($P<0.05$) in percent lipid, 13.24% vs. 17.41%. These differences originated from formulation methods. Patties formulaqted from reground chubs originated from previously-ground, 10lb chubs, formulated to an 81/19 blend, whereas patties from ground trimmings were formulated utilizing the Pearson square formula and the USDA Nutrient Database Standard Reference (U.S. Department of Agriculture, 2012). To account for the difference in crude fat, percent lipid was tested as a covariate but was not significant ($P>0.05$) in all models for sensory characteristics. Additionally, percent moisture varied between treatments in conjunction with the differences in percent lipid.

Texture Differences as Quantified by Trained Sensory Panels and Objective Measurement

Experiment 1. Least squares for texture attributes between main effects are reported in Table 4.3. Treatment differences are reported in Table 4.4. The interactions of grind size, mix time, and patty-forming technique were not significant at $P<0.05$. Therefore, only main effect differences will be discussed. Numerous sensory attribute differences existed between grind sizes and patty-forming devices, while no significant differences existed between mix times.

Trained panelists found numerous differences in texture attributes between grind plate sizes (3.175mm and 1.588mm). The smaller grind size ranked lower for hardness and higher for tenderness, indicating that smaller grind sizes were softer and more tender. Samples from the smaller grind size also ranked lower for perceived connective tissue and particle size, as expected. Literature shows mixed results for perceived sensory differences of samples from varying plate sizes. Huffman (1990) reported no differences from varying plate sizes, but the same researchers a year later found increased tenderness and texture desirability when samples were ground through a larger plate (Egbert, Huffman, Chen, & Dylewski, 1991). Elsner et al. (1997) found similar results in chicken, reporting higher texture ratings for samples with a larger grind size. On the other hand, Suman et al. (2003) found increased ratings for juiciness and texture acceptability in samples from a smaller grind size. Another study agreed, reporting high panelist responses for "rubberiness" in ground beef made with a larger plate size (Roth, McKeith, & Brewer, 1999). In the current study, objective texture measurement showed higher peak loads for larger grind sizes, which agrees with the sensory panel findings of this study in which larger grind sizes were found to be harder and tougher (Table 4.3). Suman et al. (2003) also found increased shear force values correlated with increased grind size. Although the current results show smaller grind sizes were softer and more tender, since it was conducted with a trained sensory panel we cannot draw conclusions as to whether softer and more tender patties would be desirable or not to consumers.

Panel responses also showed clear differences in texture attributes between patty-forming devices. Patties fabricated with the Formax machine were ranked lower for hardness, tenderness, and connective tissue than patties made with a portioning attachment on a vacuum stuffer (VMAG). Formax patties were also ranked substantially higher for cohesiveness, meaning that

VMAG patties were more crumbly. Formax patties were scored lower for particle size; it could have been harder to detect large particles in a more dense, cohesive patty. VMAG patties ranked higher for moisture content and beef fat/oily mouthfeel also. In objective measurement (by the texture analyzer) of peak load, VMAG patties scored lower than Formax patties, which makes sense if VMAG patties were more tender and crumbly and less cohesive.

Pearson correlation coefficients between sensory panel texture attributes and objective measurements of peak load are presented in Table 4.5. Tenderness was the only attribute significantly correlated with objective peak load, but at a very weak level. No other significant or meaningful correlations existed between objective measurement and sensory attributes.

Experiment 2. The objective of this experiment was to compare common grocery store practices of grinding bench trimmings versus re-grinding large chubs and packaging in smaller quantities. Treatment effects between fresh ground shoulder clods and re-ground chubs are reported in Table 4.6. Percent lipid as a covariate was tested in each model, as previously discussed, but percent lipid was not significant at $P<0.05$ for any sensory model. No differences were found between treatments for hardness, cohesiveness, or tenderness. Connective tissue was rated higher in the reground patties, most likely due to connective tissue present in the original raw product. Panelists also ranked the reground patties higher in moisture content and beef fat/oily mouthfeel, despite percent lipid not being significant as a covariate in these models. Furthermore, reground patties were ranked significantly higher for particle size compared to ground shoulder clods.

Objective measurement of peak load (kg) was significantly higher for the re-ground chubs. This matches the results for particle size, meaning that samples with perceived larger

particle size also require more force to shear. Peak load and particle size also had the highest Pearson correlation coefficient (r=0.55) as shown in Table 4.7. It appears that it takes a very large difference in peak load in order for trained panelists to detect a small difference.

Conclusions

Experiment 1. Panelists detected significant differences between grind size effects as well as effects of patty-forming device. Ground beef patties fabricated with smaller sized grind plates were perceived softer, more tender, and had a smaller particle size. Objective texture measurements agreed, showing lower peak loads for patties produced with smaller sized grind plates. Detectible differences also existed in ground beef patties fabricated with different patty-forming techniques. Patties made with a Formax (Formax F6, equipped with the 2874-6 plate, Mokena, IL) were softer and more cohesive, while patties made with the vacuum stuffer (Model VF50, Handtmann, Germany) equipped with a portioning device were more crumbly but also ranked higher for moisture content and oily mouthfeel. Conclusions cannot be made regarding the overall texture desirability of either grind size or patty-forming device, but this data shows that substantial differences do exist in both effects. If a foodservice or retail customer desires softer, more tender ground beef patties, then smaller grind sizes should be used. However if the customer desires a more steak-like ground beef patty, then larger grind sizes should be used. Likewise the patty-forming technique has a large impact on the perceived cohesiveness of the patty.

Experiment 2. The objective of this experiment was to compare common grocery store practices of grinding bench trimmings versus re-grinding large chubs and packaging into smaller quantities. Ground beef patties resulting from the re-ground chubs were perceived to have a greater amount of connective tissue, a larger particle size, greater moisture content, and a greater

beef fat/oily mouthfeel. Additionally, objective measures of texture showed greater peak loads for patties from re-ground chubs.

Table 4.1. Description of experimental treatments

Trt. #	Source	Product Age (from box date)	Grind Plate Size	Mixing Time (min)	Patty-Forming Device
1	81/19 Chuck Trimmings	4	1/8”	1.5	Formax (2874-6 plate)
2	81/19 Chuck Trimmings	4	1/8”	3	Formax (2874-6 plate)
3	81/19 Chuck Trimmings	4	1/8”	4.5	Formax (2874-6 plate)
4	81/19 Chuck Trimmings	4	1/16”	1.5	Formax (2874-6 plate)
5	81/19 Chuck Trimmings	4	1/16”	3	Formax (2874-6 plate)
6	81/19 Chuck Trimmings	4	1/16”	4.5	Formax (2874-6 plate)
7	81/19 Chuck Trimmings	5	1/8”	1.5	Vacuum Stuffer
8	81/19 Chuck Trimmings	5	1/8”	3	Vacuum Stuffer
9	81/19 Chuck Trimmings	5	1/8”	4.5	Vacuum Stuffer
10	81/19 Chuck Trimmings	5	1/16”	1.5	Vacuum Stuffer
11	81/19 Chuck Trimmings	5	1/16”	3	Vacuum Stuffer
12	81/19 Chuck Trimmings	5	1/16”	4.5	Vacuum Stuffer

[1] 1/8” grind = 3.175 mm; 1/16” grind = 1.5875mm

Table 4.2. Least squares means for percentage lipid, protein, moisture, and ash as determined by proximate analysis of raw samples representing 2 treatments

Treatment	Lipid, %	Protein, %	Moisture, %	Ash, %
Experiment 2				
Ground trimmings	13.24	17.96	66.01	0.88
Reground chubs	17.41	17.45	61.92	0.74
SEM	0.26	0.32	0.26	0.04
P-value	<.0001	0.2963	<.0001	0.0441

[abcdefgh] Least squares means in the same column lacking a common superscript differ (P<0.05)

Table 4.3. Sensory panel ratings[1] and objective measurements[2] for texture of ground beef samples representing overall main effects

	Sensory Panel Rating							
Main Effect	Hardness	Cohesiveness	Tenderness	Connective Tissue	Particle Size	Moisture Content	Beef Fat/ Oily Mouthfeel	Peak Load (kg)
Grind Size: 1/8"	5.37	5.41	5.35	1.11	5.78	5.62	6.04	24.95
Grind Size: 1/16"	4.77	5.48	6.68	0.38	4.60	5.61	5.98	20.08
SEM	0.08	0.07	0.06	0.04	0.07	0.06	0.05	0.90
P-value	<0.0001	0.476	<0.0001	<0.0001	<0.0001	0.881	0.422	0.0002
Mix Time[2]: Short	5.19	5.41	5.94	0.75	5.25	5.54	6.01	21.18
Mix Time: Normal	5.04	5.44	5.97	0.71	5.12	5.54	5.95	23.81
Mix Time: Long	4.98	5.48	6.13	0.79	5.20	5.76	6.09	22.56
SEM	0.10	0.09	0.07	0.04	0.09	0.07	0.07	1.08
P-value	0.322	0.816	0.107	0.439	0.515	0.037	0.328	0.228
Patty-Forming Device: Formax	4.83	6.85	5.80	0.66	4.72	5.29	5.71	23.80
Patty-Forming Device: Vmag	5.31	4.03	6.23	0.84	5.66	5.94	6.32	21.24
SEM	0.08	0.07	0.06	0.04	0.07	0.06	0.05	0.91
P-value	<0.0001	<0.0001	<0.0001	0.0005	<0.0001	<0.0001	<0.0001	0.045

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

[2]Mix Times: short = 1.5min; normal = 3min; long = 4.5min

Table 4.4. Sensory panel ratings[1] and objective measurements for texture of ground beef samples representing treatments 1-12

	Sensory Panel Rating[1]							
Treatment[2]	Hardness	Cohesiveness	Tenderness	Connective Tissue	Particle Size	Moisture Content	Beef Fat/Oily Mouthfeel	Peak Load (kg)
1	5.10^{abc}	6.47^{a}	4.85^{a}	1.07^{a}	5.53^{bc}	5.07^{a}	5.53^{a}	23.74^{ab}
2	5.26^{abc}	6.60^{a}	5.08^{ab}	0.97^{ab}	5.12^{c}	5.27^{ab}	5.79^{abc}	26.16^{ab}
3	5.26^{abc}	6.91^{a}	5.24^{ab}	1.12^{a}	5.50^{bc}	5.58^{abc}	6.01^{abcd}	25.96^{ab}
4	4.42^{c}	7.04^{a}	6.58^{d}	0.32^{c}	4.23^{d}	5.30^{ab}	5.63^{ab}	17.72^{b}
5	4.38^{c}	7.10^{a}	6.24^{cd}	0.18^{c}	3.80^{d}	4.99^{a}	5.42^{a}	28.13^{a}
6	4.54^{bc}	7.00^{a}	6.80^{d}	0.28^{c}	4.16^{d}	5.53^{abc}	5.88^{abcd}	20.9^{ab}
7	5.85^{a}	4.26^{b}	5.66^{bc}	1.11^{a}	6.10^{sb}	5.76^{bc}	6.38^{cd}	24.60^{ab}
8	5.60^{a}	3.88^{b}	5.66^{bc}	1.19^{a}	6.46^{a}	6.00^{c}	6.29^{cd}	22.82^{ab}
9	5.17^{abc}	4.32^{b}	5.63^{bc}	1.22^{a}	6.00^{ab}	6.03^{c}	6.26^{cd}	26.36^{ab}
10	5.40^{ab}	3.86^{b}	6.68^{d}	0.49^{c}	5.15^{c}	6.02^{c}	6.48^{d}	18.66^{ab}
11	4.91^{abc}	4.17^{b}	6.88^{d}	0.^{49c}	5.08^{c}	5.89^{bc}	6.29^{cd}	18.15^{b}
12	4.96^{abc}	3.68^{b}	6.85^{d}	0.55^{bc}	5.15^{c}	5.91^{bc}	6.18^{bcd}	16.82^{b}
SEM	0.20	0.17	0.14	0.09	0.17	0.14	0.13	2.11
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0003

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

[2]Treatment: T1 = 1/8", 1.5min mix, Formax; T2 = 1/8", 3min mix, Formax; T3 = 1/8", 4.5min, Formax; T4 = 1/16", 1.5min mix, Formax; T5 = 1/16", 3min mix, Formax; T6 = 1/16", 4.5min mix, Formax; T7 = 1/8", 1.5min mix, VMAG; T8 = 1/8", 3min mix, VMAG; T9 = 1/8", 4.5min mix, VMAG; T10 = 1/16", 1.5min mix, VMAG; T11 = 1/16", 3min mix, VMAG; T12 = 1/16", 4.5min mix, VMAG

[abcd] Least squares means in the same column lacking a common superscript differ (P<0.05)

Table 4.5. Pearson correlation coefficients showing relationships between objective texture measurement and sensory texture attributes for treatments 1-12

Sensory Attribute	Peak Load (kg)
Hardness	-0.01
Cohesiveness	0.14
Tenderness	-0.22*
Connective Tissue	0.11
Particle Size	0.09
Moisture Content	-0.12
Beef Fat/Oily Mouthfeel	-0.09

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

Table 4.6. Sensory panel ratings[1] and objective measurements for texture of ground beef samples representing 2 packaging treatments

	Sensory Panel Rating[1]							
Effect	Hardness	Cohesiveness	Tenderness	Connective Tissue	Particle Size	Moisture Content	Beef Fat/ Oily Mouthfeel	Peak Load (kg)
Ground trimmings	4.26	5.11	5.94	0.55	4.39	5.46	5.53	21.04
Reground chubs	4.55	5.48	5.96	1.72	5.97	5.92	6.59	27.15
SEM	0.17	0.21	0.12	0.09	0.15	0.10	0.10	1.76
P-value	0.2324	0.2155	0.8832	<0.0001	<0.0001	0.0039	<0.0001	0.0392

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

Table 4.7. Pearson correlation coefficients showing relationships between objective texture measurement and sensory texture attributes for 2 packaging treatments

Sensory Attribute	Peak Load (kg)
Hardness	0.26
Cohesiveness	0.24
Tenderness	-0.10
Connective Tissue	0.39*
Particle Size	0.55*
Moisture Content	0.19
Beef Fat/Oily Mouthfeel	0.43*

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

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APPENDIX A

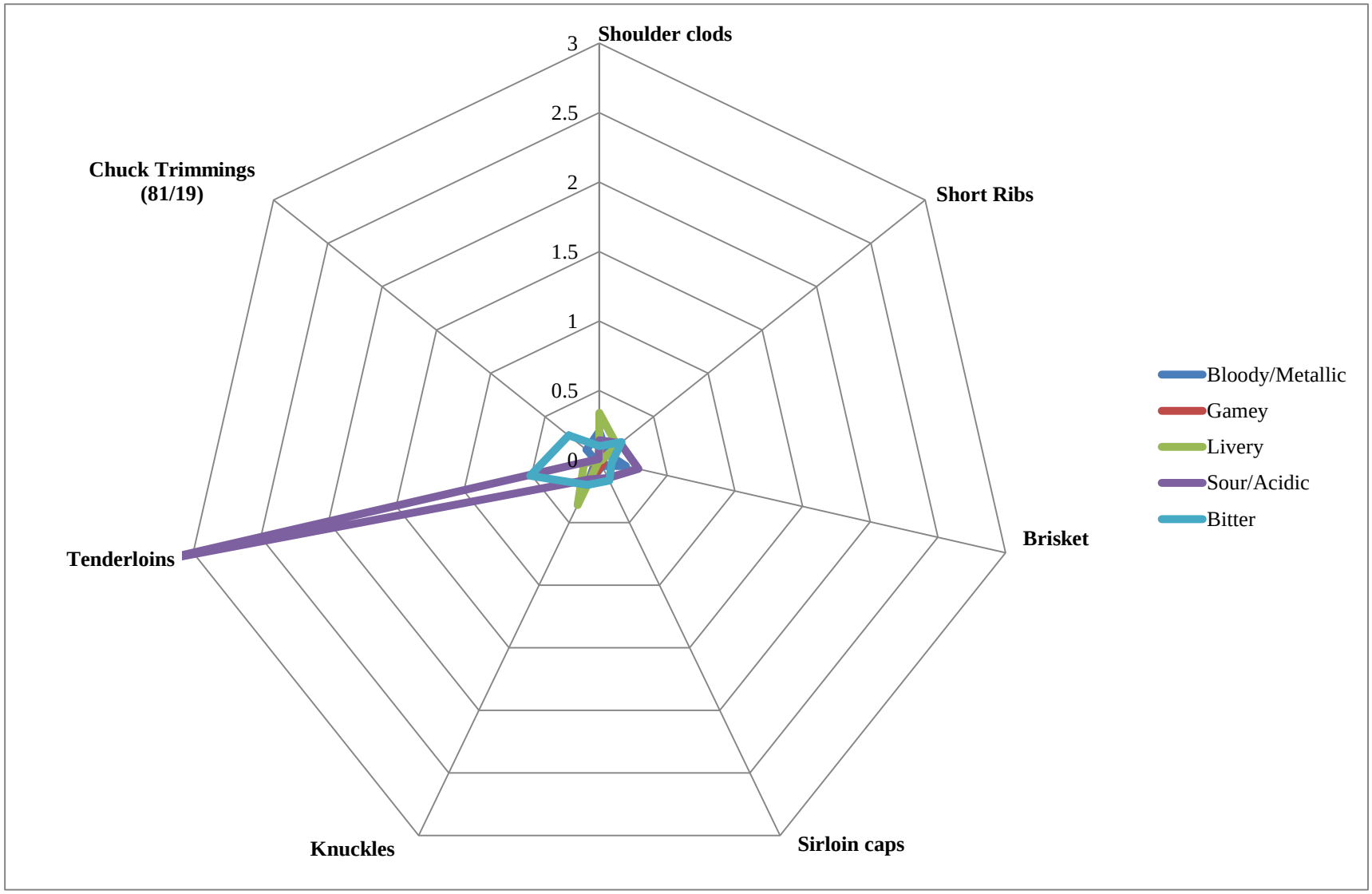

Figure A1.1. Sensory panel ratings for beef off-flavors of ground beef samples representing 7 muscle source treatments.

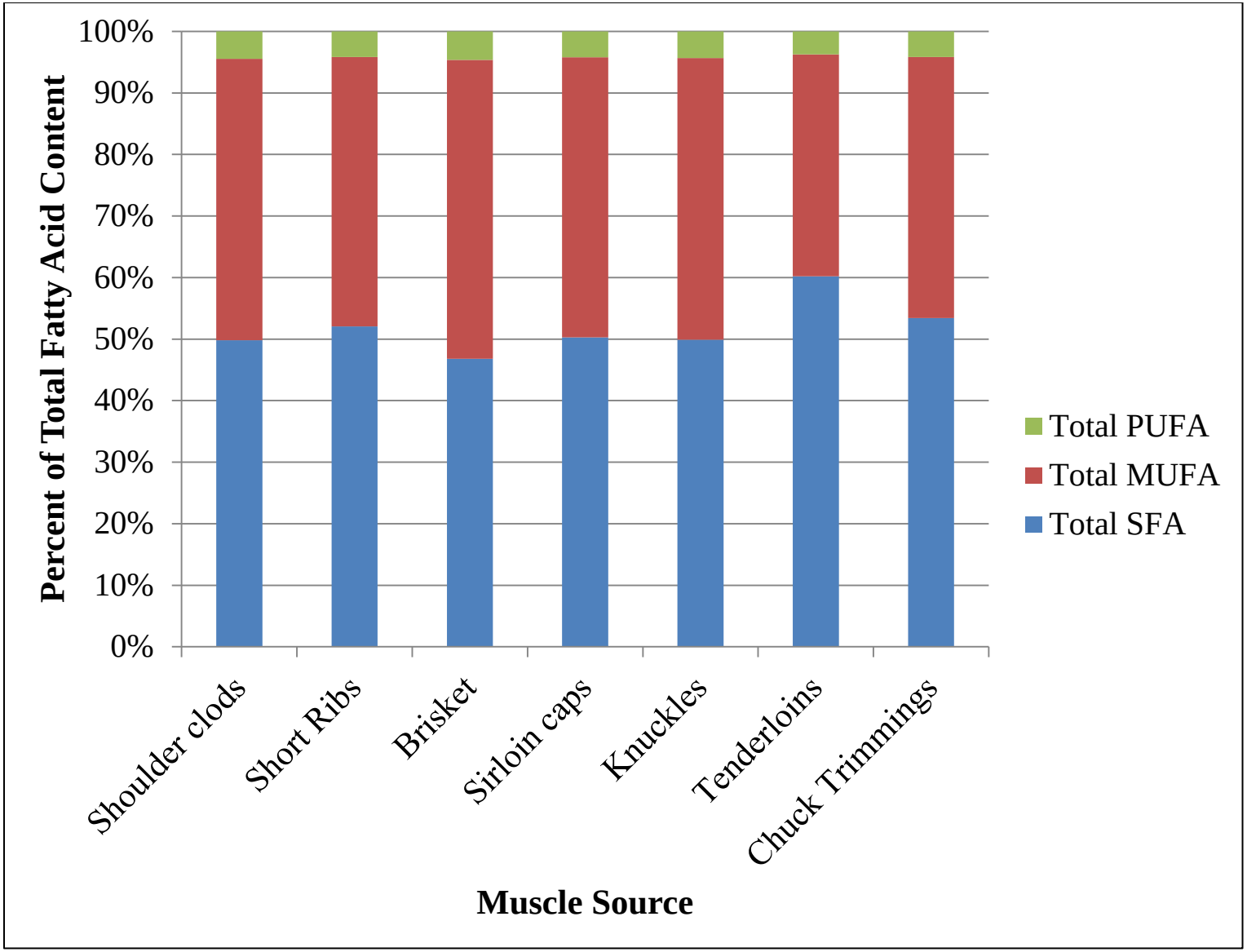

Figure A1.2. Proportions of fatty acid content in ground beef samples representing 7 muscle source treatments

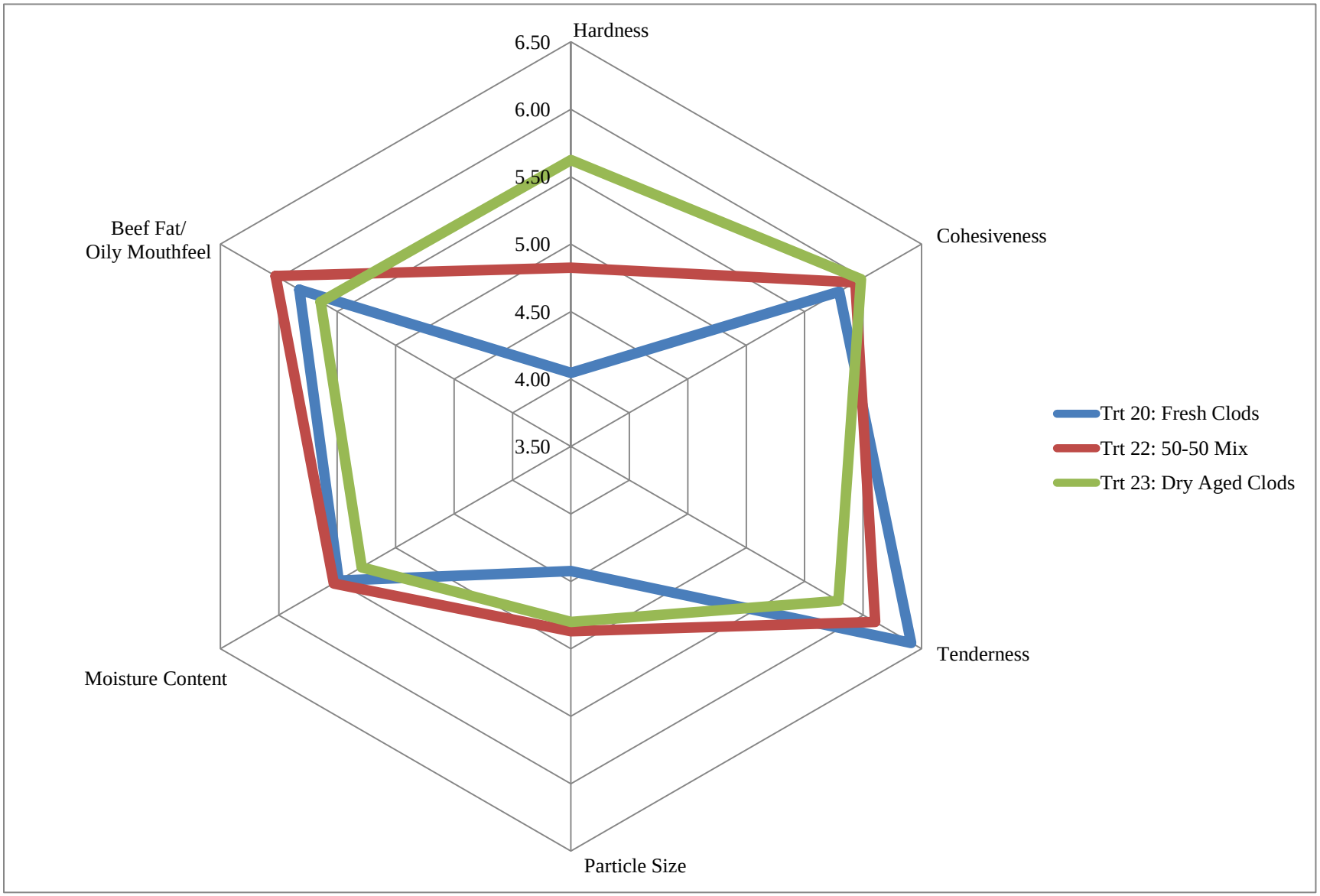

Figure A1.3. Sensory panel ratings for beef texture attributes of ground beef samples representing 3 aging treatments.

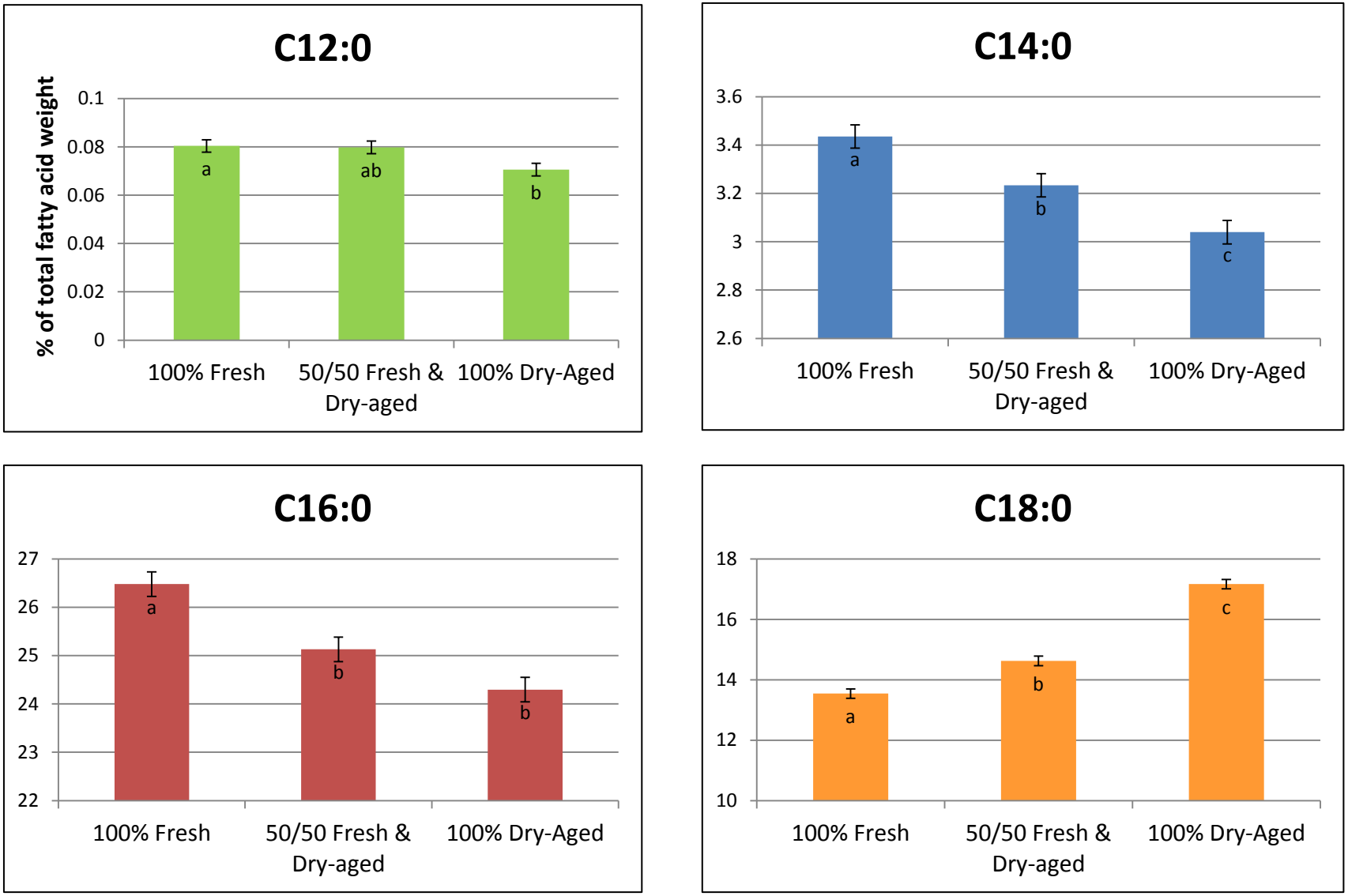

Figure A1.4. Concentrations of identified saturated fatty acids in ground beef samples representing 3 aging treatments

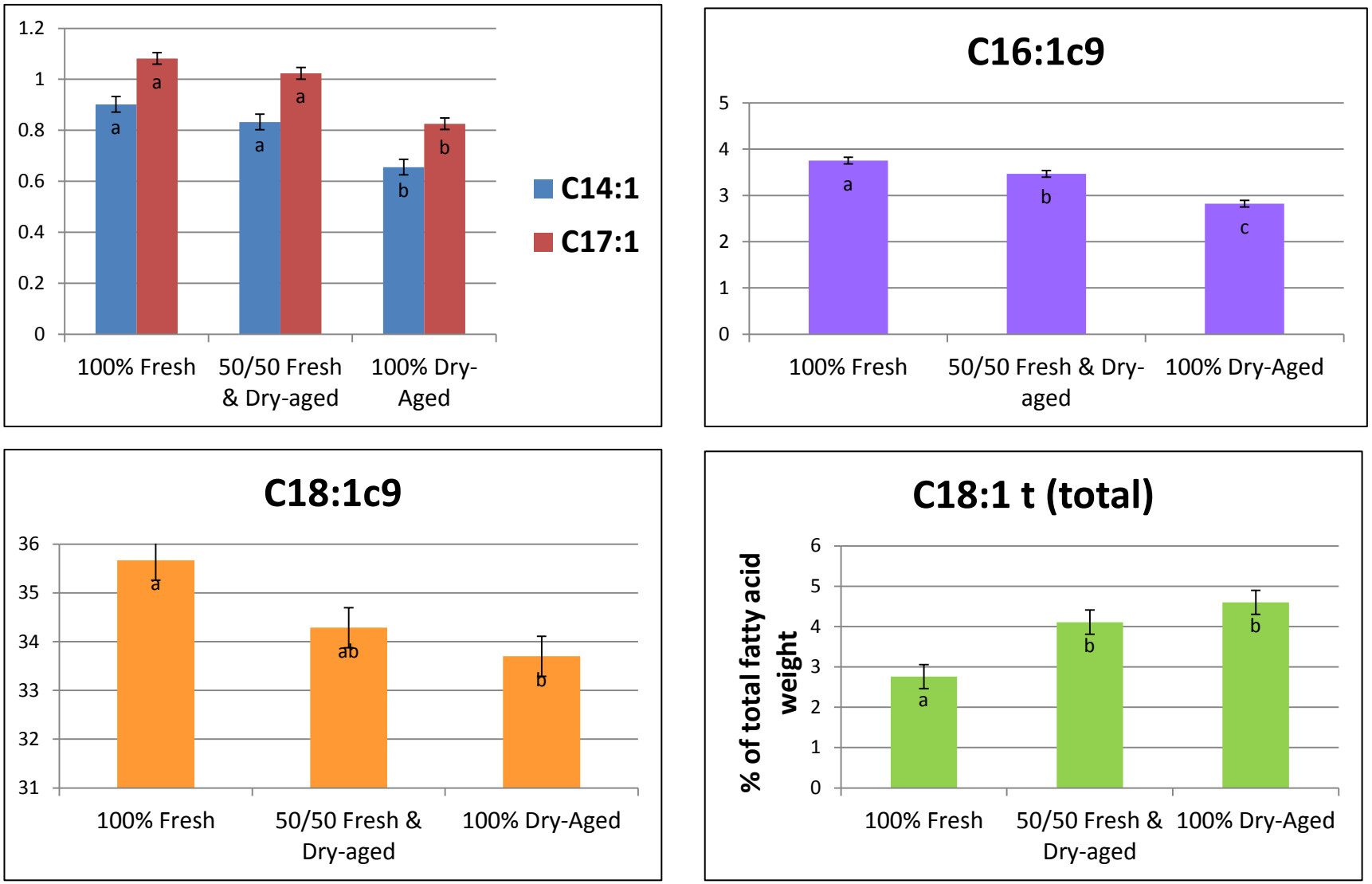

Figure A1.5. Concentrations of identified monounsaturated fatty acids in ground beef samples representing 3 aging treatments

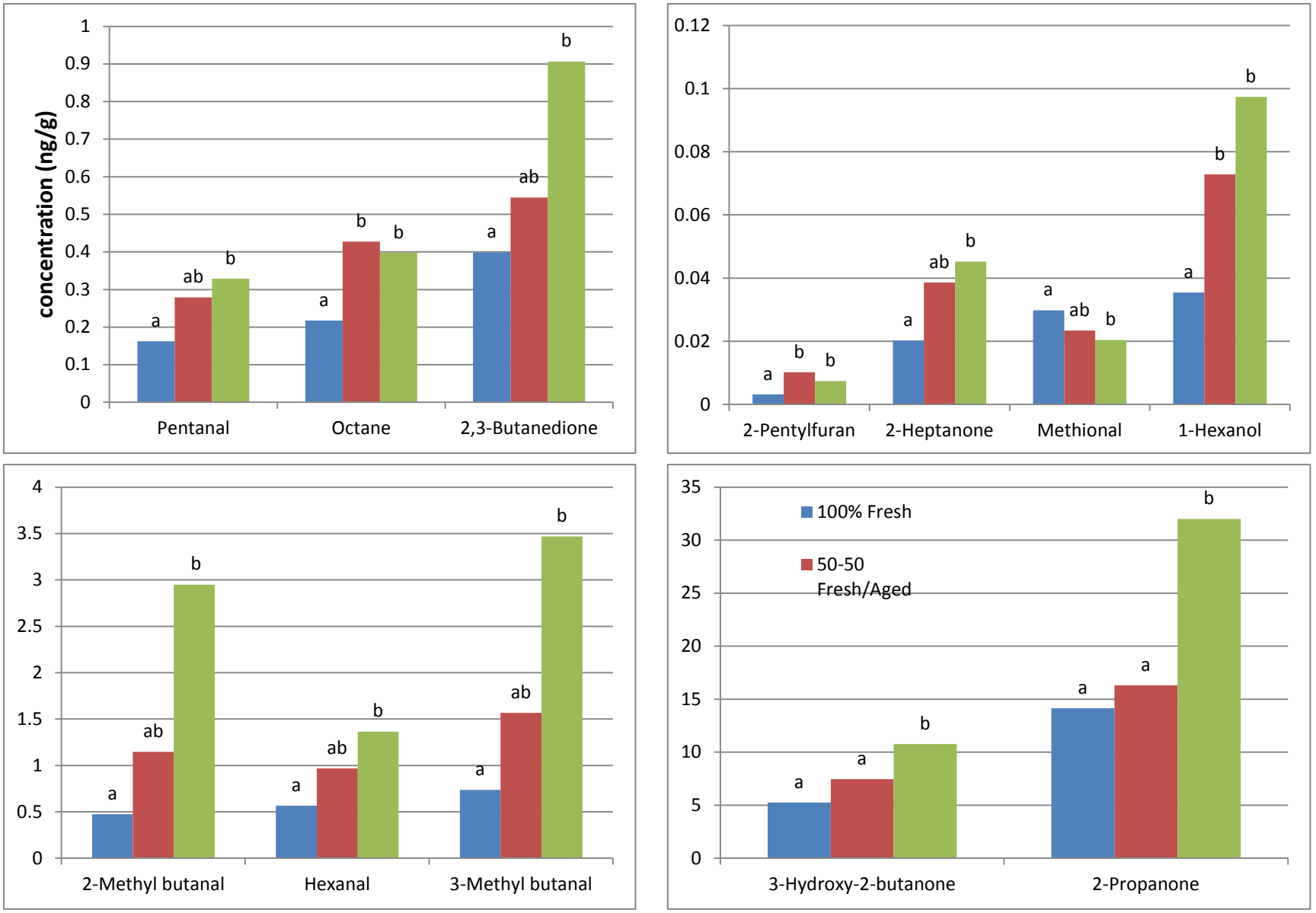

Figure A1.6. Concentrations of identified volatiles in ground beef samples representing 3 aging treatments

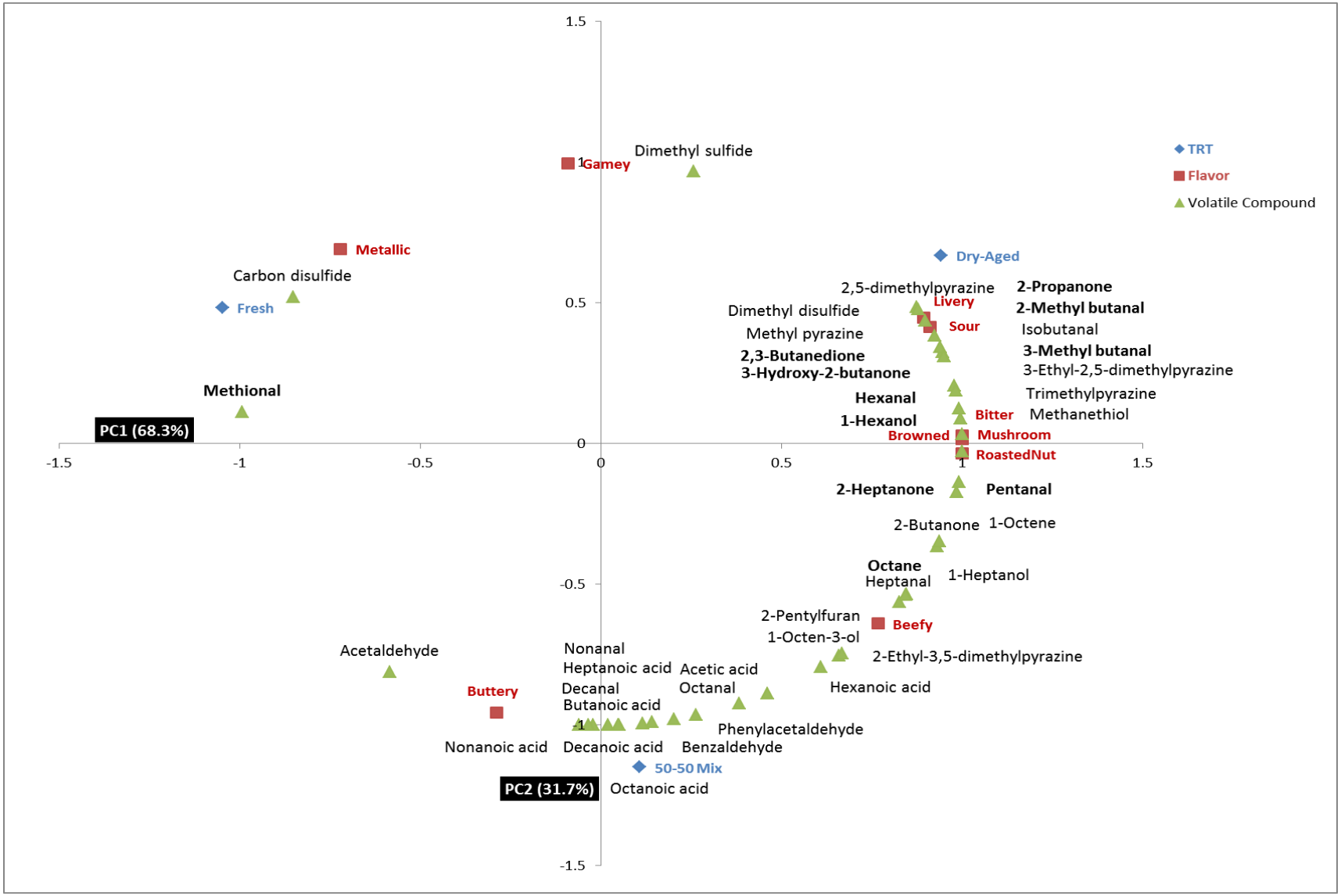

Figure A1.7. Principal component analysis showing relationships between 3 aging treatments, sensory flavor traits, and volatiles

Texture Characteristics

Hardness:
Very Soft — Very Hard

Cohesiveness:
Crumbly — Dense

Tenderness:
Very Tough — Very Tender

Connective Tissue: ☐ No Presence
Very Low Intensity — Very High Intensity

Particle Size:
Fine — Coarse

Moisture Content:
Very Dry — Very Moist

Beef Fat/Oily Mouthfeel:
Very Low Intensity — Very High Intensity

Flavor Characteristics

Beefy/Brothy:
Very Low Intensity — Very High Intensity

Browned/Grilled:
Very Low Intensity — Very High Intensity

Buttery/Beef Fat:
Very Low Intensity — Very High Intensity

Bloody/Metallic: ☐ No Presence
Very Low Intensity — Very High Intensity

Gamey: ☐ No Presence
Very Low Intensity — Very High Intensity

Earthy/Mushroom: ☐ No Presence
Very Low Intensity — Very High Intensity

Nutty/Roasted Nut: ☐ No Presence
Very Low Intensity — Very High Intensity

Livery: ☐ No Presence
Very Low Intensity — Very High Intensity

Sour/Acidic: ☐ No Presence
Very Low Intensity — Very High Intensity

Bitter: ☐ No Presence
Very Low Intensity — Very High Intensity

Figure A1.8. Example sensory ballot

```
PROC GLM  DATA=EXP1 ALPHA=0.05;
class TRT;
MODEL  Buttery Beefy Browned Metallic Gamey Mushroom Nutty Livery Bitter =
TRT lipid /solution;
lsmeans TRT /pdiff cl;
means TRT /hovtest= levene (type=abs);
RUN;


PROC GLM  DATA=EXP2 ALPHA=0.05;
Class Treatment;
MODEL  Hardness Cohesiveness Tenderness ConnectiveTissue ParticleSize
MoistureContent OilyMouthfeel PeakLoad =  Treatment;
lsmeans Treatment;
means Treatment /hovtest= levene (type=abs);
RUN;
```

Figure A1.9. SAS code