THESIS

IDENTIFYING AND CHARACTERIZING THE INFLUENCE OF CATTLE PRODUCTION HISTORY AND LEAN MUSCLE CHARACTERISTICS ON SPECIFIC BEEF FLAVOR ATTRIBUTES

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ABSTRACT

IDENTIFYING AND CHARCTERIZING THE INFLUENCE OF CATTLE PRODUCTION HISTORY AND LEAN MUSCLE CHARACTERISTICS ON SPECIFIC BEEF FLAVOR ATTRIBUTES

Experiments were conducted on ground beef patties as well as pure fat and lean samples manufactured using various sources and production techniques. Differences among 5 cattle types, 3 muscle types, and 3 lean percentages were evaluated for descriptive sensory analysis, fatty acid composition, volatile compound composition, and amino acid composition. Furthermore, an olfactory detection port (ODP) was used while analyzing volatiles to detect odorous compounds. Cattle types, breed and days-on-feed (DOF), evaluated included F1 Wagyu-Angus crosses (450 DOF), long-fed natural Holsteins (350 DOF), short-fed retail Holsteins (250 DOF), long-fed conventional beef (200 DOF), and short-fed beef (90 DOF). Muscles included in this study were *Pectorales profundi* (high connective tissue), *Longissimus dorsi* (intermediate connective tissue), and *Psoas major* (low connective tissue). Lean percentages of ground beef included 90%, 80%, and 70%. All sources were used in combination as a factorial design with 5 cattle types mixed with 3 muscles at 3 different lean percentages (5x3x3) with one treatment consisting of 45 samples with 5 replications (N=225). Trained panelists evaluated ground beef patties from each treatment and replication for 8 different flavor notes, including beefy/brothy, browned/grilled, buttery/beef fat, bloody/metallic, grassy/fishy, earthy/mushroom, nutlike/roasted nut, and livery/organy. Initial analyses consisted of least-square-means to determine differences among breed, muscle, and lean percentage and the

interactions among them. These results were significant ($P < 0.05$) for two-way and three-way interactions; however, no plausible data could be interpreted from the analysis.

Further analyses with principal component analysis were used to determine relationships between amino acids, fatty acids, volatiles, and sensory panels with cattle type and muscle separately. Relationships were identified and used to identify certain attributes as possible contributions to beef flavor. Additionally, nonmetric multidimensional scaling was used to access clustering using pairwise comparisons. This showed significant ($P < 0.05$) differences among cattle type treatments with small variance between samples while muscle treatments were not significant ($P > 0.05$) and encountered large variance between samples.

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CHAPTER I

INTRODUCTION

As the price of beef continues to rise, consumer demand continues to remain steady. One of the major contributors to this is believed to be the unique flavor of beef. As the cost to not only raise cattle, but to consume beef, continues to increase it becomes important to maintain a high quality, uniform product that consumers are willing to purchase. In the National Beef Quality Audit, conducted in 2011, it was determined that 4 out of the 5 beef industry sectors identified beef flavor as the 1st or 2nd most important attribute (Igo et al., 2013).

Differences in breed have been shown to affect beef flavor due to differences in nitrogen- and sulfur- compounds, free amino acids, alcohols, aldehydes, and ketones (Sato et al., 1995; Insausti et al., 2005). Additionally, as cattle are fed longer, phospholipid and fatty acid composition change and are correlated with flavor differences in ground beef (Larick et al., 1989). Tatum et al. (1980) also found that 90% of the steaks from cattle that were fed at 100, 130, or 160 days received at least a desirable rating for flavor. The percentages of steaks that received "very desirable" ratings for flavor increased as feeding time increased as well (Tatum et al., 1980). Furthermore, diets that include more forage alter flavor attributes by increasing linolenic acid and decreasing oleic and linoleic acids compared to cattle fed concentrate diets (Elmore et al., 2004). Similar to tenderness, flavor can also be affected by the collagen content of many cuts of meat (Yancey et al., 2005; Stetzer et al., 2006; Stetzer et al., 2007; Stetzer et al., 2008). Three muscles of different collagen content were used in this current study to identify differences among flavor.

The objective of this study was to identify and characterize different cattle and muscle types and how they are associated with specific beef flavor attributes. Amino acid, fatty acid, volatile, proximate and olfactory data were collected from ground beef combinations of five cattle types and three muscle types at three lean percentages. This information was compared with trained sensory data to determine what compounds are associated with specific beef flavor notes.

CHAPTER 2

REVIEW OF LITERATURE

Flavor

Flavor is a complex combination of taste and smell sensations evoked by substances in the mouth. Flavor can be divided into three separate areas of how humans experience food. First is the taste quality of the food known as gustatory, this is the identification by the specialized taste cells on the tongue. These cells, called taste buds, are in the thousands and have three different types of cells in different areas of the tongue. Circumvallate papillae are located at the very back of the tongue and contain thousands of taste buds (Chandrashekar et al., 2006). Foliate papillae are located in the posterior lateral edge of the tongue and contain hundreds of taste buds (Chandrashekar et al., 2006). Finally, fungiform papillae are located in the anterior two-thirds of the tongue and contain just a small number of taste buds (Chandrashekar et al., 2006). The basic tastes can be described in five different ways: sweet, sour, bitter, salt, and umami (Brewer, 2007). The various profiles are associated with different compounds. Sweet is associated with sugars, amino acids, and organic acids (MacLeod et al., 1994). Sour is from amino acids that combine with organic acids (MacLeod et al., 1994). Salty is derived from inorganic salts of glutamate and aspartate and bitterness is due to hypoxanthine, anserine, and carnosine (MacLeod et al., 1994). The fifth flavor profile, umami, is derived from the Japanese culture and is used to describe the savory taste associated with meat, fish, vegetables, and dairy products (Umami Information Center, 2014). It is a combination of glutamate and ribonucleotides (Umami Information Center, 2014).

The second area of flavor in foods is the common chemical sense known as the olfactory system, which involves tiny nerve endings found on the moist surfaces of the eyes, nose, mouth

and throat (Huang et al., 2006; Ishimaru et al., 2006; Lindeman, 2000). Nerve endings are what let the mouth know of sensations such as the coolness of mint or the burning of a pepper (Lindeman, 2000; Huang et al., 2006; Ishimaru et al., 2006). Finally, the third is the trigeminal ganglia system which is the nerve fibers also sending signals to the brain for heat, cold, and texture (Huang et al., 2006; Ishimaru et al., 2006; Lindeman, 2000).

Odor compounds also play an important role in flavor of foods. Odor sensation is produced by volatile compounds that stimulate receptors in the nasal epithelium (Farmer, 1992). These compounds can reach through the nostrils or the back of the nose while food is in the mouth (Farmer, 1992).

From a neuroscience perspective, flavor begins with the taste and odor of the food once it enters the mouth. The identification of flavor from the flavor molecule and membrane receptor leads to the production of an electrical signal (Lindeman, 2000; Huang et al., 2006; Ishimaru et al., 2006). This signal speeds along a pathway formed by neurons and axons and reaches the brain which interprets the stimulus (Barham and Edwards, 2001).

Muscle is comprised of water, protein, lipids, carbohydrates, and other water-soluble non-protein substances. Lipids, carbohydrates, and other non-protein substances represent about 6% of the entire muscle, but are the sources of meat flavor (Lawrie, 1985). The water soluble fractions include the amino acids, peptides, reducing sugars, and nucleotides. The lipid fraction is made up of triglycerides within fat and phospholipids within the structure of the cell membrane (Farmer, 1992). The flavor of raw meat has very little flavor and only has a blood-like taste. The characteristic flavors associated with meat do not appear until heated.

Beef flavor contributes to how the consumer will enjoy their eating experience. The Beef Customer Satisfaction Survey found that flavor and tenderness contributed equally to the overall

liking of beef (Lorenzen et al., 1999, Neely et al., 1999, Savell et al., 1999). Other studies have indicated that flavor had a stronger relationship to overall steak palatability than tenderness and juiciness (Igo et al., 2013; Huffman et al., 1996).

Development of Beef Flavor

Development of beef flavor includes the reactions of thermal breakdown of muscle components, reactions with amino acids and carbohydrates, oxidation of lipids, and the interactions between these reactions (Farmer, 1992). Amino acids are particularly stable and are unlikely to undergo any type of reaction during heating except at the surface of the meat, where the heat is directly applied (Mottram et al., 1993). Another substance is thiamine, which contains sulfur, and can give a variety of odorous compounds that can be described as "meaty"; these include thiophenes, thiazole, furans, and heterocyclic compounds (Mottram et al., 1993; MacLeod and Seyyedain-Ardebili, 1981; van der Linde et al., 1979; and Hartman et al., 1983).

One of the key reactions in the development of beef flavor is the Maillard reaction. This is generally described as nonenzymatic browning, and is generally caused by heat being applied to amino compounds that condense with the carbonyl group of a reducing sugar (Calkins and Hodgen, 2007). It yields a high molecular weight, brown-colored products and volatile aroma compounds (Farmer, 1992). This allows for the production of aldehydes, ketones, furans, pyrroles, pyrazines, and pyridines (Farmer, 1992). In turn, these create the beef aroma that is commonly described as characteristic of cooked beef (Mottram and Whitfield, 1994). Other than browning, there are also flavor compounds that generally are sulfurous and carbonyl that seem to be the predominant contributor to meat flavor (Mottram and Madruga, 1994; Shadhidi, 1998).

Beef flavor is highly correlated with oxidation of lipids (Moody, 1983). Lipid oxidation occurs when peroxides are formed by free radicals of PUFA and oxygen. Lipids act as a solvent

for the volatile compounds that develop during production, handling, and thermal processing (Moody, 1983). At room temperature, refrigeration, or freezing, autoxidation can occur which gives the off flavor generally described as "warmed over" or for raw meat can cause rancidity (Tims and Watts, 1958; Grosch et. al, 1982). Rancidity generally develops over long periods of time, while warmed over flavor generally occurs quite rapidly in reheated products (Farmer, 1992). However, autoxidation can occur through cooking that actually create a desirable flavor profile (Nawar, 1985). The rate of oxidation can differ due to the degree of unsaturation of fatty acids; polyunsaturated fatty acids (PUFA) are more susceptible to oxidation than monounsaturated (MUFA) or saturated (SFA) (Farmer, 1992). Phospholipids consist of high levels of PUFA and are generally thought to be responsible for warmed over flavors, as well as desirable meat flavors (Tims and Watts, 1958; Mottram and Edwards, 1983). Overall, lipids form aldehydes, lactones, hydrocarbons, furans, and ketones that ultimately lead to an off-flavor associated with oxidized meat, but also can have desirable attributes if heated for the first time (Ladikos and Lougovois, 1990).

The exact relationship between lipid oxidation and the Maillard reaction is still unclear. Initial removal of triglycerides has little effect on the aroma of meat (Mottram and Edwards, 1983). However, with the removal of phospholipids, "meaty" flavor was removed and altered the volatile compounds (Mottram and Edwards, 1983). Additionally, studies have indicated that, with removal of all lipids, it removed the meaty odor of cooked meat and increased the quantities of Maillard products (MacLeod and Ames, 1986). A study conducted by Farmer and Mottram (1990) used a model system in which various lipids were reacted with amino acids, cysteine, and sugar ribose. Phospholipids had a more intense meaty flavor than triglycerides and showed further interaction with the Maillard reaction (Farmer and Mottram, 1990).

Aspects Affecting Beef Flavor

Time on Feed

Cattle tend to increase both subcutaneous and intramuscular fat as days on feed increases. In general, flavor is more highly associated with intramuscular fat within the muscle and is generally more prevalent in grain fed cattle (Moody, 1976). However, flavor of fat is more desirable as the number of days on feed increases. According to Harrison et al. (1978), flavor desirability of fat from long-fed beef was superior to short-fed beef, which was more desirable than grass-fed beef. Furthermore, in a study comparing the number of days on feed to palatability characteristics, cattle that were fed for 130 or 160 days had a higher flavor desirability than their counterparts fed at 100 days (Tatum et al., 1980). Tatum et al. (1980) also found that 90% of the steaks from cattle that were fed at 100, 130, or 160 days received at least a desirable rating for flavor. The percentage of steaks that received "very desirable" ratings for flavor increased as feeding time increased (Tatum et al., 1980).

Nutritional regimen associated with increased days on feed has been inconclusive in associating flavor differences. Many studies have indicated that slaughter end point and age when feeding period began did not significantly influence taste panel flavor or off-flavor (Harris et al., 1997; May et al., 1992; Johnson et al., 1990; Burson et al., 1980).

Other studies have found that time on feed affects the nutrient composition of beef. According to Duckett et al. (1993) total lipid content in the *Longissimus* doubled between day 84 and day 112 within the feeding period but did not differ from day 0 to day 84 or day 112 to day 196. In terms of SFA, steric acid changed most drastically decreasing by 20% as days on feed increased (Duckett et al., 1993). Total MUFA increased 22% from day 0 to day 196, which was largely due to increasing oleic acid concentration (Duckett et al., 1993). PUFA concentration

decreased by 72% from day 0 to 196 (Duckett et al., 1993). Myristic acid and palmitic acid did not change in the diet until after 209 days on feed (Mandell et al., 1998). Melton et al. (1982b) found that ground beef had the most desirable flavor when there were lower concentrations of steric acid and linolenic acid in neutral and polar lipids, and higher concentrations of oleic acid in neutral lipids.

Breed

Considerable variations in carcass traits can be attributed to different breeds of cattle. However, in terms of flavor, cattle within the Continental and European breeds produce carcasses with little to no significant differences in flavor (Monson et al., 2005; Mckenna et al., 2004; Koch et al., 1982; Koch et al., 1976). *Bos indicus* cattle generate cuts that have a lower taste panel score for flavor than cuts from Hereford, Angus, Holsteins, and Jersey cattle (Ramsey et al., 1963). Ramsey et al. (1963) found that, despite lower marbling scores and less external fat, Holstein cattle tended to finish intermediate in terms of taste panel scores for flavor, while Jersey cattle had the highest flavor score of all breeds. Nonetheless, dairy breeds do not have a significant advantage in flavor scores when compared to conventional beef (Ramsey et al., 1963; Jeremiah and Gibson, 1999).

Wagyu and other Japanese cattle have many differences in terms of flavor when compared to other beef and dairy breeds. The Wagyu breed has the ability to express marbling unlike the other typical beef breeds (Jeremiah and Gibson, 1999). Beef from carcasses of Wagyu cattle typically has a more intense beef flavor than regular USDA Choice cuts (Jeremiah and Gibson, 1999; Busboom et al., 1993). Busboom et al. (1992) conducted a study in Japan which compared Japanese Wagyu, American Wagyu, Angus, Longhorn, and USDA Choice shabu-shabu and strip-loin steaks; flavor of shabu-shabu and strip-loin steaks from Wagyu were rated

more desirable than the flavor of others (Busboom et al., 1992). However, other recent studies have indicated that panelists preferred USDA Prime and High Choice samples over Wagyu beef (O'Quinn et al., 2015). Consumer preference has been inconclusive when comparing Wagyu with other beef breeds.

Variation in Muscle

Muscle to muscle flavor has been studied extensively; results regarding consumer preference are inconclusive. When measuring beef flavor intensity, researchers ask the consumer to rate how much of the brown, roasted, aromatic flavor associated with beef is apparent after approximately 10 chews (Carmack et al., 1995). Carmack et al. (1995) concluded that the *Biceps femoris* had the most intense beef flavor, followed by the *Psoas major* (tenderloin), while the *Longissimus lumborum* (striploin) was perceived to be more intermediate in terms of flavor intensity and *Pectoralis profundis* (brisket) and *Supraspinatus* (mock tender) had the least intense beef flavor. Agreeing with this study, Jeremiah et al. (2003) also found that the *Biceps femoris,* along with the *Transversus abdominus* (skirt) and *Infraspinatus* (flat iron) had the most intense beef flavor from an experienced panel, while the *Longissimus lumborum* and *Semitendinosus* (eye of round) had the blandest flavor. Furthermore, the *Psoas major* had the most desirable beef flavor while the *Pectorals profundis, Transversus abdominus,* and *Intercostales* (short ribs) had the least desirable flavor (Jeremiah et al., 2003). This latter finding contradicted other studies in which beef flavor intensity was highest for *Longissimus lumborum* and lowest in *Psoas major* (Rhee et al., 2004 and Shackelford et al., 1995). Legako et al. (2015) found that the *Psoas major* has significantly higher amounts of acetaldehyde and dimethyl sulfide when compared to other muscles. In conclusion, flavor variation among differing muscles is small and is different panel-to-panel and study-to-study.

Amino Acids Associated with Beef Flavor

Free amino acids contribute to the overall flavor of beef upon heating due to their participation in the Maillard reaction (Hornstein and Crowe, 1960, Kramlich and Pearson, 1958 and Macy et al., 1964). The browning that occurs is due to the interaction of the amine group of the specific amino acids and heat (Kerth and Miller, 2013). Amino acids play the most important role during the Maillard reaction by interacting with volatile compounds in the Strecker degradation (Calkens and Hodgens, 2007, Thorpe and Baynes, 2003). Amino acids have carbonyl and amine groups removed, forming aldehydes, and dicarbonyl is converted to aminoketone or aminoalcohol (Kerth and Miller, 2013). Cysteine leads to the production of hydrogen sulfide, ammonia, and acetaldehyde which lead to further flavors classes of furans, pyrazines, pyrroles, oxazoles, thiophenes, thiazoles, and other heterocyclic compounds (Kerth and Miller, 2013). Degradation of alanine, isoleucine, leucine, methionine, phenylalanine, and valine leads to the development of the volatiles acetaldehyde, 2-methylbutanal, 3-methylbutanal, methional, and phenylacetaldehyde (Cerny, 2007). Very little further research has been presented in identifying specific amino acids and their overall contribution to beef flavor due to their volatile precursor prevalence.

Volatiles Associated with Beef Flavor

The major precursors associated with meat flavor are in two categories: water soluble components and lipids (Mottram, 1998). There are two major reactions that occur during cooking that result in the production of aroma volatiles; these reactions are the Maillard reaction between amino acids and reducing sugars and the thermal degradation of lipids (Mottram, 1998). The main water soluble precursors are free sugars, sugar phosphates, nucleotide-bound sugars, free amino acids, peptides, nucleotides, other nitrogenous components, such as thiamin

(Mottram, 1998). There are several hundred compounds derived originally from lipid degradation that are in cooked meat (Mottram, 1998). These compounds generally result from oxidation of fatty acids (Mottram, 1998).

In terms of the Maillard reaction, interaction of these compounds with amines, amino acids, aldehydes, hydrogen sulfide, and ammonia (Mottram, 2007). The Strecker degradation is very important to flavor generation because it provides routes by which nitrogen and sulfur can be introduced into heterocyclic compounds (Mottram, 2007). These heterocyclic compounds provide a rich source of intermediates for further flavor forming reactions including furans and pyrazines (Mottram, 2007). Figure 1 shows the volatiles formed from the Maillard reaction that is associated with beef flavor.

Volatiles that are generally associated with beefy/meaty flavors include 1, 2-methyltridecanal, 2-methyl-3-methylthiofuran, 4-hydroxy-5-methyl-3-furanone; bis-disulfide and 2-methyl-3-furanthiol are both associated with roasted meat flavor. At times, beef can also be classified as being grassy, especially those cattle that are primarily fed on grass during their lifetime. These grassy flavors are generally from hexanal and heptanal with a more nutty flavor coming from methylpyrazine, 2, 5-dimethylpyrazine, and all other pyrazines. Finally, the compounds associated with a more buttery, fat, or tallow flavor are Nona-2-enal and 3-hydroxy-2-butanone (Rowe, 2002; Mottram, 1998; Shahidi, 1998; Guth and Grosch, 1994; MacLeod, 1994; Maga, 1994; Spanier and Miller, 1993; Spanier et al., 1992; Ha and Lindsay, 1991; Gasser and Grosh, 1988). Lower quantities of intramuscular fats generally lead to increases in volatile compounds due to the solubility of volatile aroma compounds in lipids (Legako et al., 2015, Chevance et al., 2000, Chevance and Farmer, 1999).

Olfactometry and Volatile Components

Cells in the olfactory bulb are highly sensitive and can identify one-carbon differences in stimulating molecules (Shepherd, 2005). Raw meat naturally has a salty, metallic, or bloody flavor and no further flavor is identified until meat reaches 71°C, at which point numerous "meaty" odors are released (Macleod and Ames, 1986). For each aroma to be detected, a minimum threshold is established and is usually measured in parts per million or parts per billion of the compound in water (Kerth and Miller, 2013; Grosch, 1993). Lipid-derived compounds have higher thresholds than compounds with sulfur- and nitrogen-containing compounds derived from the Maillard reaction (Kerth and Miller, 2013). The most common volatile compound found in cooked beef is hexanal (Nawar, 1969). Both extrinsic and intrinsic factors affect the olfactory component of meat when cooked. Cooking method is one of the most important extrinsic factors that involve dry versus moist cooking that release differing aroma volatiles (Kerth and Miller, 2013). For dry cooking methods, the flavor profile will change considerably with cooking time and temperature (Lorenzen et al., 2003, 1999). Intrinsic factors affecting flavor include the muscle's ability to retain water; as pH increases, water-holding capacity and heat transfer ability increases (Meynier and Mottram, 1995).

Differing classifications of volatile components produce differing odors. Furans can be produced by sugar caramelization and carbohydrate degradation (Shibamoto, 1980). Furans that produce a simulated beef flavor are 3-methylfuran (canned beef), 2-ethylfuran (roast beef), and 2-acetylfuran (roast and shallow fried beef); (Min et al., 1979; Persson and von Sydow, 1973; Watanabe and Sato, 1972). Sulphur containing compounds are important in cooked beef as heterocyclic sulphur compounds are described as having meat-like aromas (Mottram, 1994). The major sulphur compound is methanethiol, which can be detected at very low concentration due to

its low odor threshold; it is generally considered to be the primary odor in stewed beef juice (Guth and Grosch, 1994). Nitrogen-containing compounds that are associated with odor are in the pyrazine class of compounds (Moon et al., 2006). Pyrazines are one of the main components in cooked meats as most are produced from the Strecker degradation by interacting with the nitrogen groups of amino acids and dicarbonyls (Moon et al., 2006). Pyrazines are generally described at nutty, roasted, or burnt and those compounds include 2,5-dimethyl pyrazine and 2-ethyl-3,6-dimehtylpyrazine (Moon et al., 2006). Aldehydes are compounds that not only give a beef aroma but also react with other compounds to produce odors in amino-carbonyl reactions (Moon et al., 2006). Major aldehydes present in beef are hexanal, heptanal, octanal, nonanal, benzaldehyde, and pentanal (Moon et al., 2006).

Overall, many positive and negative odors are associated with differing volatile compounds. Positive compounds associated with odor are 2, 3-butanedione, 2-butanone, heptanal, 2, 3-diethyl-5-methylpyrzaine, 2, 3-pentanedione and nonanal (Machiels et al., 2004). Compounds associated with unacceptable odor are dimethyl sulfide, hexanal, and octanal (Machiels et al., 2004).

Fatty Acids Associated with Beef Flavor

Variation in fatty acid composition has an effect on firmness or softness of the fat in meat, especially the subcutaneous and intermuscular fats (Wood et al., 2004). There are also differences among muscles dependent on muscle fiber type; red muscles have a higher proportion of cell membranes, hence, phospholipids compared to white fibers, and therefore have a higher concentration of PUFA (Wood et al., 2004). Overall, the effect of fatty acids on meat flavor is due to the production of volatile, odorous, lipid oxidation products during cooking and the Maillard reaction to form other volatiles (Wood et al., 2004). Most fatty acids have little or

variable effect on beef flavor, but oleic acid (18:1) is correlated in a positive manner when presented to a semi-trained panel (Melton et al., 1982; Westerling and Hedrick, 1979l; Dryden et. al, 1970). Oleic acid is the most abundant fatty acid in a beef animal and constitutes most of the MUFA concentration as well as 45.5% of total fatty acids in beef top loin (Garmyn et al., 2001).

Diet is one of the major contributors to the types and amount of fatty acids present in cattle; as concentrations of n-3 PUFA were greatly affected by what the animal was eating (Wood et al., 2004). Results showed that samples with high n-3 PUFA concentrations had higher concentrations of lipid degradation, particularly in saturated and unsaturated aldehydes, alcohols, and ketones (Wood et al., 2004). Aldehydes are important because of their low odor thresholds which are thought to be the reason for changes of beef flavor (Elmore et al., 1999). It has been suggested that free radicals formed from n-3 PUFA cause oxidation of the abundant fatty acids present (Elmore et al., 1999). In a study conducted by Wood et al. (1999), the odor profiles between 18:1, 18:2, and 18:3 were considerably different. Odor profiles from 18:3 (n-3 PUFA) had much higher scores for a fishy off flavor, as well as grassy (Wood et al., 1999).

In terms of saturated fatty acids, lauric (12:0) is fairly minute and no concentration difference is found between grass and grain fed animals. Similar to lauric, arachidic (20:0) is present in low concentrations; however, a much higher concentration is present in grass fed animals (Alfaia et al., 2009; Leheska et al., 2008). Myristic acid (14:0) is at higher concentrations in grain fed animals (Alfaia et al., 2009; Leheska et al., 2008; Ponnampalam et al., 2006; and Realini et al., 2004). Palmitic acid (16:0) concentrations are increased in grain fed animals and this is the most abundant saturated fatty acid in beef (Alfaia et al., 2009; Nuernberg et al., 2008; Realini et al., 2007; Ponnampalam et al., 2006). Steric acid (18:0) is the second most abundant saturated fatty acid and there are higher concentrations associated with grass finished

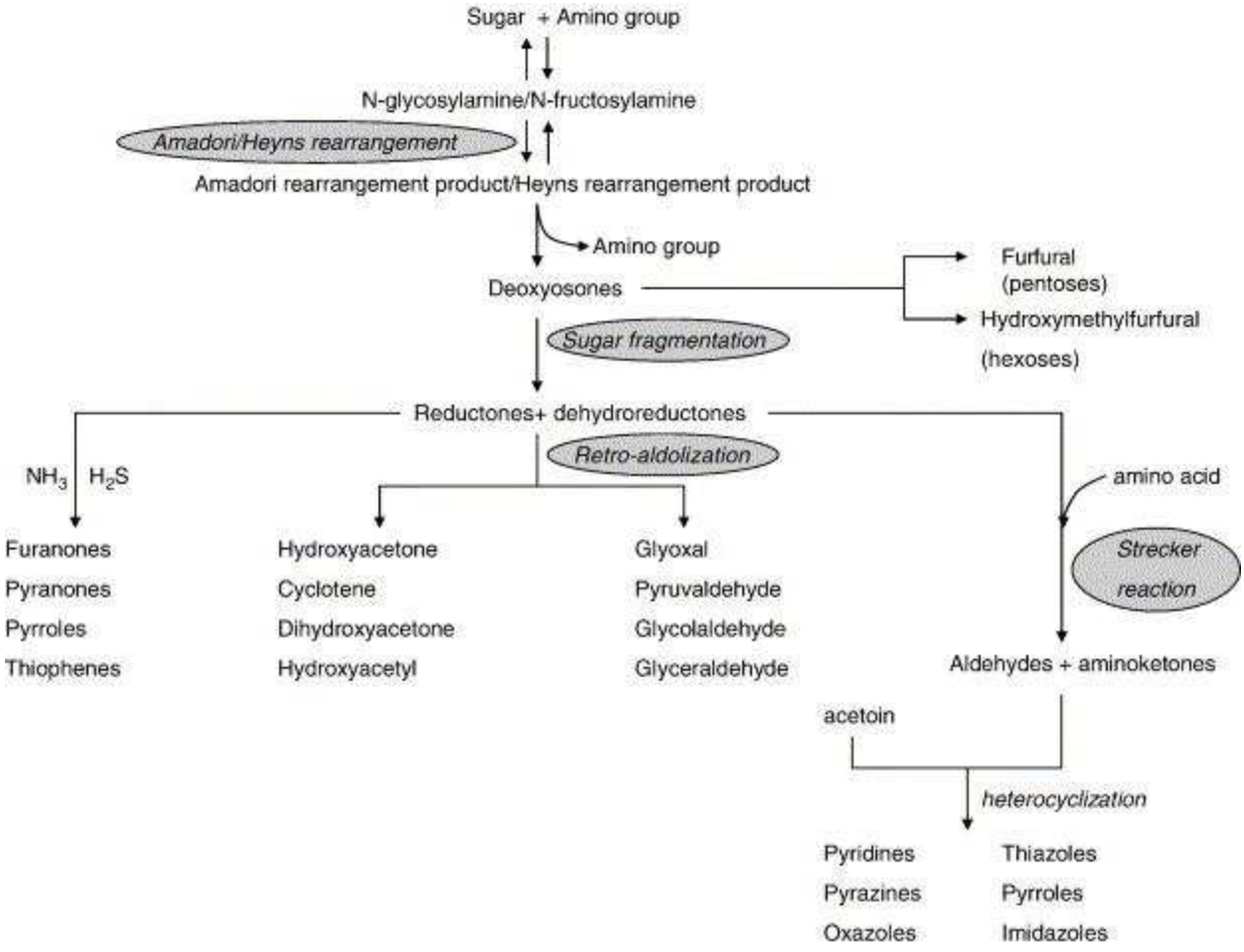
animals (Alfaia et al., 2009; Leheska et al., 2008; Garcia et al., 2008; Nuernberg et al., 2005; Realini et al., 2004). Furthermore, palmitic, steric, and linoleic acid are negatively correlated with flavor (Westerling and Hedrick, 1979).

Fatty acid concentration differences among beef breeds exist; however, breed type has the smallest effect on total beef fat and fatty acid composition (Smith et al., 2009). Brahman cattle have been shown to contain a greater proportion of MUFA and less SFA than British type steers such as Hereford and Angus (Huerta-Leidenz et al., 1993). However, these results are inconclusive as other studies have found no differences between the two types of cattle (Smith et al., 2009). This is not the same scenario for Japanese Wagyu and Korean Hanwoo cattle as they both exhibit high MUFA: SFA ratios in muscle and adipose tissues (Jung and Choi, 2003).

Conclusion

Flavor is one of the three major palatability traits that are associated with beef. Industry representatives found flavor to rank as the number 1 or number 2 most important attributes to continue to eat beef (Igo et al., 2013). Flavor is generally divided into three sensory systems: gustatory, olfactory, and trigeminal. These three systems indicate taste, odor, and aroma for all types of foods (Farmer 1994; Idolo & Spanier, 1994b; Civille & Szczesniak, 1973). The development of these flavors is generally divided in to two reactions: Maillard Reaction and lipid oxidation. The Maillard Reaction is nonenzymatic browning that gives beef its aromatic odor and flavor that ultimately yields production of hundreds of thousands of volatile compounds (Farmer, 1992). Lipid and pigment oxidation occurs when heat is added or when meat is stored for long periods of time and can give rise to both desirable and undesirable flavors (Mottram and Leseigneur, 1990). Many factors affect how beef will taste and produce many different volatile and fatty acid compounds. Time on feed, breed type, and muscle variation will be reviewed to

determine what factors have a direct effect on the overall flavor. Presently, an increased number of days on feed have been shown to increase the overall probability of consumers eating beef with a desirable flavor (Tatum et al., 1980). Breed type has shown to have little significance on the flavor attributes of beef except with Wagyu cattle that tend to have a much higher degree of intramuscular fat which contributes to a richer, more intense beef flavor (Jeremiah and Gibson, 1999; Busboom et al., 1992; Ramsey et al., 1963). Finally, it is still unclear if there are differences in muscle to muscle flavor attributes as studies have been very contradictory (Rhee et al., 2004 and Shackelford et al., 1995).



(Figure 1: van Boekel, 2006)

LITERATURE CITED

Alfaia, C. P. M., M.L. F. Castro, S.I.V. Martins, A.P.V. Portugal, S.P.A Alves, C.M.G. A. Fontes, R.J.B Bessas, & J.A.M. Prates (2009). "Effect of the feeding system on intramuscular fatty acids and conjugated linoleic acid isomers of beef cattle, with emphasis on their nutritional value and discriminatory ability." Food Chemistry **114**(3): 939-946.

Barham, P., Edwards, J. S., & Schafheitle, J. M. (2001). The science of cooking. *Food Service Technology*, *1*(3-4), 183-184.

Brewer, M. S. (2007). "The Chemistry of Beef Flavor." Retrieved 8/11/2014, from http://beefresearch.org/CMDocs/BeefResearch/The%20Chemistry%20of%20Beef%20Flavor.pdf

Burson, D., M.C. Hunt, D. M. Allen, C.L. Kastner, and D.H. Kropf. (1980). Diet energy density and time on feed effects on beef longissimus muscle palatability, American Society of Animal Science.

Busboom, J. R., P.S. Kuber, E.J. Huff-Lonergan, S.K. Duckett, P.S. Mir(1993). "Effects of biological source on cooking and palatability attributes of beef produced for the Japanese market." Meat Science **35**(2): 241-258.

Calkins, C. and J. Hodgen (2007). "A fresh look at meat flavor." Meat Science **77**(1): 63-80.

Carmack, C. F., C.L. Kastner, M.E. Dikeman, J.R. Schwenke, & C.M. Garcia Zepeda. (1995). "Sensory evaluation of beef-flavor-intensity, tenderness, and juiciness among major muscles." Meat Science **39**(1): 143-147.

Cerny, C., & Guntz-Dubini, R. (2007). Formation of aroma compounds in the Maillard reaction of xylose, cysteine and thiamine. In Poster presentation at the 8th Wartburg Flavor Symposium. Eisenach, February (Vol. 28).

Chandrashekar, J., M.A. Hoon, N.J. Ryba, C.S. Zuker (2006). "The receptors and cells for mammalian taste." Nature **444**(7117): 288-294.

Chevance, F. F., Farmer, L. J., Desmond, E. M., Novelli, E., Troy, D. J., & Chizzolini, R. (2000). Effect of some fat replacers on the release of volatile aroma compounds from low-fat meat products. Journal of agricultural and food chemistry, 48(8), 3476-3484.

Chevance, F. F., & Farmer, L. J. (1999). Identification of major volatile odor compounds in frankfurters. *Journal of agricultural and food chemistry*, *47*(12), 5151-5160.

Civille, G. V. and A. S. Szczesniak (1973). "Guidelines To Training A Texture Profile Panel." Journal of Texture Studies **4**(2): 204-223.

Daley, C. A., A. Abbott, P.S. Doyle, G.A. Nader, & S. Larson (2010). "A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef." Nutrition journal **9**(1): 10.

Descalzo, A.M., E.M. Insani, A. Biolatto, A.M. Sancho, P.T. Garcia, N.A Pensel, J.A. Josifovich (2005). "Influence of pasture or grain-based diets supplemented with vitamin E on antioxidant/oxidative balance of Argentine beef." Meat Science **70**(1): 35-44.

Marchello, J. A., Vavra, M., Dryden, F. D., & Ray, D. E. (1970). Influence of sex on certain constituents of bovine muscles. *Journal of Animal Science*, *31*(4), 707-712.

Duckett, S.K., D.G. Wagner, L.D. Yates, H.G. Dolezal, & S.G. May (1993). "Effects of time on feed on beef nutrient composition." Journal of Animal Science **71**(8): 2079-2088.

Garmyn, A. J., G.G. Hilton, R.G. Mateescu, J. B. Morgan, J.M. Reecy, R.G. Tait, D.C. Beitz, Q. Duan, J.P. Schoomaker, M.S. Mayes, M.E. Drewnoski, Q. Liu, & D.L. VanOverbeke. (2011). Estimation of relationships between mineral concerntation and fatty acid composition of longissimus muscle and beef palatability traits. *Journal of Animal Science, 89*(9), 2849-2858.

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

Farmer, L. J. (1994). "The role of nutrients in meat flavour formation." Proceedings of the nutrition society **53**(02): 327-333.

Farmer, L. J. (1992). The Chemistry of Muscle Based Foods. Cambridge, The Royal Society of Chemistry.

Farmer, L. J. and D. S. Mottram (1990). "Interaction of lipid in the Maillard reaction between cysteine and ribose: the effect of a triglyceride and three phospholipids on the volatile products." Journal of the Science of Food and Agriculture **53**(4): 505-525.

Frankel, E. (1980). "Lipid oxidation." Progress in lipid research **19**(1): 1-22.

Garcia, P.T., N.A. Pensel, A.M. Sancho, N.J. Latimori, A.M. Kloster, M.A. Amigone, and J.J. Casal (2008). "Beef lipids in relation to animal breed and nutrition in Argentina." Meat Science **79**(3): 500-508.

Gasser, U., and W. Grosh (1988). "Identification of volatile flavour compounds with high aroma values from cooked beef." Zeitschrift für Lebensmitteluntersuchung und - Forschung A (186): 489-494.

Grosch, W. (1993). "Detection of potent odorants in foods by aroma extract dilution analysis." Trends in Food Science & Technology **4**(3): 68-73.

Grosch, W., M. Czerny, F. Mayer, and A. Moors (2000). Sensory studies on the key odorants of roasted coffee. Washington, DC, ACS Publications.

Grosh, W. (1982). Lipids degradation products and flaVor. *Food FlaVours Part A*, 325-398.

Guth, H., & Grosch, W. (1994). Identification of the character impact odorants of stewed beef juice by instrumental analyses and sensory studies. *Journal of Agricultural and Food Chemistry*, *42*(12), 2862-2866.

Ha, J. and R. Lindsay (1991). "Volatile alkylphenols and thiophenol in species-related characterizing flavors of red meats." Journal of Food Science **56**(5): 1197-1202.

Harris, J. J., D.K. Lunt, S.B. Smith, W.L. Mies, D.S. Hale, M. Koohmaraie, and J.W. Savell (1997). "Live animal performance, carcass traits, and meat palatability of calf- and yearling-fed cloned steers." Journal of Animal Science **75**(4): 986-992.

Harrison, A. R.,M.E. Smith, D.M. Allen, M.C. Hunt, C.L. Klastner, and D.H. Kroft(1978). "Nutritional Regime Effects on Quality and Yield Characteristics of Beef." Journal of Animal Science **47**(2): 383-388.

Hartman, G. J. (1983). "Nitrogen-containing heterocyclic compounds identified in the volatile flavor constituents of roasted beef." Journal of Agricultural and Food Chemistry **31**(5): 1030-1033.

Hornstein, I and P. F. Crowe "Meat Flavor Chemistry, Flavor Studies on Beef and Pork" *Journal of Agricultural and Food Chemistry* **1960** *8* (6), 494-498

Huang, A. L., X. Chen, M.A. Hoon, J. Chandrashekar, W. Guo, D. Trankner, N.J.P. Ryba, & C.S. Zuker(2006). "The cells and logic for mammalian sour taste detection." Nature **442**(7105): 934-938.

Huerta-Leidenz, N., H.R. Cross, J.W. Savell, D.K. Lunt, J.F. Baker, & S.B. Smith (1996). "Fatty acid composition of subcutaneous adipose tissue from male calves at different stages of growth." Journal of Animal Science **74**(6): 1256-1264.

Huffman, K.L., M.F. Miller, L.C. Hoover, C.K. Wu, H.C. Brittin, & C.B. Ramsey (1996). "Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant." Journal of Animal Science **74**(1): 91-97.

Idolo Imafidon, G. and A. M. Spanier (1994). "Unraveling the secret of meat flavor." Trends in Food Science & Technology **5**(10): 315-321.

Igo, J.L., D.L. VanOverbeke, D.R. Woerner, J.D. Tatum, D.L. Pendell, L.L. Vedral, G.G. Mafi, M.C. Moore, R.O. McKeith, G.D. Gray, D.B. Griffin, D.S. Hale, J.W. Savell, & K.E. Belk(2013). "Phase I of The National Beef Quality Audit-2011: Quantifying willingness-to-pay, best-worst scaling, and current status of quality characteristics in different beef industry marketing sectors." Journal of Animal Science **91**(4): 1907-1919.

Ishimaru, Y., H. Inada, M. Kubota, H. Zhuang, M. Tominaga, & H. Matsunami (2006). "Transient receptor potential family members PKD1L3 and PKD2L1 form a candidate sour taste receptor." Proceedings of the National Academy of Sciences **103**(33): 12569-12574.

Jeremiah, L.E , L.L. Gibson, J. L. Aalhus, and M.E.R. Dugan (2003). "Assessment of the relationship between chemical components and palatability of major beef muscles and muscle groups." Meat Science **65**(3): 1013-1019.

Jeremiah, L. and L. Gibson (1999). "The Influence Of Genotype On Beef Palatability And Cooking Properties. An Evaluation Of Wagyu F1 Crosses And Other Genotypes Under North American Feedlot Conditions." Journal of Muscle Foods **10**(2): 177-194.

Johnson, D. D., R.D. Huffman, S.E. Williams, & D.D. Hargrove (1990). "Effects of percentage Brahman and Angus breeding, age-season of feeding and slaughter end point on meat palatability and muscle characteristics." Journal of Animal Science **68**(7): 1980-1986.

Jung, M. Y.(2003). Method for the reduction of acrylamide formation, Google Patents.

Kerth, C.R. and R. K Miller (2013). "Beef Flavor: A review from chemistry to consumer." Beef Research White Paper: Product Quality

Koch, R. M., M.E. Dikeman, & J.D. Crouse(1982). "Characterization of Biological Types of Cattle (Cycle III).III. Carcass Composition, Quality and Palatability." Journal of Animal Science **54**(1): 35-45.

Koch, R. M., M.E. Dikeman, D.M. Allen, M. May, J.D. Crouse, & D.R. Campion(1976). "Characterization of Biological Types of Cattle III. Carcass Composition, Quality and Patability." Journal of Animal Science **43**(1): 48-62.

Kramlich, W. E. and Pearson, A. M. (1958), "Some Preliminary Studies on Meat Flavor." Journal of Food Science, 23: 567–574.

Ladikos, D. and V. Lougovois (1990). "Lipid oxidation in muscle foods: A review." Food Chemistry **35**(4): 295-314.

Lawrie, R. (1985). Meat Science (4th), Oxford, UK: Pergamon Press.

Leheska, J.M., L.D. Thompson, J.C. Howe, E. Hentges, J. Boyce, J.C. Brooks, B. Shriver, L. Hoover, and M.F. Miller (2008). "Effects of conventional and grass-feeding systems on the nutrient composition of beef." Journal of Animal Science **86**(12): 3575-3585.

Lindemann, B. (2000). "A taste for umami." Nature neuroscience **3**(2): 99-100.

Legako, J. F., Dinh, T. T. N., Miller, M. F., & Brooks, J. C. (2015). Effects of USDA beef quality grade and cooking on fatty acid composition of neutral and polar lipid fractions. *Meat science*, *100*, 246-255.

Lorenzen, C. L., Miller, R. K., Taylor, J. F., Neely, T. R., Tatum, J. D., Wise, J. W., & Savell, J. W. (2003). Beef customer satisfaction: Trained sensory panel ratings and Warner-Bratzler shear force values. *Journal of Animal Science*, *81*(1), 143-149.

Lorenzen, C. L., T.R. Neely, R.K. Miller, J. D. Tatum, J.W. Wise, J.F. Taylor, M.J. Buyck, J.O. Reagan, and J.W. Savell (1999). "Beef customer satisfaction: cooking method and degree of doneness effects on the top loin steak." Journal of Animal Science **77**(3): 637-644.

MacLeod, G. (1994). The Flavor of Beef. London, Blackie Academic and Professional**:** 4-37.

Macleod, G. and J. M. Ames (1986). "The effect of heat on beef aroma: comparisons of chemical composition and sensory properties." Flavour and fragrance journal **1**(3): 91-104.

MacLeod, G., M. Seyyedain-Ardebili, & S.S. Chang (1981). "Natural and simulated meat flavors (with particular reference to beef)." Critical Reviews in Food Science & Nutrition **14**(4): 309-437.

Macy, R. L., Naumann, H. D. and Bailey, M. E. (1964), Water-Soluble Flavor and Odor Precursors of Meat. II. Effects of Heating on Amino Nitrogen Constituents and Carbohydrates in Lyophilized Diffusates from Aqueous Extracts of Beef, Pork, and Lamb. Journal of Food Science, 29: 142–148.

Machiels, D., Istasse, L., & van Ruth, S. M. (2004). Gas chromatography-olfactometry analysis of beef meat originating from differently fed Belgian Blue, Limousin and Aberdeen Angus bulls. *Food chemistry*, *86*(3), 377-383.

Maga, J. (1994). Umami flavour of meat. Flavor of meat and meat products, Springer**:** 98-115.

Mandell, I. B., Buchanan-Smith, J. G., & Campbell, C. P. (1998). Effects of forage vs grain feeding on carcass characteristics, fatty acid composition, and beef quality in Limousin-cross steers when time on feed is controlled. *Journal of Animal Science*, *76*(10), 2619.

May, S. G., H.G Dolezal, D.R. Gill, F.K. Ray, & D.S. Buchanan (1992). "Effect of days fed, carcass grade traits, and subcutaneous fat removal on postmortem muscle characteristics and beef palatability." Journal of Animal Science **70**(2): 444-453.

McKenna, D.R., C.L. Lorenzen, K.D. Pollok, W.W. Morgan, W.L. Mies, J.J. Harris, R. Murphy, M. McAdams, D.S. Hale, and J. W. Savell (2004). "Interrelationships of breed type, USDA quality grade, cooking method, and degree of doneness on consumer evaluations of beef in Dallas and San Antonio, Texas, USA." Meat Science **66**(2): 399-406.

Melton, S. L. (1990). Effects of feeds on flavor of red meat: a review. *Journal of animal science*, *68*(12), 4421-4435.

Melton, S. L., Amiri, M., Davis, G. W., & Backus, W. R. (1982). Flavor and chemical characteristics of ground beef from grass-, forage-grain-and grain-finished steers. *Journal of Animal Science*, *55*(1), 77-87.

Melton, S. L., Black, J. M., Davis, G. W., & Backus, W. R. (1982). Flavor and selected chemical components of ground beef from steers backgrounded on pasture and fed corn up to 140 days. *Journal of Food Science*, *47*(3), 699-704.

Meynier, A., & Mottram, D. S. (1995). The effect of pH on the formation of volatile compounds in meat-related model systems. *Food Chemistry*, *52*(4), 361-366.

Min, D., Ina, K., Peterson, R. J., & Chang, S. S. (1979). Preliminary identification of volatile flavor compounds in the neutral fraction of roast beef. *Journal of Food Science*, *44*(3), 639-642.

Monsón, F.C., C. Sanudo, & I. Sierra (2005). "Influence of breed and ageing time on the sensory meat quality and consumer acceptability in intensively reared beef." Meat Science **71**(3): 471-479.

Moody, W. G. (1983). "Beef flavor-a review." Food technology **37**(5): 227

Moody, W. (1976). Quantitative and qualitative differences in beef from various energy regimes. Proc. Recip. Meat Conf.

Moon, S. Y., Cliff, M. A., & Li-Chan, E. C. (2006). Odour-active components of simulated beef flavour analysed by solid phase microextraction and gas chromatography–mass spectrometry and–olfactometry. *Food Research International*, *39*(3), 294-308.

Mottram, D. S. (2007). The Maillard reaction: source of flavour in thermally processed foods. Flavours and Fragrances, Springer**:** 269-283.

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

Mottram, D. (1996). "The role of phospholipids in meat flavor: an overview."

Mottram, D. S. and M. S. Madruga (1994). Important sulfur-containing aroma volatiles in meat. ACS symposium series (USA).

Mottram, D. S. and F. B. Whitfield (1994). Aroma volatiles from meatlike Maillard systems. ACS symposium series (USA).

Mottram, D. S. (1993). "Flavor compounds formed during the Maillard Reaction Thermally generated flavors." American Chemical Society(ACS Symposium Series No. 543): 104-126.

Mottram, D. S., & Leseigneur, A. (1990). The effect of pH on the formation of aroma volatiles in meat-like Maillard systems. *Flavour Science and Technology*, 121-124.

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

Nawar, W. W. (1985). Chemistry of thermal oxidation of lipids. *Flavor chemistry of fats and oils*, 39-60.

Nawar, W. W. (1969). Thermal degradation of lipids. *Journal of Agricultural and Food Chemistry*, *17*(1), 18-21.

Neely, T.R., C.L. Lorenzen, R.K. Miller, J.D. Tatum, J.W. Wise, J.F. Taylor, M.J. Buyck, J.O. Reagan, and J.W. Savell (1999). "Beef customer satisfaction: cooking method and degree of doneness effects on the top round steak." Journal of Animal Science **77**(3): 653-660.

Nuernberg, K., D. Dannenberger, G. Nuernberg, K. Ender, J. Voigt, N.D. Scollan, J.D. Wood, G.R. Nute, & R.I. Richardson (2005). "Effect of a grass-based and a concentrate feeding system on meat quality characteristics and fatty acid composition of< i> longissimus</i> muscle in different cattle breeds." Livestock Production Science **94**(1): 137-147.

O'Quinn, T.G., J.C. Brooks, R.J. Polkinghorne, A.J. Garmyn, B.J. Johnson, J.D. Starkey, R. J. Rathmann, & M.F. Miller (2012). "Consumer assessment of beef strip loin steaks of varying fat levels." Journal of Animal Science **90**(2): 626-634.

Persson, T., & Sydow, E. (1973). Aroma of canned beef: gas chromatographic and mass spectrometric analysis of the volatiles. *Journal of Food Science*, *38*(3), 377-385.

Ponnampalam, E., Mann, N., & Sinclair, A. (2006). Effect of feeding systems on omega-3 fatty acids, conjugated linoleic acid and trans fatty acids in Australian beef cuts: potential impact on humnan health. *Asia Pacific Journal of Clinical Nutrition*, *15*(1), 21-29.

Ramsey, C.B., J.W. Cole, B.H. Meyer, & R.S. Temple (1963). "Effects of type and breed of British, Zebu and dairy cattle on production, palatability and composition. II. Palatability differences and cooking losses as determined by laboratory and family panels." Journal of Animal Science **22**(4): 1001-1008.

Realini, C.E., S.K. Duckett, G.W. Brito, M. Dalla Rizza, and D. De Mattos (2004). "Effect of pasture vs. concentrate feeding with or without antioxidants on carcass characteristics, fatty acid composition, and quality of Uruguayan beef." Meat Science **66**(3): 567-577.

Rhee, K. S., T.L. Wheeler, S.D. Shackelford, & M. Koohmaraie (2004). "Variation in palatability and biochemical traits within and among eleven beef muscles." Journal of Animal Science **82**(2): 534-550.

Rowe, D. (2002). "High impact aroma chemicals." Special Publication-Royal Society Of Chemistry **277**: 202-226.

Savell, J.W., C.L. Lorenzen, T.R. Neely, R.K. Miller, J.D. Tatum, J.W. Wise, J.F. Taylor, M.J. Buyck, & J. O. Reagan (1999). "Beef customer satisfaction: cooking method and degree of doneness effects on the top sirloin steak." Journal of Animal Science **77**(3): 645-652.

Shackelford, S. D., Koohmaraie, M., & Wheeler, T. L. (1995). Effects of slaughter age on meat tenderness and USDA carcass maturity scores of beef females. *Journal of animal science*, *73*(11), 3304-3309.

Shahidi, F. (1994). Flavor of meat and meat products - an overview. In: F. Shahidi (ed.) Flavor of Meat and Meat Products. p 1-3. Blackie Academic and Professional,London.

Shahidi, F., L. J. Rubin, L. A. D'Souza, R. Teranishi, and R. G. Buttery. (1986). Meat flavor volatiles: A review of the composition, techniques of analysis, and sensory evaluation. C R C Critical Reviews in Food Sci. and Nutrition 24: 141-243.

Shepherd, G. M. (2005). Perception without a thalamus: How does olfaction do it?. *Neuron, 46*(2), 166-168.

Shibamoto, T. (1980). Heterocyclic compounds found in cooked meats. *Journal of agricultural and food chemistry*, *28*(2), 237-243.

Smith, S. B., C.A. Gill, D.K. Lunt, and M.A. Brooks (2009). "Regulation of fat and fatty acid composition in beef cattle." Asian-Australasian Journal of Animal Sciences **22**(9): 1225-1233.

Spanier, A. and J. Miller (1993). Role of proteins and peptides in meat flavor. ACS symposium series (USA).

Spanier, A.M., J.R. Vercellotti, & C. J. James (1992). "Correlation of sensory, instrumental and chemical attributes of beef as influenced by meat structure and oxygen exclusion." Journal of Food Science **57**(1): 10-15.

Tatum, J. D., G.C. Smith, B.W. Berry, C.E. Murphey, F.L. Williams, & Z.L. Carpenter (1980). "Carcass Characteristics, Time on Feed and Cooked Beef Palatability Attributes." Journal of Animal Science **50**(5): 833-840.

Tims, M. J. and B. M. Watts (1958). "Protection of cooked meats with phosphates." Food technology **12**(5): 240-243.

Thorpe S.R., J.W. Baynes (2003). "Maillard reaction products in tissue proteins: New products and new perspectives." Springer-Verland Amino Acids .

Umami Information Center (2015). "Umami Information Leaflet." Tokyo, Japan. www.umamiinfo.com

Van Boekel, M. (2006). "Formation of flavour compounds in the Maillard reaction." Biotechnology advances **24**(2): 230-233.

Van der Linde, L. (1979). "Volatile compounds from thermally degraded thiamin." Progress in flavour research: 219-224.

Watanabe, K., & Sato, Y. (1972). Shallow-fried beef. Additional flavor components. *Journal of Agricultural and Food Chemistry*, *20*(2), 174-176.

Westerling, D. B. and H. Hedrick (1979). "Fatty acid composition of bovine lipids as influenced by diet, sex and anatomical location and relationship to sensory characteristics." Journal of Animal Science **48**(6): 1343-1348.

Wood, J. D., R.I. Richardson, G.R. Nute, A.V. Fisher, M.M. Campo, E. Kasapidou, P.R. Sheard, & M. Enser (2004). "Effects of fatty acids on meat quality: a review." Meat Science **66**(1): 21-32.

Wood, J. D., Enser, M., Fisher, A. V., Nute, G. R., Richardson, R. I., & Sheard, P. R. (1999). Manipulating meat quality and composition. *Proceedings of the nutrition society*, *58*(02), 363-370.

CHAPTER 3

MATERIALS AND METHODS

The objective of this study was to determine differences among beef flavor attributes and their associations with cattle type and muscle differences. To achieve this ground beef patties with fat trimmings from five cattle types and lean from three whole muscle cuts were created at three different lean percentages (90%, 80%, and 70%). Table 1 demonstrates the differing cattle types and lean types. Each blend that was created was replicated five times. Collection of fat samples took place at three processing plants in three different states and lean samples were collected at one plant and all samples were sent to Colorado State University for creation of blends and patties for subsequent testing.

Beef Source Selection

Subcutaneous brisket/sternum fat was collected from carcasses in commercial beef processing plants that processed cattle that represented the proposed variation in cattle type and days-on-feed (DOF). Fat sample came from F1-Wagyu Angus, long-finished (Natural) Holstein, short-finished (Retail) Holstein, long-fed (Conventional) beef, and short-fed beef. All cattle were fed on separate diets at different locations throughout the country. The F1-Wagyu Angus cross cattle originated from two separate feedlots and the amount of fat used from each source was equally dispersed among replications; cattle were fed for 490 days and 426 days at the two feedlots. The long-fed (Natural) Holstein cattle were on feed for 334 days and originated from a single feedlot. The short-fed Holstein cattle were on feed for 250 days in a single feedlot. Both the long-fed and short fed conventionally raised beef cattle were fed in separate feedlots. The long-fed beef cattle were on feed for 201 days and the short-fed beef cattle were on feed for 90

days. Fat samples were vacuum packaged on site and were allowed to chill before any other processing occurred. Fat samples aged for seven days in a dark, chilled environment before grinding and freezing.

Lean sources were randomly selected from USDA Select carcasses during normal processing fabrication. Approximately 600 pounds of each product was collected for *Psoas major* (PM; Full Tenderloin, NAMP 190), *Longissimus lumborum* (LD; Boneless Strip Loin, NAMP 180), and *Pectorales profundi* (PP; Brisket Flats, NAMP 120A). Cuts within the USDA Select grade were chosen to minimize the amount of intramuscular fat processed during grinding to isolate lean attributes only. Lean sources were aged for seven days in a dark, chilled environment before grinding and freezing.

Coarse Grinding

Before grinding in order to obtain a "pure" fat sample, each fat trimming batch was completely trimmed devoid of all excess lean and other foreign materials. For each source, fat was divided into five equal, separate batches. Each batch was ground in a 6 mm coarse grind plate, thoroughly mixed in a commercial sausage mixer for two minutes, vacuum-packaged, and frozen (-20 °C) until mixing into blends and patty formation occurred.

Lean sources were denuded of all excess fat and connective tissue to allow for pure lean samples. Each lean source was ground separately in a 6 mm coarse grind plate, thoroughly mixed in a commercial sausage mixer for two minutes. The lean was then vacuum-packaged and frozen (-20 °C) until mixing into blends and patty formation occurred.

Fine Grinding and Patty Formation

Before mixtures of lean and fat were compiled, each lean and fat batch were analyzed for fat and protein content to allow for exact percentages to be calculated for blends. Frozen fat and lean were allowed to thaw and mixtures were prepared using the fat and protein content to create six pound blends varying in lean percentages (90%, 80%, and 70%). Blends were hand mixed and passed through a 3 mm fine grind plate and mixed again using a vacuum tumbler for two minutes to allow for equal distribution of lean and fat without over-mixing. Blends were formed into one ounce (28.35 g) patties using a Patty-O-Matic® Eazy Slider (approximately 90 patties per blend) with ten patties packaged for sensory panels; twenty patties for fatty acid, amino acid, and proximate analysis; and three separately packaged patties for volatile and olfactory analysis. The remaining patties were vacuum packaged for potential further analysis. All patties were boxed and frozen (-20 °C) until sensory panels or analysis occurred. Each blend used differing batches of fat and lean for each treatment (n = 45) and was replicated five times (N = 225). Fat and lean batches were equally distributed throughout the replications.

Descriptive Sensory Analysis

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 line scale for a two-week time period.

Samples designated for sensory analysis were randomly assigned to sensory sessions so that different treatments were represented in each panel. Three panel sessions were conducted each day and panelists participated in no more than 2 sessions per day with a period of 5 h

between sessions. There were nine samples per session with nine panelists per session, so that 1 full replication representing all 45 treatments was completed in 5 sessions. This process was replicated 5 times; therefore 25 panel sessions were conducted.

Frozen patties designated for sensory analysis were tempered for 12 hours in a chilled environment at approximately 2 °C. Patties were cooked in a combination oven (Rational 5 Senses, Rational USA Inc., Rolling Meadows, IL). The oven was preheated with the cooking griddle to 232°C with 0% humidity. The ten patties were placed on the griddle and cooked for 3 minutes which allowed the patties to reach 71°C monitored by a Type 5 Thermocouple Thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation, Middlefield, CT). Immediately after cooking, patties were placed into insulated Styrofoam cups with corresponding lids. Patties were held in a warming oven at 70 °C for no longer than 30 min before being served to the panel.

During sessions, panelists were seated in a private booth, illuminated with red incandescent light to mask color differences. Each panelist was supplied with unsalted saltine crackers, unsweetened apple juice, and distilled water for palate cleansing between samples. Coffee beans were supplied to cleanse the olfactory senses of each panelist. Panelists received one (28.35 g) patty from each sample, with an opportunity to receive additional patties from the same sample, if needed, to evaluate differences in sensory attributes. Panelists evaluated 10 different flavor notes, beefy/brothy, browned/grilled flavor, buttery/beef fat flavor, bloody/serumy, grassy, earthy/mushroom, nutlike/roasted, and livery/organy. Sensory attributes of samples were quantified using an unstructured line scale anchored at both ends with descriptive terms (0 = absence of a specific flavor attribute; 100 = extreme intensity of a specific flavor attribute) on a 10.1 inch computer tablet (See Figure A3.1). After each panel session,

individual panelist's ratings were averaged to obtain a single panel rating for each sensory attribute of each sample.

Homogenization of Patties

Approximately 20 patties (600 g) per blend were split in halves for subsequent fatty acid, amino acid, and proximate analysis. Pure lean and fat samples were homogenized for each source as well. Homogenization procedures were performed in the absence of direct light and powder-free nitrile gloves were worn to prevent contamination. The 20 (half patties) were submerged in liquid nitrogen until all pieces were completely frozen. A stainless steel spoon was used to transfer the frozen samples into a 7-quart (6.62-L) Robot Coupe BLIXER 6V (Robot Coupe USA Inc., Ridgeland, MS) and blended to form a fine powder. Each sample was blended for 5 seconds on low speed (1500 rpm) and 20 seconds on high speed (3500 rpm). All samples were stored at -80 °C for nutrient analysis.

Fatty Acid Analysis

Fatty acid analysis was performed on the homogenized samples by Warren Analytical (Greeley, CO). At Warren, fatty acid methyl esters (FAMES) were prepared and analyzed as described by Phillips et al. (2010) and analyzed via lipid chromatography using Agilent (Avondale, PA) Model 6890 Series II gas chromatograph fixed with a Series 7683 injector and flame ionization detector. Separation of FAMES was performed using a fused silica capillary column with helium as the carrier gas. Individual FAMEs were quantified as a percentage of totals FAME analyzed. Extraction of neutral and polar fatty acids was performed following methods by Noci et al. (2005). Lipid extracts were dried to a constant weight under a stream of $N_{2,}$ and redissolved in 1 mL of chloroform. The lipid samples were then applied to solid-phase

extraction cartridges with 500 mg of aminopropyl packing (Bone-Elut 500 mg, 3-mL reservoir; Varian Instruments, Palo Alto, CA) previously conditioned by a 3 mL x 3 mL flush with chloroform. The neutral lipid fraction was eluted with 4 mL of chloroform and the eluate was collected. The cartridges were washed with 1 mL of 1:1 chloroform/methanol (vol/vol), followed by 5 mL of methanol to extract the polar lipid fraction.

Free Amino Acid Analysis

Following the methods of Koutsidis, Elmore, Oruna-Concha, Campo, Wood, and Mottram (2008), water soluble compounds were extracted from the homogenized samples, with an adaptation to the centrifugation step. Two grams of frozen sample homogenates were weighed into 15 mL polypropylene vials, to which 10 mL of cold water were added. The tubes were shaken for 30 minutes and centrifuged at 3000 x g for 15 minutes. Resulting material was filtered through a 0.2 µm, 30 mm nylon membrane syringe filter (MicroLiter, Millville, NJ) into a 3 kDa cutoff membrane for centrifugal filtration for 1.5 hours. Resulting aqueous extract (100 µL) from each sample were introduced to the EZ-Faast amino acid kit (Phenomenex, Torrance, CA) by which free amino acids were derivatized. Derivatized amino acids were determined by GC-MS in electron impact mode with a 3:1 split ratio. The initial injection temperature was 280 °C, while the oven was 110 °C for one minute, with a 30 °C per minute increase until 320 °C was reached. Free amino acid derivatives were separated using a Zebron ZB-AAA capillary column (10 m x 0.25 mm; 0.25 µm film thickness, Agilent J&W GC Columns, Santa Clara, CA) with helium as the carrier gas. Amino acid identity and quantity were confirmed by comparing the data to external standards. Quantities of the amino acids were determined by relative responses to Norvaline, an internal standard.

Volatile/Olfactory Analysis

Volatile analysis was carried out using procedures similar to those of Legako et al. (2015). Cooking protocols were the same as those previously described for sensory evaluations. Immediately after cooking, five 1.27-cm cores were extracted by coring perpendicular to the surface of the steak cut surface. Cores were then minced in a coffee-bean grinder (KRUPS, made in china; Type #F203). Five grams of the ground sample were weighed out in a 20 ml glass GC vials (Art # 093640-036-00; Gerstel; Linthicum, MD) and closed with a polytetrafluoroethylene septa and screw cap (Art # 093640-092-00; Gerstel; Linthicum, MD). Ten microliters of an internal standard (1, 2-Dicholorobenzene; 0.801µg/ µl) were added and the vial was loaded by a Gerstel automated sampler (MPS, Linthicum, MD) for a 5 min incubation period at 65 ºC in the Gerstel agitator (500 rotations per minute) followed by 20 min of extraction where volatile compounds were collected from the headspace of cooked samples by Solid phase microextraction (SPME) using an 85-µm film thickness carboxen polydimethylsiloxane fiber (Supelco, Bellefonte, PA). Extracted volatile compounds were injected on a VF-5ms capillary column (30m × 0.25mm × 1.00µm; Agilent J&W GC Columns, Santa Clara, CA). The electron impact mode was set at 70 eV in the mass spectrometry which detected the ions within the range of 50-500m/z. Selective ion monitoring/scan mode was used to collect the data. External standard comparison was used to validate the volatile compound identity of ion fragmentation patterns. Quantitation was carried out by an internal standard calibration with authentic standards.

Olfactory data were collected using Gerstel ODP3 (Olfactory Detection Port). As compounds were collected, from procedure noted above, a trained panelist was present to ‘sniff’ samples. The panelist ranked the samples on an intensity scale of 1-4 (quartile system, 1 = 0-25,

2 = 26-50, 3 = 51-75, 4 = 76-100) and used a voice recording device to describe the odor of the samples. This procedure was duplicated for all sample runs and replications.

Proximate Analysis

Proximate analysis for percent fat, moisture, protein, and ash was performed on the homogenized separable lean and fat from each raw material source. Proximates were performed for each blend and replication. All analyses were performed in duplicate.

Moisture Analysis

Moisture analysis was performed using the AOAC oven drying method 950.46 and 934.04 (AOAC, 1995). One gram subsamples were weighed into aluminum tins and allowed to dry for 24 hours at 100°C in a forced air oven. The percent moisture (%MC) was calculated using the formula: % MC = [(wet weight-dry weight)/ wet weight] x 100.

Protein Analysis

Crude protein was determined using the AOAC (2006) Official Method 992.15 with a nitrogen determinator (Leco TruSpec CN or Leco FP-2000; Leco Corporation, St. Joseph, MI and Rapid N cube, Elmentar, Hanau, Germany). Percent protein was calculated using the formula: Percent Protein = Total percent nitrogen (TPN) x 6.25.

Fat Analysis

Total fat was extracted using the Folch method (Fold et al. 1957; AOAC, 2000). Approximately 1 g of sample was homogenized in 2:1 chloroform to methanol solution. The homogenized sample was placed on an orbital shaker at room temperature for 20 min. The homogenate was then filtered through ashless filter paper. Four mL of 0.9% NaCl was added to

the filtered sample, and the sample was placed in a refrigerator for 24 h. When the filtrate separated into two phases, the low phase was then aspirated and placed into a pre-weighed scintillation vial. The vial was then dried under N_2 gas. Following the N_2 gas drying, the vial air dried under a hood for 2 h and was then placed in a forced air drying oven to dry for 12 h at 100°C. The formula used for percent fat was: Percent Fat= [(Total volume of chloroform: methanol)/10 x final lipid weight)/sample weight] x 100.

Ash Analysis

Total ash was determined using the ashing method described in the AOAC 923.03 and 920.153 (1995). Approximately 1.0 g sample was placed into a dry, pre-weighted crucible. Samples were placed into a Thermolyne box furnace at 600°C for 18 hours. Percent ash was calculated using the formula: Percent Ash= (ash weight/ wet weight) x 100.

Collagen Analysis

Hydroxyproline content was determined from hydrolysates of the homogenized samples. Five mL of 6 N HCl, followed by 0.7 mL of 12 N HCl, were added to 1.0 g of sample. Ultra-high-purity nitrogen gas was added to the headspace of each tube before being capped and placed in an oven at 120°C for 22 hours. After removal from the oven, hydrolysate solutions were diluted 50 times in water, and 100 µL were introduced to the EZ-Faast amino acid kit (Phenomenex, Torrance, CA) by which total amino acids were derivatized. Derivatized amino acids were determined by GC-MS in electron impact mode with a 15:1 split ratio. The initial injection temperature was 280°C, while the oven was 110°C for one minute, with a 30°C per minute increase until 320°C was reached. Total amino acid derivatives were separated using a Zebron ZB-AAA capillary column (10 m x 0.25 mm; 0.25 µm film thickness, Agilent J&W GC

Columns, Santa Clara, CA) with helium as the carrier gas. Amino acid identity and quantity were confirmed by comparing the data to external standards. Quantities of the amino acid were determined by relative responses to Norvaline, an internal standard. Hydroxyproline was converted to mg collagen/gram following methods of Cross et al. (1973) using the formula: (Hydroxyproline supernatant x 7.52)/1000 = soluble collagen.

Statistical Methods

Initial analyses were conducted using statistical procedures of SAS (SAS 9.4, Cary, NC). Treatment comparisons were tested for significance using generalized linear mixed model procedures (PROC GLIMMIX). Experimental unit was individual patty with predictor variables being cattle type, muscle, lean percentages, and replication as a random variable. Response variables for trained panels were beefy/brothy, browned/grilled, buttery/beef fat, bloody/metallic, grassy/fishy, earthy/mushroom, nutlike/roasted nut, and livery/organy. Response variables for laboratory components were the individual fatty acids (polar and neutral), amino acids, and volatiles. Least squares means were calculated for trained sensory analysis, fatty acid composition, proximate composition, amino acid composition, and volatile/olfactory across treatments; test of hypothesis were conducted at $\alpha = 0.05$.

Significant ($P < 0.05$) two-way and three way interactions occurred among breed, muscle, and lean percentages, therefore lean percentage was further analyzed at the 80% lean level. Principle component analysis (PCA) was performed using statistical procedures of SAS (SAS 9.4, Cary, NC). PRINCOMP was used for sensory panel flavor ratings for all differing treatments (cattle type/muscle combinations). The PC1 and PC2 were correlated with the treatments. Amino acids, fatty acids (polar and neutral), and volatiles compounds were correlated

with PC1 (x-axis), PC2 (y-axis, separately, and plotted to determine relationships, as shown in Figures 2.1-2.5 using the procedure PROCCORR.

Further analyses were conducted using statistical procedures of R (R 3.2.2, Vienna, Austria). The *metagenomeSeq* package was used in conjunction with the *vegan* package to create nonmetric multidimensional scaling (NMDS) graphics identifying clustering differences among breed and muscle, respectively. Points were plotted based on differences in amino acids, fatty acids (polar and neutral), taste panels, and volatiles as shown in Figures 2.12 and 2.13 with differences determined at $\alpha = 0.05$.

Table 1. Design of treatments

Treatment	Description
Cattle Type	
Wagyu	F_1 Wagyu-Angus cross; 490/426 DOF
Long-Fed Holstein	Naturally-raised/fed Holsteins; 334 DOF
Short-Fed Holstein	Conventionally-raised/fed Holsteins, high concentrate diet; 250 DOF
Long-Fed Beef	Conventionally-raised/fed beef, high concentrate diet; 201 DOF
Short-Fed Beef	Grass-fed initially, finished on high-concentrate; 90 DOF
Lean Type	
Pectorales profundi	Associated high connective tissue
Longissimus lumbordum	Associated intermediate connective tissue
Psoas major	Associated low connective tissue
Blends	
High Lean Blend	90% Lean Type, 10% Cattle Type
Intermediate Lean Blend	80% Lean Type, 20% Cattle Type
Low Lean Blend	70% Lean Type, 30% Cattle Type

CHAPTER 4

RESULTS AND DISCUSSION

Initial Results

Initially, least-square-means were performed for all treatments (Breed x Muscle x Lean Percentage). Amino acids, fatty acids, taste panels, and volatile compounds each differed ($P < 0.05$) for two-way and three-way interactions among all treatments. However, these results were inconclusive in finding meaningful trends between breed/feeding type, muscle type, and lean percentage and their associations with each chemical compound and trained sensory panels. Lean percentage was removed as an independent variable and all samples were further analyzed at the 80% lean level. Further analysis was conducted using principal components analysis and correlation procedures to identify trends in breed/feeding type and muscle.

Principle Component Analysis between Treatment and Sensory Attributes

Principle component analysis (PCA) was conducted using sensory panel ratings for beef flavor attributes. Principle components 1 and 2 explained 46.28% and 21% of variances, respectively. PC1 and PC2 were correlated with treatments that represented each blend combination (Figure 2.1). Separation between associated positive flavors (beefy/brothy, browned/grilled, buttery/beef fat, and nutlike) and associated negative flavors (bloody/metallic, grassy/fishy, earthy/mushroom, and livery/organy) is apparent in the PCA graph as more positive attributes shifted toward the right while negative attributes were to the left. In terms of cattle type observations, treatments with the Wagyu (W) fat clustered with the positive attributes on the right side of the graph. This agrees with O'Quinn et. al (2015) that Wagyu cattle tended to be associated with more positive flavor attributes. Long-Fed, conventionally raised beef (LB) tended cluster with earthy flavors while Short-fed, grass based fed beef (SB) tended to cluster

around nutlike and livery flavors. For muscle differences, *Pectorales profundi* (PP) clustered around the browned flavors which agree with McHenry et al (2012). The *Psoas major,* with the exception of the treatment combined with Wagyu fat, clustered around the negative flavor attributes which is also been identified in several other studies as having strong sour, metallic taste (Seideman, Vanderzant, Smith, Hanna, & Carpenter, 1976). Figure 2.1 was replicated and overlaid with the laboratory results collected for amino acids (Figure 2.2), polar fatty acids (Figure 2.3), neutral fatty acids (Figure 2.4), and volatiles (Figure 2.5).

Relationship between Amino Acids, Sensory Attributes, and Treatment

Twenty amino acids were isolated from raw ground beef patties. Previous studies have identified these amino acids as participating in the Maillard reaction and Strecker degradation during the cooking of beef (Hornstein and Crowe, 1960, Kramlich and Pearson, 1958 and Macy et al., 1964). PC1 and PC2 of beef flavor attributes was correlated with treatment and amino acids and plotted together, as shown in Figure 2.2, to show relationships. The differing amino acids tended to cluster together around the center of the graph giving little to no indication of differences between the correlation of each amino acid and flavor or treatment differences. However, aspartic acid and cysteine tended to cluster near the negative flavors of grassy, bloody, and livery.

Relationship between Fatty Acids, Sensory Attributes, and Treatment

Polar and neutral components were analyzed independently on twenty-three different fatty acids. These fatty acids were chosen as variations in saturated, monounsaturated, and polyunsaturated which have been previously described as attributes associated with differing flavors (Legako et. al, 2014; Kerth & Miller, 2013; Garmyn et. al, 2011; Smith et. al, 2009; Wood et. al, 2003; Melton, 1990).

Polar. PC1 and PC2 of beef flavor attributes was correlated with treatment and polar fatty acids and plotted together, as shown in Figure 2.3, to show relationships. Overall, most of the polar fatty acids tended to cluster similarly together on the left side of the graph that was associated with the negative flavor attributes. The unsaturated fatty acids C12:0, C14:0 and C16:0 cluster closely to livery flavor which disagrees with many other studies that indicate that these fatty acids contribute positively to beefy/brothy flavors (Alfaia, et al., 2007; Baublits, et al., 2009; Dryden & Marchello, 1970; Garmyn et al., 2011; Sexten, et al., 2012). However, C17:0 is also clustered near livery flavor which does agree with former studies (Baublits, et al., 2009; Garmyn et al., 2011; O'Quinn, 2012). Finally, steric acid (C18:0) is the closest point to grassy/fishy flavor which has been noted in other studies as well (Dryden & Marchello, 1970; O'Quinn, 2012).

Monounsaturated fatty acids have been shown to be associated with positive beef flavor attributes (Larick & Turner, 1990; O'Quinn 2012). In this study the majority of the MUFAs are clustered near the earthy flavor with C17:1 clustered near grassy. Little research existence on evaluating C17:1 so uncertainty still exists for this MUFA. Two separate MUFAs (C16:1 and C18:1(c9)) clustered near the positive attributes of beefy, buttery, and nutlike. Palmitoleic acid (C16:1) has been found to have a positive correlation with beefy/brothy and buttery/beef fat flavors in previous studies (Baublits, et al., 2009; Dryden & Marchello, 1970; Garmyn et al., 2011). Oleic acid (C18:1 (c9)) accounts for 1/3 of the total fatty acid content in beef and has been well documented as the MUFA most associated with positive beef flavor desirability as it does in this current study (Dryden & Marchello, 1970; Garmyn et al., 2011; Rule, Broughton, Shellito, & Maiorano, 2002; Westerling & Hedrick, 1979).

Polyunsaturated fatty acids clustered toward the negative attributes which agrees with previous studies in which PUFAs, particularly linoleic acid (C18:2), have been identified to negatively affect beef flavor (Garmyn, 2011; O'Quinn, 2012).

Neutral. PC1 and PC2 of beef flavor attributes was correlated with treatment and neutral fatty acids and plotted together, as shown in Figure 2.4, to show relationships. For the neutral unsaturated fatty acids C12:0, C14:0, C16:0, C17:0 clustering around as single flavor did not occur. This is similar to what was identified with the polar unsaturated portion with less indication for correlation which agrees with McHenry et al., 2013. As with the polar fatty acids, steric acid (C18:0) was identified near the grassy flavor attribute and this agrees with former studies (Dryden & Marchello, 1970; O'Quinn, 2012).

Neutral monounsaturated fatty acids, as with the polar MUFAs, are generally clustered near earthy with the exception of C16:1, C17:1 and C18:1 (c9). C17:1 is clustered near both grassy and livery flavors. C16:1 and C18:1 (c9) are present near the positive attributes of beefy, buttery, and nutlike which agree with previous studies (Dryden & Marchello, 1970; Garmyn et al., 2011; Rule, Broughton, Shellito, & Maiorano, 2002; Westerling & Hedrick, 1979).

Neutral polyunsaturated fatty acids tended to not cluster near any flavor attributes and had no noticeable associations which agrees with McHenry et al., 2013.

Relationship between Volatiles, Sensory Attributes, and Treatment

Sixteen different volatiles were isolated from the headspace of cooked ground beef patties. Previous research has identified these compounds present in cooked beef and formed during the Maillard reaction (Mottram, 1998). Furthermore, these specific compounds were chosen due to the most prominent odorous sensations that occurred using the olfactory detection port. PC1 and PC2 of beef flavor attributes was correlated with treatment and volatiles and

plotted together, as shown in Figure 2.5, to show relationships. The majority of the volatile compounds clustered similarly at the center of the axis of the two principle components. Therefore, no discernible trends existed between possible association between those volatiles and flavors. This disagrees with many studies that have identified that trends do exist between volatiles and flavors (Brewer, 2007; Elmore et al., 1999; Maruri & Larick, 1992; Stetzer, Cadwallader, Singh, McKeith, & Brewer, 2008; Legako, 2011; O'Quinn, 2012; Legako, 2013). Dimethyl sulfide was the only volatile appearing to cluster separate from the rest of the group. Dimethyl sulfide is a volatile that is generally found in vacuum packaged beef (Jackson et al., 1992) and is associated with microbial spoilage and odor of refrigerated beef. In this study dimethyl sulfide was most closely clustered toward livery and grassy flavors, this agrees with O'Quinn, 2015 in that dimethyl sulfide has been negatively associated with positive beef attributes.

Relationship of Cattle Type and Muscle between Amino Acids, Fatty Acids, Sensory, and Volatiles

Figure 2.6 demonstrates nonmetric multidimensional pairwise comparisons to identify differences in cattle (breed) type. Cattle type differences ($P < 0.05$) were identified among treatments variances with a strong R-value (0.82) indicating a small within treatment variance. In contrast, Figure 2.13 compares muscle differences ($P > 0.05$) among treatment variances with a negative R-value (-0.01) to indicate a large within sample treatment variance.

Conclusion

Flavor has many differing attributes that contribute to the overall perception of beef by the consumer. It has become a challenge to find out what factors affect the differences among these flavors and changes that can be made. In this study, a broad representation of multiple

cattle types and muscles were analyzed to consider certain preferences for flavor. Several amino acids, fatty acids, and volatiles were correlated with trained sensory panel data as demonstrated in principal component analysis and differences ($P < 0.05$) were identified between cattle types in the nonmetric multidimensional analysis. Further research will be necessary to determine how these compounds affect flavor and if differences in cattle types and muscles can alter the flavors produced in beef.

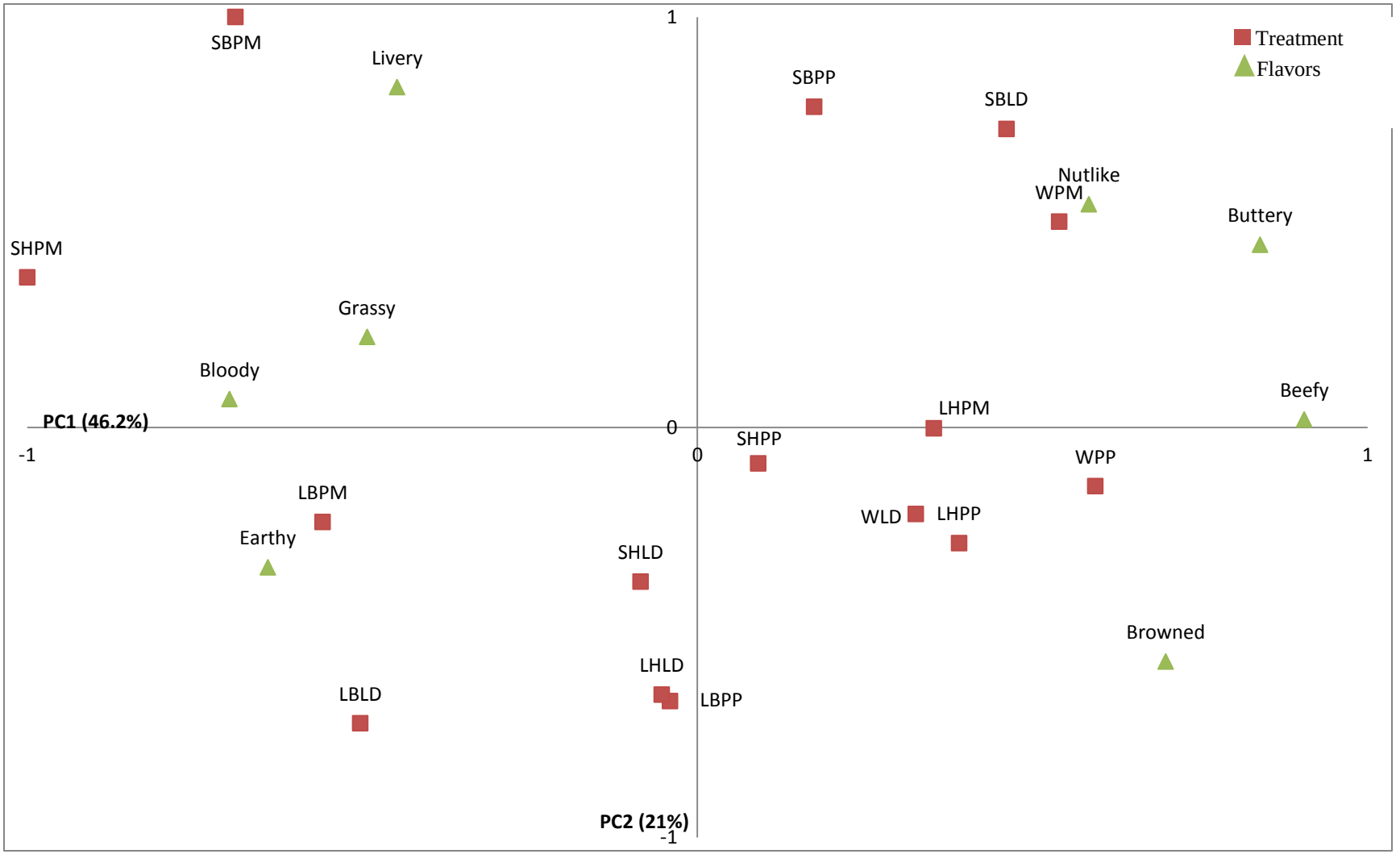


Figure 2.1 Principal component analysis (PC1 and PC2) showing relationships between treatment and flavors.

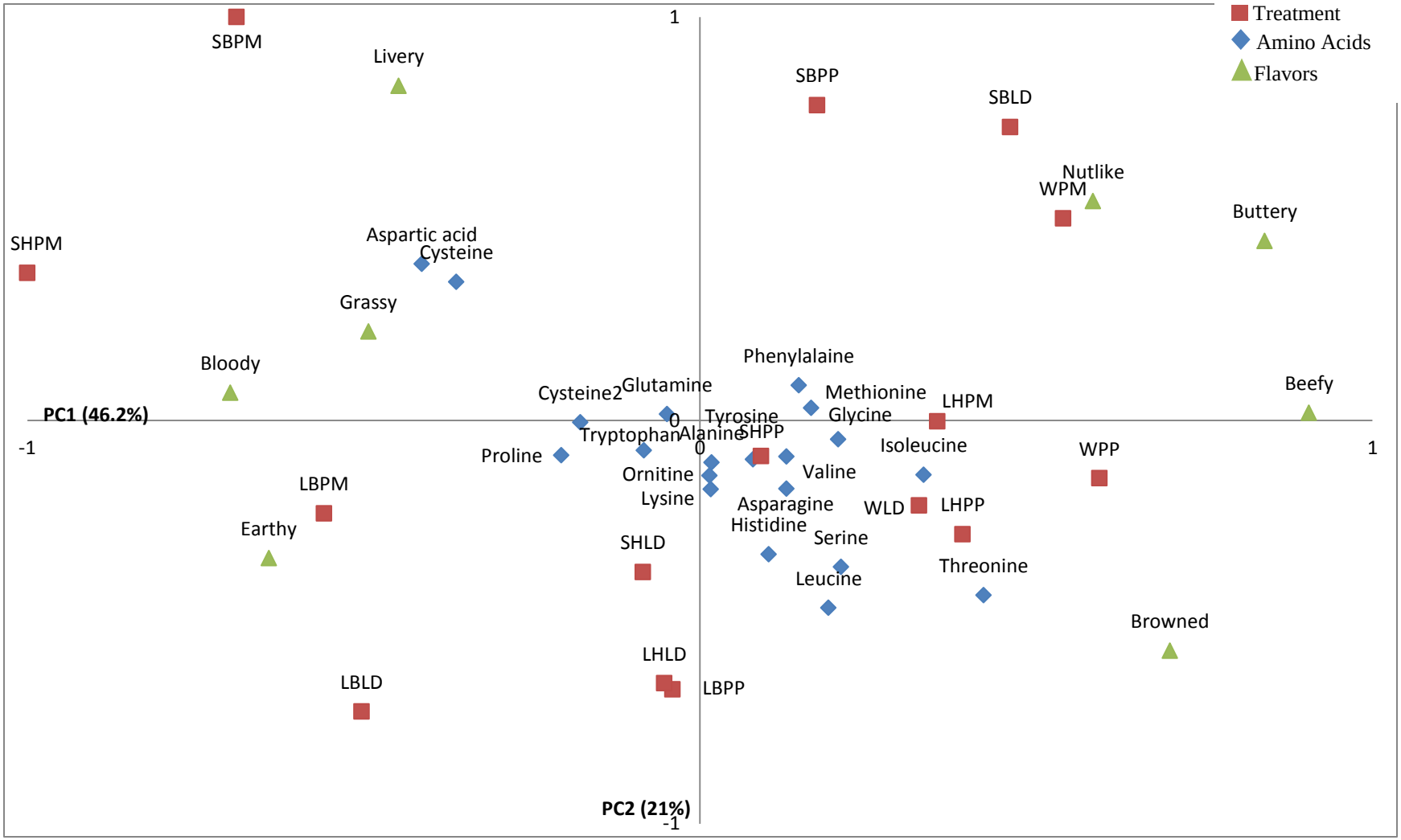


Figure 2.2 Principal component analysis (PC1 and PC2) showing relationships between amino acids, flavors, and cattle types

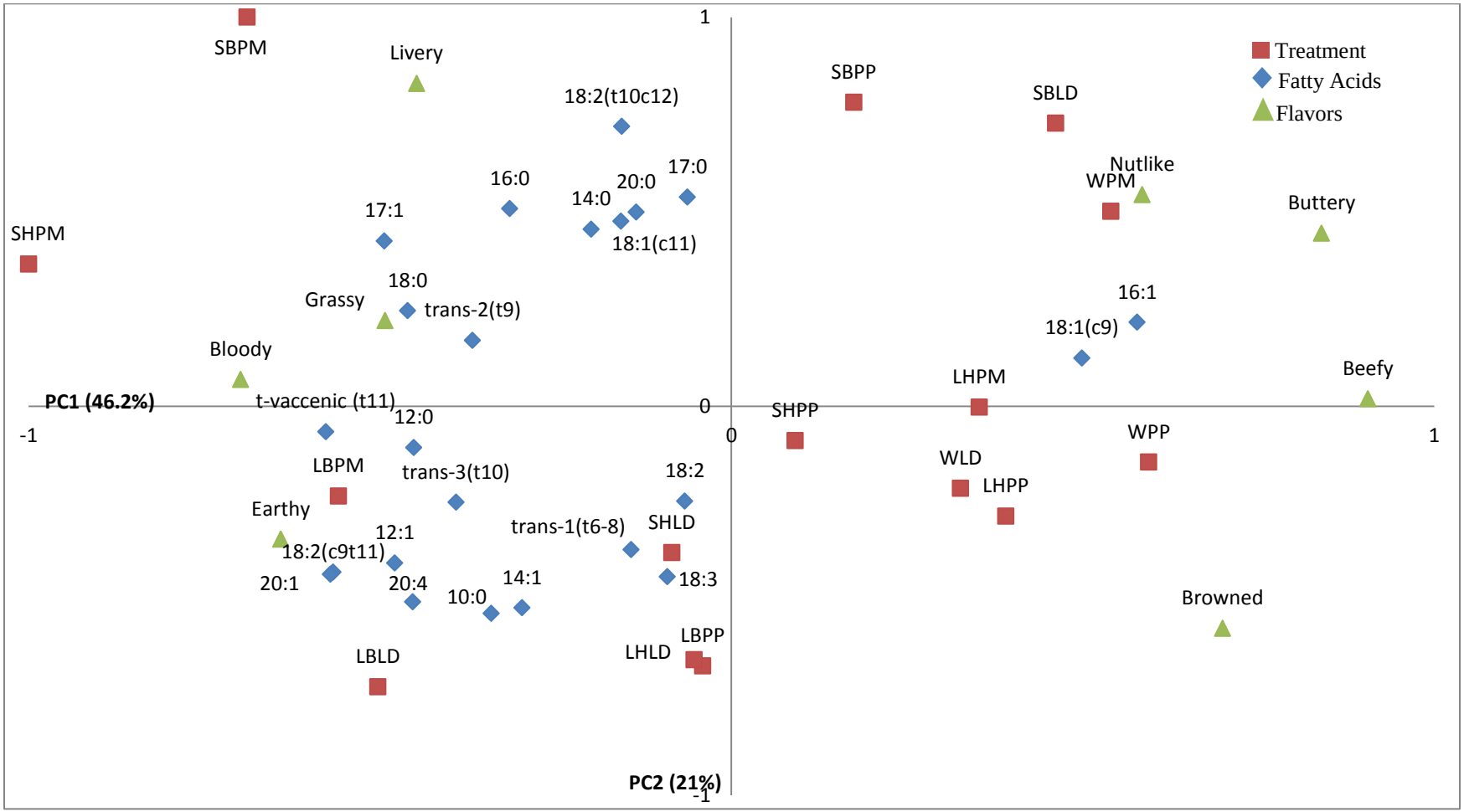


Figure 2.3 Principal component analysis showing relationships between polar fatty acids, flavors, and cattle types

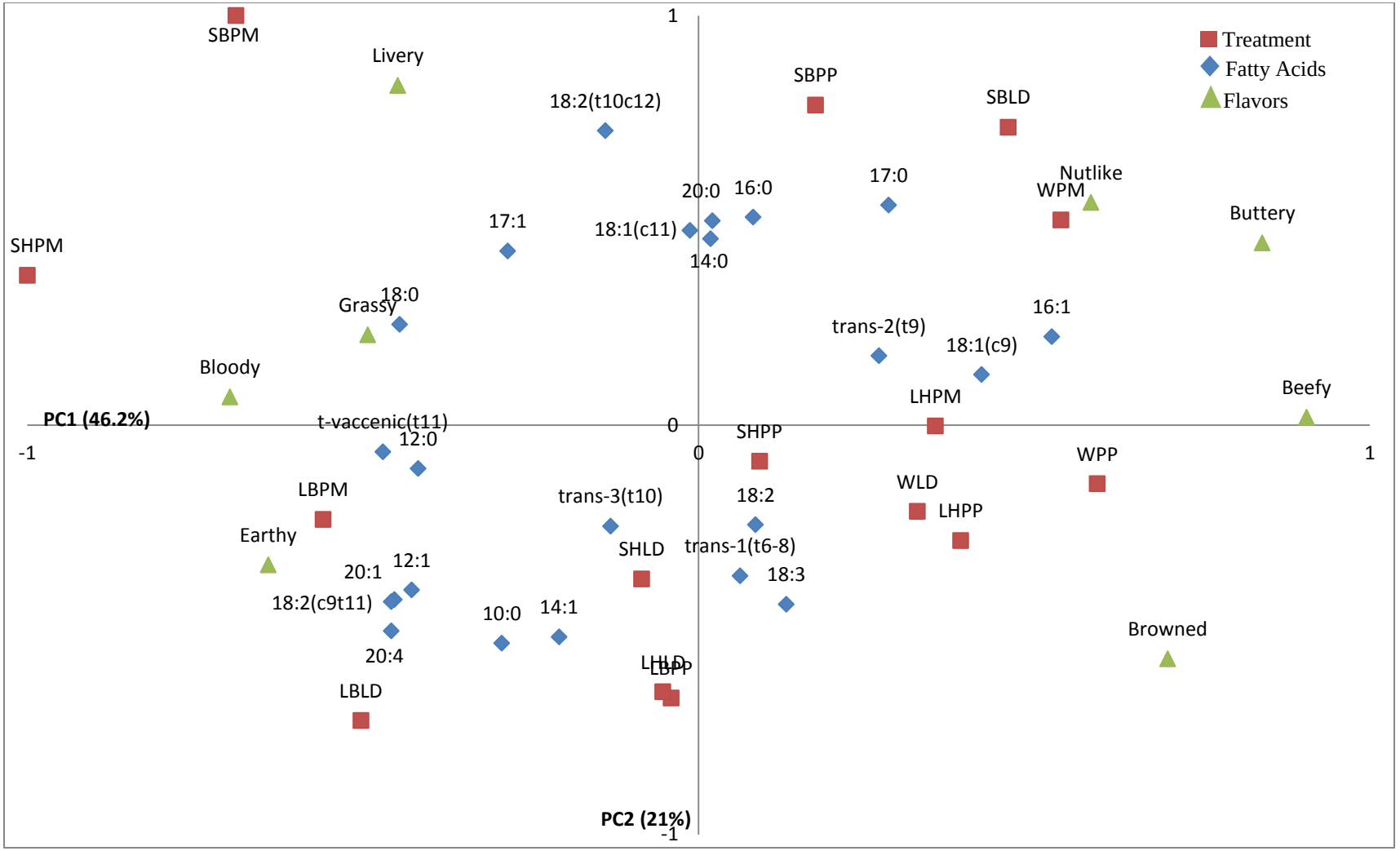


Figure 2.4 Principal component analysis (PC1 and PC2) showing relationships between neutral fatty acids, flavors, and cattle types

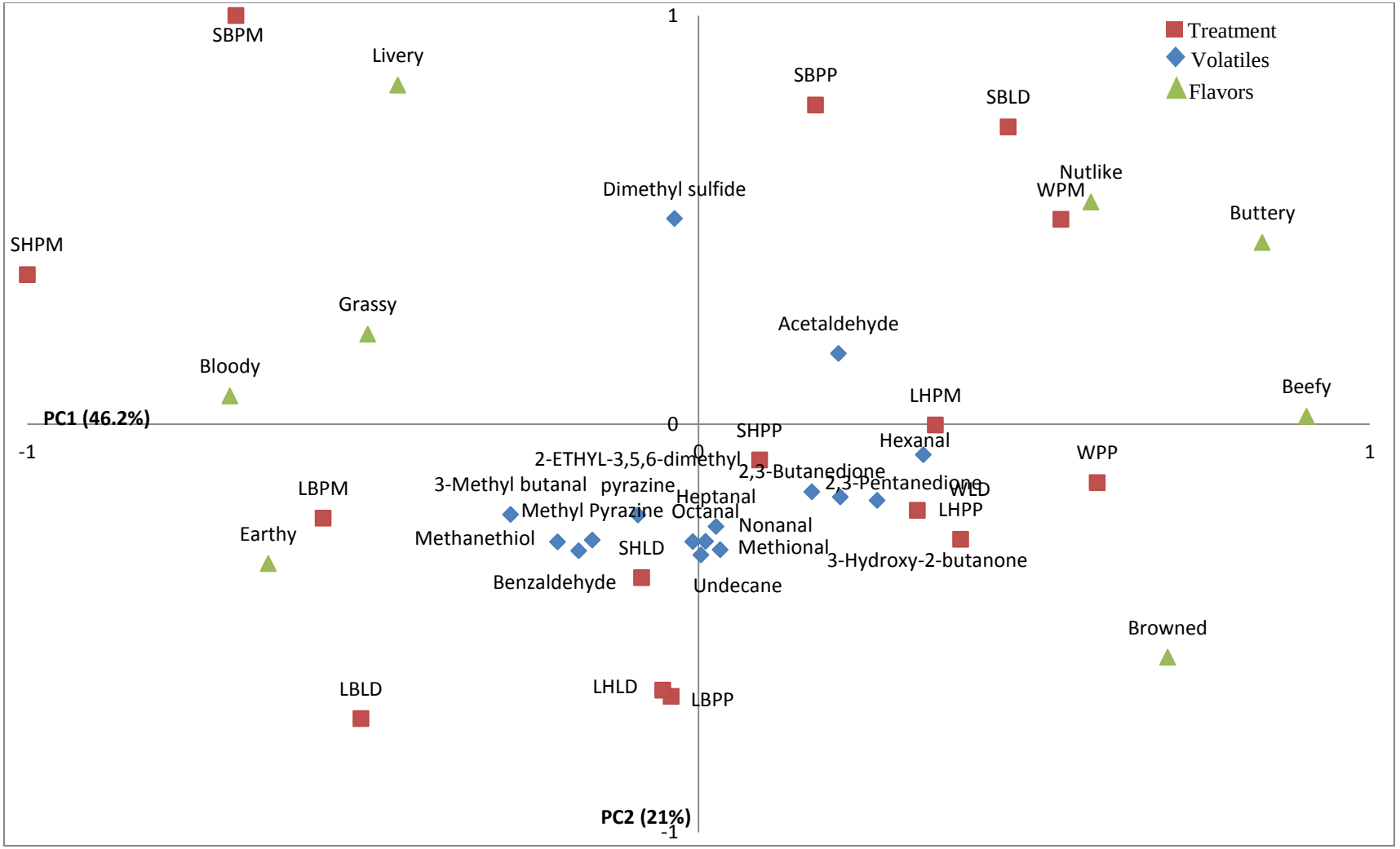


Figure 2.5 Principal component analysis (PC1 and PC2) showing relationships between volatiles, flavors, and cattle type

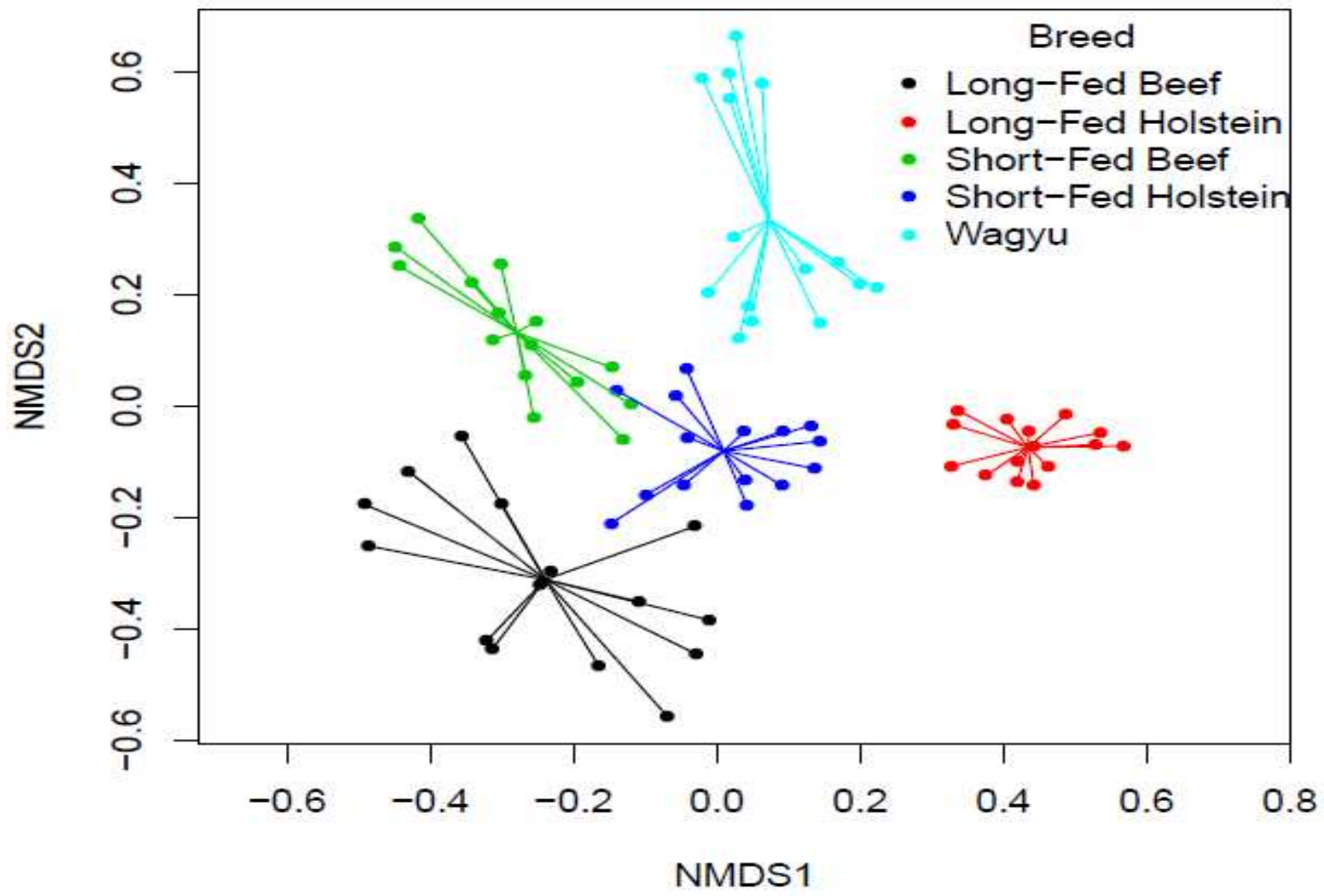


Figure 2.6 Nonmetric multidimensional scaling of amino acids, fatty acids (polar/neutral), volatiles, sensory attributes by cattle type.
P=0.001; *R*=0.8229

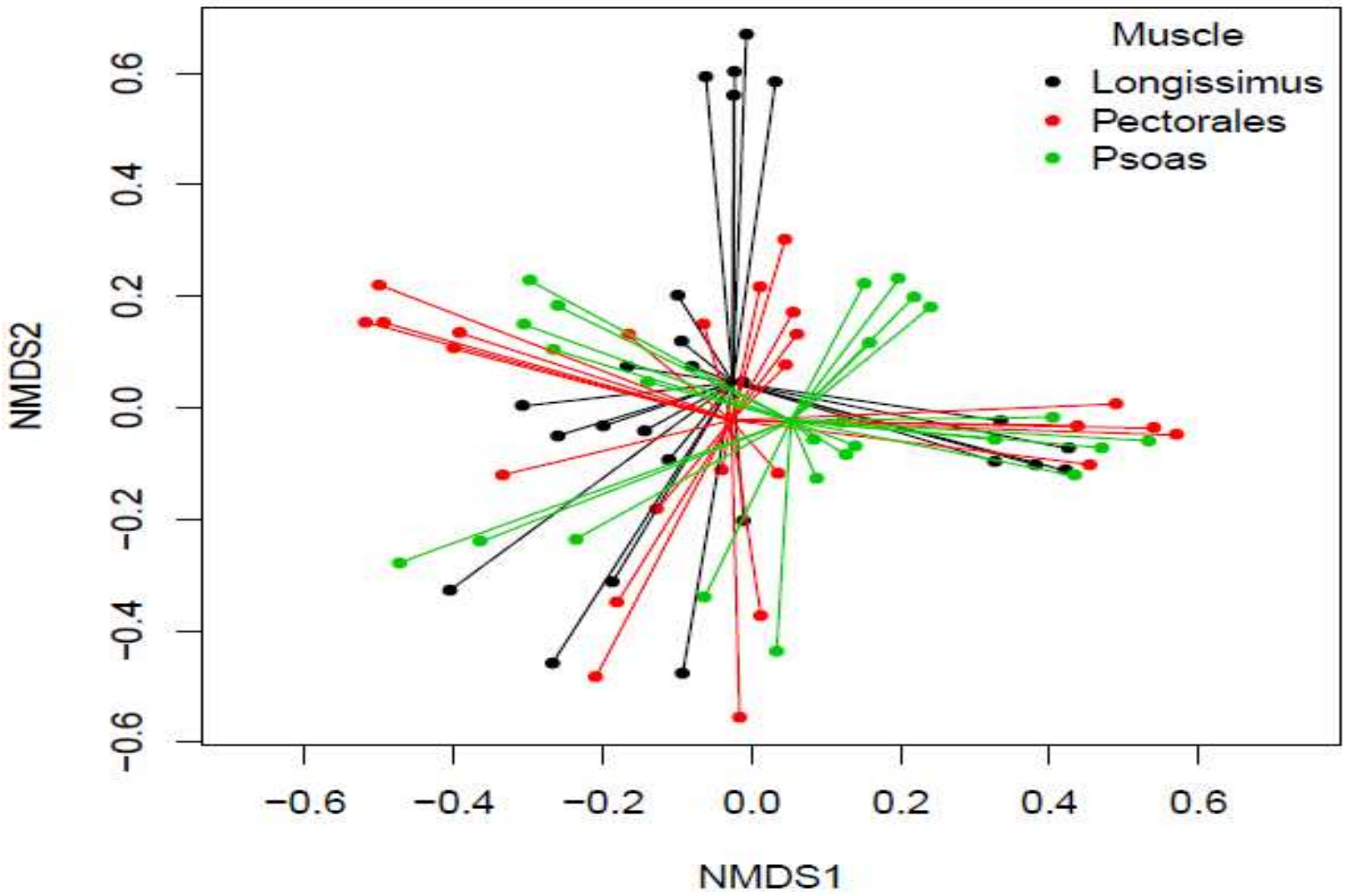


Figure 2.7 Nonmetric multidimensional scaling of amino acids, fatty acids (polar/neutral), volatiles, sensory attributes by muscle.
P=0.748; *R*=-0.01318

LITERATURE CITED

Blackmon, T., R.K. Miller, C. R. Kerth, & S.B. Smith (2014). Ground beef patties prepared from brisket, flank and plate have unique fatty acid and sensory characteristics.

Dryden, F. D., & Maechello, J. A. (1970). Influence of total lipid and fatty acid composition upon the palatability of three bovine muscles. *Journal of Animal Science, 31*(1), 36-41.

Duckett, S.K., D.G. Wagner, L.D. Yates, H.G. Dolezal, & S.G. May (1993). "Effects of time on feed on beef nutrient composition." Journal of Animal Science **71**(8): 2079-2088.

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

Garmyn, A. J., G.G. Hilton, R.G. Mateescu, J. B. Morgan, J.M. Reecy, R.G. Tait, D.C. Beitz, Q. Duan, J.P. Schoomaker, M.S. Mayes, M.E. Drewnoski, Q. Liu, & D.L. VanOverbeke. (2011). Estimation of relationships between mineral concerntation and fatty acid composition of longissimus muscle and beef palatability traits. *Journal of Animal Science, 89*(9), 2849-2858.

Hornstein, I and P. F. Crowe "Meat Flavor Chemistry, Flavor Studies on Beef and Pork" *Journal of Agricultural and Food Chemistry* **1960** *8* (6), 494-498

Igo, J.L., D.L. VanOverbeke, D.R. Woerner, J.D. Tatum, D.L. Pendell, L.L. Vedral, G.G. Mafi, M.C. Moore, R.O. McKeith, G.D. Gray, D.B. Griffin, D.S. Hale, J.W. Savell, & K.E. Belk(2013). "Phase I of The National Beef Quality Audit-2011: Quantifying willingness-to-pay, best-worst scaling, and current status of quality characteristics in different beef industry marketing sectors." Journal of Animal Science **91**(4): 1907-1919.

Insausti, K., Beriain, M.J., Gorraiz, C. and Purroy, A. 2002. Volatile compounds of raw beef from 5 local Spanish cattle breeds stored under modified atmosphere. J.Food Sci. 67:1580-1589.

Kerth, C.R. and R. K Miller (2013). "Beef Flavor: A review from chemistry to consumer." Beef Research White Paper: Product Quality

Kramlich, W. E. and Pearson, A. M. (1958), "Some Preliminary Studies on Meat Flavor." Journal of Food Science, 23: 567–574.

Larick, D. K., H. B. Hedrick, M. E. Bailey, J. E. Williams, D. L. Hancock, G. B. Garner, and R. E. Morrow. 1987. Flavor constituents of beef as influenced by forage- and grain-feeding. J. Food Sci. 52:245-251.

Legako, J. F., Dinh, T. T. N., Miller, M. F., & Brooks, J. C. (2015). Effects of USDA beef quality grade and cooking on fatty acid composition of neutral and polar lipid fractions. *Meat science*, *100*, 246-255.

Macy, R. L., Naumann, H. D. and Bailey, M. E. (1964), Water-Soluble Flavor and Odor Precursors of Meat. II. Effects of Heating on Amino Nitrogen Constituents and Carbohydrates in Lyophilized Diffusates from Aqueous Extracts of Beef, Pork, and Lamb. Journal of Food Science, 29: 142–148.

Mandell, I. B., Buchanan-Smith, J. G., & Campbell, C. P. (1998). Effects of forage vs grain feeding on carcass characteristics, fatty acid composition, and beef quality in Limousin-cross steers when time on feed is controlled. *Journal of Animal Science*, *76*(10), 2619.

May, S. G., H.G Dolezal, D.R. Gill, F.K. Ray, & D.S. Buchanan (1992). "Effect of days fed, carcass grade traits, and subcutaneous fat removal on postmortem muscle characteristics and beef palatability." Journal of Animal Science **70**(2): 444-453.

Melton, S. L. (1990). Effects of feeds on flavor of red meat: a review. *Journal of animal science*, *68*(12), 4421-4435.

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

Sato, M., Nakamura, T., Numata, M., Kuwahara, K., Homma, S., Sato, A. and Fujimaki, M. 1995. Study on factors related to beef quality on the flavor and umami taste of Japanese Black cattle branded beef. Anim. Sci. and Tech. 66:274-282

Smith, S. B., C.A. Gill, D.K. Lunt, and M.A. Brooks (2009). "Regulation of fat and fatty acid composition in beef cattle." Asian-Australasian Journal of Animal Sciences **22**(9): 1225-1233.

Stetzer, A. J., Wicklund, R.A., Paulson, D.D., Tucker, E.M., MacFarlane, B.J. and Brewer, M.S. 2006. Effect of carbon monoxide and high oxygen modified pack MAP on quality characteristics of beef strip steaks. J. Muscle Foods. 18(1) 56-66.

Stetzer, A.J., Tucker, E., McKeith, F.K and Brewer, M.S. 2007. Quality changes in various beef muscles enhanced prior to aging. I. *Gluteus medius, Infraspinatus, Psoas major, Rectus femoris and Teres major*. J. Food Sci. 72(4): S242-S246

Stetzer, A.J., Tucker, E., McKeith, F.K and Brewer, M.S. 2008. Quality changes in various beef muscles enhanced prior to aging. II. Complexus, Serratus ventralis, Vastus lateralis, Vastus medialis and Longissimus dorsi muscles. J. Food Sci.73(1) S6-S10).

Sturdivant, C. A., Lunt, D. K., Smith, G. C., & Smith, S. B. (1992). Fatty acid composition of subcutaneous and intramuscular adipose tissues and M. longissimus dorsi of Wagyu cattle. *Meat science*, *32*(4), 449-458.

Wood, J. D., R.I. Richardson, G.R. Nute, A.V. Fisher, M.M. Campo, E. Kasapidou, P.R. Sheard, & M. Enser (2004). "Effects of fatty acids on meat quality: a review." Meat Science **66**(1): 21-32.

Yancey, E.J., Dikeman, M.E., Hachmeister, K.A., Chambers, E., IV. and Milliken, G.A. 2005. Flavor characterization of top blade, top sirloin, and tenderloin steaks as affected by pH, maturity, and marbling. J. Anim. Sci. 831:2618-2623

APPENDIX A

Table A1. Proximate composition based on CATTLE TYPE by MUSCLE interaction

	Treatment[1]														
	LD					PM					PP				
Item[2]	**W**	**LH**	**SH**	**LB**	**SB**	**W**	**LH**	**SH**	**LB**	**SB**	**W**	**LH**	**SH**	**LB**	**SB**
DM	40.66^{A}	39.61^{B}	38.64^{EFG}	40.21^{A}	38.59^{EFG}	39.38^{BC}	38.29^{G}	38.89^{CDEFG}	39.24^{BCD}	38.90^{CDEF}	39.18^{BCDE}	38.71^{DEFG}	38.49^{FG}	38.91^{CDEF}	38.61^{EFG}

$^{A-G}$ Means within a row with different superscripts differ (P<0.05).

[1]Treatments: LD=*Longissimus dorsi,* PM=*Psoas major,* PP=*Pectorales profundi,* W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

[2]Items: DM= Dry Matter, CF= Crude Fat, PRO= Protein

Table A2. Proximate composition based on CATTLE TYPE by LEAN PERCENTAGE interaction

	Treatment[1]														
	90%					80%					70%				
Item[2]	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
PRO	20.55^{B}	21.20^{A}	21.40^{A}	21.48^{A}	20.53^{B}	17.70^{D}	18.64^{C}	19.14^{C}	18.94^{C}	17.29^{D}	14.33^{F}	15.69^{E}	15.72^{E}	16.22^{E}	13.88^{F}

$^{A-I}$ Means within a row with different superscripts differ (P<0.05).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content, W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

Table A3. Collagen content of lean sources

Lean Source	**Collagen Content (mg/g)**
Longissimus dorsi	5.47
Psoas major	4.69
Pectorales profundi	5.26

Table A4. Crude Fat composition based on CATTLE TYPE, LEAN PERCENTAGE, and MUSCLE interaction

	Treatment[1]		
	90%	**80%**	**70%**
LD			
W	11.20^{Q}	20.18^{IJ}	29.73^{ABC}
LH	9.31^{STU}	17.55^{NOP}	26.52^{GH}
SH	8.75^{U}	16.50^{P}	28.24^{DEF}
LB	10.00^{QRSTU}	17.28^{NOP}	28.63^{CDE}
SB	8.93^{UT}	17.68^{MNOP}	28.34^{DEF}
PM			
W	10.44^{QRS}	20.47^{I}	30.67^{A}
LH	9.34^{STU}	18.32^{LMN}	27.76^{EFG}
SH	9.37^{STU}	17.46^{NOP}	26.29^{H}
LB	10.12^{QRST}	18.33^{LMN}	27.30^{FGH}
SB	10.72^{QR}	18.85^{KLM}	29.24^{BCD}
PP			
W	10.44^{QRS}	20.04^{IJK}	30.06^{AB}
LH	9.83^{RSTU}	19.14^{JKL}	28.22^{EFG}
SH	9.46^{RSTU}	16.92^{OP}	28.27^{DEF}
LB	9.33^{STU}	18.09^{LMNO}	26.56^{GH}
SB	9.35^{STU}	20.07^{IJK}	29.24^{BCD}

$^{A-U}$Means with different superscripts differ ($P<0.05$).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content, W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF), LD=*Longissimus dorsi,* PM=*Psoas major*, PP=*Pectorales profundi*

Table A5. Trained sensory panel analysis based on cattle type by MUSCLE by LEAN PERCENTAGE interaction

Treatment[1]

Muscle	LD														
Lean %	90%					80%					70%				
Cattle Type	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
Beefy	58.00^{STU}	62.34^{LMNOPQRS}	62.40^{LMNOPQRS}	57.41^{TUV}	62.16^{LMNOPQRS}	66.16^{DEFGHIJKL}	66.73^{CDEFGHIJKL}	64.74^{GHIJKLMNO}	63.87^{HIJKLMNOPQ}	68.00^{ABCDEFGHI}	72.46^{A}	71.06^{ABC}	67.35^{BCDEFGHIJ}	70.99^{ABC}	67.04^{CDEFGHIJK}
Browned	60.38^{MNO}	64.51^{FGHIJKLMN}	65.82^{CDEFGHIJK}	61.69^{KLMNO}	63.44^{HIJKLMNO}	67.53^{ABCDEFGHI}	67.60^{ABCDEFGHI}	68.11^{ABCDEFG}	65.24^{EFGHIJKL}	65.27^{EFGHIJKL}	71.71^{A}	70.26^{ABC}	67.92^{ABCDEFGH}	70.68^{AB}	66.16^{BCDEFGHIJK}
Buttery	28.77ST	31.18^{QRST}	34.76^{PQRST}	28.51ST	30.96^{QRST}	51.56^{HIJKL}	47.20^{JKLMN}	48.12^{JKLM}	40.96^{MNOP}	60.20^{DEFG}	71.93^{AB}	70.15^{ABC}	51.83^{GHIJKL}	64.51^{BCDE}	66.60^{BCD}
Bloody	17.18^{ABCDE}	16.64^{ABCDEF}	13.91^{DEFGHIJK}	20.52^{A}	16.82^{ABCDEF}	9.89^{KLMNOPQ}	15.56^{BCDEFGH}	11.86^{IJKLMN}	14.56^{CDEFGHI}	10.03^{IJKLMNOP}	5.51^{RS}	6.33^{PQRS}	7.99^{NOPQRS}	4.33ST	8.93^{MNOPQR}
Grassy	5.14^{DEF}	1.96^{GHIJK}	2.47^{FGHIJK}	5.37^{CDE}	2.70^{EFGHIJK}	0.3111^{HIJK}	1.00^{GHIJK}	1.53^{GHIJK}	1.38^{GHIJK}	1.11^{GHIJK}	0.10^{JK}	0.0677^{K}	1.61^{GHIJK}	0.07^{K}	2.91^{EFGHI}
Earthy	13.76^{ABCDE}	13.43^{ABCDEF}	12.73^{ABCDEF}	15.61^{AB}	12.84^{ABCDEF}	12.11^{BCDEFG}	11.11^{CDEFGHIJ}	12.12^{BCDEFG}	14.71^{ABCD}	11.24^{CDEFGHI}	10.03^{EFGHIJ}	8.34^{GHIJ}	13.63^{ABCDE}	7.76^{HIJ}	12.11^{BCDEFG}
Nutty	2.86^{KLMN}	1.53^{LMN}	3.49^{IJKLM}	1.62^{LMN}	1.27^{LMN}	5.60^{FGHIJK}	2.04^{LMN}	2.77^{KLMN}	3.22^{JKLMN}	8.04^{EF}	14.30^{AB}	11.97^{BCD}	6.49^{FGHIJ}	11.44^{BCD}	11.64^{BCD}

Muscle	PM														
Lean %	90%					80%					70%				
Cattle Type	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
Beefy	53.11^{V}	55.07^{UV}	59.40^{QRSTU}	60.94^{MNOPQRST}	59.92^{PQRST}	68.91^{ABCDEFG}	69.47^{ABCDEF}	58.90^{RSTU}	63.34^{IJKLMNOPQR}	64.15^{HIJKLMNOP}	65.18^{FGHIJKLMN}	65.49^{EFGHIJKLM}	69.81^{ABCDE}	63.20^{JKLMNOPQR}	69.81^{ABCDE}
Browned	55.11^{P}	54.73^{P}	59.94^{O}	61.95^{KLMNO}	62.08^{JKLMNO}	65.87^{CDEFGHIJK}	66.98^{BCDEFGHI}	60.54^{MNO}	64.87^{FGHIJKLM}	62.19^{JKLMNO}	64.00^{GHIJKLMNO}	65.89^{CDEFGHIJK}	66.89^{BCDEFGH}	65.40^{DEFGHIJKL}	66.89^{BCDEFGH}
Buttery	26.82^{T}	33.00^{PQRST}	30.39^{RST}	32.12^{QRST}	32.12^{QRST}	59.45^{DEFGH}	55.36^{FGHIJ}	41.19^{MNOP}	37.62^{OPQR}	47.53^{JKLMN}	57.89^{EFGHI}	55.22^{FGHIJ}	58.39^{DEFGHI}	52.80^{GHIJK}	58.39^{DEFGHI}
Bloody	19.24^{AB}	18.62^{ABC}	17.29^{ABCDE}	19.55^{AB}	18.84^{ABC}	10.16^{JKLMNOP}	14.19^{DEFGHIJK}	14.28^{DEFGHIJ}	12.18^{GHIJKLMN}	17.06^{ABCDEF}	9.36^{LMNOPQR}	8.74^{NOPQR}	7.93^{NOPQRS}	11.84^{HIJKLMN}	7.93^{NOPQRS}
Grassy	7.98^{ABC}	2.73^{EFGHIJK}	3.06^{CDEFGH}	8.21^{AB}	5.32^{CDE}	0.36^{HIJK}	0.4222^{HIJK}	1.55^{GHIJK}	1.90^{GHIJK}	2.32^{GHIJK}	0.9111^{GHIJK}	1.03^{GHIJK}	0.4444^{HIJK}	2.47^{FGHIJK}	0.4444^{HIJK}
Earthy	16.02^{AB}	14.67^{ABCD}	16.53^{A}	15.85^{AB}	16.50^{A}	10.31^{EFGHIJ}	10.49^{DEFGHIJ}	13.90^{ABCDE}	13.52^{ABCDEF}	11.92^{BCDEFGH}	11.82^{BCDEFGH}	8.30^{GHIJ}	9.37^{FGHIJ}	15.96^{AB}	9.37^{FGHIJ}
Nutty	0.6444^{MN}	1.20^{LMN}	1.51^{LMN}	2.80^{KLMN}	2.20^{LMN}	5.91^{FGHIJK}	4.46^{GHIJKL}	3.13^{KLMN}	3.23^{JKLMN}	4.50^{GHIJK}	8.87^{DEF}	6.90^{FGH}	7.54^{FG}	6.96^{FGH}	7.54^{FG}

Table A5 (continued). Trained sensory panel analysis based on cattle type by MUSCLE by LEAN PERCENTAGE interaction

Muscle	PP														
Lean %	90%					80%					70%				
Cattle Type	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
Beefy	60.18^{OPQRST}	$62.53^{KLMNOPQRS}$	$64.67^{GHIJKLMNO}$	$60.78^{NOPQRST}$	$62.53^{KLMNOPQRS}$	$67.47^{BCDEFGHIJ}$	$69.24^{ABCDEFG}$	$66.14^{DEFGHIJKL}$	$66.69^{CDEFGHIJKL}$	$67.83^{BCDEFGHI}$	70.60^{ABCD}	71.91^{AB}	69.96^{ABCDE}	69.34^{ABCDEF}	$68.27^{ABCDEFGH}$
Browned	61.72^{KLMNO}	$63.16^{IJKLMNO}$	$63.16^{IJKLMNO}$	61.18^{LMNO}	61.02^{LMNO}	68.66^{ABCDEF}	$67.23^{ABCDEFGHI}$	$66.21^{BCDEFGHIJK}$	69.60^{ABCDE}	$66.58^{BCDEFGHIJ}$	68.64^{ABCDEF}	69.04^{ABCDEF}	60.12^{NO}	69.84^{ABCD}	$65.87^{CDEFGHIJK}$
Buttery	41.23^{MNOP}	39.29^{NOPQ}	46.51^{KLMN}	35.88^{OPQRS}	44.04^{LMNO}	57.70^{EFGHI}	53.29^{FGHIJK}	48.31^{IKLM}	50.11^{IJKL}	61.81^{CDEF}	75.51^{A}	70.18^{ABC}	67.78^{ABC}	68.86^{ABC}	71.91^{AB}
Bloody	$14.54^{CDEFGHI}$	$16.42^{ABCDEFG}$	$13.47^{EFGHIJKL}$	$15.61^{BCDEFGH}$	17.96^{ABCD}	$10.27^{IJKLMNOP}$	$10.80^{IJKLMNO}$	$11.74^{HIJKLMN}$	$12.18^{GHIJKLMN}$	$12.84^{FGHIJKLM}$	5.69^{QRS}	7.29^{OPQRS}	5.69^{QRS}	7.03^{OPQRS}	8.13^{NOPQRS}
Grassy	5.74^{BCD}	5.40^{CDE}	1.76^{GHIJK}	3.56^{DEFG}	2.38^{FGHIJK}	0.8306^{GHIJK}	1.37^{GHIJK}	1.80^{GHIJK}	2.18^{GHIJK}	2.88^{EFGHIJ}	0.56^{HIJK}	0.13^{IJK}	9.33^{A}	0.80^{GHIJK}	3.60^{DEFG}
Earthy	15.21^{ABC}	13.93^{ABCDE}	$10.80^{DEFGHIJ}$	12.64^{ABCDE}	9.82^{EFGHI}	$11.84^{BCDEFGH}$	10.08^{EFGHIJ}	12.16^{BCDEFG}	15.16^{ABC}	12.10^{BCDEFG}	7.40^{IJ}	6.91^{J}	13.62^{ABCDE}	7.56^{IJ}	9.73^{EFGHI}
Nutty	4.48^{GHIJK}	3.89^{HIJKLM}	5.58^{FGHIJK}	3.10^{KLMN}	3.76^{HIJKLM}	7.46^{FG}	3.13^{KLMN}	6.58^{FGHI}	4.36^{GHIJKL}	7.24^{FG}	16.58^{A}	12.18^{BC}	0.25^{N}	11.23^{BCDE}	10.87^{CDE}

$^{A-S}$Means within row with different superscripts differ (P<0.05).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content, W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF), LD=*Longissimus dorsi,* PM=*Psoas major*, PP=*Pectorales profundi*

Table A6. Trained sensory panel analysis for livery flavor for MUSCLE by CATTLE TYPE

	Treatment[1]														
	Longissimus Dorsi					***Psoas major***					***Pectorales profundi***				
	W	**LH**	**SH**	**LB**	**SB**	**W**	**LH**	**SH**	**LB**	**SB**	**W**	**LH**	**SH**	**LB**	**SB**
Livery	1.44^{BCD}	0.51^{D}	1.46^{BCD}	0.58^{D}	2.16^{BC}	4.62^{A}	2.60^{B}	2.10^{BC}	2.07^{BC}	2.42^{B}	0.81^{CD}	0.84^{CD}	0.48^{D}	0.79^{CD}	2.36^{B}

[A-D]Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: LD= *Longissimus dorsi,* PM=*Psoas major,* PP=*Pectorales profundi*, W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

Table A7. Trained sensory panel analysis for livery flavor for LEAN PERCENTAGE by CATTLE TYPE

	Treatment[1]														
	90%					80%					70%				
	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
Livery	4.65^{A}	3.21^{B}	2.34^{BCDE}	2.09^{BCDEFH}	2.66^{BCD}	1.16^{EFGH}	0.54^{GH}	1.66^{CDEFG}	0.89^{FGH}	2.94^{BC}	1.05^{EFGH}	0.19^{H}	0.042^{H}	0.47^{GH}	1.34^{DEFGH}

$^{A-H}$Means within a row with different superscripts differ (P<0.05).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content, W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

Table A8. Trained sensory panel analysis for livery flavor for LEAN PERCENTAGE by MUSCLE

	Treatment[1]								
	Longissimus dorsi			***Psoas major***			***Pectorales profundi***		
	90%	***80%***	***70%***	***90%***	***80%***	***70%***	***90%***	***80%***	***70%***
Livery	2.17^{B}	0.98^{CD}	0.54^{D}	4.84^{A}	2.60^{B}	0.85^{D}	1.96^{BC}	0.74^{D}	0.47^{D}

$^{A-D}$Means within a row with different superscripts differ (P<0.05).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content, 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

Table A9. Polar Fatty Acid Composition for *LD* by CATTLE TYPE

	Treatment[1]				
Fatty Acid[2]	W	LH	SH	LB	SB
C10:0	0.0498^{C}	0.0712^{B}	0.05293^{C}	0.9920^{A}	0.05633^{BC}
C14:1	1.02^{B}	1.43^{A}	1.43^{A}	1.32^{A}	1.08^{B}
C18:0	8.21^{C}	9.16^{AB}	9.75^{A}	8.93^{B}	9.31^{AB}
t-vacc (t11)	1.19^{B}	1.34^{A}	1.30^{A}	1.33^{A}	1.36^{A}
C18:1c11	4.09^{B}	3.32^{C}	4.76^{A}	3.17^{C}	4.11^{B}
C20:1	0.3397^{C}	0.3955^{A}	0.4032^{A}	0.4103^{A}	0.3607^{B}

$^{A-C}$Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

[2]Measured as a percentage of total polar fatty acid content

Table A10. Polar Fatty Acid Composition for *LD* by LEAN PERCENTAGE

	Treatment[1]		
Fatty Acid[2]	90%	80%	70%
C10:0	0.04708^{B}	0.0738^{A}	0.0768^{A}
C14:1	1.01^{C}	1.28^{B}	1.47^{A}
C17:0	1.23^{C}	1.53^{B}	1.73^{A}
C18:0	8.66^{B}	8.98^{B}	9.58^{A}
t-vacc (t11)	1.16^{B}	1.36^{A}	1.40^{A}
C18:1c11	2.91^{C}	4.16^{B}	4.61^{A}
C20:1	0.3047^{C}	0.3890^{B}	0.4520^{A}

$^{A-C}$Means with different superscripts differ (P<0.05).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A11. Polar Fatty Acid Composition for *PM* by CATTLE TYPE

	Treatment[1]				
Fatty Acid[2]	W	LH	SH	LB	SB
C10:0	0.05867^{B}	0.06053^{B}	0.05227^{B}	0.1015^{A}	0.05433^{B}
C14:0	0.3346^{C}	0.3379^{BC}	0.3688^{AB}	0.3257^{C}	0.3798^{A}
C14:1	1.03^{C}	1.45^{A}	1.38^{AB}	1.31^{B}	1.07^{C}
C18:0	8.24^{C}	9.14^{B}	9.91^{A}	8.97^{B}	9.28^{B}
trans3(t10)	3.18^{B}	3.60^{A}	3.36^{AB}	3.62^{A}	3.42^{AB}
C18:2	19.94^{B}	20.77^{B}	19.16^{B}	22.64^{A}	20.29^{B}
C20:0	0.1415^{C}	0.1371^{C}	0.1655^{A}	0.1187^{D}	0.1509^{B}
C18:2c9t11	0.3499^{C}	0.4271^{A}	0.4217^{A}	0.4338^{A}	0.3809^{B}
C20:4	14.10^{C}	17.06^{A}	16.09^{B}	17.30^{A}	15.23^{B}

$^{A-D}$Means within a row with different superscripts differ (P<0.05).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

[2]Measured as a percentage of total polar fatty acid content

Table A12. Polar Fatty Acid Composition for *PM* by LEAN PERCENTAGE

	Treatment[1]		
Fatty Acid[2]	90%	80%	70%
C10:0	0.04616^{B}	0.07128^{A}	0.07896^{A}
C14:0	0.4090^{A}	0.3386^{B}	0.3004^{C}
C14:1	0.9877^{C}	1.29^{B}	1.47^{A}
C17:0	1.23^{C}	1.53^{B}	1.73^{A}
C18:0	8.52^{C}	8.96^{B}	9.85^{A}
C18:2	23.15^{A}	20.37^{B}	18.16^{C}
C20:0	0.1173^{C}	0.1456^{B}	0.1654^{A}
C18:2c9t11	0.4362^{A}	0.3901^{B}	0.3818^{B}
C20:4	13.96^{C}	16.39^{B}	17.52^{A}

$^{A-C}$Means with different superscripts differ (P<0.05).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A13. Polar Fatty Acid Composition for *PP* for CATTLE TYPE

	Treatment[1]				
Fatty Acid[2]	W	LH	SH	LB	SB
C10:0	0.07393^{A}	0.06467^{BC}	0.04673^{D}	0.1021^{A}	0.0482^{CD}
C14:0	0.3525^{A}	0.3459^{A}	0.3565^{A}	0.3141^{B}	0.3713^{A}
C14:1	0.9889^{C}	1.44^{A}	1.38^{A}	1.34^{A}	1.10^{B}
C17:0	1.48^{AB}	1.47^{AB}	1.54^{A}	1.41^{B}	1.55^{A}
C18:0	8.41^{D}	9.11^{BC}	9.69^{A}	8.92^{CD}	9.52^{AB}
C18:3	0.6889^{C}	0.7540^{A}	0.7115^{BC}	0.7382^{AB}	0.6931^{C}
C20:0	0.1322^{C}	0.1339^{C}	0.1669^{A}	0.1193^{D}	0.1521^{B}
C18:2c9t11	0.3272^{C}	0.4176^{A}	0.4253^{A}	0.4313^{A}	0.3802^{B}
C20:4	13.17^{C}	16.69^{A}	15.09^{B}	17.21^{A}	15.23^{B}

$^{A-D}$Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

[2]Measured as a percentage of total polar fatty acid content

Table A14. Polar Fatty Acid Composition for *PP* for LEAN PERCENTAGE

	Treatment[1]		
Fatty Acid[2]	90%	80%	70%
C10:0	0.04684^{C}	0.0680^{B}	0.08656^{A}
C14:0	0.3988^{A}	0.3418^{B}	0.3034^{C}
C14:1	0.9852^{C}	1.27^{B}	1.50^{A}
C17:0	1.24^{C}	1.52^{B}	1.71^{A}
C18:0	8.67^{C}	9.15^{B}	9.73^{A}
C18:3	0.8420^{A}	0.6281^{C}	0.6813^{B}
C20:0	0.1165^{C}	0.1438^{B}	0.1623^{A}
C18:2c9t11	0.4254^{A}	0.3852^{B}	0.3784^{B}
C20:4	13.51^{C}	15.97^{B}	16.96^{A}

$^{A-C}$Means with different superscripts differ (P<0.05).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A15. Polar Fatty Acid composition of *LD* muscle based on CATTLE TYPE and LEAN PERCENTAGE interaction

	Treatment[1]														
	90%					80%					70%				
Fatty Acid[2]	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
C12:0	0.0928^{EFG}	0.0828^{FG}	0.1122^{DEFG}	0.0844^{FG}	0.1246^{CDEF}	0.1156^{DEFG}	0.0738^{G}	0.1420^{BCD}	0.231^{A}	0.1624^{BC}	0.1362^{BCDE}	0.1726^{B}	0.1776^{B}	0.2470^{A}	0.1286^{CDE}
C12:1	0.0386^{G}	0.0412^{EFG}	0.0346^{G}	0.0460^{DEFG}	0.0418^{EFG}	0.0390^{FG}	0.0616^{C}	0.0508^{CDEF}	0.0840^{B}	0.0604^{CD}	0.0544^{CDE}	0.0864^{B}	0.0776^{B}	0.1360^{A}	0.0850^{B}
C14:0	0.4066^{AB}	0.4308^{A}	0.4032^{AB}	0.3496^{CD}	0.4214^{A}	0.3374^{CD}	0.3154^{DEF}	0.3692^{BC}	0.3020^{DEF}	0.3394^{CD}	0.2682^{F}	0.2852^{EF}	0.3318^{CDE}	0.3118^{DEF}	0.3140^{DEF}
C16:0	19.52^{C}	21.70^{AB}	20.89^{B}	19.25^{C}	22.59^{A}	14.63^{GF}	15.58^{EF}	16.72^{D}	15.50^{EF}	16.99^{D}	13.85^{G}	15.39^{EF}	16.47^{DE}	15.26^{F}	16.39^{DE}
C16:1	1.46^{C}	1.33^{CD}	1.26^{DE}	1.26^{DE}	1.37^{CD}	1.70^{B}	1.29^{DE}	1.24^{DE}	1.19^{E}	1.35^{CD}	2.28^{A}	1.34^{CD}	1.34^{CD}	1.27^{DE}	1.35^{CD}
C17:1	1.10^{F}	0.9676^{F}	1.11^{F}	1.04^{F}	1.09^{F}	1.35^{DE}	1.27^{E}	1.41^{CD}	1.46^{CD}	1.51^{BC}	1.47^{CD}	1.61^{AB}	1.67^{A}	1.39^{CDE}	1.69^{A}
trans1(t6-8)	0.2306^{CD}	0.2478^{BC}	0.2932^{A}	0.2072^{D}	0.2516^{BC}	0.2228^{CD}	0.2774^{AB}	0.2504^{BC}	0.2426^{BCD}	0.2396^{CD}	0.2184^{CD}	0.2524^{BC}	0.2512^{BC}	0.2376^{CD}	0.2908^{A}
trans2(t9)	0.5392^{DE}	0.5174^{E}	0.6138^{CD}	0.4944^{E}	0.5834^{DE}	0.6906^{BC}	0.6902^{BC}	0.7468^{B}	0.6862^{BC}	0.6938^{BC}	0.7334^{B}	0.9178^{A}	0.9718^{A}	0.9404^{A}	0.9128^{A}
trans3(t10)	3.23^{DEFG}	3.92^{AB}	3.60^{BC}	3.37^{CDEF}	3.52^{CDE}	3.17^{EFG}	3.66^{ABC}	3.08^{FG}	3.56^{CD}	3.35^{CDEF}	2.96^{G}	3.42^{CDEF}	2.92^{G}	4.01^{A}	3.34^{CDEF}
C18:1c9	18.28^{CDE}	17.80^{DEF}	18.23^{CDE}	16.67^{G}	18.96^{C}	26.81^{B}	17.50^{EFG}	18.82^{C}	17.44^{EFG}	18.50^{CD}	28.61^{A}	16.84^{FG}	17.64^{DEF}	17.48^{EFG}	17.68^{DEF}
C18:2	26.23^{A}	22.76^{BC}	21.13^{BCD}	26.14^{A}	20.56^{CDE}	18.01^{EF}	24.12^{AB}	18.75^{DEF}	22.36^{BC}	21.67^{BCD}	14.88^{G}	18.75^{DEF}	17.45^{FG}	19.75^{CDEF}	19.92^{CDEF}
C18:3	0.7410^{CD}	0.8462^{B}	0.9546^{A}	0.8538^{B}	0.7720^{BC}	0.5622^{F}	0.6510^{DEF}	0.6024^{EF}	0.6580^{DEF}	0.6154^{EF}	0.6082^{EF}	0.7600^{BC}	0.6208^{EF}	0.7006^{CDE}	0.6802^{CDE}
C18:2t10c12	0.0562^{EF}	0.0352^{F}	0.0462^{EF}	0.0416^{EF}	0.1012^{BC}	0.0528^{EF}	0.0490^{EF}	0.1096^{BC}	0.0454^{EF}	0.1442^{A}	0.0646^{DE}	0.0658^{DE}	0.1294^{AB}	0.1142^{BC}	0.0896^{DC}

[A-G]Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF), 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A16. Polar Fatty Acid composition of *PM* muscle based on CATTLE TYPE and LEAN PERCENTAGE interaction

	Treatment[1]														
	90%					80%					70%				
Fatty Acid[2]	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
C12:0	0.1094^{EF}	0.0962^{EF}	0.1298^{EF}	0.0982^{EF}	0.1208^{DE}	0.1224^{DE}	0.0726^{F}	0.1298^{DE}	0.2450^{A}	0.1636^{CD}	0.1322^{DE}	0.1422^{CDE}	0.1842^{BC}	0.2184^{AB}	0.1564^{CD}
C12:1	0.0396^{FGH}	0.0402^{FGH}	0.0372^{GH}	0.0460^{DEFGH}	0.04760^{DEFG}	0.03160^{H}	0.0566^{DE}	0.0530^{DEF}	0.0820^{B}	0.0594^{CD}	0.0420^{EFGH}	0.0736^{BC}	0.0746^{BC}	0.1316^{A}	0.0848^{B}
C16:0	19.92^{CD}	21.24^{B}	20.50^{BC}	19.30^{D}	23.14^{A}	14.87^{I}	16.38^{EFG}	17.11^{E}	15.21^{GHI}	16.99^{EF}	13.19^{J}	15.83^{FGHI}	16.26^{EFGH}	15.11^{HI}	16.38^{EFG}
C16:1	1.41^{CD}	1.35^{CDE}	1.24^{EF}	1.25^{DEF}	1.35^{CDE}	1.78^{B}	1.33^{CDEF}	1.28^{CDEF}	1.18^{F}	1.33^{CDEF}	2.25^{A}	1.33^{CDEF}	1.28^{CDEF}	1.27^{DEF}	1.43^{C}
C17:1	1.09^{FG}	0.9722^{G}	1.01^{FG}	1.06^{FG}	1.11^{F}	1.30^{E}	1.32^{DE}	1.45^{CD}	1.43^{CDE}	1.53^{C}	1.42^{CDE}	1.68^{B}	1.80^{AB}	1.34^{DE}	1.81^{A}
trans1(t6-8)	0.2250^{DEF}	0.2422^{CDE}	0.2808^{AB}	0.2062^{F}	0.2520^{BCD}	0.2236^{DEF}	0.2880^{A}	0.2566^{ABCD}	0.2454^{BCDE}	0.2358^{DEF}	0.2110^{EF}	0.2358^{DEF}	0.2720^{ABC}	0.2294^{DEF}	0.2914^{A}
trans2(t9)	0.6102^{CDE}	0.5444^{EF}	0.5992^{DEF}	0.5106^{F}	0.5728^{DEF}	0.6614^{BCD}	0.7034^{BC}	0.7506^{B}	0.6688^{BCD}	0.7108^{B}	0.6988^{BC}	0.9158^{A}	0.9972^{A}	0.9100^{A}	0.9116^{A}
t-vacc (t11)	1.11^{D}	1.15^{D}	1.21^{CD}	1.08^{D}	1.18^{D}	1.17^{D}	1.42^{AB}	1.48^{A}	1.37^{AB}	1.40^{AB}	1.18^{D}	1.40^{AB}	1.33^{BC}	1.48^{A}	1.50^{A}
C18:1c9	18.79^{CD}	17.92^{CDEF}	17.63^{DEF}	17.14^{F}	18.79^{CD}	26.71^{B}	18.39^{CDEF}	18.74^{CDE}	17.77^{CDEF}	19.04^{C}	28.69^{A}	17.14^{F}	17.44^{EF}	17.28^{F}	17.51^{DEF}
C18:1c11	3.35^{E}	2.07^{F}	3.48^{DE}	2.36^{F}	3.41^{E}	4.30^{BC}	3.56^{DE}	4.91^{B}	4.04^{CD}	4.42^{BC}	4.29^{C}	4.21^{C}	6.25^{A}	3.39^{E}	4.53^{BC}
C18:3	0.7986^{BC}	0.8316^{ABC}	0.9028^{A}	0.8634^{AB}	0.7842^{C}	0.5682^{H}	0.6902^{EF}	0.5804^{GH}	0.6502^{EFG}	0.6184^{FGH}	0.5682^{H}	0.7688^{CD}	0.6178^{FGH}	0.7034^{DE}	0.6890^{EF}
C18:2t10c12	0.02320^{H}	0.0352^{H}	0.0716^{DEF}	0.0434^{FGH}	0.0994^{BCD}	0.0418^{GH}	0.0510^{FGH}	0.0812^{CDE}	0.0438^{FGH}	0.1480^{A}	0.0448^{FGH}	0.0662^{EFG}	0.1128^{B}	0.1074^{BC}	0.0956^{BCD}
C20:1	0.2904^{GH}	0.3106^{FGH}	0.3364^{EF}	0.3190^{FGH}	0.2846^{H}	0.3274^{EFG}	0.4134^{BC}	0.4300^{B}	0.4272^{B}	0.3670^{DE}	0.3836^{CD}	0.4940^{A}	0.4442^{B}	0.4870^{A}	0.4340^{B}

[A-I]Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF), 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A17. Polar Fatty Acid composition of *PP* muscle based on CATTLE TYPE and LEAN PERCENTAGE interaction

	Treatment[1]														
	90%					80%					70%				
Fatty Acid[2]	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
C12:0	0.0958^{EF}	0.0870^{EF}	0.1000^{DEF}	0.0944^{EF}	0.1138^{CDEF}	0.1192^{CDEF}	0.0720^{F}	0.1460^{BCD}	0.2450^{A}	0.1604^{BC}	0.1508^{BC}	0.1248^{CDE}	0.1934^{B}	0.1874^{B}	0.1468^{BCD}
C12:1	0.0400^{CD}	0.03780^{CD}	0.0330^{D}	0.0444^{CD}	0.04740^{CD}	0.0540^{C}	0.0532^{C}	0.0554^{C}	0.0814^{B}	0.0572^{C}	0.04580$^{C D}$	0.0780^{B}	0.0840^{B}	0.1280^{A}	0.0874^{B}
C16:0	19.71^{B}	22.33^{A}	20.37^{B}	19.57^{B}	23.52^{A}	15.04^{E}	15.27^{E}	17.60^{C}	15.16^{E}	16.90^{CD}	12.87^{F}	15.07^{E}	15.80^{DE}	15.05^{E}	15.97^{DE}
C16:1	1.39^{CD}	1.34^{CDEF}	1.23^{EFG}	1.21^{FG}	1.34^{CDEF}	1.83^{B}	1.26^{DEFG}	1.27^{DEFG}	1.17^{G}	1.29^{CDEFG}	2.32^{A}	1.36^{CDE}	1.32^{CDEF}	1.27^{DEFG}	1.41^{C}
C17:1	1.05^{F}	1.05^{F}	1.10^{F}	1.06^{F}	1.13^{EF}	1.37^{DC}	1.25^{DE}	1.42^{C}	1.46^{C}	1.47^{C}	1.49^{C}	1.67^{B}	1.87^{A}	1.43^{C}	1.78^{AB}
trans1(t6-8)	0.2238^{EFG}	0.2390^{DEF}	0.2710^{ABCD}	0.1996^{G}	0.2502^{BCDE}	0.2222^{EFG}	0.2714^{ABCD}	0.2416$^{CDE F}$	0.2508^{BCDE}	0.2280^{EFG}	0.2104^{FG}	0.2828^{AB}	0.2722^{ABC}	0.2228^{EFG}	0.2868^{A}
trans2(t9)	0.5342^{D}	0.5358^{D}	0.5628^{D}	0.4942^{D}	0.5682^{D}	0.7116^{C}	0.6646^{C}	0.7086^{C}	0.6592^{C}	0.6848^{C}	0.6976^{C}	0.9420^{B}	1.04^{A}	0.8844^{B}	0.9422^{B}
trans3(t10)	3.39^{BCDE}	3.88^{A}	3.66^{ABC}	3.25^{DEF}	3.60^{ABCD}	2.94^{F}	3.41^{BCDE}	3.21^{DEF}	3.57^{ABCD}	3.35^{CDE}	2.90^{F}	3.59^{ABCD}	3.11^{EF}	3.78^{AB}	3.44^{BCDE}
t-vacc (t11)	1.09^{CD}	1.15^{CD}	1.17^{C}	1.04^{D}	1.18^{C}	1.18^{C}	1.38^{AB}	1.49^{A}	1.41^{AB}	1.37^{AB}	1.11	1.38^{AB}	1.35^{B}	1.43^{AB}	1.49^{A}
C18:1c9	18.46^{CDE}	18.19^{DE}	17.24^{EF}	16.86^{F}	18.80^{CD}	27.70^{B}	17.39^{EF}	19.69^{C}	17.98^{DEF}	18.30^{DE}	29.66^{A}	16.74^{F}	17.56^{DEF}	16.80^{F}	17.72^{DEF}
C18:1c11	3.07^{E}	1.86^{F}	3.43^{E}	2.29^{F}	3.38^{E}	4.37^{CD}	3.35^{E}	4.98^{B}	3.98^{D}	4.52^{BC}	4.44^{CD}	4.41^{CD}	6.16^{A}	3.29^{E}	4.45^{BCD}
C18:2	25.57^{AB}	21.66^{CDE}	23.48^{BCD}	26.64^{A}	20.03^{EFG}	18.73^{FGH}	24.43^{ABC}	18.22^{GH}	21.64^{CDE}	21.12^{DEF}	16.83^{H}	19.85^{EFG}	18.63^{GH}	20.95^{DEFG}	19.74^{EFG}
C18:2t10c12	0.0320^{E}	0.0364^{DE}	0.0568^{DE}	0.0432^{DE}	0.0986^{C}	0.0368^{DE}	0.0486^{DE}	0.0968^{C}	0.0436^{DE}	0.1470^{A}	0.0412^{DE}	0.0638^{D}	0.1296^{AB}	0.1008^{BC}	0.1006^{B}
C20:1	0.2750^{I}	0.3020^{GHI}	0.3318^{EFG}	0.3150$^{FG H}$	0.2790^{HI}	0.3070^{GHI}	0.4096^{D}	0.4370^{CD}	0.4204^{CD}	0.3656^{E}	0.3520^{EF}	0.4794^{AB}	0.4568^{ABC}	0.4922^{A}	0.4422^{BCD}

$^{A-G}$Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF), 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A18. Neutral Fatty Acid composition of *LD* muscle based on CATTLE TYPE

	Treatment[1]				
Fatty Acid[2]	W	LH	SH	LB	SB
C10:0	0.03700^{C}	0.04820^{B}	0.03367^{C}	0.06820^{A}	0.03667^{C}
C14:1	0.7512^{B}	0.9713^{A}	0.9341^{A}	0.9217^{A}	0.7125^{B}
C16:0	26.19^{B}	26.81^{AB}	26.89^{AB}	26.22^{B}	27.41^{A}
C17:0	1.12^{A}	1.02^{B}	1.00^{B}	0.9863^{B}	1.00^{B}
t-vacc (t11)	1.07^{BC}	1.13^{AB}	1.06^{C}	1.14^{A}	1.10^{ABC}
C18:1c9	36.15^{A}	34.99^{B}	35.26^{B}	35.41^{AB}	35.49^{AB}
C20:0	0.1055^{A}	0.09247^{C}	0.1090^{A}	0.0822^{D}	0.09773^{B}
C18:2c9t11	0.3478^{C}	0.3835^{B}	0.3723^{B}	0.4093^{A}	0.3353^{c}
C20:1	0.2484^{C}	0.2682^{B}	0.2660^{B}	0.2862^{A}	0.2351^{C}
C20:4	0.1774^{C}	0.1916^{B}	0.1900^{B}	0.2045	0.1679^{C}

$^{A-C}$Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

[2]Measured as a percentage of total polar fatty acid content

Table A19. Neutral Fatty Acid composition of *LD* muscle based on LEAN PERCENTAGE

	Treatment[1]		
Fatty Acid[2]	90%	80%	70%
C10:0	0.04084	0.04948	0.04392
C14:0	3.45	3.342	3.47
C14:1	0.868	0.8594	0.8471
C16:0	27.10	26.47	26.54
C16:1	3.74	3.76	3.78
C17:0	1.06^{A}	1.02^{AB}	0.9989^{B}
C18:0	14.84	15.00	14.62
trans2(t9)	1.08	1.08	1.08
t-vacc (t11)	1.10	1.11	1.10
C18:1c9	35.13	35.42	35.83
C20:0	0.09936	0.09748	0.09532
C18:2c9t11	0.3704	0.3697	0.3688
C20:1	0.2616	0.2607	0.26
C20:4	0.1868	0.1863	0.1857

[A-B]Means with different superscripts differ ($P<0.05$).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A20. Neutral Fatty Acid composition of *PM* muscle based on CATTLE TYPE

	Treatment[1]				
Fatty Acid[2]	W	LH	SH	LB	SB
C10:0	0.04393^{B}	0.04047^{B}	0.0330^{B}	0.06953^{A}	0.03493^{B}
C14:0	3.50	3.31	3.51	3.29	3.59
C14:1	0.7449^{C}	0.9849^{A}	0.9017^{B}	0.9119^{AB}	0.6992^{C}
C16:0	25.95^{B}	27.03^{A}	26.94^{A}	25.97^{B}	27.51^{A}
C16:1	3.93^{A}	3.80^{AB}	3.57^{B}	3.69^{AB}	3.83^{A}
C17:1	0.9301	0.8853	0.9223	0.8984	0.9601
C18:0	14.25^{B}	14.60^{B}	15.48^{A}	14.83^{AB}	14.38^{B}
t-vacc (t11)	1.04	1.11	1.09	1.12	1.10
C18:1c9	36.63^{A}	35.49^{BC}	34.77^{C}	35.79^{AB}	35.47^{BC}
C18:2	3.05^{AB}	3.00^{B}	2.66^{C}	3.34^{A}	2.82^{BC}
C20:0	0.1037^{B}	0.09273^{C}	0.1089^{A}	0.08273^{D}	0.09880^{B}
C18:2c9t11	0.3425^{C}	0.3899^{AB}	0.3737^{B}	0.4089^{A}	0.3357^{c}
C20:1	0.2447^{C}	0.2727^{AB}	0.2669^{B}	0.2859^{A}	0.2355^{C}
C20:4	0.1747^{C}	0.1947^{AB}	0.1907^{B}	0.2044^{A}	0.1683^{C}

$^{A-C}$Means within a row with different superscripts differ (P<0.05).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

[2]Measured as a percentage of total polar fatty acid content

Table A21. Neutral Fatty Acid composition of *PM* muscle based on LEAN PERCENTAGE

	Treatment[1]		
Fatty Acid[2]	90%	80%	70%
C16:0	27.14[A]	26.42[B]	26.47[B]
C20:0	0.1006[A]	0.09628[B]	0.09524[B]

[A-B]Means with different superscripts differ ($P<0.05$).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A22. Neutral Fatty Acid composition of *PP* muscle based on CATTLE TYPE

	Treatment[1]				
Fatty Acid[2]	W	LH	SH	LB	SB
C10:0	0.05313^{B}	0.04320^{B}	0.02993^{C}	0.0698^{A}	0.0316^{C}
C14:0	3.69^{A}	3.41^{BC}	3.41^{BC}	3.21^{C}	3.50^{AB}
C14:1	0.7137^{C}	0.9829^{A}	0.9020^{B}	0.9410^{AB}	0.7153^{C}
C16:1	3.97^{A}	3.80^{AB}	3.59^{C}	3.66^{BC}	3.76^{BC}
trans3(t10)	4.06^{B}	4.52^{A}	3.98^{B}	4.52^{A}	4.13^{B}
C20:0	0.09660^{BC}	0.09193^{C}	0.1093^{A}	0.08367^{D}	0.09987^{B}

[A-C]Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

[2]Measured as a percentage of total polar fatty acid content

Table A23. Neutral Fatty Acid composition of *PP* muscle based on LEAN PERCENTAGE

	Treatment[1]		
Fatty Acid[2]	90%	80%	70%
C10:0	0.04052	0.0456	0.05048
C16:1	3.65^{B}	3.75^{AB}	3.87^{A}
C17:0	1.06^{A}	1.01^{B}	0.9904^{B}
C20:0	0.09972^{A}	0.09548^{AB}	0.09364^{B}

$^{A-B}$Means with different superscripts differ (P<0.05).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A24. Neutral Fatty Acid composition of *LD* muscle based on CATTLE TYPE and LEAN PERCENTAGE interaction

	Treatment[1]														
	90%					80%					70%				
Fatty Acid[2]	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
C12:0	0.0832^{BC}	0.0700^{CD}	0.0920^{BC}	0.0766^{BCD}	0.1018^{B}	0.0824^{BC}	0.0502^{D}	0.0906^{BC}	0.1568^{A}	0.1046^{B}	0.0862^{BC}	0.0984^{BC}	0.0988^{BC}	0.1406^{A}	0.0714^{CD}
C12:1	0.0348^{DEF}	0.0348^{DEF}	0.0282^{EF}	0.0420^{CD}	0.0342^{DEF}	0.0276^{F}	0.0418^{CD}	0.0328^{DEF}	0.0574^{B}	0.0386^{CDE}	0.0340^{DEF}	0.0492^{BC}	0.0434^{CD}	0.0774^{A}	0.0472^{BC}
C17:1	0.9862^{AB}	0.8218^{FG}	0.8346^{EFG}	0.9472^{ABCD}	0.8868^{CDEF}	0.9626^{ABC}	0.8618^{DEFG}	0.9004^{BCDEF}	0.9934^{A}	0.9710^{ABC}	0.9282^{ABCD}	0.9178^{ABCDE}	0.9330^{ABCD}	0.7868^{G}	0.9428^{ABCD}
trans1(t6-8)	0.3126^{CD}	0.3156^{CD}	0.3600^{ABC}	0.2828^{D}	0.3072^{D}	0.3172^{CD}	0.3780^{A}	0.3192^{CD}	0.3300^{ABCD}	0.3082^{D}	0.3168^{CD}	0.3308^{ABCD}	0.3232^{BCD}	0.3108^{CD}	0.3724^{AB}
trans3(t10)	4.07^{CD}	4.68^{AB}	4.12^{CD}	4.29^{BC}	4.01^{CDE}	4.29^{BC}	4.73^{AB}	3.75^{DE}	4.60^{AB}	4.10^{CD}	4.12^{CD}	4.28^{BC}	3.58^{E}	5.01^{A}	4.08^{CD}
C18:1c11	1.96^{BC}	1.26^{G}	2.08^{AB}	1.51^{EFG}	1.89^{BCD}	2.03^{ABC}	1.51^{EFG}	2.01^{ABC}	1.61^{DEF}	1.88^{BCD}	2.10^{AB}	1.77^{CDE}	2.28^{A}	1.39^{FG}	1.76^{CDE}
C18:2	3.56^{AB}	2.93^{CDEF}	2.60^{EF}	3.58^{AB}	2.52^{F}	2.82^{DEF}	3.62^{A}	2.64^{DEF}	3.35^{ABC}	3.06^{BCDE}	2.63^{EF}	3.00^{CDEF}	2.74^{DEF}	3.15^{ABCD}	3.10^{ABCDE}
C18:3	0.1334^{CDE}	0.1438^{ABCD}	0.1562^{A}	0.1554^{AB}	0.1260^{DE}	0.1334^{CDE}	0.1478^{ABC}	0.1282^{DE}	0.1492^{ABC}	0.1316^{CDE}	0.1370^{BCDE}	0.1546^{AB}	0.1236^{E}	0.1420^{ABCDE}	0.1348^{CDE}
C18:2t10c12	0.05020^{CDE}	0.0296^{F}	0.0376^{EF}	0.0378^{EF}	0.0826^{AB}	0.0376^{EF}	0.0336^{EF}	0.0702^{BC}	0.0312^{EF}	0.0926^{A}	0.0402^{EF}	0.0374^{EF}	0.0728^{AB}	0.0648^{BCD}	0.0496

[A-G]Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF), 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A25. Neutral Fatty Acid composition of *PM* muscle based on CATTLE TYPE and LEAN PERCENTAGE interaction

	Treatment[1]														
	90%					80%					70%				
Fatty Acid[2]	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
C12:0	0.0972^{BC}	0.0830^{C}	0.0908^{C}	0.0886^{C}	0.0982^{BC}	0.0856^{C}	0.0478^{D}	0.0824^{C}	0.1666^{A}	0.1040^{BC}	0.0844^{C}	0.0802^{C}	0.1022^{BC}	0.1250^{B}	0.0866^{C}
C12:1	0.0352^{DEF}	0.0346^{DEF}	0.0308^{EFG}	0.0412^{CD}	0.0388^{CDE}	0.0220^{G}	0.0376^{CDE}	0.0338^{DEF}	0.0556^{B}	0.0382^{CDE}	0.0272^{FG}	0.0416^{CD}	0.0414^{CD}	0.0754^{A}	0.0470^{BC}
C17:0	1.12^{ABC}	1.12^{DE}	0.9928^{DE}	1.02^{ABC}	1.02^{BCD}	1.05^{ABCD}	0.9830^{CD}	1.07^{ABCD}	0.9518^{AB}	0.9956^{AB}	1.05^{ABCD}	0.9988^{ABC}	0.9600^{A}	0.9728^{E}	1.01^{A}
trans1(t6-8)	0.3002^{DE}	0.3128^{CDE}	0.3516^{ABC}	0.2788^{E}	0.3076^{CDE}	0.3136^{CDE}	0.3814^{A}	0.3254^{BCDE}	0.3334^{BCD}	0.3014^{DE}	0.3104^{CDE}	0.3064^{CDE}	0.3470^{BCD}	0.3026^{DE}	0.3712^{AB}
trans2(t9)	1.25^{A}	1.07^{BC}	1.16^{AB}	1.06^{BC}	1.07^{BC}	1.07^{BC}	1.07^{BC}	1.10^{B}	1.05^{BC}	1.04^{BC}	0.9340^{C}	1.08^{B}	1.16^{AB}	1.09^{B}	1.06^{BC}
trans3(t10)	4.05^{DC}	4.64^{AB}	4.30^{BCD}	4.23^{BCD}	3.93^{D}	4.05^{CD}	4.51^{ABC}	3.92^{D}	4.64^{AB}	4.21^{BCD}	4.58^{ABC}	4.1624^{BCD}	3.84^{D}	4.92^{A}	4.07^{CD}
C18:1c11	2.08^{B}	1.25^{I}	2.03^{BC}	1.49^{GHI}	1.94^{BCD}	1.96^{BCD}	1.53^{FGH}	2.03^{BC}	1.79^{CDEF}	1.83^{BCDE}	1.92^{BCDE}	1.66^{EFG}	2.42^{A}	1.36^{HI}	1.76^{DEF}
C18:3	0.1414^{BCDE}	0.1428^{ABCDE}	0.0151^{AB}	0.01558^{A}	0.1276^{FG}	0.1328^{DEFG}	0.1520^{AB}	0.1228^{FG}	0.1472^{ABC}	0.1312^{DEFG}	0.1296^{EFG}	0.1548^{AB}	0.1220^{G}	0.1440^{ABCD}	0.1362^{CDEF}
C18:2t10c12	0.0206^{E}	0.0304^{E}	0.0592^{C}	0.0390^{DE}	0.0810^{AB}	0.0294^{E}	0.0338^{DE}	0.0518^{CD}	0.0300^{E}	0.0942^{A}	0.0290^{E}	0.0372^{DE}	0.0626^{BC}	0.0612^{BC}	0.0530^{CD}

[A-I]Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF), 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A26. Neutral Fatty Acid composition of *PP* muscle based on CATTLE TYPE and LEAN PERCENTAGE interaction

	Treatment[1]														
	90%					80%					70%				
Fatty Acid[2]	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
C12:0	0.0854^{BC}	0.0726^{CD}	0.0852^{BC}	0.0856^{BC}	0.0920^{BC}	0.0834^{BC}	0.0496^{D}	0.0920^{BC}	0.1646^{A}	0.1026^{BC}	0.0966^{BC}	0.0720^{CD}	0.1058^{B}	0.1098^{B}	0.0818^{BCD}
C12:1	0.0356^{CDE}	0.0316^{DE}	0.0282^{E}	0.0404^{BCDE}	0.0384^{CDE}	0.0370^{CDE}	0.0370^{CDE}	0.0352^{CDE}	0.0546^{B}	0.0366^{CDE}	0.0288^{E}	0.0448^{BCD}	0.0460^{BCD}	0.0746^{A}	0.0484^{BC}
C16:0	26.37^{CDE}	27.95^{AB}	26.92^{BC}	26.74^{BCD}	28.62^{A}	26.14^{CDE}	26.34^{CDE}	25.28^{EF}	25.53^{DEF}	27.01^{BC}	24.36^{F}	26.00^{CDE}	27.30^{BC}	26.30^{CDE}	26.70^{BCD}
C17:1	0.9342^{ABCD}	0.8802^{BCD}	0.9418^{ABCD}	0.9618^{ABC}	0.9144^{ABCD}	0.9520^{ABC}	0.8656^{CD}	0.8934^{BCD}	0.9812^{AB}	0.9416^{ABCD}	0.9370^{ABCD}	0.9600^{ABC}	1.02^{A}	0.8320^{D}	0.9930^{AB}
trans1(t6-8)	0.3000^{CD}	0.2994^{CD}	0.3454^{AB}	0.2730^{D}	0.3044^{BCD}	0.3100^{BCD}	0.3756^{A}	0.3052^{BCD}	0.3376^{ABC}	0.2920^{D}	0.3064^{BCD}	0.3750^{A}	0.3426^{ABC}	0.2994^{CD}	0.3674^{A}
trans2(t9)	1.10^{ABC}	1.03^{CD}	1.10^{ABC}	1.04^{CD}	1.06^{BC}	1.19^{AB}	1.09^{ABC}	1.06^{BC}	1.06^{BC}	1.05^{CD}	0.9240^{D}	1.14^{ABC}	1.20^{A}	1.08^{ABC}	1.10^{ABC}
t-vacc (t11)	1.09^{ABCD}	1.06^{BCD}	1.11^{ABC}	1.06^{BCDE}	1.06^{ABCD}	1.00^{DE}	1.16^{A}	1.14^{AB}	1.15^{AB}	1.07^{ABCD}	0.9600^{E}	1.09^{ABCD}	1.01^{CDE}	1.15^{AB}	1.14^{AB}
C18:1c9	35.17^{DE}	35.17^{DE}	33.95^{E}	35.58^{BCD}	35.32^{CD}	36.88^{AB}	35.37^{CD}	36.59^{BC}	35.71^{BCD}	34.49^{DE}	38.17^{A}	34.97^{DE}	34.89^{DE}	35.57^{BCD}	35.84^{BCD}
C18:1c11	1.92^{BC}	1.09^{F}	2.04^{B}	1.46^{E}	1.92^{BC}	1.99^{BC}	1.51^{DE}	2.05^{B}	1.75^{CD}	1.88^{BC}	1.96^{BC}	1.78^{C}	2.36^{A}	1.34^{E}	1.73^{CD}
C18:2	3.44^{AB}	2.72^{CDE}	3.02^{BCD}	3.64^{A}	2.44^{E}	2.88^{CDE}	3.73^{A}	2.53^{DE}	3.21^{ABC}	2.97^{BCD}	3.00^{BCD}	3.22^{ABC}	2.79^{CDE}	3.43^{AB}	3.08^{BC}
C18:3	0.1480^{AB}	0.1426^{AB}	0.1516^{A}	0.1542^{A}	0.1286^{C}	0.1370^{BC}	0.1532^{A}	0.1282^{C}	0.1506^{A}	0.1290^{C}	0.1470^{AB}	0.1526^{A}	0.1242^{C}	0.1460^{AB}	0.1354^{BC}
C18:2c9t11	0.3452^{DEF}	0.3602^{BCD}	0.3946^{AB}	0.4104^{A}	0.3208^{EFG}	0.3004^{G}	0.4042^{A}	0.3854^{ABC}	0.4056^{A}	0.3346^{DEFG}	0.3112^{FG}	0.3952^{AB}	0.3506^{CDE}	0.4104^{A}	0.3524^{CDE}
C18:2t10c12	0.0286^{GH}	0.0304^{GH}	0.0492^{DEFG}	0.0394^{EFGH}	0.0802^{AB}	0.0262^{H}	0.0336^{GH}	0.0612^{BCD}	0.0296^{GH}	0.0938^{A}	0.0260^{H}	0.0368^{FGH}	0.0716^{BC}	0.0588^{CDE}	0.0562^{CDEF}
C20:1	0.2466^{CD}	0.2518^{BC}	0.2818^{A}	0.2868^{A}	0.2264^{CDE}	0.2144^{E}	0.2828^{A}	0.2752^{AB}	0.2834^{A}	0.2338^{CDE}	0.2226^{DE}	0.2762^{AB}	0.2506^{BC}	0.2870^{A}	0.2466^{CD}
C20:4	0.7162^{CD}	0.1798^{BC}	0.2012^{A}	0.2048^{A}	0.1618^{CDE}	0.1532^{E}	0.2020^{A}	0.1966^{AB}	0.2026^{A}	0.1672^{CDE}	0.1588^{DE}	0.1974^{AB}	0.1790^{BC}	0.2050^{A}	0.1762^{CD}

[A-H]Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF), 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured as a percentage of total polar fatty acid content

Table A27. Volatile components by CATTLE TYPE

	Treatment[1]				
Compound[2]	W	LH	SH	LB	SB
Acetaldehyde	697.69^{A}	366.69^{B}	441.98^{B}	449.68^{B}	464.80^{B}
Dimethyl Sulfide	8.09^{A}	4.86^{B}	5.62^{B}	4.77^{B}	5.74^{B}
2, 3 Butanedione	62.54^{A}	34.72^{B}	41.40^{B}	39.83^{B}	38.89^{B}
2, 3 Pentanedione	124.10^{A}	101.77^{AB}	67.43^{B}	75.67^{B}	79.18^{B}

$^{A-B}$Means within a row with different superscripts differ (P<0.05).

[1]Treatments: W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

[2]Measured in nanograms/grams

Table A28. Volatile components by MUSCLE

	Treatment[1]		
Compound[2]	LD	PM	PP
Acetaldehyde	489.39	494.08	469.04
Dimethyl Sulfide	4.65^{B}	7.73^{A}	5.06^{B}

$^{A-B}$Means within a row with different superscripts differ (P<0.05).

[1]Treatments: LD=*Longissimus dorsi,* PM=*Psoas major*, PP=*Pectorales profundi*

[2]Measured in nanograms/grams

Table A29. Volatile components by LEAN PERCENTAGE

	Treatment[1]		
Compound[2]	90%	80%	70%
Acetaldehyde	325.56[B]	512.05[A]	614.89[A]
2, 3 Butanedione	31.23[B]	47.16[A]	52.04[A]
2, 3 Pentanedione	56.77[B]	108.03[A]	104.10[A]

[A-B]Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured in nanograms/grams

Table A30. Volatile components based on cattle type by MUSCLE interaction

	Treatment[1]														
	Longissimus Dorsi					*Psoas major*					*Pectorales profundi*				
Volatile Compound[2]	**W**	**LH**	**SH**	**LB**	**SB**	**W**	**LH**	**SH**	**LB**	**SB**	**W**	**LH**	**SH**	**LB**	**SB**
Hexanal	127.60^{BC}	85.11^{BC}	294.77^{A}	32.95^{C}	39.00^{BC}	177.02^{ABC}	197.51^{AB}	136.37^{BC}	66.13^{BC}	163.70^{ABC}	83.01^{BC}	113.51^{BC}	100.95^{BC}	206.25^{AB}	44.04^{BC}
2-ethyl-3,5/6 dimethyl pyrazine	0.6684^{C}	0.4789^{C}	1.83^{A}	0.4694^{C}	0.2074^{C}	0.5660^{C}	0.1239^{C}	0.2083^{C}	0.5098^{C}	0.7133^{BC}	0.1368^{C}	0.3197^{C}	0.3082^{C}	1.68^{AB}	0.8385^{BC}
3-Methyl Butanal	61.94^{A}	29.36^{BCD}	45.67^{AB}	19.41^{CD}	19.69^{CD}	23.04^{CD}	11.31^{D}	14.67^{D}	28.42^{BCD}	29.91^{BCD}	17.34^{CD}	24.55^{CD}	22.00^{CD}	35.52^{BC}	18.14^{CD}

$^{A-D}$ Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: LD=*Longissimus dorsi,* PM=*Psoas major*, PP=*Pectorales profundi*, W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

[2]Measured in nanograms/grams

Table A31. Components of Heptanal based on CATTLE TYPE by MUSLCE by LEAN PERCENTAGE interaction

	Treatment[12]		
	90%	**80%**	**70%**
LD			
W	5.88^{CD}	14.9081^{BCD}	9.712^{BCD}
LH	2.68^{D}	6.6497^{CD}	7.2386^{CD}
SH	5.11^{CD}	11.072^{BCD}	27.9911^{B}
LB	1.75^{D}	2.1633^{D}	3.7290^{CD}
SB	1.05^{D}	3.5381^{D}	1.0891^{D}
PM			
W	4.56^{CD}	7.39^{CD}	17.05^{BCD}
LH	5.08^{CD}	5.46^{CD}	8.11^{BCD}
SH	3.71^{D}	4.39^{CD}	6.13^{CD}
LB	2.22^{D}	5.24^{CD}	11.75^{BCD}
SB	5.90^{CD}	4.23^{CD}	19.49^{BCD}
PP			
W	1.99^{D}	3.40^{D}	4.92^{CD}
LH	5.34^{CD}	4.12^{D}	14.08^{BCD}
SH	3.31^{D}	19.66^{BCD}	7.08^{CD}
LB	3.19^{D}	24.95^{BC}	75.49^{A}
SB	3.16^{D}	3.68^{D}	3.95^{CD}

$^{A-D}$Means with different superscripts differ (P<0.05).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content, W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF), LD=*Longissimus dorsi,* PM=*Psoas major*, PP=*Pectorales profundi*

[2]Measured in nanograms/grams

Table A32. Olfactory odors associated with specific volatile compounds

Compound	Associated Odor(s)
Acetaldehyde	Fruity, Floral
Methanethiol	Sulphur
2,3 Butanedione	Buttery, Browned
Methyl Butanal	Sweat, Expo Marker, Oxidized, Chemical
Hexanal	Grass
Heptanal	Oxidized, Browned, Cooking Oil, Plastic
Methional	Baked Potato, Browned
Benzaldehyde	Propane, Burning, Grass
Octanal	Aromatic, Oxidized, Plastic, Earthy
2-ethyl-3,5/6-dimethyl pyrazine	Chocolate
Nonanal	Plastic, Burning

Table A33. Amino Acid composition based on CATTLE TYPE by MUSCLE interaction

	Treatment[1]														
	LD					PM					PP				
Amino Acid[2]	**W**	**LH**	**SH**	**LB**	**SB**	**W**	**LH**	**SH**	**LB**	**SB**	**W**	**LH**	**SH**	**LB**	**SB**
Alanine	4.24^{A}	3.86^{A}	1.20^{E}	1.14^{E}	2.20^{BC}	1.04^{E}	1.48^{CDE}	2.53^{B}	1.32^{DE}	1.01^{E}	0.87^{E}	2.53^{B}	2.09^{BCD}	2.25^{BC}	2.71^{B}
Asparagine	0.11^{B}	0.06^{B}	0.08^{B}	0.47^{B}	0.12^{B}	0.05^{B}	0.31^{B}	0.25^{B}	0.04^{B}	2.08^{A}	0.03^{B}	0.46^{B}	0.45^{B}	0.58^{B}	0.22^{B}
Aspartic Acid	0.05^{C}	0.10^{BC}	0.05^{C}	0.12^{BC}	0.06^{BC}	0.06^{BC}	0.23^{B}	0.10^{BC}	0.08^{BC}	0.44^{A}	0.054^{BC}	0.13^{BC}	0.13^{BC}	0.13^{BC}	0.09^{BC}
Cysteine	0.32^{AB}	0.21^{CD}	0.03^{GF}	0.14^{DEF}	0.11^{EFG}	0.02^{G}	0.09^{EFG}	0.13^{DE}	0.01^{G}	0.38^{A}	0.20^{FG}	0.26^{BC}	0.25^{BC}	0.33^{AB}	0.12^{EFG}
Cysteine 2	0.01^{A}	0.009^{AB}	0.0001^{F}	0.004^{CDEF}	0.005^{CDEF}	0.0006^{EF}	0.002^{DEF}	0.003^{DEF}	0.00006^{F}	0.01^{AB}	0.0002^{EF}	0.006^{CDE}	0.09^{ABCD}	0.008^{BCD}	0.005^{CDEF}
Glycine	1.91^{A}	1.03^{CDE}	0.7459^{DEF}	0.6426^{DEF}	0.5226^{F}	0.4699^{F}	0.5316^{EF}	1.13^{CD}	0.5572^{EF}	0.5136^{F}	0.5918^{DEF}	1.55^{AB}	1.32^{BC}	1.41^{BC}	1.11^{CD}
Isoleucine	0.5014^{A}	0.37^{B}	0.253^{CDEF}	0.224^{DEF}	0.2097^{DEF}	0.1638^{F}	0.2521^{CDEF}	0.216^{DEF}	0.2478^{CDEF}	0.1886^{EF}	0.2008^{DEF}	0.2994^{BCD}	0.3214^{BC}	0.2751^{CD}	0.2567^{CDE}
Leucine	2.76^{A}	2.12^{B}	0.3428^{G}	1.13^{EF}	1.13^{EF}	0.2698^{G}	0.6519^{FG}	1.33^{DE}	0.3004^{G}	1.24^{DEF}	0.2171^{G}	1.90^{BC}	2.01^{BC}	1.69^{BCD}	1.59^{CDE}
Lysine	1.36^{A}	0.6335^{BC}	0.09493^{FG}	0.1706^{EFG}	0.4147^{D}	0.0446^{G}	0.05695^{FG}	0.3928^{DE}	0.02785^{G}	0.169^{FG}	0.01501^{G}	0.4578^{CD}	0.4453^{CD}	0.3249^{DEF}	0.8152^{B}
Methionine	0.5349^{A}	0.3115^{BC}	0.1436^{DE}	0.1317^{DE}	0.1305^{DE}	0.07523^{DE}	0.1796^{CDE}	0.3089^{BC}	0.02068^{E}	0.1811^{CD}	0.01639^{E}	0.3724^{B}	0.2833^{BC}	0.3426^{B}	0.3369^{B}
Ornithine	0.3391^{A}	0.1946^{B}	0.0152^{F}	0.04854^{EF}	0.1321^{CD}	0.01701^{F}	0.02544^{EF}	0.1114^{CD}	0.006029^{F}	0.08053^{DE}	0.001366^{F}	0.1405^{C}	0.1316^{CD}	0.111^{CD}	0.2403^{B}
Phenylalanine	4.01^{AB}	4.27^{A}	0.9183^{GF}	2.85^{CDE}	2.43^{DE}	0.09405^{G}	1.33^{EFG}	2.02^{DEF}	0.3213^{G}	3.08^{BCD}	0.1880^{G}	2.80^{CDE}	3.78^{ABC}	2.81^{CDE}	1.83^{EF}
Proline	0.4729^{A}	0.2909^{CD}	0.3263^{BC}	0.1856^{E}	0.1890^{E}	0.1621^{E}	0.2689^{CDE}	0.2800^{CD}	0.3064^{BCD}	0.2069^{DE}	0.3217^{BCD}	0.3819^{B}	0.3812^{BC}	0.3804^{BC}	0.3710^{BC}
Serine	0.2826^{A}	0.2286^{AB}	0.2060^{BCD}	0.09532^{FG}	0.1116^{DEF}	0.1543^{CDEFG}	0.1585^{BCDEFG}	0.1075^{FG}	0.1462^{CDEFG}	0.08707^{G}	0.1257^{DEFG}	0.2116^{BC}	0.1604^{BCDEF}	0.1668^{BCDE}	0.1700^{BCD}
Threonine	0.3507^{BC}	0.2239^{CDE}	0.05244^{E}	0.5917^{A}	0.1205^{DE}	0.1078^{DE}	0.5322^{AB}	0.2152^{CDE}	0.003080^{E}	0.6135^{A}	0.1221^{CDE}	0.2949^{BCD}	0.4525^{AB}	0.2692^{BCDE}	0.2167^{CDE}
Tryptophan	0.5799^{A}	0.4436^{B}	0.02233^{E}	0.1535^{DE}	0.2409^{CD}	0.01432^{E}	0.05710^{E}	0.1474^{DE}	0.01543^{E}	0.2517^{CD}	0.00711^{E}	0.3091^{C}	0.3213^{C}	0.2821^{C}	0.2384^{CD}
Tyrosine	1.4440^{A}	0.7164^{B}	0.1073^{FG}	0.2770^{DEFG}	0.3817^{DE}	0.07162^{FG}	0.1278^{EFG}	0.3582^{DE}	0.04851^{FG}	0.3356^{DEF}	0.01759^{G}	0.5137^{CD}	0.7376^{B}	0.4854^{CD}	0.6109^{BC}
Valine	1.5710^{ABC}	1.97^{A}	1.74^{AB}	0.6516^{EF}	0.9820^{DEF}	1.6874^{ABC}	1.4617^{ABCD}	0.6785^{F}	1.69^{ABC}	1.38^{BCD}	1.72^{ABC}	1.09^{DE}	1.25^{CDE}	1.01^{DEF}	1.11^{DE}

[A-G]Means within a row with different superscripts differ ($P<0.05$).

[1]Treatments: LD=*Longissimus dorsi,* PM=*Psoas major*, PP=*Pectorales profundi,* W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

[2]Measured in millimole/kilogram

Table A34. Amino Acid composition based on CATTLE TYPE by MUSCLE interaction

Treatment[1]															
	90%					80%					70%				
Compound[2]	W	LH	SH	LB	SB	W	LH	SH	LB	SB	W	LH	SH	LB	SB
GLN	0.9157^{CD}	2.7593^{A}	0.5316^{D}	0.6295^{D}	2.1056^{AB}	2.3107^{AB}	1.4640^{BCD}	0.7139^{D}	0.3812^{D}	1.8490^{ABC}	2.5188^{AB}	1.4143^{BCD}	0.3898^{D}	0.4972^{D}	1.2130^{CD}
THR	0.2096^{CD}	0.6437^{A}	0.2147^{CD}	0.3034^{BCD}	0.3173^{BCD}	0.1889^{CD}	0.1731^{CD}	0.2171^{CD}	0.1610^{CD}	0.4873^{AB}	0.1821^{CD}	0.2342^{CD}	0.2884^{BCD}	0.3996^{BC}	0.1460^{D}

$^{A-D}$Means within a row with different superscripts differ (P<0.05).

[1]Treatments: 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content W= Wagyu (490 DOF), LH= Long-Fed/Natural Holstein (334 DOF), SH= Short-Fed/Retail Holstein (250 DOF), Long-Fed/Conventional Beef (201 DOF), Short-Fed Beef (90 DOF)

[2]Measured in millimole/kilograms

Table A35. Composition of Asparagine based on MUSCLE by LEAN PERCENTAGE interaction

	Treatment[12]		
	LD	**PM**	**PP**
90%	0.08608[B]	0.3070[A]	0.1076[B]
80%	0.05941[B]	0.1324[B]	0.08677[B]
70%	0.08194[B]	0.1070[B]	0.1242[B]

[A-B]Means with different superscripts differ (P<0.05).

[1]Treatments: LD=*Longissimus dorsi,* PM=*Psoas major*, PP=*Pectorales profundi,* 90%=Patties with 90% lean content, 80%=Patties with 80% lean content, 70%=Patties with 70% lean content

[2]Measured in millimole/kilogram

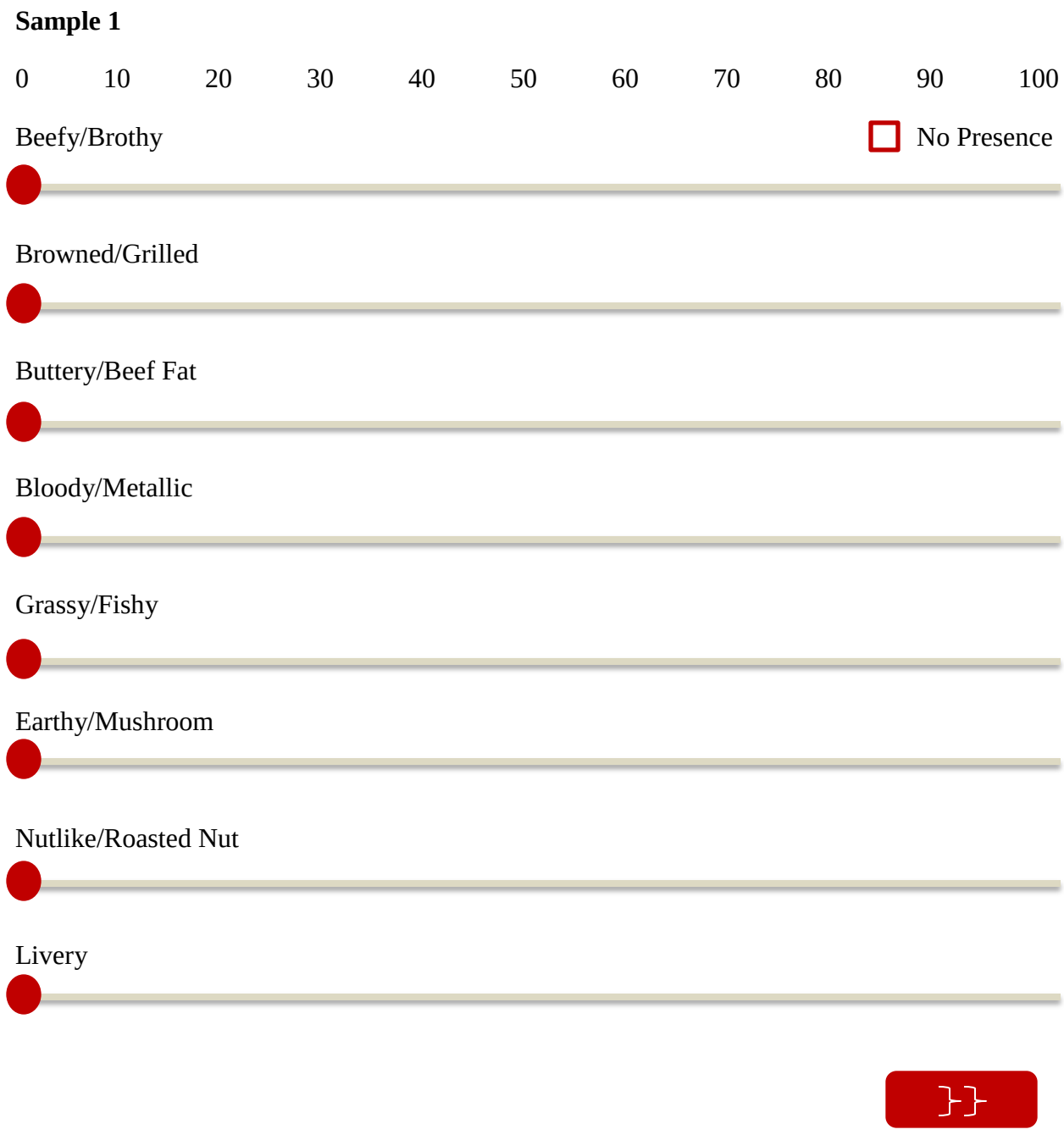


Figure A3.1 Example sensory ballet