DISSERTATION

IDENTIFYING PREFERENCES FOR SPECIFIC BEEF FLAVOR CHARACTERISTICS

Submitted by

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ABSTRACT

IDENTIFYING PREFERENCES FOR SPECIFIC BEEF FLAVOR CHARACTERISTICS

Descriptive sensory analysis of beef samples was conducted at culinary institutions in three regions of the United States to determine differences in beef flavor attributes and flavor preferences among 12 different beef product categories (treatments). Treatments were chosen specifically to permit identification and characterization of production-related beef flavor differences, including effects of USDA grade (Prime, Premium Choice, Low Choice, Select), cattle breed-type (Angus, Holstein, American Wagyu), finishing diet (grass-fed, corn-fed, barley-fed), use of growth technologies (non-implanted, implanted, implanted & fed β agonists), and postmortem aging method (wet-aged, dry-aged). Panelists (N = 307) rated ground strip loin samples from each treatment for 13 different flavor notes (beefy/brothy, browned/grilled, buttery/beef fat, nutty/roasted nut, earthy/mushroom, bloody/metallic, grassy, livery, fishy, sour, sweet, and bitter) and overall flavor desirability. Each sensory attribute was rated on a 10-cm, unstructured line scale with 0 cm verbally anchored at very low intensity for all flavors and dislike extremely for flavor desirability and 10 cm verbally anchored at very high intensity for all flavors and like extremely for flavor desirability. In addition, samples were analyzed to determine percentage chemical lipid, moisture, protein, and ash of raw products, fatty acid composition of cooked products, and quantities of volatiles produced during cooking. Of the factors analyzed, USDA Quality grade and finishing diet (grain-fed vs grass-fed) had the largest effects on beef flavor attributes. Differences in cattle-breed type (Angus vs Wagyu), grain source (corn vs barley), aging technique (dry-aged

vs wet-aged), and use of growth technology (non-implanted vs implanted vs implanted & fed β agonists) had only minimal effects on flavor. Extending the wet-aging period from 14 to 46 d had a negative effect on flavor, producing samples that scored higher ($P < 0.05$) for sour flavor than all other treatments. Panelists preferred samples with flavors described as beefy/brothy, browned/grilled, buttery/beef fat, nutty/nutty roasted nut, and sweet, and disliked flavors identified as bloody/metallic, grassy, gamey, livery, fishy, sour, and bitter. Moreover, overall flavor desirability scores were positively correlated ($P < 0.05$) with the concentration of several monounsatured fatty acids including C12:1, C14:1, C16:1 c9, and C18:1 c9. Stearic acid (C18:0) concentration was negatively correlated ($P < 0.05$) with overall flavor desirability and positively correlated ($P < 0.05$) with bloody/metallic, grassy/hay like, gamey, livery, fishy, sour, and bitter flavors. The concentration of several polyunsaturated fatty acids including C18:2t (total), C18:3 n-3, and C22:5 n-3, were found highest ($P < 0.05$) in Organic grass-fed samples and were negatively correlated ($P < 0.05$) with overall flavor desirability. Overall flavor desirability was positively correlated ($P < 0.05$) with diacetyl (2, 3-butanedione), acetoin (3-hydroxy-2-butanone), 3-methyl butanal, and pentanal concentrations. Samples with higher concentrations of dimethyl sulfide were rated lower ($P < 0.05$) for overall flavor desirability. The concentrations of several volatile compounds were correlated with various beef flavors including beefy/brothy, buttery/beef fat, browned/grilled, earthy/mushroom, nutty/roasted nut, sour, bitter, and sweet.

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CHAPTER I

INTRODUCTION

Flavor is a complex, multifaceted concept. The overall flavor of a food product is comprised of the taste, odor/aroma, chemical feeling sensations in the mouth and airways, and the interaction and combination of these factors. Additionally, the visual and auditory characteristics of a food product contribute to flavor perception (Clydesdale, 1993; Spence and Zampini, 2006; Verhagen and Engelen, 2006). Five basic tastes including sweet, sour, salty, bitter, and umami are detected by the taste buds located primarily on the tongue, but also on the hard and soft palate, in the throat, on the cheeks, and on the floor of the mouth (Carden and Baird, 2000). The olfactory system is responsible for the detection of the odor/aroma component of flavor. Volatile flavor compounds are detected by olfactory neurons and are responsible for the aromatic sensation perceived by the brain (Meilgaard et al., 2007). It is believed that this aroma component of flavor is responsible for the majority of the total flavor that is perceived from a product. Humans are able to detect and discriminate among thousands of different odorant compounds, many at very low thresholds (Carden and Baird, 2000). However, due to natural differences in the olfactory system, large variation in flavor perception often exists among individuals. This, combined with the numerous factors that affect flavor makes the topic difficult to study.

In beef, two reactions that occur in the cooking process are largely responsible for beef flavor development: 1) the Maillard reaction and 2) the thermal oxidation of fatty acids. The Maillard reaction, also known as non-enzymatic browning or the “browning reaction”, is a complex network of reactions which begins with the condensation of

amino acids (or peptides) with the carbonyl group of a reducing sugar in the presence of heat (Rhee, 1989; Calkins and Hodgen, 2007). As the Maillard reaction progresses, numerous low molecular weight products are produced that contribute to beef flavor. Additionally, intermediates of the Maillard reaction can react with other amines, amino acids, aldehydes, hydrogen sulfide, and ammonia through the Amadori rearrangement, Strecker degradation, and Schiff base pathways, creating additional volatile compounds that have been shown to contribute to beef flavor (Calkins and Hodgen, 2007).

The oxidation of lipids during cooking also produces volatile compounds that contribute to beef flavor. The thermal oxidation of lipids in cooking follows a pathway that is similar to that of lipid autoxidation, but produces slightly different products (Farmer, 1994). Products formed through lipid oxidation contributing to flavor development include numerous saturated and unsaturated hydrocarbons, alcohols, aldehydes, ketones, acids, and esters (Rhee, 1989; Farmer, 1994). Products formed from the thermal oxidation of lipids may also interact with intermediates in the Maillard reaction, providing yet another source of volatile flavor compounds.

Numerous studies have demonstrated the importance of beef flavor to consumer overall eating satisfaction. Many authors have cited tenderness as the most important trait affecting beef palatability (Dikeman, 1987; Savell et al., 1987; Miller et al., 1995; Savell et al., 1999). However, more recent studies have shown that when tenderness reaches an acceptable level, flavor becomes the most important driver of beef eating satisfaction (Goodson et al., 2002; Killinger et al., 2004b; Behrends et al., 2005a, b). Additionally, several studies have shown consumer overall acceptability ratings to be more highly correlated with flavor ratings than tenderness or juiciness ratings, regardless of tenderness

variation (Neely et al., 1998; Killinger et al., 2004b; Thompson, 2004; O'Quinn et al., 2012). Surveys of beef purchasing motivators have also shown the importance of flavor to consumers. In a nation-wide survey of U.S. beef consumers, flavor was rated as the most important purchasing motivator for beef steaks and roasts (Reicks et al., 2011). Numerous studies using experimental auction techniques have shown consumers are willing to pay a higher premium for steaks with a flavor profile that they prefer (Killinger et al., 2004b, a; Sitz et al., 2005), indicating the financial importance of a desirable flavor profile to the beef industry. Collectively, these studies indicate the importance of flavor not only to the overall beef eating experience, but also to beef consumers' willingness to purchase beef products.

Results of the two most recent Beef Tenderness surveys showed that over 94% of beef from the rib and loin in foodservice and at the retail level were classified as tender or very tender based on WBSF values (Voges et al., 2007; Savell, 2011). With such a high proportion of beef in the U.S. rating as tender, flavor becomes the most important driver of overall beef eating satisfaction. A detailed understanding of beef flavor and its causes is needed in order to continue to meet the demands and expectations of U.S. beef consumers.

In today's industry, many different "types" of beef are present. Differences in animal production practices, breed type, meat aging strategies, and quality level all contribute to a heterogeneous beef supply. The majority of published studies evaluating the effects of these different practices and meat characteristics have focused on overall eating experience, with flavor measured by either trained or untrained consumer panelists as one of many traits evaluated. Additionally, most studies have treated beef flavor as a

single trait and have not attempted to segregate overall flavor into various flavor components. Some producers have marketed many of these different "types" of beef as having a unique or superior flavor profile. However, scientific literature supporting these claims is limited. Numerous published reports have shown an increase in beef flavor ratings as USDA quality grade increases from USDA Standard to Prime (Tatum et al., 1980; Smith et al., 1983; Emerson, 2011; O'Quinn et al., 2012). However, a significant difference has not always been reported between samples from adjacent marbling scores.

The effect of aging on beef tenderness has been well established (Smith et al., 1978; Savell et al., 1981; Calkins and Seideman, 1988), however few studies have been conducted with the objective of evaluating the effects of postmortem age on beef flavor. As age time increased from 0 to 28 days, beef flavor intensity and desirability scores have been shown to increase (Campo et al., 1999; Jeremiah and Gibson, 2003). However, undesirable flavor notes, specifically livery and acid flavors, increased in the samples throughout the aging period (Campo et al., 1999; Jeremiah and Gibson, 2003). Other authors reported that postmortem age has no effect on beef flavor (Minks and Stringer, 1972; Jones et al., 1991; Xie et al., 1996; Sapp et al., 1999). The effect of dry-aging on beef flavor has produced mixed results, with some authors reporting increased beefy, brown/roasted, and dry-aged flavor notes (Warren and Kastner, 1992; Campbell et al., 2001) and others reporting no flavor difference when dry-aged samples were compared to wet-aged samples (Sitz et al., 2006; Laster et al., 2008; Smith et al., 2008).

Several studies have been conducted comparing the effects of grain vs forage feeding on beef palatability (Bowling et al., 1978; Schroeder et al., 1980; Davis et al., 1981; Killinger et al., 2004a; Sitz et al., 2005). The majority of these studies have found

desirable beef flavor traits to increase as the time on grain increased, however other authors have reported no difference in flavor traits between samples from grain and forage-finished cattle (Bidner et al., 1981; Reagan et al., 1981; Bidner et al., 1986; Sapp et al., 1999). With increased corn prices in the U.S., barley has become a substitute for corn in cattle finishing diets in some regions of the country. Additionally, barley is commonly fed as the major concentrate in cattle finishing diets in Canada. Few studies have been conducted comparing grain source's effect on beef flavor, but the studies that have been conducted have reported only minimal differences in beef flavor between samples from corn and barley finished cattle (Miller et al., 1996; Jeremiah et al., 1998; Busboom et al., 2000).

The effect of cattle breed type on beef palatability has been widely studied over the past 50 years. Most published reports show cattle breed as having little to no effect on beef flavor ratings (Adams et al., 1982; Cross et al., 1984; McKeith et al., 1985; McKenna et al., 2004). One specific breed, Wagyu, has gained some popularity in the U.S. due to this breed's ability to produce highly-marbled carcasses. Mixed results have been reported concerning beef flavor of samples from Wagyu and Wagyu crossbred cattle when compared to more traditional U.S. breeds. Consumers have rated steaks from imported Japanese Wagyu cattle as higher for beef flavor than steaks from Angus cattle (Busboom et al., 1993), however most published reports have found no difference in beef flavor traits of beef from Wagyu crossbred cattle vs other breeds of cattle (May et al., 1993; Jeremiah et al., 1999; Wheeler et al., 2004).

Recently, use of β-adrenergic agonists (βAA), specifically zilpaterol hydrochloride (ZIL) and ractopamine hydrochloride (RAC), to increase lean gain has

become common in the beef industry. These repartitioning agents have been marketed for use in improving rate of gain and feed efficiency, as well as increasing carcass leanness. The effects of ZIL on carcass traits has been well documented (Vasconcelos et al., 2008; Hilton et al., 2009; Kellermeier et al., 2009; Montgomery et al., 2009a; Montgomery et al., 2009b). As have the effects of RAC on carcass traits (Gruber et al., 2007; Bryant et al., 2010; Gonzalez et al., 2010; Scramlin et al., 2010). To date, little research has been conducted evaluating the effects of these βAA on beef flavor. Trained panels have rated beef flavor lower for samples supplemented with a βAA (Hilton et al., 2009; Leheska et al., 2009), as well as have found no difference in flavor ratings, regardless of βAA supplementation (Gruber et al., 2008; Garmyn et al., 2010). Most consumer studies have found no change in beef flavor rating due to βAA supplementation (Hilton et al., 2009; Mehaffey et al., 2009; Brooks et al., 2010).

Studies comparing beef from many of the different cattle and meat production practices used in today's industry have produced mixed results. Additionally, no study has been conducted utilizing discriminating consumers with the objective of determining differences among and preferences for flavor traits of beef representing a large diversity of different animal and meat production practices and traits. Due to the diversity of beef present in foodservice and at retail, as well as the importance of flavor to overall eating satisfaction, an understanding of the differences in flavor traits within the U.S. beef supply is needed. If practices or traits that positively or negatively affect beef flavor can be identified, then the U.S. beef industry can gain a better understanding of how to manage flavor traits and correspondingly improve consumer beef eating satisfaction. Therefore the objectives of the current study were to characterize specific beef flavors

that are associated with differences in cattle and meat production practices and quantify their relationship to untrained, discriminating sensory panelist preference, as well as to use analytical chemistry techniques to identify factors associated with observed flavor differences.

CHAPTER II

REVIEW OF LITERATURE

Flavor Defined

The flavor of a food is a complex, multi-dimensional concept that is often difficult to describe. Flavor is more than just the taste perceived by the tongue. It also is comprised by the aroma detected by the olfactory, the chemical feeling sensations in the mouth and airways as well as the combination and interaction of all of these factors. Additionally, the visual and auditory characteristics of a food product contribute to flavor perception (Clydesdale, 1993; Spence and Zampini, 2006; Verhagen and Engelen, 2006). Flavor is most often used to refer to a response to a stimulus; however the term can be used to refer to the chemical producing the stimulus as well. In food science, two definitions of flavor are generally accepted. The first refers to flavor as a human response to a chemical stimulus and defines flavor as "…the sum of those characteristics of any material taken in the mouth, perceived principally by the senses of taste and smell and also by the general tactile and pain receptors in the mouth as received and interpreted by the brain." (Hall, 1968). The Society of Flavor Chemists defines flavor as "... a substance which may be a single chemical entity, or a blend of chemicals of natural or synthetic origin whose primary purpose is to provide all or part of the particular flavor effect to any food or other product taken into the mouth" (Carden and Baird, 2000). The second definition addresses flavor as the chemical stimulant itself as opposed to the perceived sensation.

The first definition addresses flavor as a composite of three chemosensations: taste, olfaction, and tactile sensations. Tactile sensations or "chemical feeling factors"

address sensations that are sensed in the mouth such as spice, heat, astringency, metallic, and cooling (Meilgaard et al., 2007). Therefore, complete flavor describes the impact of taste, aroma, and other sensations within the mouth (Meilgaard et al., 2007).

Taste is perceived when a chemical molecule in solution with saliva or another liquid is absorbed onto a receptor site in a taste bud (Carden and Baird, 2000). The intensity and duration of the taste is dependent upon the fit of the stimulant to the receptor on the taste bud (Carden and Baird, 2000). The tongue is the major taste organ, however taste buds located on the hard and soft palate, in the throat, cheeks, and floor of the mouth all contribute to the taste sensation of a food (Carden and Baird, 2000). Early research proposed a "taste map" of the tongue with certain regions of the tongue only capable of detecting certain tastes; however more recent research has shown that no such "taste map" exists. Taste buds capable of detecting each of the four basic tastes are present in all regions of the tongue (Carden and Baird, 2000).

Taste can be broken down into four basic taste components: sweet, sour, salty, and bitter. Each of these taste components have been identified in meat and have been linked to various chemical compounds found in beef. Many water-soluble compounds found in beef contribute the most to the taste component of flavor (Rhee, 1989). Sweet flavor notes in beef are attributed to naturally occurring sugars, amino acids, and organic acids (Rhee, 1989; MacLeod, 1994). Amino acids and organic acids are also responsible for the sour taste found in some beef (Rhee, 1989; MacLeod, 1994). Salty flavors can be found in beef as a result of inorganic salts and sodium salts of glutamate and aspartate (Rhee, 1989; MacLeod, 1994). Bitter flavors are caused by hyoxanthine, anserine, carnosine, and some amino acids (Rhee, 1989; MacLeod, 1994).

In addition to these four basic tastes, a fifth taste "umami" described as savory, brothy, or beefy has recently been discovered and is believed to play a role in the flavor of beef. It is produced by flavor enhancing compounds such as MSG (monosodium glutamate), IMP (5-necleotides, 5'-ionsine monophosphate), and GMP (5'-guanosine monophosphate) (Brewer, 2007). Beef is high in these umami precursors. Umami layers flavor allowing for a more full-flavor to be perceived (Brewer, 2007). In addition to these umami creating nucleotides, beef also contains the "Beefy Meaty Peptide" (BMP), which has been shown to have a similar umami producing effect (Yamasaki and Maekawa, 1978).

The olfactory system is responsible for the detection of the odor/aroma component of flavor. Volatile compounds are detected by the olfactory neurons and are responsible for the aromatic sensation perceived by the brain (Meilgaard et al., 2007). Receptor cells that are found in the nasal cavity are responsible for the detection of odorants and the conduction of the signal along the olfactory nerve to the brain (Carden and Baird, 2000). Unlike other nerve cells in the body, olfactory receptor cells are replaced approximately every 60 days (Carden and Baird, 2000). Humans are able to detect and discriminate among thousands of different odorant compounds, many at very low thresholds (Carden and Baird, 2000).

In complex food matrixes such as meat, it is the combination of these volatile compounds that responsible for many of the flavor notes associated with the food (Buettner and Schieberle, 2000). In these foods that produce a mixture of volatile components, the perceived intensity of the odorant mixture is almost always less than the sum of the intensities of the individual compounds (Jones and Woskow, 1964; Laing et

al., 1984). Additionally, in odorant mixtures, volatiles present at low levels may be completely suppressed if a compound eliciting a stronger intensity also is present in the mixture (Cain, 1975; Laing et al., 1984). However, multiple odorants can be detected in an odorant mixture when the intensity levels are equal (Cain, 1975; Laing et al., 1984).

Many factors have been shown to affect the release of volatile compounds from the food matrix. During the mastication process, volatile compounds released from the food are detected retronasally. In retronasal olfaction, volatile flavor compounds released in the mouth travel through the back of the mouth and through the posterior nares and are detected by the olfactory (Farmer, 1994). Mouth temperature, presence of saliva, absorption, and reabsorption of volatile compounds by the mouth mucosa can all influence this process (Buettner and Schieberle, 2000). The presence of proteins, polysaccharides, and lipids in the food matrix have been shown to cause a reduction in the volatility of flavor producing compounds (Druaux and Voilley, 1997; Guichard, 2002). The temperature of a meat product has also been shown to affect the volatility of flavor producing compounds. When the temperature of meat is raised from 25^{o}C to 50^{o}C, higher flavor intensities have been observed (Ventanas et al., 2010).

There have been hundreds of volatile compounds isolated from cooked beef (Calkins and Hodgen, 2007). In a comprehensive review of meat flavor, Calkins and Hodgen (2007) presented a table containing over 60 different compounds that have been identified in cooked beef and the characteristic flavor or aroma associated with each. However, it is believed that only a relatively small number of these compounds that have been identified play an important role in cooked meat flavor (Farmer, 1994). The concentration and odor threshold of these compounds determine whether or not they are

one of the key odor impact compounds affecting the flavor of a meat product (Farmer, 1994). Numerous compounds that are released during the cooking process from either the Maillard reaction or thermal oxidation of lipids are believed to play the largest role in beef flavor development (Farmer, 1994). Individually, each of these compounds possess a unique aroma; however, the combination of these compounds give cooked beef its characteristic flavor (Farmer, 1994).

The volatiles produced during cooking can be subdivided into various classes based on their chemical structure. The chemical classes of volatiles produced during the cooking of beef include acids, alcohols, esters, ethers, furans, hydrocarbons, ketones, lactones, pyrazines, pyridines, pyrroles, sulfides, thiazoles, and thiophenes (Rhee, 1989; Shahidi, 1994). The origin of many of these compounds, as well as their contribution to beef flavor has been explored in published literature.

Alcohols are believed to be derived from the thermal degradation of phospholipids (Mottram, 1998). Numerous aldehydes have been identified in the volatile profile of cooked beef and are believed to play an important role in beef flavor formation. Aldehydes are formed through the oxidation of unsaturated fatty acids such as oleic, linoleic, and linolenic acid (Shahidi et al., 1986). Additionally, aldehydes can be formed from the Strecker degradation reaction of certain amino acids such as isoleucine, leucine, methionine, phenylalanine, and valine (Shahidi et al., 1986). Pyrazines are nitrogen containing compounds that are also derived from the Maillard reaction (Shahidi et al., 1986). Hydrocarbons, ketones, carboxylic acids, esters, and lactones are formed through the oxidation of lipids and the thermal degradation of fats during cooking (Mottram,

1998). The volatile compounds that are formed from lipid sources occur at much higher levels than the volatile compounds formed from the Maillard reaction (Mottram, 1998).

The thermal degradation of sulfur containing amino acids contributes to the development of many sulfur containing flavor volatile compounds (Gasser and Grosch, 1990). Thiophenes, thiazoles, thiazolines, dithianes, dithiolanes, trithiolanes, and trithianes are all sulfur containing compounds that have been identified from cooked beef (Shahidi et al., 1986). These sulfur containing compounds have been shown to have extremely low odor thresholds (Gasser and Grosch, 1988). The odor threshold of lipid derived compounds is much higher than that of many sulfur and nitrogen containing flavor compounds (Mottram, 1998). Therefore, even at low abundance levels, sulfur and nitrogen containing volatile flavor compounds may have a larger impact on beef flavor perception than high levels of lipid derived compounds.

Flavor Development in Beef

Uncooked beef has little to no aroma and possesses only a blood-like taste (Mottram, 1998). However, raw beef is a reservoir for numerous flavor precursor compounds. Proteins, lipids, and carbohydrates all play a role in beef flavor development (Spanier and Miller, 1993; Mottram, 1998). During heating, these meat constituents provide numerous compounds that are capable of developing into important flavor precursors (Spanier and Miller, 1993; Mottram, 1998). Two reactions play a key role in the development of flavor: the Maillard reaction and the oxidation of lipids during heating (Rhee, 1989; Farmer, 1994; Mottram, 1998; Calkins and Hodgen, 2007).

The Maillard reaction plays an important role in the development of flavor of cooked beef in addition to being responsible for the color change associated with cooked meat. The Maillard reaction, also known as non-enzymatic browning or the "browning reaction", is a complex network of reactions which yield both high molecular-weight brown colored products and numerous volatile aroma compounds (Farmer, 1994). Figure 2.1 provides a general scheme detailing how many of the volatile compounds from the Maillard reaction are formed. The reaction involves the condensation of amino acids (or peptides) with the carbonyl group of a reducing sugar in the presence of heat (Calkins and Hodgen, 2007). This produces glycosylamine which is rearranged and dehydrated to form furfural, furanone derivatives, hydroxyketones, and dicarbonyl compounds, which all contribute to flavor (Calkins and Hodgen, 2007). These low molecular weight compounds may further lead to the formation of additional compounds which contribute to beef flavor including furans, pyrazines, pyrroles, oxazoles, thiazoles, and numerous other heterocylic compounds (Fay and Brevard, 2005). As the reaction progresses, the intermediate products can react with other amines, amino acids, aldehydes, hydrogen sulfide, and ammonia through the Amadori rearrangement, Strecker degradation, and Schiff base pathways (Calkins and Hodgen, 2007). Many of the compounds formed through these Amadori rearrangements, Strecker degradation, and Schiff base pathways comprise the majority of the flavor contributing compounds formed through the Maillard reaction (Mottram, 1998). The amino acid and reducing sugar involved in the initial condensation reaction can lead to the production of different end products (Calkins and Hodgen, 2007). Additionally, the pH at which the reaction occurs can have an effect on which end products are produced (Calkins and Hodgen, 2007).

The second major reaction involved in beef flavor development is the oxidation of lipids. Lipids can break down via oxidation of fatty acids to give volatile odor compounds that can be either desirable or undesirable (Mottram, 1998). During storage, autoxidation of lipids can occur to give raw meat a "rancid" odor or a "warmed-over" flavor to previously cooked meat (Farmer, 1994). During heating in the cooking process, the thermal oxidation of lipids leads to various compounds that contribute to the desirable flavor of cooked beef (Farmer, 1994). Figure 2.2 diagrams volatile compound formation pathways from a fatty acid following oxidation and the formation of a hydroperoxide. Though thermal oxidation of lipids follows a similar pathway to lipid autoxidation, the process produces slightly different products (Farmer, 1994). The oxidation of lipids during cooking produce many different products including saturated and unsaturated hydrocarbons, alcohols, aldehydes, ketones, acids, and esters (Farmer, 1994).

The lipid component of meat is believed to contribute to the species specific flavors associated with beef, lamb, and pork (Calkins and Hodgen, 2007). The degree of saturation of the fatty acids in the lipids present in meat plays a large role in the extent to which oxidation occurs (Farmer, 1994). Polyunsaturated fatty acids are more susceptible to oxidation than monounsaturated or saturated fatty acids. Because of this, many of the key volatiles in beef flavor are derived from polyunsaturated fatty acids (Gasser and Grosch, 1988). Phospholipids are a major component of the cell membrane of muscle cells in beef. Of the different classes of lipids in beef, phospholipids have a higher proportion of polyunsaturated fatty acids and are thus more susceptible to oxidation than triacylglycerides (Farmer, 1994). The oxidation products formed from phospholipids during heating are believed to contribute to the desirable aroma of cooked beef (Mottram,

1998). The importance of phospholipids to flavor development was demonstrated in a study by Mottram and Edwards (1983). When the neutral triacylglycerides comprising intermuscular and intramuscular fat deposits were removed with hexane prior to cooking, panelists were unable to detect differences in a triangle test between samples with lipids removed and untreated samples (Mottram and Edwards, 1983). Both treated and untreated samples were described as "meaty". However, when all lipids were removed (triglycerides and phospholipids) with a more polar solvent prior to cooking, the "meaty" aroma was replaced by a biscuit-like aroma in treated samples (Mottram and Edwards, 1983). Additionally, many of the lipid oxidation products found in the untreated samples were lost in the samples with phospholipids removed, but were present in samples that only had triglycerides removed (Mottram and Edwards, 1983). Evidence from this study indicated the importance of phospholipids in the development of normal beef flavor.

Products formed in the oxidation of lipids also can interact with various products in the Maillard reaction. Lipid derived aldehydes may participate in the initial condensation reactions of the Maillard reaction as well as in the aroma forming reactions in the later stages of the process including the Amadori rearrangement, Strecker degradation, and Schiff base pathways (Mottram, 1998).

Importance of Flavor

The need for an industry-wide standardized lexicon for beef flavor was addressed by Adhikari et al. (2011). Though much research has been conducted evaluating beef flavor, the descriptors of the individual flavor notes and the flavor notes evaluated differ greatly from study to study. In order to address these differences, a study was conducted

to identify the major flavor notes found in beef and to determine specific definitions for each (Adhikari et al., 2011). In this study, a wide variety of different types of beef were used in order to maximize the variation in flavor, including samples from various muscles, USDA quality grades, animal ages, and aging regimes (Adhikari et al., 2011). Samples were cooked to various final end-point temperatures using multiple cooking methods (Adhikari et al., 2011). Twelve flavor notes were found to be the most common occurring and were found in almost every sample; beef identity, brown/roasted, bloody/serumy, metallic, fat-like, overall sweet, sour aromatics, and the five basic tastes of sour, bitter, salty, sweet, and umami (Adhikari et al., 2011). In total, the finalized flavor lexicon included 26 flavor attributes and standardized definitions for each, including animal hair, burnt, chemical, cocoa, cooked milk, dairy, green, green-hay, leather, liver-like, rancid, sour dairy, spoiled, warmed-over, and the 12 flavor traits previously listed (Adhikari et al., 2011). The beef flavor lexicon developed by Adhikari et al. (2011) provides a standardized basis for beef flavor evaluation by trained sensory panels across a wide variety of meat products and research institutions. Moreover, international standards have been developed for training assessors for the detection and recognition of odors (ISO, 2006), for measuring flavor and taste detection thresholds in a forced choice procedure (ISO, 2002), as well as for assessing changes in flavor of food products due to packaging (ISO, 2003).

Numerous studies have cited tenderness as the most important trait affecting beef eating satisfaction (Dikeman, 1987; Savell et al., 1987; Miller et al., 1995; Savell et al., 1999). However, more recent studies have shown that when tenderness reaches an acceptable level, flavor becomes the most important driver of beef eating satisfaction

(Goodson et al., 2002; Killinger et al., 2004b; Behrends et al., 2005a, b). Several studies have shown consumer overall acceptability ratings to be more highly correlated with flavor than tenderness or juiciness ratings (Neely et al., 1998; Killinger et al., 2004a, b; Thompson, 2004; O'Quinn et al., 2012). Neely et al. (1998) found consumer overall like scores most highly correlated with flavor ratings ($r = 0.86$) and suggested that beef flavor may be as important as tenderness in determining overall beef eating experience. In an in-home consumer trial, flavor accounted for 67% of the variation in overall palatability scores of consumers (Huffman et al., 1996). Even small changes in consumer flavor scores have been shown to result in large changes in consumer overall palatability acceptance (Platter et al., 2003). Moreover, multiple studies using experimental auction techniques have shown consumers are willing to pay a higher premium for steaks with a flavor profile that they prefer (Killinger et al., 2004a, b; Sitz et al., 2005). Consumers ranked taste attributes as the most important factor influencing beef purchasing decisions when compared to product consistency, ease of preparation, nutritional value, natural and organic practices, and price (Reicks et al., 2011). Tenderness, juiciness, flavor, meal enjoyment, and consistent quality have been shown to have the greatest influence on consumer beef purchasing decisions (Moeller and Courington, 1998).

Results of the 2006 Beef Tenderness survey showed that over 96% of beef in foodservice and at the retail level are classified as tender or very tender based on WBSF values (Voges et al., 2007). With such a high proportion of beef in the U.S. rating as tender, beef flavor becomes a much more important driver of overall beef eating satisfaction. A detailed understanding of beef flavor and its causes is needed in order to continue to meet the demands and expectations of U.S. beef consumers. Many “types” of

beef are present in the U.S. meat supply including beef from various production methods, aging strategies, different breed types, and different quality levels. Many of these "types" of beef are believed to have unique flavor characteristics; however scientific literature supporting this is limited. An understanding of which "types" of beef in the U.S. possess a favorable flavor profile is needed in order to understand what flavor profile is desirable to consumers and subsequently, the beef industry should be targeting.

Factors Affecting Beef Flavor:

Marbling

The USDA beef quality grading system segregates beef carcasses into groups of similar expected eating experience and plays a large role in the marketing and value determination of beef. Marbling level plays an important role in quality grade determination and is therefore of importance. Because of this, the effect of marbling on beef tenderness, juiciness, flavor, and overall eating experience has been widely studied. Marbling has been shown to have a positive effect on each of these traits determining beef eating satisfaction. The effects of marbling have been studied over a wide range of marbling levels as well as in numerous muscles and muscle groups in the beef carcass. With regard to beef flavor of steaks and roasts, marbling repeatedly has been shown to have a positive effect, both in trained sensory panels and untrained consumer panels. Marbling is believed to affect beef flavor in two ways: 1) the oxidation products produced from fatty acids upon heating are believed to play a role in beef flavor development and 2) fat may act as a storage depot for other volatile compounds released during the cooking process (Hornstein, 1971). A review paper evaluating the relationship

of USDA quality grade to beef flavor concluded that USDA quality grade is related to flavor because quality grades indirectly assess the extent to which flavor and aroma producing compounds and precursors are likely to be present in the beef (Smith et al., 1983).

Numerous studies utilizing trained panelists have evaluated the effects of marbling on beef flavor. In an early study in the 1960s, beef flavor scores of beef short loin steaks were shown to increase as marbling score increased from practically devoid to moderately abundant, however, significant differences were not always found at successive increases in marbling score (McBee and Wiles, 1967). A later study by Smith et al. (1984) evaluated the role of marbling on top loin, top round, bottom round, and eye of round steaks from all beef maturity groups (A - E) with marbling scores from practically devoid to moderately abundant. In this study, the flavor ratings of top loin steaks from A maturity carcasses increased as marbling level increased from practically devoid to moderately abundant, though significant differences were not found between every successive marbling score (Smith et al., 1984). Additionally, top round steaks from A maturity carcasses with moderately abundant marbling were rated higher for flavor than top round steaks from all other marbling levels (Smith et al., 1984). Trained panel flavor ratings of top loin steaks increased as USDA quality grade increased from Standard through Prime, with significant differences detected at each successive increase in quality grade (Smith et al., 1987). Moreover, in the same study, USDA Prime top round steaks had higher flavor scores than USDA Standard, Select, and Choice top round steaks (Smith et al., 1987). Similar results were found in a study using beef rib steaks, which found trained panel flavor desirability scores increased as USDA quality grade

increased from High Standard to High Choice (Tatum et al., 1980). In this study, more than 14% of the variation in beef flavor ratings was explained by marbling and greater than 99% of steaks having slight or higher marbling scores received desirable sensory panel scores for flavor desirability (Tatum et al., 1982). The same trend was observed in a study evaluating the palatability of beef loin steaks ranging in marbling from traces to slightly abundant (Savell et al., 1987). Trained panel flavor intensity scores increased as marbling level increased from traces to slightly abundant, however, as with previous studies, significant differences were not always found between successive marbling level increases (Savell et al., 1987).

Multiple studies evaluating steaks from a narrow range of quality grades also have been conducted. In a study evaluating top loin, top sirloin, and top round steaks representing Top Choice (Modest and Moderate marbling), Low Choice, High Select, and Low Select quality grades, Top Choice and Low Choice steaks scored higher for cooked beef fat flavor intensity than Select samples, with Top Choice steaks scoring higher than Low Choice (Lorenzen et al., 2003). Beef flavor intensity ratings for Top Choice steaks were higher than those for Low Choice, High Select and Low Select samples (Lorenzen et al., 2003). Certified Angus Beef® (Modest and Moderate marbling scores) and USDA Choice steaks from the *triceps brachii*, *longissimus lumborum*, *gluteus medius*, *semimembranosus*, *biceps femoris*, and *quadriceps femoris* complex scored higher than USDA Select samples for beef fat flavor and flavor intensity (Nelson et al., 2004). In a study evaluating the palatability traits of *longissimus* muscle (LM) steaks, USDA Low Choice samples scored higher for trained panel beef flavor ratings than USDA Select,

Prime or Top Choice samples; however, no difference was found between quality grades for livery/metallic flavor intensity (Garmyn et al., 2011).

Numerous studies have found no difference between USDA quality grades for trained panel beef flavor ratings. In a study evaluating beef rib steaks with Slight, Modest, and Moderately Abundant marbling degrees, no difference was found in beef flavor amongst steaks differing in marbling degree (Parrish et al., 1973). No difference was found by trained panelists for beef flavor ratings between USDA Choice and Select top loin steaks, top sirloin steaks, eye of round steaks, rib roasts, and eye of round roasts (Luchak et al., 1998). In a study evaluating the effects of breed type on beef palatability, no difference was found for beef flavor intensity in steaks from *Bos taurus* animals ranging in marbling score from Traces to Moderate nor in steaks from *Bos indicus* animals with marbling scores from Traces to Small (Wheeler et al., 1994).

Several studies utilizing untrained consumers have found that increasing marbling level results in higher beef flavor scores in various muscles. A recent study by O'Quinn et al. (2012) found that as USDA quality grade in LM steaks increased from Standard to Prime, consumer beef flavor scores increased. Additionally, beef flavor acceptability scores were shown to increase as marbling level increased (O'Quinn et al., 2012). These results were in agreement with the findings of Lorenzen et al. (1999) who found Top Choice and Low Choice top loin steaks to have higher consumer flavor desirability ratings than Select steaks. In the same study, High Select steaks had higher flavor desirability ratings than Low Select steaks (Lorenzen et al., 1999). In a multi-city study, consumers in San Antonio rated Low Choice LM steaks higher for flavor than Select samples; however Dallas consumers were unable to detect differences between the

quality grades (McKenna et al., 2004). A study by Killenger et al. (2004b) found high marbled LM steaks to score higher for flavor than low marbled steaks in controlled laboratory consumer panels; however, no difference in flavor was found between marbling level treatments by consumers when steaks were prepared in the home. A large consumer study in Australia found beef flavor to have a positive curvilinear relationship with intramuscular fat percentage, with flavor scores plateauing at 14% fat when tenderness was standardized (Thompson, 2004).

In addition to LM steaks, consumer studies have shown marbling level to have an effect on the flavor of several other cuts. Steaks from USDA Choice short loins scored higher for flavor like than USDA Select steaks when short loins were both dry- and wet-aged (Smith et al., 2008). In a multi-city, nation-wide consumer study evaluating top loin, top sirloin, and top round steaks, consumer flavor intensity and flavor desirability scores tended to increase as USDA quality grade increased from Select to Top Choice (Neely et al., 1998). In a separate study, Top Choice top round steaks were rated higher for flavor like by consumers than High Select top round steaks (Behrends et al., 2005b).

Increased marbling level has not been shown by all consumer studies to be result in increased beef flavor ratings. Results from the 2006 National Beef Tenderness Survey showed consumers were unable to detect differences in beef flavor ratings in foodservice ribeye steaks ranging in quality grade from Select to Prime (Voges et al., 2007). However, USDA Select steaks were rated higher for flavor like than USDA Prime, Top Choice, or Low Choice steaks (Voges et al., 2007). Additionally, USDA quality grades for top loin and top sirloin steaks had no effect on consumer beef flavor ratings or flavor like ratings (Voges et al., 2007). The same was shown for top sirloin steaks by Savell et

al. (1999). Consumer beef flavor desirability was found to be dependent on cooking method, with consumers finding no difference in beef flavor desirability among sirloin steaks representing USDA Select, Choice, and Top Choice quality grades when the steaks were outdoor grilled, broiled, or pan-fried (Savell et al., 1999). Moreover, no difference was found for flavor desirability or flavor intensity by consumers among USDA Choice, Select or Top Choice top round steaks cooked to medium, medium-well, medium-rare or less, or very well-done degrees of doneness (Neely et al., 1999). In a study evaluating consumer preferences for various muscles of the chuck, no difference was found between USDA Choice and Select steaks for beef flavor rating for steaks from the *complexus*, *infraspinatus*, *serratus ventralis*, *supraspinatus*, *triceps brachii*, *deep pectoral*, and *longissimus thoracis* (Kukowski et al., 2004).

Results from both trained and consumer panels indicate that increased marbling level will increase beef flavor ratings. However, numerous published reports failed to detect a difference in flavor among beef steaks varying in marbling level. Evidence exists that the effect of marbling on beef flavor may differ among muscles. Several published reports indicate that though beef flavor does increase with marbling level, large differences in marbling level may be required to observe a difference. Thus, not every successive increase in marbling degree results in an increase in beef flavor ratings.

Animal Diet

Today, in the United States, the majority of cattle in the beef industry are finished on high concentrate diets in feedlots. In most situations, corn comprises the major concentrate in the finishing ration. However, with increased corn prices over the past five

years, alternatives to corn in the finishing diet are being explored. Additionally, a segment of the beef industry produces beef from animals that are raised exclusively on grass or forage and are never finished on a high concentrate diet. Many of these grass-fed beef producers market the product under an Organic or Natural claim. The effect of animal diet on beef flavor and eating experiance has been heavily researched over the past 40 years.

Many studies focusing on the effects of grain vs forage feeding on beef eating experience and flavor have been conducted and several review articles on this subject have been published (Melton, 1990; Muir et al., 1998). Though conflicting reports exist, most studies have found beef from forage finished animals to rate lower for beef flavor ratings and higher for undesirable off-flavor characteristics. A study by Schroeder et al. (1980) found trained panel scores for beef rib steaks from cattle finished on grain to be higher for beef flavor than ratings for steaks from cattle finished on a forage-only diet. Additionally, steaks from grain-finished cattle scored higher for "fatty" flavors, whereas steaks from forage-finished animals scored higher for "grassy" flavors (Schroeder et al., 1980). The same results were found in short loin steaks by Davis et al. (1980). Trained-panel flavor scores increased as the amount of grain in the finishing diet increased (Davis et al., 1981). In another study, beef loin and round steaks from cattle finished on a forage diet were rated lower for flavor than steaks from cattle finished on corn or corn silage (Hedrick et al., 1983). Moreover, Bowling et al. (1978) reported that trained panelists rated beef loin steaks from cattle finished on grain in a feedlot higher for flavor desirability than steaks from cattle finished exclusively on grass. In a more recent consumer study, U.S. consumers in San Francisco and Chicago rated LM steaks from

domestic grain-finished cattle higher for beef flavor than steaks of similar tenderness from Argentinian grass-finished cattle (Killinger et al., 2004a). Consumers also rated U.S.-sourced LM steaks higher for beef flavor intensity than Canadian-sourced steaks and Australian grass-fed steaks of similar tenderness levels (Sitz et al., 2005). In the same study, consumers indicated that they were willing to pay a premium for the U.S. sourced samples over the Australian grass-finished samples.

Similar results to those reported in steaks have been reported in ground beef as have been found in steaks. A study by Melton et al. (1982) compared ground beef patties formulated to 20% fat from carcasses of both grass-fed and grain-fed steers. Trained panelists found samples from carcasses of grass-fed animals to be less desirable for beef flavor due to less intense beef fat flavor scores (Melton et al., 1982). Additionally, ground beef samples from carcasses of grass-fed steers possessed more intense dairy or milky flavors as well as a more intense sour dairy flavor and other off-flavors (Melton et al., 1982). In a study utilizing ground beef formulated to a fat level of 25%, trained panelists rated samples from carcasses of forage-finished steers higher for sour, metallic, liver, and salty flavors compared with samples from grain-finished steers (Mandell et al., 1998). Additionally, samples from carcasses of grain-finished animals rated higher for sweet and beef flavor than samples from forage-finished steers (Mandell et al., 1998). In the same study, trained panelists rated LM roast samples from carcasses of grain-finished steers higher for beef flavor than LM roast samples from forage-finished cattle.

Other studies have found no difference in beef flavor between samples from grain and forage-finished cattle. Consumers were unable to detect differences for beef flavor ratings in chuck, loin, and round steaks between cattle finished on a forage diet and those

finished on a grain-based diet (Bidner et al., 1981; Bidner et al., 1986). Trained panelists found no difference in flavor ratings in beef rib steaks stored up to 28 days under vacuum from cattle finished on a grass or a grain-based diet (Reagan et al., 1981). The same was found in strip loin steaks, where trained panelists found no difference in beef flavor intensity between steaks from animals finished on grain or pasture (Sapp et al., 1999). However, a much larger proportion of samples from pasture-finished animals were rated as having an off-flavor (Sapp et al., 1999). In a more recent study, trained panelists found no difference in flavor or off-flavor presence in LM steaks or ground beef samples from cattle finished on grain or forage (Jiang et al., 2010b). In a study comparing forage finishing to barley finishing, trained panelists found no difference in flavor of LM steaks between the two feeding regimes (Faucitano et al., 2008).

In parts of the northern U.S. and Canada the climate conditions are better suited for the production of barley rather than other cereal grains such as corn. In these regions use of barley in finishing diets of cattle rather than corn is common. Several studies have compared beef from cattle finished on barley to beef from cattle finished on corn. A trained panel conducted in the U.S. found no difference in beef flavor intensity scores in steaks from cattle finished on barley compared to steaks from cattle finished on corn (Miller et al., 1996). A trained panel conducted in Canada found steaks from corn-finished cattle to rate higher for overall flavor intensity than steaks from barley-finished cattle, however no difference was found between grain types for gamey, metallic, livery, or beefy flavors (Wismer et al., 2008). Another trained panel in Canada found no difference in flavor intensity or desirability between samples from corn and barley finished cattle (Jeremiah et al., 1998). The same was found by a consumer study

conducted in the U.S. in which consumers found no difference in flavor between steaks from corn and barley finished cattle (Busboom et al., 2000). However, panelists identified samples from the carcasses of barley-finished cattle as having metallic aftertaste when compared to samples from the carcasses of corn-finished cattle (Jeremiah et al., 1998; Busboom et al., 2000).

Animal diet plays a large role on the flavor of beef. Numerous studies have evaluated effects of forage vs grain finishing of cattle on subsequent beef flavor and eating experience. Many of these studies have shown forage finishing having a negative effect on beef flavor; however, some studies have shown forage finishing having no effect on flavor. Though conflicting results have been reported, the overwhelming majority of research comparing barley vs corn in the finishing ration of cattle has shown grain source to have only a minimal effect on beef flavor.

Time on Feed

Upon weaning, cattle in the U.S. can either be backgrounded on forages for a time and allowed to grow to a heavier weight before being placed in a feedlot or can be sent directly into a feedlot and fed a growing diet prior to finishing on a high concentrate diet. In many circumstances, Holstein steers are placed in a feedlot immediately following weaning and are calf-fed. Limited studies have been conducted comparing tenderness, juiciness, and flavor traits of beef from calf-fed versus yearling-fed animals.

When comparing LM and *semimembranosus* steaks from carcasses of calf-fed cattle finished on a high concentrate diet for 139 to 242 days with steaks from carcasses of yearling-fed cattle finished on a high concentrate diet for 174 days following 110 days

of backgrounding on pasture, no difference in beef flavor was observed. (Dikeman et al., 1985a). Moreover, no difference was observed in LM steaks from carcasses from calf-fed cattle fed for 160 days verses steaks of carcasses of yearling-fed cattle finished for 119 days following a 162 day backgrounding period (Dikeman et al., 1985b). A study by Johnson et al. (1990) found no difference in flavor ratings of steaks from calf-fed animals and steaks from cattle that were backgrounded prior to finishing. In this study calf-fed steers were fed for 126 days and yearling finished cattle were fed a high concentrate diet for 103 days (Johnson et al., 1990). In a study utilizing cloned cattle, top loin steaks from calf-fed cattle fed for greater than 200 days were not different for beef flavor ratings than steaks from yearling-fed cattle finished for only 93 days (Harris et al., 1997). A more recent study found no difference in flavor ratings for steaks from calf-fed cattle fed for 191 days and steaks from yearling-fed cattle finished for 91 days (Brewer et al., 2007).

In addition to calf-feeding, multiple studies have evaluated the effects of prolonged feeding periods on beef palatability. No difference was found for trained panel beef flavor ratings for LM steaks from cattle fed from 56 to 175 days (Burson et al., 1980). Moreover, no change in beef flavor was observed in steaks from cattle fed for 0 to 196 days (May et al., 1992). However, steaks from cattle finished for 130 and 160 days had higher flavor ratings than steaks from cattle fed for only 100 days (Tatum et al., 1980). Additionally, LM steaks from cattle finished for 98 days had higher trained panel flavor desirability scores for both the lean and fat portions than steaks from cattle finished for only 49 days (Harrison et al., 1978). Grassy flavor of beef steaks and ground beef was shown to decrease as the amount of time cattle were finished on a grain-based diet after backgrounding on forage increased from 0 to 112 days (Larick et al., 1987).

Age Time

The effect of postmortem aging on beef tenderness has been well documented (Smith et al., 1978; Savell et al., 1981; Calkins and Seideman, 1988). Additionally, increased tenderness of numerous muscles in the beef carcass has been studied over a 28 day postmortem aging period (Gruber et al., 2006; Dixon et al., 2012). However, data detailing the effects of prolonged postmortem aging periods on beef flavor are lacking.

Trained panel beef flavor intensity scores as well as flavor desirability scores increased in beef short loin and rib steaks as postmortem age time increased from 0 to 4 weeks (Jeremiah et al., 2003). However, a livery flavor also increased in steak samples throughout the four week aging period (Jeremiah et al., 2003). Campo et al. (1999) found beef flavor intensity increased in LM steaks as time was extended from 1 to 21 days postmortem. Additionally, undesirable livery and acid flavors also increased throughout the aging period (Campo et al., 1999). Trained panelists rated LM steak samples aged 14 days higher for beef flavor intensity than samples aged only 7 days (Miller et al., 1996). In top round steaks, beefy, brothy, browned/caramel, and sweet flavors all decreased as age time increased from 0 to 14 days (Spanier et al., 1997). However, as in other studies, undesirable flavor notes including painty, cardboard, bitter, and sour all increased as the aging period progressed (Spanier et al., 1997). Metallic, rancid, and sour flavors increased in top blade, top sirloin, and tenderloin steaks as age time was increased from 7 to 35 days (Yancey et al., 2005).

Numerous studies have shown aging time up to 28 days postmortem to have no on trained panel ratings for beef LM flavor intensity and desirability (Minks and Stringer, 1972; Jones et al., 1991; Xie et al., 1996a; Sapp et al., 1999). Similar results were

observed by consumers in LM steaks, who found no difference in beef flavor ratings in steaks aged 3 to 6 days (Aalhus et al., 1992). Additionally, consumers found no difference in "flavor like" in short loins that had been either wet or dry-aged for 14 to 35 days (Smith et al., 2008). In the same study, beef flavor level was rated the highest in samples aged 21 days.

Effects of aging on beef flavor are unclear. Many studies have shown increased aging time to have no effect on beef flavor, whereas other studies have shown flavor ratings to increase with longer aging periods. However, multiple studies have shown increased undesirable off-flavor development such as livery and sour with increased aging times. To date, sufficient evidence is lacking to determine if increased aging periods produce desirable flavor changes in beef or if any desirable changes are masked by off-flavor development.

Dry Aging

Vacuum packaging of beef for storage and marketing is common in the United States. Vacuum packaging offers packers, producers, purveyors, and foodservice institutions the advantage of avoiding the excess shrinkage and trim loss that are common when beef is not vacuum packaged. Typically, in today's beef industry, beef remains in the vacuum bag throughout postmortem aging. Thus, "wet-aged" beef represents the most common form of aged beef in the retail and foodservice market. However, some beef is "dry-aged" in open air throughout the aging period. Typical conditions for the dry-aging of beef involve storing beef at 0 to 4^{o}C at approximately 80% humidity for 14 to 35 days (Savell, 2008). The most common reason beef is dry-aged is to impart a unique flavor

profile that is believed to be different and preferred by some consumers to that of wet-aged beef. To date, limited research has been conducted with the objective of comparing the flavor profiles of wet and dry-aged beef. Available reports conflicting results as to the effects of aging method (dry vs wet) on beef flavor.

A number of studies have shown dry-aging beef to produce positive effects on beef flavor. A study by Campbell et al. (2001) evaluated Certified Angus Beef® strip-loins and short loins that had been dry-aged for various time periods (0, 7, 14, or 21 days). A trained panel evaluated grilled steak samples for aged beef flavor, beef flavor, brown/roasted, bloody serumy, metallic, and astringent flavor notes (Campbell et al., 2001). The aged beef flavor increased and the metallic flavor decreased when the dry-aging period was increased from seven to 21 days (Campbell et al., 2001). However, beef flavor ratings for the dry-aged samples were found to be be no different from control samples (Campbell et al., 2001). Additionally, between control samples and samples dry-aged for 7 and 21 days, no differences were found for the brown/roasted trait (Campbell et al., 2001).

Warren and Kastner (1992) conducted a study evaluating effects of aging method (dry-aged, wet-aged, and unaged) on flavor profiles of USDA Choice strip loins. Strip loins were either dry-aged or wet-aged for 11 days before sensory panel evaluation (Warren and Kastner, 1992). Dry-aged products received higher ratings for the beefy and brown/roasted flavor traits (Warren and Kastner, 1992). Moreover, dry-aged samples scored lower than wet-aged beef for the bloody/serumy, metallic, and sour flavors (Warren and Kastner, 1992). These results indicate that aging method has a large impact on the flavor profiles developed in beef.

Other studies have shown dry-aging to have no effect on beef flavor characteristics. Two studies evaluating aging method (dry vs wet) in USDA Choice and Select beef short loins, ribeyes, strip loins, and top sirloin butts found no difference in beef flavor like, level of beef flavor, and overall like ratings for samples either wet or dry-aged for 14, 21, 28, or 35 days (Laster et al., 2008; Smith et al., 2008). Additionally, no changes in aged beef flavor, beef flavor, brown/roasted flavor, bloody/serumy, or metallic flavor notes were identified by a trained panel in beef strip loins dry-aged either in a bag or traditionally for 14 or 21 days (Ahnstrom et al., 2006). An additional study evaluating the effects length of dry aging in beef strip loins found no changes in beef flavor ID, brown/roasted, bloody/serumy, metallic, astringent, sweet, salty, sour, or bitter flavor notes between samples aged 21 and 28 days (DeGeer et al., 2009). Consumers were unable to detect differences between USDA Choice strip loin samples that were either wet-aged or dry-aged for 30 days for beef flavor (Sitz et al., 2006). Wet-aged USDA Prime samples were rated higher for flavor and overall acceptability ratings than dry-aged samples (Sitz et al., 2006). However, in the same study, results from a Vickrey auction showed that consumers who preferred the dry-aged USDA Prime samples were willing to pay more for the samples than consumers who preferred wet-aged samples (Sitz et al., 2006).

Conflicting reports are present in published literature detailing the effects of dry-aging on beef flavor. However, evidence suggests that dry-aging for a minimum of 11 days can produce a detectable difference in beef flavor traits as opposed to beef that is wet-aged for the same length of time. Additionally, consumers who prefer dry-aged beef

may be willing to pay a higher premium for this product than consumers who prefer wet-aged product would for wet-aged beef.

Breed

The palatability traits of different beef cattle breeds have been widely studied throughout the past 50 years. Many of these studies have focused on the effects of breed-type on beef tenderness with the effects on beef flavor being only a minor objective. However, sufficient evidence exists in published reports to detail the effects of the influence of cattle breed type on beef flavor.

The U.S. Meat Animal Research Center conducted one of the largest series of studies evaluating the effects of cattle breed type on beef carcass quality and LM palatability; the cattle Germplasm Evaluation program (GPE). Over the past 35 years, over 40 different beef breeds were evaluated for effects of breed type on a range of traits. In each of these studies, a different group of beef breeds was studied in detail, with many of the breeds being re-evaluated periodically. In each study cycle, sires from the chosen breeds were mated to Angus, Hereford, or British breed-cross females. LM steak samples from steers of these matings were aged for 7 or 14 days and evaluated by trained sensory panelists. Additionally, sensory panel results were reported at a standardized animal age, carcass weight, fat thickness, marbling score, and fat trim level.

The first study cycle utilized Hereford, Angus, Jersey, South Devon, Limousin, Charolais, and Simmental sires (Koch et al., 1976). In Cycle I of the study, beef flavor was evaluated on a 9 point scale for flavor desirability. No differences in beef flavor desirability were found for LM steaks from the breeds studied in Cycle I of the study

(Koch et al., 1976). Starting in Cycle II, beef flavor was evaluated as a flavor intensity score, ranging from extremely flavorful to extremely bland. No difference between breeds in flavor intensity was found in Cycle II, which utilized Hereford, Angus, Red Poll, Brown Swiss, Gelbvieh, Maine Anjou, and Chianina sires (Koch et al., 1979). Cycle III evaluated breeds that were newly introduced to the United States in the 1970's including Tarentaise, Pinzgauer, and Sahiwal, as well as Brahman, Hereford and Angus sires (Koch et al., 1982). Only minimal differences were observed between breeds for flavor intensity scores (Koch et al., 1982). In the mid 1990's Cycle IV evaluated five breeds that had been studied in previous cycles (Hereford, Angus, Charolais, Gelbvieh, and Pinzgauer) as well as six new breeds (Longhorn, Piedmontese, Salers, Galloway, Nellore, and Shorthorn) (Wheeler et al., 1996). Results of Cycle IV were consistent with the findings of previous studies, finding minimal variation in panel flavor intensity ratings (6%) among breeds when animal age, carcass weight, fat thickness, marbling, and fat trim level were standardized (Wheeler et al., 1996). Cycle V of the study evaluated Angus, Hereford, Tuli, Boran, Brahman, Piedmontese, and Belgian Blue breeds (Wheeler et al., 2001). Once again, minimal differences were found among breed types for beef flavor intensity ratings (Wheeler et al., 2001). The breed types used in Cycle VI of the GPE program included Angus, Hereford, Norwegian Red, Swedish Red and White, Friesian, and Wagyu. Trained panelists found no difference in beef flavor intensity ratings when data were adjusted to a standardized age, fat thickness, marbling or fat trim level (Wheeler et al., 2004). Cycle VII looked at the seven breeds with the most herd book registrations in the U.S. as of 2004, including Angus, Hereford, Charolais, Limousin, Simmental, Red Angus, and Gelbvieh (Wheeler et al., 2005). As with many of

the previous cycles, no difference in beef flavor intensity rating was found among these seven breeds (Wheeler et al., 2005). In the most recent cycle, Cycle VIII, several tropically adapted breeds were evaluated (Brangus, Beefmaster, Bonsmara, and Romosinuano) as well as the Herford and Angus breed (Wheeler et al., 2010). Results from this cycle produced more differences among breed types for beef flavor intensity ratings than had been observed in previous cycles. When adjusted to a constant carcass weight, no differences were found in flavor intensity ratings among the six breeds (Wheeler et al., 2010). However, Angus sired steers had higher flavor intensity ratings than all other breeds studied, except Hereford, when data were at a standardized age, fat thickness, marbling, or fat level (Wheeler et al., 2010). Samples from Hereford sired steers rated higher for beef flavor intensity than all of the tropically adapted breeds studied. No flavor intensity differences were found among samples from the tropical adapted breeds (Wheeler et al., 2010).

In addition to the GPE studies, studies have been conducted by various groups evaluating the effects of breed type on beef palatability. Many of these studies support the findings of the GPE studies, citing little to no difference in beef flavor intensity and desirability among different breed types. Trained panelists were unable to detect a difference in flavor intensity among LM steaks from Simmental, Charolais, Herford, and Angus steers and bulls (Cross et al., 1984). A lack of difference in flavor desirability was observed in a study evaluating LM steaks from Longhorn, Hereford, Angus, Brahman, Holstein, and the two and three-way breed crosses from these breeds (Adams et al., 1982). Likewise, no differences in flavor desirability were found among LM steaks from Brahman, Angus, and Brahman-Angus crosses when cattle were fed for 0, 112, and 224

days (McKeith et al., 1985). A study in Spain found no differences in beef odor intensity, liver odor intensity, beef flavor intensity, liver flavor intensity, and bitter flavor intensity for beef LM steaks from Spanish Holstein, Brown Swiss, Limousin, and Blonde d'Aquitaine bulls aged 1 – 35 days (Monson et al., 2005). In a large multi-city consumer study, consumers were unable to detect differences in flavor satisfaction rating for LM steaks from cattle of different breed types (English, Continental/European cross, and Brahman cross) (McKenna et al., 2004).

Other studies have reported differences among breed type for beef flavor. Trained panelists rated beef LM steaks from Brahman cattle lower for flavor desirabilitythan steaks from Hereford, Angus, Brahman cross, Santa Gertrudis, Holstein and Jersey cattle (Ramsey et al., 1963). In the same study, round steaks from Jersey cattle were rated higher for flavor desirability than all other breeds studied except Santa Gertrudis. Hereford and Holstein round steaks were also rated higher for flavor desirability than steaks from Brahman cattle (Ramsey et al., 1963). Consumers rated loin steaks from Hereford, Angus, and Jersey cattle higher than steaks from Brahman and Santa Gertrudis cattle; however found no differences in flavor desirability among breed types for round steaks (Ramsey et al., 1963). In a more recent study, trained panelists rated LM and *semitendinosus* steaks from Simmental cattle higher for beef flavor present after eight chews than steaks from Red Angus cattle (Laborde et al., 2001).

One specific breed type that has gained interest in terms of its effect on beef palatability is the Wagyu breed. The Wagyu or Japanese Black breed of cattle are characterized by their ability to deposit high levels of intramuscular fat (marbling). This unique ability of the Wagyu breed to produce highly marbled beef has created an interest

in the utilization of Wagyu genetics in the United States. High marbling levels have been shown to be associated with increased beef palatability (Smith et al., 1984). Additionally, the current USDA beef grading system places a premium on carcasses with high marbling levels. For these reasons, the use of Wagyu genetics in the U.S. beef industry could be advantageous.

Traditionally, extended feeding periods for greater than 300 days have been used in Japan with Wagyu cattle in order to reach the high marbling levels these cattle are known for. Multiple studies have been conducted in North America to determine if these cattle and their progeny can reach high marbling levels under traditional U.S. feeding practices (Xie et al., 1996b; Jeremiah and Gibson, 1999; Wheeler et al., 2004). In addition to increased marbling levels, beef from Wagyu cattle have a different fatty acid profile than beef from other breeds of cattle (May et al., 1993; Zembayashi et al., 1995). An increased amount of oleate has been found in beef from Wagyu cattle, which has a positive relationship with desirable flavor scores (Melton et al., 1982). Therefore, it is believed that beef from cattle of Wagyu influence could have a unique, and perhaps more favorable, flavor profile than beef from other breeds of cattle.

A study by May et al. (1993) conducted trained and untrained, consumer sensory analysis on beef from purebred Angus and Wagyu crossbred cattle fed a diet according to traditional Japanese standards. Trained sensory panelists were unable to detect a difference in flavor intensity of ribeye steaks between the two breeds (May et al., 1993). However, consumers were able to identify differences between the two breed types in a triangle test 47.5% of the time, citing flavor as a distinguishing feature greater than 15% of the time (May et al., 1993).

In a study comparing strip steaks from Japanese Wagyu (imported from Japan), American Wagyu (3/4 Wagyu), Angus, and Longhorn cattle, trained panelists were unable to detect differences in flavor desirability or flavor intensity among Japanese Wagyu, American Wagyu, and Angus samples (Busboom et al., 1993). In the same study, untrained consumers rated Japanese sourced Wagyu samples higher for flavor than Angus samples. A recent consumer study compared Australian-sourced LM steaks from carcasses of Black Wagyu (3/4 Wagyu) with steaks representing four USDA quality grades. In this study consumers rated Wagyu samples lower for beef flavor liking than USDA Prime and High Choice samples (O'Quinn et al., 2012). Additionally, Wagyu samples were rated the same for flavor acceptability as USDA Low Choice, Select, and Standard samples and lower than USDA Prime and High Choice samples for the same trait (O'Quinn et al., 2012).

Beef flavor intensity of beef strip steaks from Wagyu F1 crosses did not differ from that of steaks produced by purebred Angus, Hereford, Holstein, and the F1 crosses from each of these breeds (Jeremiah and Gibson, 1999). The same was observed in a study comparing the F1 cross progeny from Hereford, Angus, Norwegian Red, Swedish Red and White, Friesian, and Wagyu (full-blood Wagyu imported from Japan and 15/16 blood Wagyu) sires on British breed influenced dams (Wheeler et al., 2004). No differences in beef flavor intensity of LM steaks were found by a trained sensory panel amongst all breed types studied when palatability traits were adjusted to a common age, fat thickness, marbling level, or fat trim level (Wheeler et al., 2004). However, when data were adjusted to a standardized carcass weight, steaks from Wagyu-sired steers received

higher ratings for beef flavor intensity than steaks from steers sired by Hereford bulls (Wheeler et al., 2004).

Sufficient evidence supporting beef from Wagyu cattle having a unique or preferred flavor profile when compared with beef from other breeds is lacking. Though published studies showing a difference in flavor between beef from Wagyu cattle and beef from other breed types do exist, the majority of studies that have compared beef flavor amongst breeds have found little or no difference.

The effects of more than 50 different breeds on beef eating traits have been reported in the past 50 years. Published reports indicate that beef cattle breed type has little effect on beef flavor. However, some studies have reported differences in flavor ratings among steaks from cattle of different breed types. Though breed type has been shown to have a large effect on beef tenderness and overall eating experience, evidence is lacking to support breed type have a large or consistent effect on beef flavor intensity or desirability.

β-adrenergic Agonists

Recently, use of two β-adrenergic agonists (βAA), specifically zilpaterol hydrochloride (ZIL) and ractopamine hydrochloride (RAC), to increase lean gain has become common in the beef industry. These repartitioning agents have been marketed with claims for improvement in rate of gain, feed efficiency and increasing carcass leanness. Effects of ZIL on carcass traits has been well documented (Vasconcelos et al., 2008; Hilton et al., 2009; Kellermeier et al., 2009; Montgomery et al., 2009a; Montgomery et al., 2009b), as have the effects of RAC on carcass traits (Gruber et al.,

2007; Bryant et al., 2010; Gonzalez et al., 2010; Scramlin et al., 2010). Both products increase hot carcass weight, ribeye size, and dressing percentage. However, both products, especially ZIL, decrease LM tenderness (Brooks et al., 2009; Leheska et al., 2009; Rathmann et al., 2009; Claus et al., 2010; Scramlin et al., 2010).

To date, research evaluating the effects of these products on beef flavor intensity and desirability has been limited to studies evaluating these characteristics as one of several traits evaluated by trained or consumer panels. Several studies have been conducted evaluating the effects of ZIL and RAC on beef palatability and have produced mixed results with respect to beef flavor. In a large study evaluating the effects of ZIL on beef palatability, a trained sensory panel rated beef flavor characteristic (extremely characteristic to extremely uncharacteristic) and flavor intensity higher in beef LM steaks aged 28 days from heifers that had received no ZIL supplementation when compared with steaks from heifers that had been supplemented with ZIL for 20 or 40 days (Leheska et al., 2009). In the same study, LM steaks from steers that had not been supplemented with ZIL were rated higher for flavor intensity than steaks from steers supplemented with ZIL for 20 or 40 days; howeve,r no difference was found in these samples for beef flavor rating.

These results were in agreement with the findings of Hilton et al. (2009) who found that steaks aged 14 days from cattle that were supplemented with ZIL were rated lower for beef flavor intensity and beef flavor by a trained panel when compared with samples from cattle that received no ZIL supplementation. Conflicting results were found in a study evaluating the palatability of calf-fed Holstein steers fed ZIL. Trained panelists found no affect of ZIL supplementation on beef flavor, painty/fishy flavor, and

livery/metallic flavors in LM and inside round steaks from calf-fed Holsteins (Garmyn et al., 2010).

Several consumer panels have been conducted with the objective of evaluating the effects of ZIL on beef eating satisfaction. Consumers were unable to detect a difference in beef flavor in LM steaks aged 14 days from cattle supplemented with ZIL and those from cattle receiving no ZIL (Hilton et al., 2009). The same results were found by Brooks et al. (2010) in a study evaluating the effects of enhancement and blade tenderization on eating characteristics of beef from cattle supplemented with ZIL. In that study, consumers found no difference in beef flavor desirability of LM steaks aged 14 days from cattle supplemented with ZIL and control samples, regardless of enhancement or tenderization treatment (Brooks et al., 2010). In a nationwide study, beef flavor desirability rating did not differ for USDA Choice and Select strip steaks aged 14 and 21 days from beef-type cattle supplemented with ZIL for 0, 20, and 30 days (Mehaffey et al., 2009). In the same study, consumers rated beef flavor desirability higher for 14-day aged steaks from calf-fed Holsteins that were not supplemented with ZIL when compared with samples from calf-fed Holsteins that received ZIL supplementation. However, no difference in flavor desirability rating was found after samples were aged for 21 days (Mehaffey et al., 2009).

Trained sensory panelists found no difference in beef flavor or off-flavor presence between LM steak samples aged 14 days from cattle that had been supplemented with RAC and samples from cattle that received no RAC (Gruber et al., 2008). A study evaluating beef eating charecteristics of market dairy cull-cows that had been fed a high concentrate diet for 90 days prior to slaughter also found no significant differences in

flavor intensity and off-flavor presence between LM steaks from cows supplemented with RAC and steaks from cows fed no RAC (Allen et al., 2009).

Some published reports indicate that the inclusion of βAA in the finishing diets of beef can have an effect on beef flavor. However, data indicate that the type of βAA fed has an effect on beef flavor. Additionally, most flavor differences identified in the literature were from studies utilizing trained sensory panels. The majority of studies utilizing untrained consumers evaluating flavor desirabilty failed to find a difference amongst βAA treatments. This indicates that though βAA may change the flavor profile of beef, the alteration in flavor may not be enough for untrained consumers to detect.

Fatty Acid Profile

The role of fatty acids on beef flavor has been the subject of several studies. In a study evaluating the role of fatty acids on the palatability of LM steaks, trained panel flavor scores were negatively correlated with C16:0, C18:0, C18:2, and total saturated fatty acid (SFA) content (Westerling and Hedrick, 1979). Additionally, panel flavor scores were positively correlated with C18:1 and total unsaturated fatty acid (UFA) content (Westerling and Hedrick, 1979). These results were in agreement with findings of Dryden and Marchello (1970) who found C18:1 content to be highly correlated ($r = 0.66$) with trained panel flavor desirability ratings of LM steaks. However, when results from LM steaks were combined with results from *triceps brachii* and *semimembranosus* steaks, no significant correlations were found between fatty acids and flavor ratings (Dryden and Marchello, 1970). A study by Melton et al. (1982) also found flavor scores to be positively correlated with C18:1 content. In the same study, flavor scores were

found to be negatively correlated with C14:1, C18:0, and C18:3 content (Melton et al., 1982). A recent study found trained panel ratings for beef flavor to be significantly correlated with C14:0, C16:0, C16:1, C17:0, C18:1 *cis*-9, C18:1 *trans*-10/11, and total SFA content (Garmyn et al., 2011). Moreover, flavor ratings were negatively correlated with C18:2, C20:4, total polyunsaturated fatty acid (PUFA), n-3 fatty acid, and n-6 fatty acid content (Garmyn et al., 2011). However, in this study, correlations between fatty acids and flavor ratings, though statistically significant, were much lower than those reported by previous studies.

The fatty acid profile of grain-finished beef has been well established (Cabezas et al., 1965; Dryden and Marchello, 1970; Rule et al., 2002; Wood et al., 2008; Dinh et al., 2010; Sexten et al., 2012). Beef from grain finished cattle contains high levels of palmitic acid (C16:0) (20-26%), stearic acid (C18:0) (12-24%), and oleic acid (18:1 *cis*-9) (35-40%). Beef fat from grain-finished cattle is comprised of 43 to 46% saturated fatty acids and contains only 5 to 7 % polyunsaturated fatty acids.

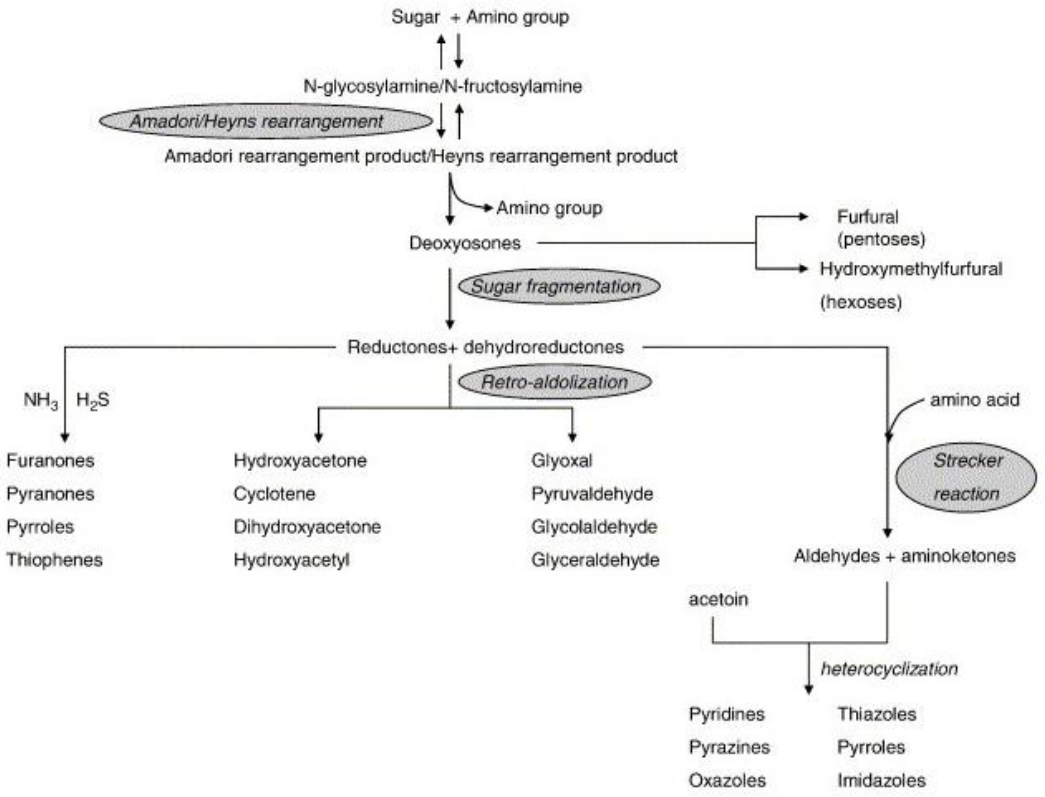
Beef from Wagyu cattle has been shown to have a different fatty acid profile than beef from other breeds. In a study comparing the fatty acid profile of Wagyu (3/4 Wagyu) cattle and Angus cattle, subcutaneous and intramuscular fat from Wagyu cattle was shown to have higher percentages of C16:1 and C18:1 fatty acids as well as less C16:0 and C18:0 fatty acids than fat from Angus cattle (May et al., 1993). The same was seen in the fatty acid profile of LM, with samples from Wagyu cattle having less C18:0 than samples from Angus cattle (May et al., 1993). In a study comparing Holstein and pure-bred Japanese Black cattle, subcutaneous fat from Japanese Black cattle had a higher percentage of C18:1, C16:1 and a lower percentage of C18:0, C16:0, and total SFA

(Zembayashi et al., 1995). Several studies also have reported beef from Wagyu cattle to have lower C18:0 and higher C18:1 content than those in published reports for other breeds of cattle (Yang et al., 1999; Elias Calles et al., 2000; Oka et al., 2002; Cho et al., 2005; Okumura et al., 2007). However, published reports that have utilized beef from F1 crosses of Wagyu sires with Angus or Hereford dams have reported fatty acid profiles that do not possess the same unique fatty acid profile (Sturdivant et al., 1992; Xie et al., 1996b). Xie et al. (1996) reported differences in fatty acid profiles between Wagyu and Wagyu F1 cross cattle; however the differences were minimal in magnitude. Based on the findings of Dryden and Marchello (1970) and Westerling et al. (1979), the higher C18:1 and lower C18:0 content of beef from Wagyu cattle could indicate beef from Wagyu cattle could have a superior flavor than beef from other cattle breeds.

It is well documented that beef from animals finished exclusively on grass or forage has a different fatty acid profile than beef from cattle finished on a grain based diet. Daley et al. (2010) wrote a thorough review paper on the topic. In terms of saturated fatty acids, beef from grass-finished animals possesses a greater percentage of stearic acid (C18:0) than beef from grain-finished animals (Realini et al., 2004; Nuernberg et al., 2005; Alfaia et al., 2007; Garcia et al., 2008; Leheska et al., 2008). Some reports have shown beef from grass finished cattle to have a decreased amount of palmitic acid (C16:0) (Realini et al., 2004; Nuernberg et al., 2005; Alfaia et al., 2007) others have found no difference in C16:0 concentration (Descalzo et al., 2005; Garcia et al., 2008; Leheska et al., 2008). Most reports have found no difference in the amount of total SFA between grain and grass-finished beef (Realini et al., 2004; Descalzo et al., 2005; Nuernberg et al., 2005; Alfaia et al., 2007). The greatest difference in fatty acid profile

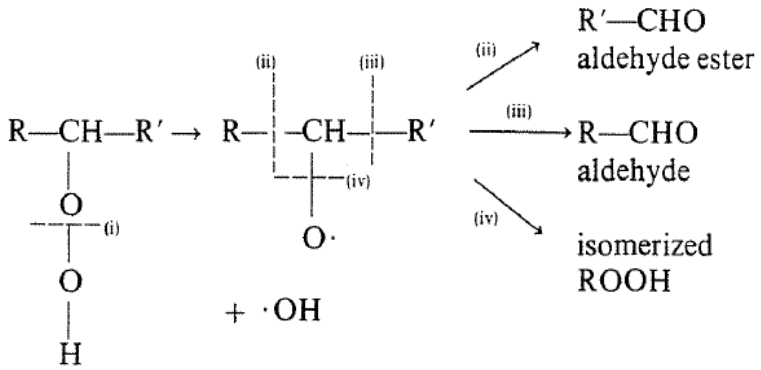
between forage and grain-finished cattle occurs in the amount of unsaturated fatty acids present. Grass-finished beef is higher than grain-finished beef in linolenic (C18:3 n-3), eiconsapentaenoic acid (EPA) (C20:5 n-3), and DPA (C22:5 n-3) (Realini et al., 2004; Descalzo et al., 2005; Nuernberg et al., 2005; Alfaia et al., 2007; Garcia et al., 2008; Leheska et al., 2008). However, the amount of linoleic acid (C18:2 n-6) is similar between grass and grain-finished beef (Descalzo et al., 2005; Nuernberg et al., 2005; Alfaia et al., 2007; Garcia et al., 2008; Leheska et al., 2008). The total amount of total monounsaturated fatty acids (MUFA) is lower in grass-finished beef compared with grain finished beef (Descalzo et al., 2005; Alfaia et al., 2007; Garcia et al., 2008; Leheska et al., 2008). Moreover, the total proportion of n-3 fatty acids is higher in grass-finished beef compared with grain-finished beef (Nuernberg et al., 2005; Alfaia et al., 2007; Garcia et al., 2008; Leheska et al., 2008). The higher proportion of PUFA in grass-finished beef, which are more susceptible to lipid oxidation, likely contributes to the different flavor profile of grass-finished beef observed by sensory panelists.

The fatty acid profile of beef has been shown to have an impact on beef flavor (Dryden and Marchello, 1970; Westerling and Hedrick, 1979; Melton et al., 1982; Garmyn et al., 2011). Differences in the fatty acid profile of beef caused by different feeding regimes or by cattle breed-type can have an impact on the flavor of the beef that is produced. The unique fatty acid profiles produced can either have positive or negative effects on beef flavor.



(figure: van Boekel, 2006)

Figure 2.1 Generic scheme for volatile compounds formed from the Maillard reaction



R′ = fatty ester end.

[1] Decomposition shown by numbers in parentheses which represent carbon-carbon cleavages.

(figure: Frankel, 1980)

Figure 2.2 Volatile formation from the decomposition[1] of an unsaturated hydroperoxide

CHAPTER III

IDENTIFYING PREFERENCES FOR SPECIFIC BEEF FLAVOR CHARACTERISTICS

SUMMARY

Descriptive sensory analysis of beef samples was conducted at culinary institutions in three regions of the United States to determine differences in beef flavor attributes and flavor preferences among 12 different product categories (treatments). Treatments were chosen specifically to permit identification and characterization of production-related beef flavor differences associated with the effects of USDA grade (Prime, Premium Choice, Low Choice, Select), cattle breed-type (Angus, Holstein, American Wagyu), finishing diet (grass-fed, corn-fed, barley-fed), use of growth technologies (non-implanted, implanted, implanted & fed β agonists), and postmortem aging method (wet-aged, dry-aged). Panelists (N = 307) rated samples from each treatment for 13 different flavor notes (beefy/brothy, browned/grilled, buttery/beef fat, nutty/roasted nut, earthy/mushroom, bloody/metallic, grassy, livery, fishy, sour, sweet, and bitter) and overall flavor desirability. Additionally, percentage chemical lipid, moisture, protein, and ash were determined for samples from each treatment. Of the factors analyzed, USDA Quality grade and finishing diet (grain-fed vs grass-fed) had the largest effects on beef flavor attributes. Prime samples were scored higher ($P < 0.05$) for overall flavor desirability, beefy/brothy, buttery/beef fat, nutty/roasted nut, and sweet flavors than all other treatments. Certified Organic, grass-fed samples scored higher ($P < 0.05$) for fishy, gamey, and livery flavors than all other treatments. Differences in cattle-

breed type (Angus vs Wagyu), grain source (corn vs barley), aging technique (dry-aged vs wet-aged), and use of growth technology (non-implanted vs implanted vs implanted & fed β agonists) had only minimal effects on flavor. Extending the wet-aging period from 14 to 46 d had a negative effect on flavor traits, producing samples that scored higher ($P < 0.05$) for sour flavor than all other treatments. Panelists preferred samples with flavors described as beefy/brothy, browned/grilled, buttery/beef fat, nutty/roasted nut, and sweet and disliked flavors identified as bloody/metallic, grassy, gamey, livery, fishy, sour, and bitter.

INTRODUCTION

Numerous studies have demonstrated the importance of beef flavor to consumer overall eating satisfaction. Recent studies have shown that when tenderness reaches an acceptable level, flavor becomes the most important driver of beef eating satisfaction (Goodson et al., 2002; Killinger et al., 2004a; Behrends et al., 2005a, b). Additionally, several studies have shown consumer overall acceptability ratings to be more highly correlated with flavor ratings than tenderness or juiciness ratings, regardless of tenderness variation (Neely et al., 1998; Thompson, 2004; O'Quinn et al., 2012).

Previous research has identified several factors along the beef production and processing chain that influence beef flavor characteristics, including cattle breed (Brewer, 2007), whether animals are finished on forages or grain (Melton et al., 1982a; Larick and Turner, 1990), type of grain included in the finishing diet (Jeremiah et al., 1998; Busboom et al., 2000; Sitz et al., 2005), duration of the grain-finishing period (Melton et al., 1982b; Larick et al., 1987), degree of marbling or USDA quality grade (Emerson,

2011; O'Quinn et al. 2012), and method used for postmortem aging of beef cuts (Warren and Kastner, 1992; Campbell et al., 2001; Sitz et al., 2006). In recent years, innovative marketing strategies involving differentiation of beef products according to production-related differences in flavor have emerged and are gaining momentum. However, scientific information linking consumer preferences with particular beef flavor characteristics, originating from differences in production history, is limited. Therefore the objective of this study was to identify and characterize specific beef flavors that are associated with differences in cattle production history and method of postmortem aging and to quantify relationships between these specific flavors and preferences of discriminating beef consumers.

MATERIALS AND METHODS

Experimental Treatments and Sample Preparation

Beef strip loins (IMPS #180; NAMP, 2010), representing 12 different product categories (treatments) currently available to beef consumers in U.S. retail and food service markets, were purchased for use in the study. Details describing the 12 experimental treatments are provided in Table 3.1. Treatments were chosen specifically to permit identification and characterization of production-related beef flavor differences associated with the effects of USDA grade (Prime, Premium Choice, Low Choice, Select), cattle breed-type (Angus, Holstein, American Wagyu), finishing diet (finished exclusively on forages, finished on corn-based grain diet, finished on barley-based grain diet), use of growth technologies (none, implants only, implants plus β-adrenergic agonists), and postmortem aging method (wet-aged, dry-aged). Treatment specifications

listed in Table 3.1 were verified by CSU personnel through visual appraisal of product at the time of selection, USDA grade and certification programs, and through contact with producers to verify cattle feeding practices prior to selection of product for use in the study.

Strip loins representing treatments 1 through 7 (n = 9/treatment) were selected by Colorado State University (**CSU**) personnel at a commercial beef processing plant in Northern Colorado and transported, under refrigeration (2ºC), to the CSU Meat Laboratory where they were vacuum packaged and wet-aged (i.e., stored in vacuum packages in the absence of light at 2 to 4ºC) for the specified aging period (Table 3.1). Samples were checked daily throughout the wet-aging period to ensure that vacuum seals were maintained on all packages.

Strip loins representing treatments 8 through 11 (n = 9/treatment) and treatment 12 (n = 12) were purchased from commercial meat purveyors. Strip loins from T10 were from Wagyu cross-bred cattle (50% Wagyu, 50% Angus). All dry-aged strip loins (treatments 8, 9, and 10) were aged (without protective packaging) at a commercial dry-aging facility at 1 to 2ºC and approximately 77% relative humidity for 30 d following an initial wet-aging period of 16 or 17 d. Strip loins representing T11 and T12 were wet-aged for 14 d at the CSU Meat Laboratory using procedures described previously for other wet-aged samples. Strip loins from T12 were certified USDA Organic and strip loins from T11 were from a certified USDA Naturally Raised program.

Following postmortem aging, each strip loin was trimmed, removing all exterior fat and connective tissue. Within each treatment, 3 batches were created by randomly assigning an equal number of trimmed strip loins to each batch (3 strip loins/batch for

treatments 1 through 11; 4 strip loins/batch for treatment 12). Each batch of strip loins was then ground using a meat grinder (Model 84186, Hobart, Troy, OH) equipped with a coarse grinding plate (1 cm). Following grinding, batches were mixed for 120 s in a twin-shaft paddle mixer (Keebler Engineering Co., Chicago, IL). After mixing, each batch was ground a second time using the same grinder equipped with a fine grinding plate (4 mm). Beef samples were ground before sensory analysis in order to eliminate treatment differences in tenderness. This was done to minimize any "halo effect" that tenderness variation may have imparted on panelists' ability to identify flavor differences between samples.

Each ground batch was stuffed into cellulose casings (6.4 cm in diameter) using a vacuum stuffer (Model VF50, Handtmann, Germany). Filled casings were placed in a freezer (-20ºC) and allowed to freeze overnight (approximately 18 h) before portioning into patties. After freezing, casings were removed from the samples and a band saw (Model 400, AEW-Thurne, AEW Engineering Co., Ltd., Norwich, UK) was used to cut the samples into patties (1.9 cm thick and 6.4 cm in diameter). Patties from each batch were randomly assigned to predetermined cooking groups, vacuum packaged, and placed in frozen storage (-20ºC) for subsequent sensory analysis. A set of 3 patties (consisting of 1 patty from the beginning, 1 patty from the middle, and 1 patty from the end of each processed batch) was obtained from each batch to be used for proximate analysis.

Descriptive Sensory Analysis

Sensory analysis was conducted at culinary schools in the Eastern, Central, and Western regions of the U.S. Untrained discriminating panelists (n = 307) consisted of

culinary students and professionals trained in the culinary arts. Each panel session included 24 to 26 panelists and lasted approximately 1 h. Individual panelists were supplied with a ballot, plastic eating utensils, a napkin, an expectorant cup, a cup of water, and unsalted crackers to serve as a palate cleanser. Verbal instructions outlining procedures for the tasting session were discussed immediately before each panel session. During this discussion, panelists were instructed to focus their evaluations primarily on the flavor attributes of each sample and to disregard between-sample differences in juiciness and texture when assigning flavor ratings. Before sample tasting, participants filled out a brief demographic questionnaire and were asked to rank the importance (1 = most important; 10 = least important) of the following 10 factors when making beef purchase decisions: (a) nutrient content, (b) visual appearance (fresh beef), (c) marbling level (fresh beef), (d) where and how the animal was raised, (e) whether or not the animal had received growth promotants or antibiotics, (f) brand name of product, (g) breed of animal that produced the product, (h) USDA grade of product, (i) whether the animal was raised exclusively on pasture or fed grain in a feedlot for any period of time, and(j) taste/eating experience.

Samples were thawed at 2 to 4^{o}C for 24 h before sensory evaluation. All samples were cooked over open gas burners on griddle pans with a non-stick coating. Pans were allowed to heat to 246^{o}C prior to sample cooking. Samples were turned once, half-way through cooking, and were cooked to an internal temperature of 74^{o}C monitored by a Type K Thermocouple Thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation, Middlefield, CT). Samples were cooked by treatment, 13 at a time. Within each set of 13 sample patties, eight patties represented two separate batches (4 from each)

and five patties represented the remaining batch from each treatment. Following cooking, sample patties were halved into two equally sized pieces, resulting in 26 servings, and served immediately to the panelists.

Panelists received 1 sample from each of the 12 treatments served in random order. Within each treatment, each batch was served to one third of the panelists, with two additional panelists receiving samples from the same batch in panels consisting of 26 panelists. Batch assignment to panelists was randomized between panel sessions so that in each panel session, panelists evaluated a unique combination of treatment batches. Each sample was identified with a random three digit numeric code. Panelists evaluated each sample for flavor desirability and 13 different flavors described as: beefy/brothy, browned/grilled, buttery/beef fat, bloody/metallic, grassy/hay like, gamey, earthy/mushroom, nutty/roasted nut, livery, fishy, sour/acidic, sweet, and bitter. Panelists were given detailed written descriptions of each of the flavors, which are shown in Table 3.2. Each sensory attribute was rated on a 10-cm, unstructured line scale with 0 cm verbally anchored at very low intensity for all flavors, dislike extremely for flavor desirability, and 10 cm verbally anchored at very high intensity for all flavors and like extremely for flavor desirability.

Panels were designed to imitate informal wine-tasting sessions that are commonly conducted at culinary schools and vineyards that allow for the comparison of different wines and their flavor profiles. This was done to present panelists with a format of flavor discrimination that they were previously familiar with and is commonly used in the wine industry to demonstrate subtle flavor differences among similar products. Moreover, similar to many wine tastings, samples were served in 3 “flights” of 4 samples to better

allow panelists to evaluate the flavor differences within a small set of samples. Panelists were allowed to retain all 4 samples until the conclusion of the flight. After each flight and following completion of the ballots, all samples were discarded and panelists were asked to verbally discuss any differences among the samples that may have been present. Discussions (data not reported) were informal and focused on flavor-related differences among samples. Additionally, serving of samples in flights and the interim discussion period between flights were used to reduce panelist fatigue and maintain the interest and engagement of participants throughout the 12-sample panel session. After each panel session, individual panelists' ratings were averaged to obtain a single panel rating for each sensory attribute of each sample tested.

Proximate Analysis

Frozen patties from each batch within each treatment (n = 3) were broken into smaller pieces (approximately 1 cm × 1 cm × 1 cm), submerged in liquid nitrogen, and then homogenized into a fine powder using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc., Ridgeland, MS). Homogenized samples were individually identified, placed in Whirl-Pak bags (Nasco, Ft. Atkinson, WI), and stored at -80^{o}C until further analysis.

Total Lipid Analysis. Total lipid was extracted from 1 g of each homogenized sample using the method described by Folch et al. (1957) and modified by Bligh and Dyer (1959). Following extraction, the lipid-containing fraction was dried under N_2 gas and then placed into a 100^{o}C drying oven for 3 h. Samples were allowed to cool to room temperature (22°C) in a desiccator before weighing. Samples were weighed and the total

percentage of sample weight comprised of lipid was determined by dividing the final weight of the residual sample by the initial sample weight and multiplying by 100. Percentage lipid was reported on a wet-weight basis.

Moisture Analysis. Moisture was determined using the moisture removal process described in the AOAC (2005). Approximately 2 g of each sample was weighed into an aluminum tin (low form, aluminum, fluted; Fisher Scientific, Pittsburgh, PA) and dried for 24 h in a forced air drying oven (Thelco lab oven, Mandel Inc., Guelph, Ontario, Canada) set at 100^{o}C. Dried samples were allowed to cool to room temperature (22°C) in a desiccator before re-weighing. Samples were reweighed and weight lost was reported as percent moisture.

Crude Protein Analysis. Crude protein was determined by the AOAC (2005) method (TruSpec CN Carbon/Nitrogen Determination Instruction Manual, December 2004, Leco Corp., St. Joseph, MI) using 6.25 as the conversion factor (Merrill and Watt, 1973).

Ash Analysis. Ash analysis was performed using the AOAC ashing method (AOAC, 2005). Approximately 1 g of each sample was placed in a pre-weighed, dry crucible. Sample containing crucibles were then placed in a Thermolyne box furnace (Thermo Fisher Scientific, Pittsburgh, PA) at 600^{o}C for 24 h. Incinerated samples were removed from the furnace and allowed to cool to room temperature (22°C) in a desiccator before re-weighing. Samples were re-weighed and the percentage of sample weight comprised of ash was calculated by dividing the quantity of material remaining in the crucible after incineration by the quantity of sample initially placed into the crucible and multiplying by 100.

Statistical Methods

All analyses were conducted using statistical procedures of SAS (SAS Inst. Inc., Cary, NC). Treatment comparisons were tested for significance using linear, mixed model procedures (PROC MIXED). For these analyses, denominator degrees of freedom were calculated using the Kenward-Roger approximation.

Statistical models differed slightly depending upon response variable. Consumer rankings of 10 factors considered when purchasing beef were analyzed using a least squares model that included the fixed effect of factor and the random effect of panel session. Values quantifying the proximate composition of each beef product (total lipid, protein, moisture, and ash) were analyzed using statistical models that included the fixed effect of treatment and the random effect of batch nested within treatment. Sensory panel ratings were analyzed using a model that included the fixed effect of treatment, along with the random effects of panel session and batch nested within treatment.

The experiment was designed to include several pre-planned treatment comparisons that were constructed to isolate and characterize effects of differences in USDA grade, cattle breed-type, finishing diet, use of growth technologies, and postmortem aging method on beef flavor characteristics. Pre-planned comparisons included: (1) a comparison of conventional beef products representing carcasses grading Premium Choice (T1), Low Choice (T2), and Select (T3); (2) a comparison of 3 premium, dry-aged beef products – Premium Choice, Angus (T8) vs. Prime, Angus (T9) vs. Prime, Wagyu (T10); (3) a comparison of products produced by Holstein vs. Angus-type cattle (T4 vs. T1, T2 and T3); (4) a comparison of Low Choice, Angus products produced using different growth management strategies – no growth technologies (T11)

vs implants only (T2) vs. implants and β adrenergic agonists (T5); (5) a comparison of U.S. Select products generated from carcasses of cattle that were grass-fed (T12) vs. grain-finished (T3); (6) a comparison of Low Choice products generated from carcasses of cattle grain-finished on corn (T5) vs. barley (T6); and (7) a comparison of Premium Choice products either dry-aged (T8) or wet-aged for 14 d (T1) or 46 d (T7). In order to test all effects, it was necessary to utilize some treatments in more than 1 pre-planned comparison. The PDIFF option was used to compare treatment least squares means when the F-test for the effect of treatment was significant. All comparisons were tested using a comparison-wise significance level of $\alpha = 0.05$.

Correlation analyses (PROC CORR) were used to identify and quantify relationships among sensory panel ratings for beef flavor attributes, overall desirability scores, and IM fat content. For these analyses, batch served as the experimental unit.

RESULTS AND DISCUSSION

Participant Demographics and Factors Emphasized When Purchasing Beef

Results obtained from demographic questionnaires completed by the 307 study participants are summarized in Table 3.3. Sensory analysis of samples in the current study was performed by male (56.4%) and female (43.7%) culinary specialists with discriminating palates and some prior experience in flavor evaluation of foods. Many of the sensory panelists involved in the study were culinary students completing their post-secondary degrees at culinary institutes immediately after high school graduation. As a result, 76.2% of the panelists were between 18 and 34 years old and only 22.8% reported ages of 35 years or older (Table 3.3). More than half (56.7%) of the participants indicated

that they ate beef between 1 and 3 times weekly and more than one-third (38.7%) of the panelists stated that they consumed beef 4 to 6 times per week. All of the study participants said they consume beef at least once a week (Table 3.3).

When asked to rank 10 factors generally considered to be important when purchasing beef, study participants identified "taste (eating experience)," "marbling level," and "visual appearance of fresh products" as most ($P < 0.05$) important (Table 3.4). The "USDA grade of the product" ranked next in importance and was considered more important ($P < 0.05$) than "nutrient content," "brand name," or the various production-related factors that were included on the list (Table 3.4). Among panelists participating in this study, "nutrient content," "animal breed," "where and how the animal was raised," and "whether or not the animal had received growth promotants" did not differ ($P > 0.05$) in ranking and were of moderate importance with respect to their influence on beef purchase decisions (Table 3.4). Of least ($P < 0.05$) importance to study participants when purchasing beef were "whether or not the animal was raised exclusively on pasture or fed grain in a feedlot for any period of time" and "brand of the product" (Table 3.4).

Results reported in Table 3.4 are similar to those of Reicks et al. (2011), who found that consumers rank factors related to taste (specifically beef flavor, tenderness, and juiciness) as the most important motivators for purchasing beef steaks and roasts. Reicks et al. (2011) also reported that nutritional content was of moderate importance and that various animal production traits, including natural and organic, were least important to consumers when making beef purchase decisions, which was in general agreement with results of our study. In the present study, visual characteristics of the fresh product

ranked among the top 3 factors considered when purchasing beef. The importance of visual product characteristics to purchasers of retail beef cuts also was observed by Robbins et al. (2003). In that study (which did not consider any factors related to eating quality), consumers ranked cut, color, amount of visible fat, price, and amount of liquid in the package as the most important considerations when purchasing beef (Robbins et al., 2003).

It was noteworthy that, in the current study, credence attributes (such as production or process claims, cattle breed, brand of product, etc.), along with nutrient content, all were considered to be of lesser ($P < 0.05$) importance than the inherent quality attributes of the product (taste, marbling level, and visual appearance) when making beef purchase decisions. These findings underscored the importance of continued industry focus on ensuring a positive eating experience and providing fresh retail beef products that meet consumers' expectations for visual appearance at the point of sale.

Proximate Composition of Beef Products

Least squares means for percentages of lipid, moisture, protein, and ash determined using raw samples from each of the 12 treatments are compared in Table 3.5. Due to treatment differences in USDA quality grade (Table 3.1), lipid percentages differed ($P < 0.001$) widely among treatments (Table 3.5), ranging from 2.82% in T12 (Select, grass-fed) to 12.02% in T10 (Prime, Wagyu). However, no differences ($P > 0.05$) in lipid percentage were observed within each set of treatments representing the same USDA quality grade (Table 3.5). Mean lipid percentages observed in the current study for Select, Low Choice, Premium Choice, and Prime samples were similar to those

previously reported for LM samples from carcasses representing the same USDA quality grades (Savell et al., 1986; Dow et al., 2011; Emerson, 2011).

Moisture percentage was inversely related to lipid percentage (r = -0.92) and ranged from 73.07% (T12) to 66.76% (T1) among wet-aged samples (Table 3.5). Dry-aged samples (T8, T9, and T10) contained less ($P < 0.05$) moisture than all wet-aged samples (Table 3.5). Sitz et al. (2006) reported samples from USDA Prime and Choice dry-aged strip loins contained approximately 5% less moisture than samples from comparable wet-aged strip loins, which was similar to results from the current study.

Treatment had no effect ($P > 0.05$) on protein percentage, with all samples having between 23.04% (T4) and 26.58% (T8) protein (Table 3.5). Percentage of ash differed ($P < 0.05$) among treatments (Table 3.5); however, the magnitude of the difference in ash percentage between the 2 most extreme groups (T7 vs. T8) was less than 0.4%. Wahrmund-Wyle et al. (2000) compared the proximate composition of 13 different muscles from USDA Choice and Select retail beef cuts and found no differences in percentages of protein or ash.

Effects of USDA Grade and Cattle Type on Beef Flavor Attributes

USDA Quality Grade Comparisons. According to results of the most recent National Beef Quality Audit (Savell et al., 2012), more than 90% of all fed steers and heifers produced in the U.S. qualify for one of 2 USDA quality grades – U.S. Choice or U.S. Select. Of the carcasses that qualify for the U.S. Choice grade, those that grade Average or High Choice usually are designated for use in various Premium Choice beef programs, thereby creating 3 predominant commodity beef marketing categories

(Premium Choice, Low Choice, and Select) that differ in value in the U.S. beef trade due to expected differences in eating quality.

Beef flavor characteristics of LM samples representing the Premium Choice (T1), Low Choice (T2), and Select (T3) quality grade categories are compared in Figure 3.1 and Table 3.6. In this comparison, all samples were produced by conventionally raised, Angus-type cattle that had been implanted and finished on corn-based diets for at least 100 d. Furthermore, all samples in this comparison were wet-aged for 14 d. When compared with Premium Choice and Low Choice strip loin samples, samples from Select strip loins had a flavor profile that was perceived to be more ($P < 0.05$) bloody/metallic in flavor and less ($P < 0.05$) intense in flavors described as beefy/brothy, browned/grilled, and buttery/beef fat (Figure 3.1, Table 3.6). In addition, livery flavor was more ($P < 0.05$) pronounced in Select samples than in Premium Choice samples (Figure 3.1, Table 3.6). Select samples were rated as less ($P < 0.05$) desirable in overall flavor than Premium Choice samples, but had similar ($P = 0.091$) overall flavor desirability ratings to those for Low Choice samples (Figure 3.1, Table 3.6). Premium Choice samples possessed a browned/grilled flavor that was more intense ($P < 0.05$) than that of Low Choice samples and, therefore, were rated as more desirable ($P < 0.05$) in overall flavor than were Low Choice samples (Figure 3.1, Table 3.6). Otherwise, Premium Choice and Low Choice samples had very similar flavor profiles (Figure 3.1, Table 3.6).

Differences in flavor characteristics observed among samples representing the 3 quality grade categories (Figure 3.1, Table 3.6) were attributed, at least in part, to differences in intramuscular (**IM**) fat content (Table 3.5). Emerson (2011) evaluated the effect of degree of marbling (ranging from Traces to Moderately Abundant) on flavor

attributes of LM steaks and found that increased degree of marbling was associated with greater intensity of beefy/brothy and buttery/beef fat flavors and reduced intensity of flavors characterized as bloody/serumy, livery/organy, and grassy.

Comparison of Angus and Calf-Fed Holstein Beef. To many U.S. beef consumers, the breed name Angus is synonymous with quality as a result of breed marketing. Use of the Angus breed of cattle in quality oriented beef marketing programs has grown steadily since the inception of the Certified Angus Beef® program more than 3 decades ago. Of the 77 different programs to which beef carcasses may be certified by USDA's Agricultural Marketing Service (USDA, 2012), 54 programs now feature a GL1 specification (i.e., Angus phenotype, requiring ≥ 51% black hair color). Today, more than 60% of fed steers and heifers marketed in the U.S. are predominantly black in color (Savell et al., 2012) and would meet the GL1 specification for phenotypic Angus-based marketing programs.

Another cattle breed that has experienced a more limited degree of success in the quality oriented retail beef market is Holstein. In 1992, Ralphs Grocery developed the Holstein-based California Branded Beef program in response to complaints and comments by customers about the quality and consistency of their beef. Following extensive research, Ralphs determined that calf-fed Holstein steers, fed a high-energy diet for at least 300d and harvested at comparatively young ages, produced a consistent supply of high quality beef that would satisfy demands of their customers and, in 1993, California Beef was introduced in 134 stores with a "double your money back" guarantee if customers were dissatisfied (Tronstad and Unterschultz, 2005). Within the first 7 months of the program, consumer expenditures on beef in those stores increased by

nearly 4%, during a time period when retail beef sales figures throughout Southern California were flat to negative (Tronstad and Unterschultz, 2005). Ralphs, now a division of Kroger, no longer features California Beef; however, 2 other branded beef programs, JBS American Reserve® and Vintage Natural Beef®, currently feature Holstein beef products and utilize production protocols and product specifications very similar to those originally developed by Ralphs.

Flavor attributes of Calf-fed Holstein beef (Low Choice) are compared with those of Angus beef (Premium Choice, Low Choice, and Select) in Figure 3.1 and Table 3.6. Samples from Calf-fed Holstein steers (T4) had an overall flavor that was comparable ($P > 0.05$) to that of Premium Choice Angus (T1) beef and more desirable ($P < 0.05$) than that of Low Choice Angus (T2) and Select Angus (T3) beef products (Figure 3.1, Table 3.6). When compared to Select Angus beef, Calf-fed Holstein beef had more intense ($P < 0.05$) beefy/brothy, browned/grilled, and buttery/beef fat flavors, all of which contributed to its more desirable ($P < 0.05$) overall flavor (Figure 3.1, Table 3.6). In general, Calf-fed Holstein beef (T4) and Choice Angus beef (T1 and T2) had very similar flavor profiles, although Holstein beef had a stronger ($P < 0.05$) bloody/metallic flavor. The more desirable ($P < 0.05$) overall flavor for Holstein beef vs. Low Choice Angus beef was attributed to the tendency ($P = 0.051$) for Holstein samples to have a slightly stronger buttery/beef fat flavor (Table 3.6). It was noteworthy that Calf-fed Holstein beef had several flavor attributes that were as desirable as those of Premium Choice Angus beef despite the fact that the Holstein beef contained 2.5% less fat (Table 3.5). Others who have compared Holstein beef with beef produced by other cattle breeds (Ramsey et al.,

1963; Adams et al., 1982; Jeremiah and Gibson, 1999) reported no flavor differences between Holstein and other breeds.

Comparison of Premium Dry-aged Beef Products. In their efforts to provide the ultimate dining experience, most of the finest steakhouses in the U.S. feature USDA Prime beef or beef from one of several Premium Choice programs. Moreover, Angus and Wagyu are the 2 cattle breeds most-frequently mentioned in marketing materials or on menus of high-end steakhouses that feature premium beef products. In addition, many of these upscale restaurants dry-age their beef to create a unique flavor profile that has been described as "buttery and rich," "mellow and intense," and "earthy and nutty" (Savell, 2008).

Flavor attributes of 3 premium dry-aged beef products (Premium Choice Angus, Prime Angus, and Prime American Wagyu) are compared in Figure 3.2 and Table 3.6. The flavor profiles of dry-aged Prime Angus (T9) and dry-aged Prime American Wagyu (T10) were indistinguishable in our comparison (Figure 3.2, Table 3.6). However, compared with dry-aged Premium Choice Angus beef (T8), samples from both dry-aged Prime products (T9 and T10) possessed greater intensity ($P < 0.05$) of several desirable beef flavors including beefy/brothy, browned/grilled, buttery/beef fat, nutty/roasted nut, and sweet, together with a less pronounced ($P < 0.05$) livery flavor (Figure 3.2, Table 3.6). Correspondingly, both dry-aged Prime products were rated as superior ($P < 0.05$) in overall flavor desirability (Table 3.6). Of all products tested in this study, the 2 dry-aged Prime products had the most desirable ($P < 0.05$) overall flavor and the greatest intensity ($P < 0.05$) of flavors described as beefy/brothy, buttery/beef fat, nutty/roasted nut, and sweet (Table 3.6).

The superior flavor desirability of USDA Prime beef observed in this study has been documented by others as well (Smith et al., 1983; Savell et al., 1987; Smith et al., 1987). Specific flavor differences observed between Prime and Premium Choice beef in the current study were similar to results of Emerson (2011), who compared flavor attributes of Prime and Premium Choice LM steaks and reported that Prime steaks had greater intensity of meaty/brothy and buttery/beef fat flavors. Results of the current study also are in general agreement with several previous studies that have evaluated the sensory properties of beef from imported Japanese Wagyu and American Wagyu crosses and identified little or no difference in flavor ratings of beef from Wagyu influenced cattle, when compared to beef from other breed types (Busboom et al., 1993; May et al., 1993; Jeremiah and Gibson, 1999; Wheeler et al., 2004). In a study by May et al. (1993) evaluating differences in eating characteristics of LM steaks from Wagyu cross-bred (at least ¾ Wagyu) cattle and Angus cattle fed for 552 days, trained sensory panelists were unable to detect a difference in beef flavor intensity between samples from Wagyu cross-bred cattle and samples from Angus cattle; however, consumers were able to identify differences between samples from Wagyu cross-bred cattle and samples from Angus cattle in a triangle test 47.5% of the time, citing flavor as the distinguishing attribute more than 15% of the time (May et al., 1993).

Effects of Growth Enhancement on Beef Flavor Attributes

In today's commercial cattle feeding industry, most cattle produced in conventional finishing systems receive 1 or 2 growth-promoting (hormonal) implants (Tatum, 2009). Additionally, it has been estimated that between 50 and 70% of

conventionally raised, implanted feedlot cattle also are supplemented with a β adrenergic agonist (**βAA**), either Optaflexx™ (Elanco Animal Health; Greenfield, IN; ractopamine hydrochloride) or Zilmax™ (Merck Animal Health; Summit, NJ; zilpaterol hydrochloride), during the final few wk of finishing. It is well documented that aggressive use of growth enhancement technologies can reduce USDA quality grade and meat tenderness (Morgan, 1997; Strydom et al., 2009); however, effects of these technologies on specific beef flavor characteristics have not been thoroughly studied.

Data presented in Table 3.6 and Figure 3.3 compare flavor attributes of beef produced by cattle subjected to 3 different growth-management programs (T2, T5, and T6). Strip loins in T2 were produced by conventionally raised, Angus-type cattle that were implanted, but received no βAA; strip loins in T5 were produced by conventionally raised, Angus-type cattle that were implanted and supplemented with a βAA (zilpaterol hydrochloride); and strip loins in T11 were produced by naturally raised, Angus-type cattle that never received antibiotics, implants, or βAA. Though it is not a certainty, finishing diets of conventionally raised cattle (T2 and T5) most likely included antibiotics and ionophores. Strip loins in all 3 treatments graded Low Choice and all were wet-aged for 14 d.

When compared with an all-natural production system (T11), use of implants alone (T2) or implants plus βAA (T5) had no effect ($P > 0.05$) on ratings for beefy/brothy, browned/grilled, bloody/metallic, grassy/hay like, gamey, earthy/mushroom, nutty/roasted nut, livery, fishy, sour, sweet, or bitter flavors (Figure 3.3, Table 3.6). Though ratings for overall flavor desirability were numerically reduced by the use of growth enhancement technologies (Figure 3.3, Table 3.6), treatment

differences in overall flavor desirability were not large enough for statistical significance. Strip loins in all 3 treatment groups had a Small degree of marbling, graded Low Choice, and did not differ (P > 0.05) in overall lipid content (Table 3.5). Nevertheless, samples from cattle that were implanted and supplemented with βAA (T5) were rated lower ($P < 0.05$) for buttery/beef fat flavor than samples in the other 2 treatment groups (T2 and T11).

Previous studies that have examined the effects of implanting on beef flavor attributes have produced equivocal results. Roeber et al. (2000) reported that the use of anabolic implants had little effect on consumer panel ratings for beef flavor intensity ($P = 0.073$) or overall flavor desirability ($P = 0.083$) of LM steaks. Platter et al. (2003), on the other hand, found that consumers rated LM steaks from implanted cattle as less desirable ($P < 0.05$) in flavor than steaks from non-implanted cattle. In the latter study, the negative effect of implant use on consumers' ratings for flavor was attributed to a concomitant reduction in marbling score due to implanting (Platter et al., 2003). Conflicting reports concerning the effect of βAA supplementation on beef flavor also exist in the published literature. Studies involving consumers (Hilton et al., 2009; Mehaffey et al., 2009; Brooks et al., 2010) have shown that supplementation of implanted cattle with a βAA (specifically zilpaterol hydrochloride, Zimax™) had no effect on beef flavor ratings, whereas similar studies involving trained sensory panelists (Hilton et al., 2009; Leheska et al., 2009) found that steaks from implanted cattle supplemented with zilpaterol hydrochloride rated lower for beef flavor traits than those from implanted cattle receiving no supplement. Results of the current study suggest that, when LM samples from beef

carcasses of the same USDA quality grade are compared, growth enhancement, using implants only or implants plus ßAA, has a negligible effect on beef flavor characteristics.

Effects of Finishing Diet on Beef Flavor Attributes

Comparison of Corn-Fed and Grass-Fed Beef. In conventional U.S. beef production systems, most cattle are finished on high-energy, corn-based diets for at least 100 d prior to harvest. In recent years, however, grass-fed beef (produced by cattle finished exclusively on forages) has gained popularity among a segment of American consumers, who for a variety of reasons are seeking alternatives to beef produced by conventionally raised, grain-finished cattle. Grass-fed beef and grain-fed beef have very different flavor profiles (Melton et al., 1982 a, b; Larick and Turner, 1990) and, while some consumers prefer the distinctive flavor of grass-fed beef, marketing research has shown that most U.S. consumers prefer the flavor of grain-finished beef. Killinger et al. (2004b) conducted a beef marketing study in which U.S. corn-fed beef was compared with Argentine grass-fed beef. In that study, 60% of consumers preferred the flavor of corn-fed beef, 18% preferred the flavor of grass-fed beef, and 22% had no preference for either product (Killinger et al., 2004b). In a similar study, Sitz et al. (2005) compared U.S. corn-fed beef with Australian grass-fed beef and found that 64% of consumers preferred the flavor of domestic corn-fed beef, 19% preferred the flavor of Australian grass-fed beef and 16% expressed no preference (Sitz et al., 2005). In both studies, consumers demonstrated a willingness to pay higher average prices for steaks from corn-fed cattle, based on flavor preference (Killinger et al., 2004b; Sitz et al., 2005).

In the current study, USDA Select beef from carcasses of cattle that were conventionally raised and of Angus-type finished on corn-based diets (T3) was compared with beef from carcasses that were generated from live cattle that were Certified Organic, grass-finished, and of Angus-type cattle that were never fed grain (100% grass diet) and never received implants or antibiotics (T12). In this comparison both products had a Slight degree of marbling and samples from the two treatments contained comparable ($P > 0.05$) percentages of lipid (Table 3.5). In addition, both products were wet-aged for 14 d.

Results of sensory analysis comparing flavor attributes of corn-fed (T3) and grass-fed (T12) beef are summarized in Figure 3.4 and Table 3.6. Corn-fed beef had greater intensities of beefy/brothy and buttery/beef fat flavors and was rated as more desirable ($P < 0.05$) in overall flavor than grass-fed beef (Figure 3.4, Table 3.6). In contrast, the less desirable ($P < 0.05$) flavor of grass-fed beef was rated as more intense ($P < 0.05$) with respect to several distinctive flavor notes including grassy/hay like, gamey, earthy/mushroom, livery, fishy, sour, and bitter. Grass-fed and corn-fed samples received similar ($P > 0.05$) ratings for flavors described as browned/grilled, bloody/metallic, nutty/roasted nut, and sweet (Figure 3.4, Table 3.6).

The distinctly different flavor profiles observed for corn-fed and grass-fed beef in the current study were very similar to those identified in previous comparisons of grain-finished and grass-finished beef. The unique flavor notes that typify the rich, buttery taste of well-marbled grain-finished beef have been described as an intense “beef fat,” “beefy,” or “brothy” flavors (Melton et al., 1982a, b; Larick and Turner, 1990, Maughan, 2011). In contrast, the undesirable flavor notes often used to describe grass-fed beef have been

characterized as grassy, gamey, dairy/milky, barny, fishy, sour, metallic, and livery (Melton et al., 1982a, b; Larick and Turner, 1990; Mandell et al., 1998, Maughan, 2011). Of the 12 beef products tested in the current study, organic grass-fed beef had the most ($P < 0.05$) pronounced fishy, livery, and gamey flavors, the least ($P < 0.05$) pronounced beefy/brothy and buttery/beef fat flavors, and one of the two least preferred overall flavor profiles (Table 3.6).

Comparison of Corn-Fed and Barley-Fed Beef. Corn is the predominant cereal grain used in cattle finishing diets throughout the High Plains region of the U.S. However, barley is widely used for finishing cattle in much of western Canada (Beauchemin and Koenig, 2005) and in the northern U.S. (Lardy and Bauer, 1999). Sitz et al. (2005) examined consumers' beef flavor preferences in a head-to-head comparison involving U.S. corn-fed beef and Canadian barley-fed beef of similar Warner-Bratzler shear values. Consumers in that study rated the flavor of U.S. corn-fed beef as significantly more desirable than that of Canadian barley-fed beef. Of the consumers that tested the 2 products, 44% preferred the flavor of corn-fed beef, 29% preferred the flavor of barley-fed beef, and 27% had no preference for either product (Sitz et al., 2005).

Flavor attributes of corn-fed (T5) and barley-fed (T6) beef samples tested in the current study are compared in Figure 3.5 and Table 3.6. This comparison included 2 USDA Low Choice products, both of which were derived from conventionally raised, Angus-type cattle that had been implanted and supplemented with a βAA (zilpaterol hydrochloride). Samples in T5 were from cattle finished on corn-based diets in the U.S., whereas samples in T6 were from cattle finished on barley-based diets in Alberta, Canada. Both groups of cattle were harvested in the same U.S. processing facility and

strip loins representing both treatments were wet-aged for 14 d. Samples in the 2 treatments (T5 and T6) contained similar percentages of IM lipid (Table 3.5).

Samples generated from the carcasses of barley-fed cattle (T6) had a more pronounced ($P < 0.05$) livery flavor compared with corn-fed beef samples (T5). Otherwise, flavor characteristics for corn-fed and barley-fed beef were indistinguishable by sensory panelists in the current study (Figure 3.5, Table 3.6). No differences ($P > 0.05$) in beefy/brothy, browned/grilled, buttery/beef fat, bloody/metallic, grassy/hay like, gamey, earthy/mushroom, nutty/roasted nut, fishy, sour, sweet, or bitter flavors were observed between corn-fed (T5) and barley-fed (T6) samples. Moreover, samples from the 2 treatments received similar ($P > 0.05$) ratings for overall flavor desirability (Figure 3.5, Table 3.6). These findings were consistent with other previously-reported comparisons in which little or no difference in flavor of beef generated from cattle that were corn-fed vs. barley-fed (Miller et al., 1996; Jeremiah et al., 1998; Busboom et al., 2000). Miller et al. (1996) reported that grain type (corn vs. barley) had no effect on flavor characteristics of beef, whereas Jeremiah et al. (1998) and Busboom et al. (2000) reported only minor flavor differences between corn-fed and barley-fed beef. In the latter 2 studies, finishing cattle on barley-based diets produced beef with a metallic aftertaste (Jeremiah et al., 1998; Busboom et al., 2000). Our results suggest that replacing corn with barley as the primary energy source in cattle finishing diets may produce a slightly more intense livery flavor, but would not be detrimental to overall flavor desirability.

Effects of Postmortem Aging Method on Beef Flavor Attributes

Aging of fresh beef involves holding carcasses or wholesale cuts at refrigerated temperatures to allow naturally occurring enzymatic and biochemical processes to gradually improve beef tenderness and flavor (Hedrick et al., 1993; Savell, 2008). Two forms of postmortem aging, wet-aging and dry-aging, are used in the U.S. beef industry. Wet-aging is the most commonly used technique and involves storing beef wholesale cuts at above-freezing temperatures in sealed, moisture-impermeable vacuum packages (Campbell et al., 2001). In today's commercial beef processing industry, nearly all beef sub-primal cuts are vacuum-packaged and boxed at the point of fabrication before distribution and, therefore, are subjected to differing periods of wet-aging during shipping and storage. Dry-aging is used primarily in the foodservice industry, not only to improve tenderness, but also to enhance flavor (Savell, 2008). In the dry-aging process, beef carcasses or, more commonly, beef wholesale cuts, are stored under carefully regulated conditions (temperature, humidity, and air flow) without protective packaging (Savell, 2008). Because beef sub-primal cuts almost always are distributed in vacuum packages, most dry-aged beef has been subjected to a brief wet-aging period before being dry-aged (Campbell et al., 2001).

Three Premium Choice treatments (T1, T7, T8) were compared to determine the effects of aging method on beef flavor attributes (Figure 3.6, Table 3.6). Strip loins representing all 3 treatments were from carcasses of conventionally-raised, implanted, Angus-type cattle finished on corn-based diets. Strip loins in T1 were wet-aged for 14 d to represent a conventional wet-aging protocol. To represent a conventional dry-aging protocol, strip loins in T8 were wet-aged for 17 d and then dry-aged for 30 d. Strip loins

included in T7 were wet-aged for 46 d to closely match the entire 47-d aging period (wet plus dry) that was used in T8. Samples in all 3 treatments contained comparable ($P > 0.05$) percentages of IM lipid (Table 3.5).

Results showing the effects of aging treatment on beef flavor attributes are presented in Figure 3.6 and Table 3.6. Sensory panelists detected only 2 flavor differences between dry-aged beef samples and samples that were wet-aged for 14-d. Dry-aged samples had a stronger ($P < 0.05$) browned/grilled flavor, whereas 14-d wet aged samples tasted less ($P < 0.05$) livery (Figure 3.6, Table 3.6). However, compared with dry-aged (T8) and 14-d wet-aged (T1) samples, 46-d wet-aged samples (T7) had a much less desirable ($P < 0.05$) overall flavor with less pronounced ($P < 0.05$) beefy/brothy, browned/grilled, and buttery/beef fat flavor notes and more pronounced ($P < 0.05$) bloody/metallic, grassy/hay like, gamey, sour, and bitter flavor notes (Figure 3.6, Table 3.6). Comparison of means for the 2 wet-aging treatments (T1 and T7, Table 3.6) showed that 46-d wet-aged samples (T7) had a stronger ($P < 0.05$) earthy/mushroom flavor, whereas 14-d wet-aged samples tasted sweeter ($P < 0.05$) and less ($P < 0.05$) livery. Aging treatment had no effect ($P > 0.05$) on nutty/roasted nut or fishy flavors.

Figure 3.6 clearly shows that wet-aging beef for a period of 46 d produced an undesirable flavor profile with comparatively strong off-flavors described as sour, grassy/hay like, gamey, livery, and bitter. Of the 12 beef products tested in this study, the 46-d wet-aged product (T7) had the most pronounced ($P < 0.05$) sour flavor and was rated as 1 of the 2 least desirable products with respect to overall flavor. The distinct sour flavor of T7 samples was likely associated with growth of lactic acid bacteria within vacuum packages during the extended wet-aging period. According to Seideman et al.

(1976), growth of lactobacilli on refrigerated vacuum-packaged beef cuts increases rapidly between 14 and 35 d of storage, so that by the 28th d of storage, lactic acid bacteria represent about 90% of the psychrotrophic microflora. Campo et al. (1999) and Jeremiah and Gibson (2003) reported the development of several undesirable flavor notes, including livery and acid flavors, in beef subjected to a 28-d wet-aging period. Likewise, Yancey et al. (2005) found that metallic, rancid, and sour flavors increased in top blade, top sirloin, and tenderloin steaks as wet-aging time increased from 7 to 35 d. According to Egan (1983), spoilage of vacuum packaged beef stored for an extended period of time is reflected by the development of off-flavors described as sour, acid, cheesy, bitter, and liver-like.

In the current study, dry-aging strip loins for 30 days following a 17-d wet-aging period increased intensity of the browned/ grilled flavor, but had no other positive effects on beef flavor, when compared with the 14-d wet-aging treatment (Figure 3.6, Table 3.6). Warren and Kastner (1992) compared flavor attributes of dry-aged and wet-aged Choice strip loins and found that dry-aged samples were more beefy in flavor and had a more brown/roasted flavor, whereas wet-aged samples had more intense sour and bloody/metallic flavor notes than did dry-aged samples. Similar findings were reported by Campbell et al. (2001). Other reports suggest that dry-aged and wet-aged beef do not differ in flavor (Sitz et al., 2006; Laster et al., 2008; Smith et al., 2008). Our results suggest that a 30-d dry-aging period did not enhance the overall flavor desirability of Premium Choice strip loins when compared with a conventional 14-d wet-aging protocol.

Relationships among IM Fat Content and Beef Flavor Attributes

Many of the flavor differences observed among the assorted beef products tested in this study (Table 3.6) appeared to be related to treatment differences in IM fat content (Table 3.5). Pearson correlation coefficients, quantifying associations between the various flavor attributes and IM lipid percentage, are presented in Table 3.7.

Several of the correlations between IM lipid percentage and flavor attributes were quite high, suggesting that total IM fat content was a primary driver of beef flavor differences in the current study. The correlation between IM lipid percentage and overall flavor desirability (not shown in Table 3.7) was 0.77 ($P < 0.01$). Data summarized in Table 3.7 show that increased IM fat content was associated ($P < 0.01$) with higher ratings for beefy/brothy, browned/grilled, buttery/beef fat, earthy/mushroom, nutty/roasted nut, and sweet flavors and lower ($P < 0.05$) ratings for flavors characterized as bloody/metallic, grassy/hay like, gamey, livery, fishy, and sour.

Also shown in Table 3.7 are correlations between the various flavor attributes and overall flavor desirability. Overall flavor desirability ratings were positively correlated ($P < 0.01$) with beefy/brothy, buttery/beef fat, browned/grilled, sweet, and nutty/roasted nut flavors (Table 3.7), indicating that panelists preferred beef products with these flavor notes. In contrast, overall flavor desirability ratings were negatively correlated ($P < 0.01$) with livery, sour, gamey, bloody/metallic, fishy, bitter, and grassy/hay like flavors (Table 3.7), indicating a dislike for products with these flavor notes among study participants.

Further analyses of the relationships between beef flavor attributes and overall flavor desirability (data not presented in tabular form) showed that 2 specific flavor attributes, beefy/brothy and buttery/beef fat, accounted for 96% of the observed variation

in ratings for overall flavor desirability. As shown in Table 3.7, both of these flavors were closely correlated with IM fat percentage. These results underscore the importance of IM fat (marbling) for delivering products with desired beef flavor characteristics. Similar results were reported by Emerson (2011) who evaluated flavor characteristics of beef strip loin steaks with marbling scores ranging from Traces to Moderately Abundant. In that study, buttery/beef fat flavor, which increased with each incremental increase in degree of marbling, was the flavor note most closely related to overall sensory experience (Emerson, 2011).

Conclusions

Results of the current study showed that USDA quality grade and animal diet (grass vs grain feeding) had the largest impact on beef overall flavor desirability and flavor profile. Samples with greater percentages of IM fat were associated with higher scores for overall flavor desirability and beefy/brothy, browned/grilled, and buttery/beef fat flavors. Conversely, samples from cattle finished exclusively on grass received higher ratings for several less desirable flavor including metallic, grassy, gamey, livery, bitter, and fishy. Only slight differences in flavor profiles and flavor desirability were observed among comparisons of other production-related factors including aging method (dry vs wet-aged), grain source (corn vs barley), growth enhancement technology (non-implanted vs implanted vs implanted and fed a βAA), and breed type (Angus vs Wagyu). However, wet-aging products for an extended period of time (46 vs 14 d) produced samples with an undesirable flavor characterized as sour. Additionally, samples from calf-fed Holsteins were rated higher for overall flavor desirability than other samples with similar IMF

content; indicating that flavor based marketing opportunities could be present for beef from this product type.

Table 3.1. Description of experimental treatments

Treatment	Production system	USDA grade (marbling degree)	Breed-type	Finishing diet (days on grain)	Growth technologies	Postmortem aging method
1	Conventionally raised	Premium Choice (≥ Modest^{00})	Angus (≥ 51% black)	Corn-based (> 100 d)	Implants only	Wet aged 14 d
2	Conventionally raised	Low Choice (Small)	Angus (≥ 51% black)	Corn-based (> 100 d)	Implants only	Wet aged 14 d
3	Conventionally raised	Select (Slight)	Angus (≥ 51% black)	Corn-based (> 100 d)	Implants only	Wet aged 14 d
4	Conventionally raised	Low Choice (Small)	Calf-fed Holstein	Corn-based (> 200 d)	Implants only	Wet aged 14 d
5	Maximized growth	Low Choice (Small)	Angus (≥ 51% black)	Corn-based (> 100 d)	Implants & β agonists	Wet aged 14 d
6	Maximized growth	Low Choice (Small)	Angus (≥ 51% black)	Barley-based (> 100 d)	Implants & β agonists	Wet aged 14 d
7	Conventionally raised	Premium Choice (≥ Modest^{00})	Angus (≥ 51% black)	Corn-based (> 100 d)	Implants only	Wet aged 46 d
8	Conventionally raised	Premium Choice (≥ Modest^{00})	Angus (≥ 51% black)	Corn-based (> 100 d)	Implants only	Wet aged 17 d, dry aged 30 d
9	Conventionally raised	Prime (≥ Slightly Abundant^{00})	Angus (≥ 51% black)	Corn-based (> 100 d)	Implants only	Wet aged 17 d, dry aged 30 d
10	Naturally raised	Prime (≥ Slightly Abundant^{00})	≥ 50% Wagyu	Corn-based (> 100 d)	None	Wet aged 16 d, dry aged 30 d
11	Naturally Raised	Low Choice (Small)	Angus (≥ 51% black)	Corn-based (> 100 d)	None	Wet aged 14 d
12	Grass-fed, Organic	Select (Slight)	Angus (≥ 51% black)	Forages only (no grain)	None	Wet aged 14 d

Table 3.2. Flavor descriptions provided to panelists before sensory analysis

Flavor	Flavor description
Beefy/brothy	The flavor associated with cooked beef; basic meaty flavor of unseasoned beef broth
Browned/grilled	The flavor associated with grilled or broiled beef; caramelized
Buttery/beef fat	The flavor and mouth-feel associated with melted, unsalted butter or beef fat
Bloody/metallic	The flavor associated with a very-rare steak; flavor associated with iron; similar to putting a penny in your mouth
Grassy/hay-like	The flavor or odor of fresh cut grass; similar to dried parsley
Gamey	The intense flavor associated with wild game
Earthy/mushroom	The flavor associated with fresh soil; musty
Nutty/roasted nut	The flavor associated with nuts or roasted nuts
Livery	The flavor associated with cooked beef liver and organ meats
Fishy	The flavor of fresh fish or seafood
Sour/acidic	A sour flavor and mouth-feel; tangy; fermented
Sweet	A sweet flavor
Bitter	A bitter flavor

Table 3.3. Demographic characteristics of study participants (N = 307)

Characteristic	Response	Percentage of participants
Sex	Male	56.4
	Female	43.7
Age	Under 18	1.0
	18 – 34	76.2
	35 – 50	14.7
	Over 50	8.1
Weekly beef consumption	None	0.0
	1 to 3	56.7
	4 to 6	38.7
	7 or more	4.6

Table 3.4. Panelists' rankings[1] of the importance of factors considered when purchasing beef

Factor	Ranking
Taste/eating experience	3.4[a]
Marbling level (fresh meat)	3.5[a]
Visual appearance (fresh meat)	3.5[a]
USDA grade of the product	4.4[b]
Where and how the animal was raised	6.3[c]
Nutrient content	6.4[c]
Whether or not the animal received growth promotants and/or antibiotics	6.5[c]
Breed of the animal that produced the product	6.7[c]
Whether or not the animal was raised exclusively on pasture or fed grain in a feedlot for any period of time	7.1[d]
Brand of the product	7.2[d]

[1]Consumers ranked the importance of the 10 factors from 1 to 10; 1 = most important. 10 = least important.

[abcd] Least squares means lacking a common superscript differ ($P < 0.05$)

Table 3.5. Least squares means for percentage lipid, moisture, protein, and ash as determined by proximate analysis of raw samples representing 12 beef treatments

Treatment[1]	Lipid, %	Moisture, %	Protein, %	Ash, %
T1	7.61^{bc}	66.76^{e}	23.99	1.04^{de}
T2	5.44^{d}	68.63^{de}	25.14	1.12^{bcd}
T3	3.74^{ef}	71.95^{ab}	23.65	1.06^{de}
T4	4.99^{de}	70.74^{abc}	23.04	1.07^{cde}
T5	4.98^{de}	69.45^{cd}	25.05	1.15^{bcd}
T6	5.15^{de}	70.59^{bc}	23.70	1.03^{de}
T7	7.68^{b}	67.98^{de}	23.24	0.97^{e}
T8	7.24^{bc}	64.50^{f}	26.58	1.34^{a}
T9	11.37^{a}	61.29^{g}	25.26	1.22^{ab}
T10	12.02^{a}	61.00^{g}	24.81	1.19^{bc}
T11	6.18^{cd}	68.63^{de}	24.34	1.06^{de}
T12	2.82^{f}	73.07^{a}	24.24	1.15^{bcd}
SEM[1]	0.50	0.64	0.71	0.04
P-value	< 0.0001	< 0.0001	0.0788	0.0002

[1] Treatments: 1 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 14 d; 2 = Low Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 14 d; 3 = Select, Angus, implanted, fed corn-based diet ≥ 100 d, wet-aged 14 d; 4 = Low Choice, calf-fed Holstein, implanted, fed corn-based diet ≥ 200 d, wet aged 14 d; 5 = Low Choice, Angus, implanted and supplemented with β agonists, fed corn-based diet ≥ 100 d, wet aged 14 d; 6 = Low Choice, Angus, implanted and supplemented with β agonists, fed barley-based diet ≥ 100 d, wet aged 14 d; 7 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 46 d; 8 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 9 = Prime, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 10 = Prime, American Wagyu, no growth enhancement, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 11 = Low Choice, Angus, no growth enhancement, fed corn-based diet ≥ 100 d, wet aged 14 d; 12 = Select, Angus, no growth enhancement, grass fed (no grain), wet aged 14 d.

[2]Standard error of the least squares mean.

[abcdefg] Means in the same column lacking a common superscript differ (P < 0.05).

Table 3.6. Sensory panel ratings[1] for beef flavor attributes of ground strip loin samples representing 12 beef treatments

	Treatment[2]													
Flavor attribute (cm)	1	2	3	4	5	6	7	8	9	10	11	12	SEM[3]	*P*-value
Overall flavor desirability	5.15^{bc}	4.72^{def}	4.35^{f}	5.26^{b}	4.43^{ef}	4.65^{def}	3.67^{g}	4.90^{bcd}	6.14^{a}	6.53^{a}	4.80^{cde}	3.29^{g}	0.18	< 0.0001
Beefy/brothy flavor	4.94^{b}	4.80^{b}	4.28^{c}	4.99^{b}	4.73^{b}	4.75^{b}	3.77^{d}	4.59^{bc}	5.41^{a}	5.75^{a}	4.82^{b}	3.64^{d}	0.19	< 0.0001
Browned/grilled flavor	4.44^{c}	3.83^{de}	3.18^{f}	4.14^{cd}	3.92^{d}	4.07^{cd}	3.34^{ef}	5.07^{b}	5.51^{ab}	5.86^{a}	3.95^{d}	3.21^{f}	0.24	< 0.0001
Buttery/beef fat flavor	3.15^{b}	2.74^{b}	2.27^{c}	3.20^{b}	1.97^{cd}	2.20^{c}	2.27^{c}	2.99^{b}	4.39^{a}	4.32^{a}	2.98^{b}	1.53^{d}	0.20	< 0.0001
Bloody/metallic flavor	1.99^{def}	2.12^{cde}	2.68^{ab}	2.62^{ab}	2.31^{bcd}	2.32^{bcd}	2.47^{abc}	1.99^{def}	1.77^{ef}	1.55^{f}	1.99^{def}	2.80^{a}	0.24	0.0003
Grassy/hay like flavor	1.02^{b}	1.19^{b}	1.16^{b}	0.99^{b}	0.95^{b}	1.18^{b}	1.59^{a}	1.14^{b}	1.18^{b}	0.85^{b}	1.19^{b}	1.67^{a}	0.15	0.0037
Gamey flavor	1.03^{cd}	1.14^{cd}	1.37^{c}	1.21^{cd}	1.18^{cd}	1.13^{cd}	1.73^{b}	1.24^{cd}	1.09^{cd}	0.93^{d}	1.29^{c}	2.34^{a}	0.14	< 0.0001
Earthy/mushroom flavor	1.53^{bcd}	1.41^{cd}	1.32^{d}	1.43^{cd}	1.52^{bcd}	1.52^{bcd}	1.96^{a}	1.66^{abcd}	1.71^{abc}	1.79^{ab}	1.53^{bcd}	1.79^{ab}	0.16	0.0134
Nutty/roasted nut flavor	1.00^{bc}	0.78^{bc}	0.72^{c}	0.96^{bc}	0.86^{bc}	0.86^{bc}	0.97^{bc}	1.13^{b}	1.51^{a}	1.71^{a}	0.97^{bc}	0.81^{bc}	0.16	0.0002
Livery flavor	0.95^{ef}	1.11^{de}	1.39^{bcd}	1.14^{cde}	1.12^{de}	1.50^{bc}	1.65^{b}	1.31^{bcd}	0.70^{f}	0.67^{f}	1.21^{cde}	2.41^{a}	0.17	< 0.0001
Fishy flavor	0.24^{bc}	0.25^{bc}	0.28^{bc}	0.38^{bc}	0.23^{bc}	0.40^{bc}	0.49^{b}	0.24^{bc}	0.23^{bc}	0.12^{c}	0.40^{bc}	1.75^{a}	0.12	< 0.0001
Sour flavor	0.76^{cd}	0.84^{cd}	1.01^{c}	0.88^{cd}	1.00^{c}	0.90^{c}	1.83^{a}	0.87^{cd}	0.74^{cd}	0.58^{d}	0.78^{cd}	1.39^{b}	0.13	< 0.0001
Sweet flavor	0.86^{b}	0.69^{bcd}	0.69^{bcd}	0.79^{bc}	0.65^{bcd}	0.65^{bcd}	0.57^{cd}	0.64^{bcd}	1.40^{a}	1.18^{a}	0.78^{bc}	0.48^{d}	0.10	< 0.0001
Bitter flavor	0.81^{b}	0.83^{b}	0.91^{b}	0.76^{b}	0.94^{b}	1.00^{ab}	1.41^{a}	0.85^{b}	0.73^{b}	0.67^{b}	0.81^{b}	1.38^{a}	0.17	0.0238

[1] Sensory scores: 0 = Dislike extremely for overall flavor desirability; Very low intensity for all flavor notes; 10 = Like extremely for overall flavor desirability; Very high intensity for all flavor notes.

[2] Treatments: 1 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 14 d; 2 = Low Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 14 d; 3 = Select, Angus, implanted, fed corn-based diet ≥ 100 d, wet-aged 14 d; 4 = Low Choice, calf-fed Holstein, implanted, fed corn-based diet ≥ 200 d, wet aged 14 d; 5 = Low Choice, Angus, implanted and supplemented with β agonists, fed corn-based diet ≥ 100 d, wet aged 14 d; 6 = Low Choice, Angus, implanted and supplemented with β agonists, fed barley-based diet ≥ 100 d, wet aged 14 d; 7 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 46 d; 8 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 9 = Prime, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 10 = Prime, American Wagyu, no growth enhancement, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 11 = Low Choice, Angus, no growth enhancement, fed corn-based diet ≥ 100 d, wet aged 14 d; 12 = Select, Angus, no growth enhancement, grass fed (no grain), wet aged 14 d.

[3] SE of the least squares mean.

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

Table 3.7. Pearson correlation coefficients quantifying relationships of beef flavor attributes to intramuscular lipid content and overall flavor desirability ratings

Flavor Trait	Intramuscular lipid, %	Overall flavor desirability
Beefy/Brothy	0.64**	0.94**
Browned/Grilled	0.81**	0.88**
Buttery/Beef Fat	0.85**	0.91**
Bloody/Metallic	-0.72**	-0.64**
Grassy/Hay Like	-0.34*	-0.57**
Gamey	-0.47**	-0.71**
Earthy/Mushroom	0.34*	-0.05
Nutty/Roasted Nut	0.78**	0.69**
Livery	-0.67**	-0.81**
Fishy	-0.47**	-0.62**
Sour	-0.34*	-0.72**
Sweet	0.77**	0.81**
Bitter	-0.31	-0.62**

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

** Correlation coefficient differs from 0 ($P < 0.01$).

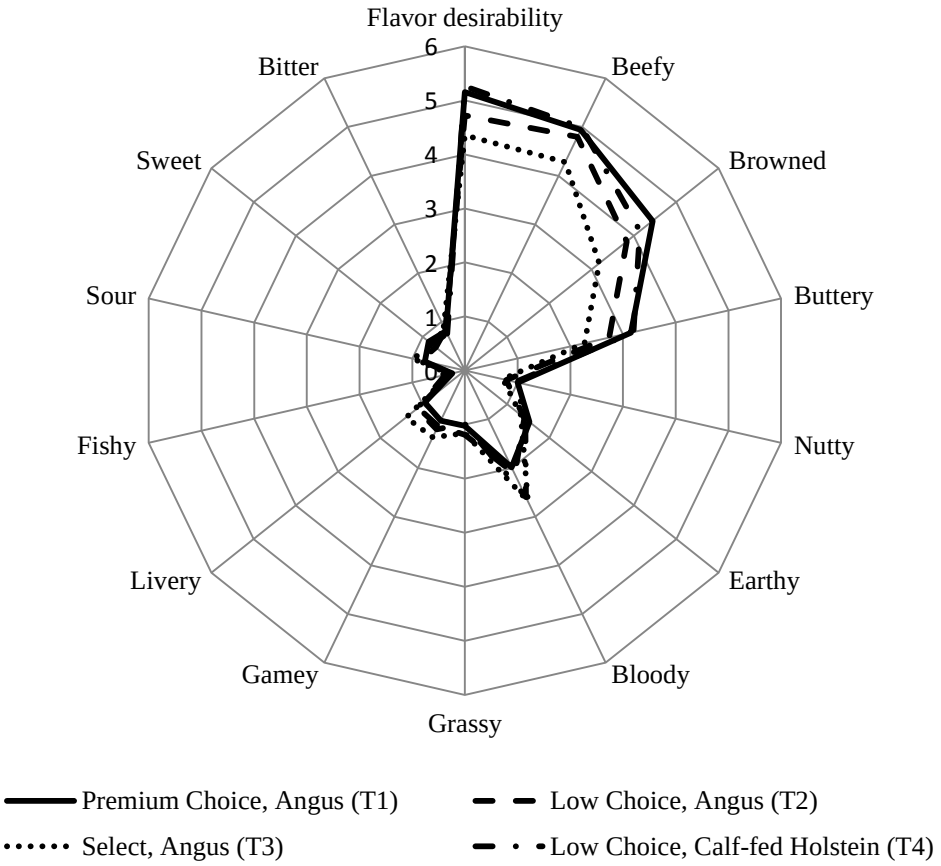


Figure 3.1. Flavor profiles (cm) of Premium Choice Angus, Low Choice Angus, Select Angus, and Low Choice calf-fed Holstein beef

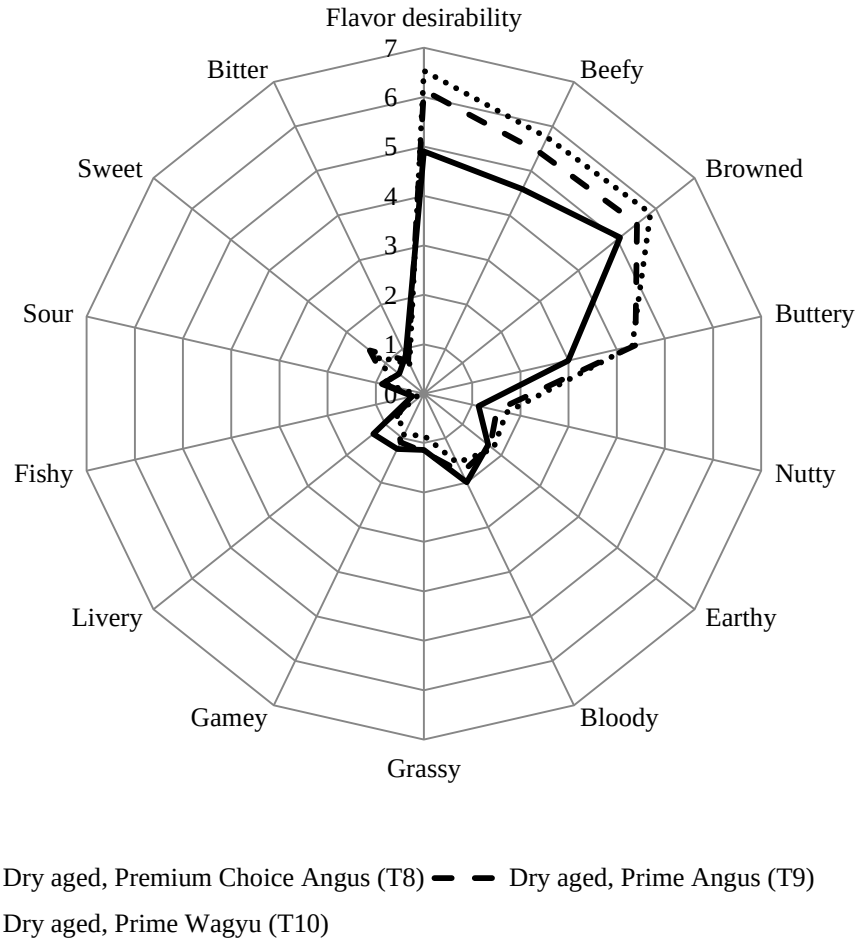


Figure 3.2. Flavor profiles (cm) of 3 different dry-aged, premium beef products: Premium Choice Angus, Prime Angus, and Prime Wagyu

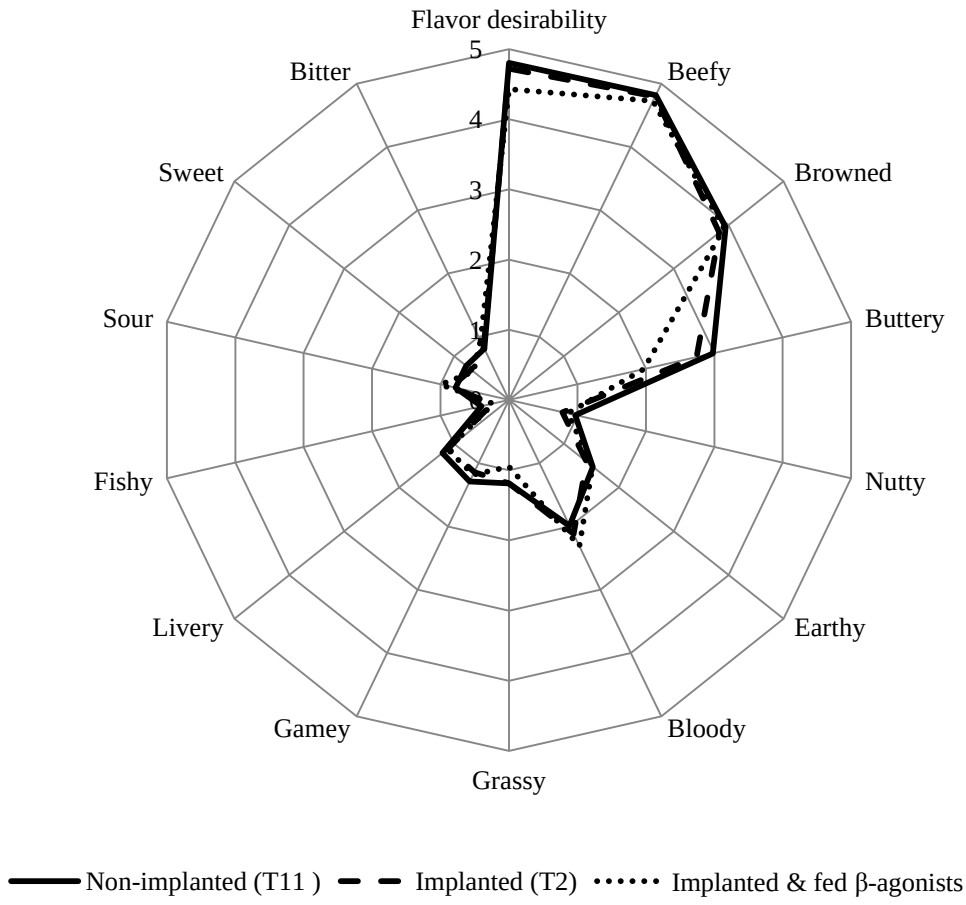


Figure 3.3. Flavor profiles (cm) Low Choice Angus beef from cattle produced using 3 different growth-management programs: non-implanted (naturally raised), implanted (conventionally raised), and implanted & fed β agonists (conventionally raised)

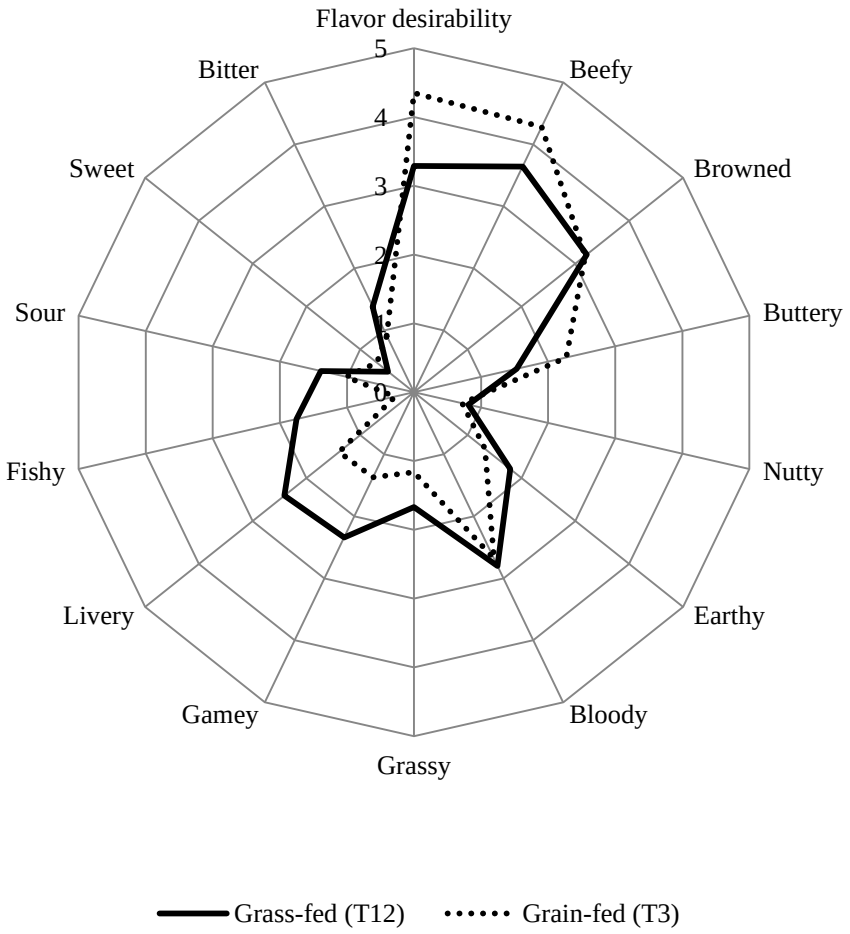


Figure 3.4. Flavor profiles (cm) of beef produced by grass-fed and grain-fed cattle

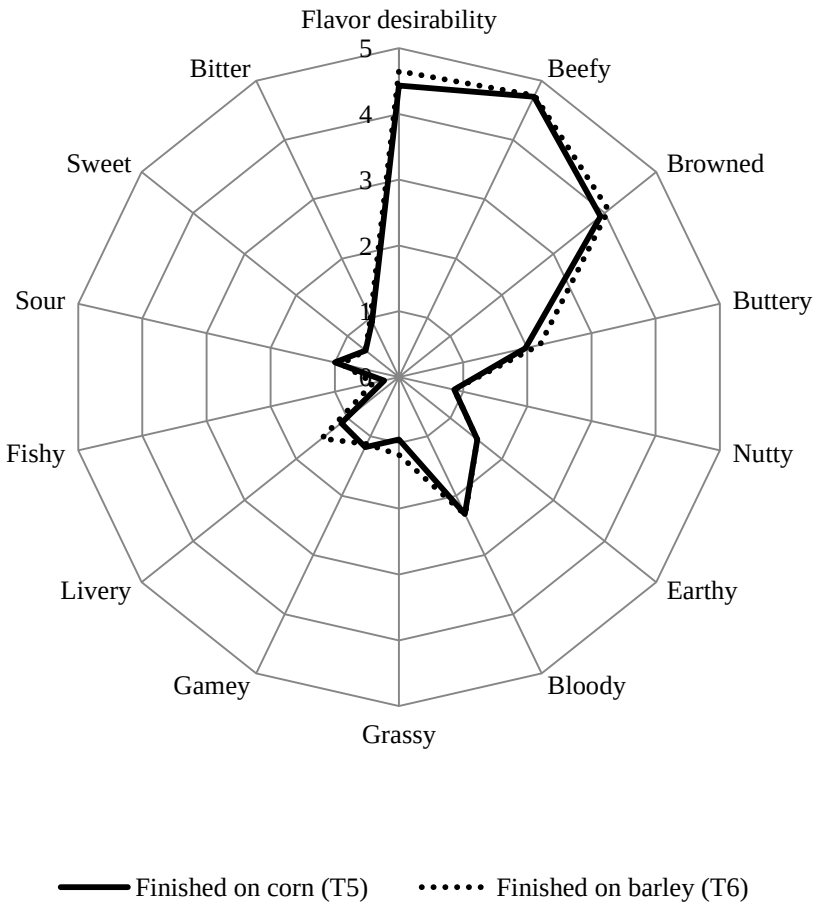


Figure 3.5. Flavor profiles (cm) of beef produced by cattle finished on corn vs. barley

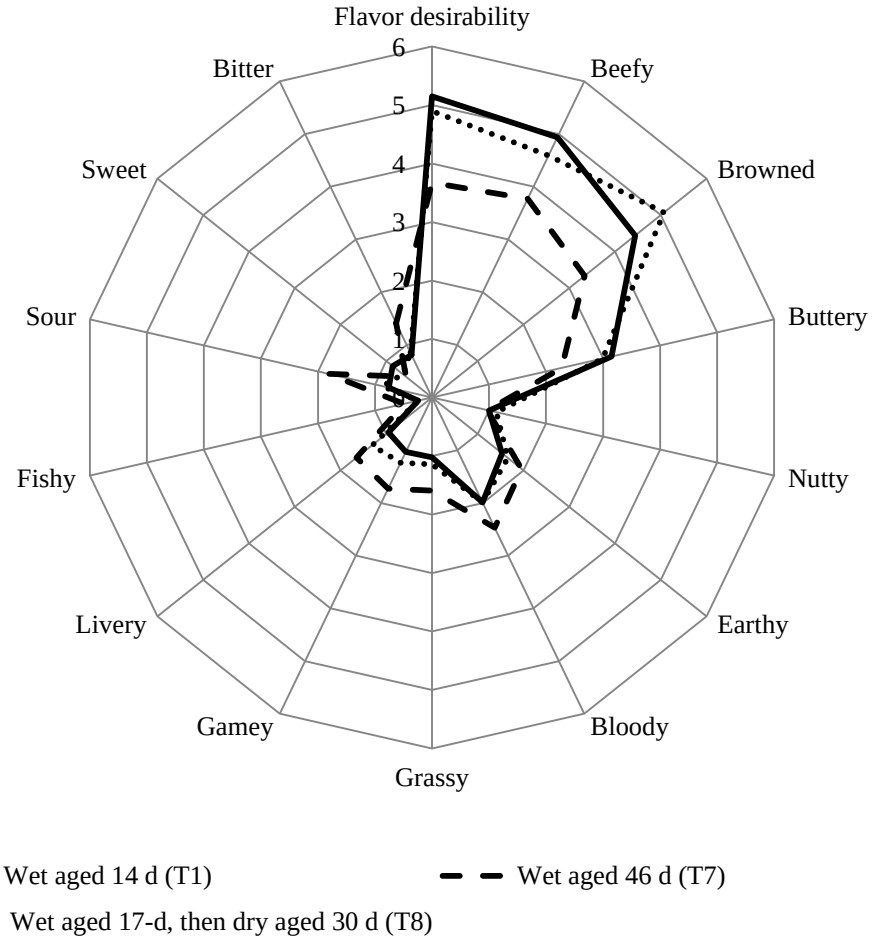


Figure 3.6. Flavor profiles (cm) comparing dry-aged beef with beef that was wet-aged for either 14 or 46 d

CHAPTER IV

RELATIONSHIPS AMONG BEEF FLAVOR TRAITS, FATTY ACID PROFILE, AND COOKED BEEF VOLATILES

SUMMARY

A study was conducted to identify and quantify the various fatty acids present in, and volatile compounds released during cooking of 12 different beef products (treatments) and determine their relationships to flavor attributes identified by an untrained, discriminating sensory panel. Treatments were selected in order to represent flavor differences associated with differences in cattle breed (Angus, Wagyu, Holstein), animal growth management (non-implanted, implanted, implanted & fed β agonists), finishing diet (grass-fed, corn-fed, barley-fed), USDA Quality grade (Prime, Premium Choice, Low Choice, Select), and aging technique (wet-aged, dry-aged). Fatty acids were extracted from cooked beef samples and analyzed using gas chromatography methods. Volatile compounds were extracted from the head space of beef samples immediately following cooking using solid phase microextraction and analyzed using gas chromatography mass spectrometry. Overall flavor desirability was positively correlated ($P < 0.05$) with several monounsatured fatty acids including C12:1, C14:1, C16:1 c9, and C18:1 c9. Stearic acid (C18:0) was negatively correlated ($P < 0.05$) with overall flavor desirability and positively correlated ($P < 0.05$) with bloody/metallic, grassy/hay like, gamey, livery, fishy, sour, and bitter flavors. Polyunsaturated fatty acids including C18:2t (total), C18:3 n-3, and C22:5 n-3, were found in the highest concentration ($P < 0.05$) in Certified Organic grass-fed samples and were negatively correlated ($P < 0.05$) with

overall flavor desirability. Twenty-four different volatile compounds including numerous aldehydes, ketones, sulfides, furans, pyrazines, and alkanes were identified in the headspace of cooked beef samples. Overall flavor desirability was positively correlated ($P < 0.05$) with diacetyl (2, 3-butanedione), acetoin (3-hydroxy-2-butanone), 3-methyl butanal, and pentanal concentrations. Samples having higher concentrations of dimethyl sulfide rated lower ($P < 0.05$) for overall flavor desirability. Several identified volatile compounds were correlated with various beef flavor traits including beefy/brothy, buttery/beef fat, browned/grilled, earthy/mushroom, nutty/roasted nut, sour, bitter, and sweet.

INTRODUCTION

Overall flavor of a food product is comprised of taste, aroma, chemical feeling sensations, and the combination of these factors. In beef, two reactions that occur during the cooking process (the Maillard reaction and the thermal oxidation of fatty acids) are largely responsible for flavor development (Farmer, 1994; Calkins and Hodgen, 2007). These reactions produce numerous low-molecular weight volatile compounds that contribute to beef flavor development (Mottram, 1998).

Relationships between beef flavor and various fatty acids have been identified in published literature as affecting beef flavor (Dryden and Marchello, 1970; Baublits et al., 2009). Oleic acid (C18:1) has been shown to have a positive relationship with beef flavor (Dryden and Marchello, 1970; Westerling and Hedrick, 1979; Garmyn et al., 2011), and stearic acid (C18:0) concentration has been shown to negatively affect beef flavor (Dryden and Marchello, 1970; Westerling and Hedrick, 1979). Concentrations of C18:3

have also been shown to be negatively correlated with beef flavor rating (Melton et al., 1982; Mandell et al., 1998). However, most flavor research studies focused on a narrow range of treatments and only assessed a select number of fatty acids.

Many published reports evaluating volatile compounds released from beef during cooking have focused on compound identification (Gasser and Grosch, 1988; Cerny and Grosch, 1992), differences between beef from grain- and grass-finished cattle (Larick et al., 1987; Jiang, 2011), or study only a limited number of treatments (Elmore et al., 2004; Stetzer et al., 2008). Additionally, few studies have compared volatile compound concentrations with panel ratings for various flavor traits.

The objective of the current study was to determine the relationships between panel flavor traits and fatty acid and volatile compound concentrations of cooked beef samples representing a variety of animal and meat production practices.

MATERIALS AND METHODS

Experimental Treatments and Sample Preparation

Details regarding sample collection and preparation have previously been described in Chapter 3. In brief, beef strip loins (IMPS #180; NAMP, 2010), derived from carcasses of cattle representing 12 different production categories (treatments) currently available to beef consumers in U.S retail and food service markets and representing diverse cattle and meat management strategies and practices, were purchased for use in the study. Detailed descriptions of experimental treatments are reported in Table 3.1. Within each treatment, three batches consisting of an equal number of strip loins (3 strip loins/batch for treatments 1 through 11; 4 strip loins/batch for

treatment 12) were created. Strip loins in each batch were trimmed of all exterior fat and connective tissue, ground and mixed together to form the batch. Each ground batch was stuffed into cellulose casings (6.4 cm in diameter) using a vacuum stuffer (Model VF50, Handtmann, Germany). Filled casings were placed in a freezer (-20ºC) and allowed to freeze overnight (approximately 18 h) before portioning into patties. After freezing, casings were removed from the samples and a band saw (Model 400, AEW-Thurne, AEW Engineering Co., Ltd., Norwich, UK) was used to cut the samples into patties (1.9 cm thick and 6.4 cm in diameter). Two sets of 3 patties (each set consisting of 1 patty from the beginning, 1 patty from the middle, and 1 patty from the end of each processed batch) were selected from each batch to be used for fatty acid analysis and quantification of cooked volatiles (1 set of 3 patties was used for each analytical procedure). Samples for use in analytical procedures were stored frozen (-20ºC) before evaluation for a period of one month for fatty acid analysis and four months for volatile analysis.

Fatty Acid Analysis

Frozen patties (n = 3) from each batch within treatment were thawed at 2 to 4^{o}C for 24 h before cooking. Samples were cooked over open gas burners on griddle pans with a non-stick coating. Pans were allowed to heat to 246^{o}C before sample cooking. Samples were turned once, half-way through cooking, and were cooked to an internal temperature of 74^{o}C monitored by a Type K Thermocouple Thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation, Middlefield, CT). Cooked patties were allowed to cool to room temperature (22°C). After cooling, the patties were cut into small cubes (approximately 1 cm × 1 cm × 1 cm), individually identified, vacuum

packaged, and frozen. Frozen pieces were submerged in liquid nitrogen and homogenized into a fine powder using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc., Ridgeland, MS). Homogenized samples were individually identified, placed in Whirl-Pak bags (Nasco, Ft. Atkinson, WI) and stored at -80^{o}C until further analysis.

Saponification and methylation was occurred according to the method of Park and Goins (1994) as described by Phillips et al. (2010). Lipids were extracted with a chloroform:methanol solution (2:1, vol/vol) and then saponified by hydrolysis (0.5 *N* KOH in methanol) at 70^{o}C for 10 min. Fatty acids were derivatized to methyl esters (**FAME**) by adding 14% BF_3 in methanol and heating at 70^{o}C for 30 min. Samples were then reconstituted in hexane prior to analysis. Analysis utilized a Hewlett Packard (Avondale, PA) model 6890 series II gas chromatograph (GC) fixed with a series 7683 injector and flame-ionization detector. The GC was equipped with a 100 m × 0.25 mm (i.d.) fused silica capillary column (SP-2560 Supelco Inc., Bellefonte, PA). Helium was used as the carrier gas with a flow rate of 2.0 mL/min. Column oven temperature was increased from 40^{o}C to 150^{o}C at a rate of 8^{o}C/min, held for 20 min at 150^{o}C, and, then, increased from 150^{o}C to 160^{o}C at 0.5^{o}C/min and from 160^{o}C to 190^{o}C at 0.2^{o}C/min. The detector was maintained at 300^{o}C and the inlet at 250^{o}C throughout the run. The total run time was 203.75 min. The split-ratio used was 1:100. Individual FAME were quantified as a percentage of the total amount of FAME identified based on fatty acid authentic standards (Nu-Chek Prep, Elysian, MN).

Volatile Analysis

Patties (n = 3) from each batch within each treatment were thawed and cooked as previously described. Immediately after cooking, 3 cores (1.3 cm in diameter) were excised from each sample using a Warner-Bratzler coring device. A 3 g sample obtained from the cores was weighed into individually labeled 15-mL clear glass vials (Supelco, Bellefonte, PA) and closed with a polytetrafluoroethylene septa and screw cap. A solution of 4-octanol (Supelco, Bellefonte, PA) in DI water was used as an internal standard with 10 µl (0.818 ng/µl) placed into each sample vial prior to equilibration. Samples were placed into a 65^{o}C water bath (Thermo Scientific, Waltham, MA) for 5 min, allowing volatile compounds to equilibrate within the headspace. Following equilibration, volatiles were extracted using an 85-µm film thickness carboxen polydimethylsiloxane solid phase microextraction (**SPME**) fiber in a manual SPME needle and holder (Supelco, Bellefonte, PA). The SPME fiber was exposed to the headspace above the sample for 10 min. After extraction, the SPME fiber was withdrawn into the SPME fiber apparatus and capped with a GC inlet septum in order to prevent contamination of the sample from the atmosphere. Samples were immediately injected at the GC-MS or held for a period no longer than 3 h before injection.

Volatile separation and detection was conducted using an Agilent 6890 series gas chromatograph (Agilent Technologies, Santa Clara, CA) equipped with a 5975 mass selection detector (**GC-MS**; Agilent Technologies, Santa Clara, CA). Before each run, the GC column was cryogenically focused to -60^{o}C using liquid N_2. After the column had reached -60^{o}C, the SPME fiber was injected into the machine and the software program was started. Extracted volatile compounds were desorbed at the GC inlet at 250^{o}C for a

period of 5 min before the SPME fiber was removed from the machine. The GC was equipped with a BPX-5 capillary column (25m x 0.32mm x 0.25μm) (SGE, Austin, TX) and helium was used as the carrier gas with a flow rate of 1 mL/min. Column oven temperature was maintained at -60^{o}C for a period of 3 min, followed by a 20ºC/min ramp to 20ºC held 5 min, then a 5ºC/min ramp to 100ºC, followed by a 10ºC/min ramp to 125ºC and 20ºC/min ramp to 260ºC, and concluding with a 3-minute hold period at 260ºC. The total run time was 40 min. The inlet was operated in split-less mode for the first 3 minutes followed by a 10:1 split.

The MS detected ions within 33-500 m/z mass range in the electron impact mode at 70 eV. Chromatography data were collected in the selective ion monitoring/scan mode (SIM/Scan; Agilent MSD Chemstation D.03.00.611 software, Agilent Technologies, Santa Clara, CA). Ions were selected based on the presence of 3 primary ions from compounds of interest. Agilent MSD Chemstation D.03.00.611 software (Agilent Technologies, Santa Clara, CA) was used to operate the GC-MS and conduct data analysis.

A mixture of alkane standards (C_8-C_{22}; Supelco, Bellefonte, PA) was analyzed before analysis of samples on each working day. The alkane retention times were used to calculate expected linear retention indexes (LRI) for compounds of interest. These retention indexes were used to calculate SIM windows, so the MS would selectively look for ions of interest that were inherent to compounds of interest. Additionally, instrumental performance was monitored throughout the study by use of alkane standard abundances.

Analytical standard grade chemicals (Sigma Aldrich, St. Louis, MO) were used as external reference compounds. These compounds were analyzed separately under identical GC-MS operation conditions and were used to validate volatile compound identity by comparison of ion fragmentation patterns. Three target ions were selected for the comparisons between sample and standard runs with one quantitative ion and two qualifying ions being selected for each compound of interest. Semi-quantitative estimates of compounds of interest were conducted by an external standard method. Quantitative ion abundances of sample runs were compared with quantitative ion abundances of standard runs of known concentration.

Statistical Methods

All analyses were conducted using statistical procedures of SAS (SAS Inst. Inc., Cary, NC). Treatment comparisons were tested for significance using linear, mixed model procedures (PROC MIXED).For these analyses, denominator degrees of freedom were calculated using the Kenward-Roger approximation.

Values quantifying the fatty acid content of each cooked product and the volatile compounds emitted during cooking of each product were analyzed using statistical models that included the fixed effect of treatment and the random effect of batch nested within treatment. The PDIFF option was used to compare treatment least squares means when the F-test for the effect of treatment was significant. All comparisons were tested using a comparison-wise significance level of $\alpha = 0.05$.

Correlation analyses (PROC CORR) were used to identify and quantify relationships between sensory panel ratings for beef flavor attributes (reported in Chapter 3) and

amounts of fatty acids and volatiles released during cooking and isolated from the headspace of cooked beef samples. For these analyses, batch served as the experimental unit.

RESULTS AND DISCUSSION

Relationships between Fatty Acid Composition and Beef Flavor Attributes

Results from descriptive sensory analysis of the beef samples are described in Chapter 3 and presented in Table 3.6. Data from least squares analyses showing differences in LM fatty acid composition among the 12 experimental treatments are presented in Table 4.1. Of the fatty acids that were quantified in this study, only 3 (C12:0, C14:1, and C20:1 c11) did not differ ($P > 0.05$) in mean concentration across treatments. In addition, differences in percentages of many of the fatty acids were associated ($P < 0.05$) with differences in sensory ratings for beef flavor attributes (Table 4.2).

Of the 7 saturated fatty acids (SFA) that were identified, only stearic acid (C18:0) was correlated (r = -0.44) with overall flavor desirability (Table 4.2). Increased stearic acid percentage was associated with less intense ($P < 0.05$) beefy/brothy (r = -0.51) and buttery/beef fat (-0.38) flavors and more intense ($P < 0.05$) bloody/metallic (r = 0.40), grassy/hay like (r = 0.53), gamey (r = 0.61), livery (r = 0.64), fishy (r = 0.71), sour (r = 0.35) and bitter (r = 0.45) flavor notes (Table 4.2). The experimental treatment with the greatest ($P < 0.05$) percentage of stearic acid was the organic grass-fed treatment (T12, Table 4.1). Westerling and Hedrick (1979) compared beef derived from carcasses of cattle that were grass-fed with beef from carcasses of cattle finished on grain for 56 or 112 d. As in the current study, their results showed that the stearic acid content of IM fat

was greatest for grass-fed cattle and that the concentration of stearic acid was negatively correlated (r = -0.60) with sensory scores for flavor desirability of cooked LM samples (Westerling and Hedrick, 1979). Additionally, Westerling and Hedrick (1979) found that another SFA, palmitic acid (C16:0), was negatively correlated (r = -0.52) with sensory panel ratings for beef flavor desirability. However, Baublits et al. (2009) reported palmitic acid concentration to be positively correlated with beefy/brothy (r = 0.42) and beef fat flavors (r = 0.46). In the current study, C16:0 was moderately correlated (r = 0.35) with intensity of the sour flavor note, but was not associated ($P > 0.05$) with any other flavor attribute or with overall flavor desirability (Table 4.2). In agreement with the current study, two odd-chain SFA, C15:0 and C17:0, previously were reported as having a negative impact on beef flavor traits. Baublits et al. (2009) found C15:0 concentration to be negatively correlated with beefy/brothy (r = -0.47) and beef fat (r = -0.52) flavors, while increased C17:0 concentration was associated with lower beef fat flavor (r = -0.36). In the current study, C15:0 concentration was positively correlated with bloody/metallic flavor (r = 0.48) and negatively corrlelated with buttery/beef fat (r = -0.37) and nutty/roasted nut (r = -0.50) flavors. Additionally, increased C17:0 concentration was associated with lower ratings for browned/grilled (r = -0.45), buttery/beef fat (r = -0.33), earthy/mushroom (r = -0.45), and nutty/roasted nut (r = -0.52) flavors.

Several monounsaturated fatty acids (MUFA) were positively correlated ($P < 0.05$) with overall flavor desirability ratings (Table 4.2), including C12:1 (r = 0.47), C14:1 (r = 0.40), C16:1 c9 (r = 0.35), and C18:1 c9 (r = 0.49). The presence and intensity of many of the desirable flavor notes (beefy/brothy, browned/grilled, buttery/beef fat, nutty/roasted nut, and sweet) were positively correlated ($P < 0.05$) with concentrations of

some or all of these MUFA (Table 4.2). Buttery/beef fat flavor, for example, was positively correlated ($P < 0.05$) with quantities of all 4 MUFA (Table 4.2). Similarly, Larick and Turner (1990) reported that greater concentrations of C14:1, C16:1, and C18:1, produced positive effects on cooked beef fat flavor. Additionally, Baublits et al. (2009) reported C16:1c concentration to be positively correlated with beef fat flavor and negatively correlated with grassy flavors.

Oleic acid (18:1 c9) represents more than one-third of the total fatty acid content of LM IM fat in cattle (Rule et al., 2002) and is frequently identified as the MUFA having the most beneficial effect on beef flavor desirability (Dryden and Marchello, 1970; Westerling and Hedrick, 1979; Garmyn et al., 2011). In the current study, C18:1 c9 was more closely correlated with the beefy/brothy (r = 0.52), browned/grilled (r = 0.55), buttery/beef fat (r = 0.45), and sweet flavors (r = 0.34) than any of the other MUFA and was negatively correlated ($P < 0.05$) with the bloody/metallic (r = -0.76), gamey (r = -0.49), livery (r = -0.55), fishy (r = -0.45), and sour (r = -0.41) flavor notes (Table 4.2). As shown in Table 4.1, beef products that contained the highest total percentage of C12:1, C14:1, C16:1 c9, and C18:1 c9 included Prime Wagyu (T10), naturally raised Low Choice (T11), and conventionally raised, barley-fed Low Choice (T6) beef, whereas products containing the lowest total percentage of these 4 MUFA were organic grass-fed (T12) and conventionally raised USDA Select (T3).

Mean concentrations of C20:1 c11 in the array of products tested were very small (0.13 to 0.31 %) and did not differ ($P = 0.113$) among treatment groups (Table 4.1). However, C20:1 c11 content was negatively correlated ($P < 0.05$) with sensory ratings for flavors identified as beefy/brothy (r = -0.34), buttery/beef fat (r = -0.42), and sweet (r

= -0.45), as well as with desirability of overall flavor (r = - 0.43). Percentage of C20:1 c11 also was positively correlated (r = 0.52) with intensity of livery flavor (Table 4.2).

Total percentage of C18:1trans fatty acid isomers was associated ($P < 0.05$) with the presence and intensity of several of the less desirable flavor notes (Table 4.2), including grassy/hay like (r = 0.48), gamey (r = 0.56), livery (r = 0.63), and fishy (r = 0.61). It is well documented that fat of grass-finished cattle contains greater amounts of total C18:1t, compared with fat of cattle finished on cereal grains (Rule et al., 2002; Descalzo et al., 2005; Nuernberg et al., 2005; Leheska et al., 2008; Alfaia et al., 2009). Our results, which were consistent with those of previous studies, showed that samples representing the organic grass-fed treatment (T12) contained a considerably higher concentration ($P < 0.05$) of C18:1t than samples of any other treatment group (Table 4.1).

Polyunsaturated fatty acids (PUFA), including C18:2t (total), C18:3 n-3, and C22:5 n-3, were negatively correlated ($P < 0.05$) with ratings for overall flavor desirability (Table 4.2). All of these fatty acids were found in the greatest ($P < 0.05$) concentrations in samples of organic grass-fed beef (T12, Table 4.1). Of particular interest were the 2 omega-3 PUFA, because advocates of grass-fed beef frequently promote its comparatively high omega-3 content as a potential health benefit. Feeding cattle grass, rather than grain, does increase the concentration of omega-3 fatty acids, but also can increase the incidence of undesirable flavors and aromas (Mandell et al., 1998; Wood et al., 2004; French et al., 2000). High levels of omega-3 fatty acids in fat of grass-fed cattle have been found to produce flavors and odors frequently characterized as "grassy" and "fishy" (Melton et al., 1982, Wood et al., 2004; Campo et al., 2003; Nuernberg et al., 2005). In the current study, panel ratings for gamey, livery, and fishy

flavors were more closely correlated with concentrations of the 2 omega-3 PUFA (C18:3 n-3 and C22:5 n-3) than with any other fatty acid (Table 4.2). Elmore et. al (2002) suggested four reasons for off-flavor development in samples with higher omega-3 content including: (1) the shorter chain length of breakdown products of n-3 fatty acids cause them to be more volatile and have lower odor thresholds than the n-6 and n-9 breakdown products they replace; (2) many of the n-3 breakdown products are more reactive than n-6 and n-9 products, allowing for more interaction with Maillard reaction substrates and products; (3) the products formed from the interaction of n-3 breakdown products and Maillard compounds have their own characteristic aromas; and (4) As n-3 fatty acids are oxidized, they can lead to the oxidation of more saturated fatty acids, leading to more breakdown products from n-6 and n-9 fatty acids. In the current study, the only volatile compounds found to be correlated ($P < 0.05$) with any omega-3 fatty acids were phenylacetaldehyde with C18:3 n-3 (r = 0.39) and C22:5 n-3 (r = 0.33) and trimethylpyrazine with C18:3 n-3 (r = 0.42), neither of which were found to be correlated with overall flavor desirability (Table 4.4). Nonetheless, increased amounts of omega-3 fatty acids had a negative effect on flavor desirability.

Data summarized in Tables 4.1 and 4.2 suggest that study participants had a strong preference for the flavor profiles of beef products with high percentages of IM fat that contained greater concentrations of MUFA and lesser amounts of SFA and PUFA. As cattle become fatter and the amount of IM fat increases and the proportion of MUFA in IM fat increases. In the current study, increased IM lipid percentage was associated with increased ($P < 0.01$) percentages of C14:1 (r = 0.63), C16:1 c9 (r = 0.53), and C18:1 c9 (r = 0.59). Amount of marbling and concentration of MUFA are both increased by

finishing cattle on high-energy, grain-based finishing diets. Feeding cattle grain diets increases the MUFA: SFA ratio by stimulating the activity of adipose tissue stearoyl-CoA desaturase which converts SFA to MUFA (Smith et al., 2009). In addition, the proportion of PUFA in adipose tissue is reduced by grain-finishing. The net effect of grain finishing is an increase in IM fat percentage, along with a large increase in the proportion of MUFA in the IM fat (Smith et al., 2009) and, according to our results, a concomitant improvement in beef flavor desirability.

Relationships between Volatile Concentration and Beef Flavor Attributes

Twenty-four different volatiles (13 aldehydes and a variety of other compounds including ketones, sulfides, furans, pyrazines, and alkanes) were isolated and identified from the headspace of cooked beef samples. Previous research has identified many of these volatile compounds as products formed via oxidation of fatty acids or from the Maillard reaction (Mottram, 1998; Shahidi et al., 1986). Volatile concentrations detected in the headspace of heated samples representing the 12 experimental treatments are compared in Table 4.3. Pearson correlation coefficients quantifying relationships between each of the volatiles to various beef flavor attributes are presented in Table 4.4. Of the 24 volatiles that were identified, only a few showed meaningful relationships with beef flavor characteristics.

Many of the previous studies that have evaluated the volatiles generated from cooked beef were conducted by research groups in Europe (Gasser and Grosch, 1988; Farmer and Patterson, 1991; Cerny and Grosch, 1992, 1993; Insausti et al., 2005). Most of these studies utilized beef from local markets and suppliers and, as a consequence,

evaluated samples with lower fat content than typical U.S. beef samples. According to results of the most recent National Beef Quality Audit (Savell et al., 2012), more than 90% of all fed steers and heifers produced in the U.S. qualify for one of 2 USDA quality grades – U.S. Choice or U.S. Select. These quality grades correspond to approximately 3 to 8% IM fat (Savell et al., 1986; Dow et al., 2011; O'Quinn et al., 2012). Treatments in the current study ranged from 2.8% (T12) to 12.0% (T10) IM fat. Additionally, only two treatments (T3 and T12) possessed less than 4% IM fat. Few studies have evaluated cooked beef volatiles from samples representing such a wide range in IM fat content.

Samples representing the 3 dry-aging treatments (T8, T9, and T10) produced the greatest ($P < 0.05$) amount of diacetyl (2, 3-butanedione) when cooked (Table 4.3). In addition, cooked samples of dry-aged, Prime Angus (T9) and dry-aged, Premium Choice Angus (T8) beef produced comparatively high concentrations of acetoin (3-hydroxy-2-butanone). The production of these ketones in cooked beef products result from the thermal degradation of fatty acids (Mottram et al., 1998) or are formed as products from the Maillard reaction (Mottram, 1993). Of the volatiles identified in this study, diacetyl and acetoin were most closely correlated with ratings for overall flavor desirability (Table 4.4). These 2 compounds are primary contributors to the flavor and aroma of sour cream butter and are widely used in the manufacture of artificial butter flavorings (Schutte, 1999). In addition, these compounds have been associated with buttery flavors in beef (Hirai et al., 1973; Peterson et al., 1975). The same was observed in the current study, with acetoin and diacetyl concentration being highly correlated ($P < 0.01$) with buttery/beef fat flavor (Table 4.4). Additionally, both volatiles were positively correlated ($P < 0.05$) with flavors described as beefy/brothy, browned/grilled, and sweet and

negatively correlated ($P < 0.05$) with most of the undesirable flavor notes (Table 4.4). Of the volatiles detected, diacetyl had the strongest, positive association with the buttery/beef fat, browned/grilled, and nutty/roasted nut flavor notes (Table 4.4). In the current study, amount of diacetyl increased ($P < 0.01$) as IM lipid percentage increased (r = 0.60).

Samples of dry-aged, Prime Angus beef (T9) had the greatest abundance of 2-methylbutanal and 3-methylbutanal (Table 4.3). Comparatively high concentrations of these 2 volatiles also were found in samples of dry-aged, Premium Choice Angus beef (T8, Table 4.3). These compounds are key odorants in various foods, including chocolate, roasted hazelnuts, French bread crust, cheddar cheese, and roasted coffee, and impart a unique aroma described as malty, toasty, nutty, and roasted (Schnermann and Schieberle, 1997; Zehentbauer and Grosch, 1997; Grosch et al., 2000; Carunchia-Whetstine et al., 2006; Burdack-Freitag and Schieberle, 2012). In meat systems, these two compounds are products of the Strecker degradation of isoleucine and leucine (Elmore et al., 1999). In the current study, both compounds were positively correlated ($P < 0.05$) with beef flavors characterized as browned/grilled, buttery/beef fat, and nutty/roasted nut (Table 4.4). In addition, samples with greater amounts of 3-methylbutanal had a sweeter ($P < 0.05$) flavor and received higher ($P < 0.05$) ratings for overall flavor desirability. Concentration of 3-methylbutanal was negatively correlated ($P < 0.05$) with bloody metallic and livery flavors (Table 4.4).

Phenylacetaldehyde is produced as a Strecker degradation product of the amino acid phenylalanine (Gasser and Grosch, 1988). Mean values for phenylacetaldehyde concentration did not differ ($P > 0.05$) among treatments (Table 4.3); however, this

compound was related to a specific flavor note identified in some beef samples in the current study. Phenylacetaldehyde has been identified as a primary volatile related to the green, floral, and sweet odors of certain species of mushrooms (Cho et al., 2006; Miyazawa et al., 2010) and, in our study, was correlated ($P < 0.01$) with the earthy/mushroom flavor note in cooked beef samples (Table 4.4).

Dimethyl sulfide, 2-propanone, and 2-butanone were detected in the greatest ($P < 0.05$) concentration in the headspace of cooked samples of beef that had been wet-aged for 46-d (T7, Table 4.3). All 3 of these compounds were positively correlated ($P < 0.05$) with the distinctively sour flavor of samples in that treatment (Table 4.4). Concentration of dimethyl sulfide also was positively correlated ($P < 0.01$) with ratings for the bloody/metallic and bitter flavors and negatively correlated ($P < 0.05$) with many of the desirable flavors and overall flavor desirability (Table 4.4). Dimethyl sulfide is a volatile found in vacuum packaged beef (Jackson et al., 1992) that has been linked to the unpleasant aroma that develops during microbial spoilage of refrigerated beef (Stutz et al., 1991). In a study by Insausti et al. (2002), deterioration of beef odor quality during 15 d of storage in modified atmosphere packaging was attributed, in part, to a marked increase in 2-propanone. Increased quantities of 2-propanone in the current study were associated not only with a sour flavor, but also with greater ($P < 0.05$) bitterness (Table 4.4).

Quantities of butanal, pentanal, and octanal did not differ ($P > 0.05$) among treatments (Table 4.3). However these 3 aldehydes were associated ($P < 0.05$) with increased intensities of an assortment of desirable and undesirable flavor notes (Table 4.4). Of the undesirable flavors, those characterized as sour and bitter became more

pronounced ($P < 0.01$) as the amount of butanal increased, whereas a greater amount of octanal was associated with more pronounced ($P < 0.05$) gamey, liver, and fishy flavors (Table 4.4). In contrast with our results, Bolton (1987) reported that octanal was postitively correlated with cooked beef fat flavor.

In the current study, pentanal concentration was positively correlated ($P < 0.05$) with desirable flavors identified as buttery/beef fat and sweet and was associated with higher ($P < 0.05$) ratings for overall flavor desirability (Table 4.4). These findings also were inconsistent with previous reports. Maruri and Larick (1992) found that pentanal was positively correlated with a gamey/stale flavor in beef. Likewise, Jiang (2011) reported that pentanal was positively correlated with intensity of off-flavor in ground beef.

Previous research has identified a number of additional volatiles that have been linked to differences in beef flavor (Larick et al., 1987; Larick and Turner, 1990; Melton, 1982; Maruri and Larick, 1992; Mottram, 1998). However, many of these compounds were not identified in the current study.

Conclusions

Results from the current study found only a limited number of identified volatile compounds to have a positive effect on overall flavor desirability, including 2,3 butanedione, 3-hydroxy-2-butanone, 3-methyl butanal, and pentanal. Consistent with the current study, 2,3 butanedione and 3-hydroxy-2-butanone have previously been associated with buttery flavor notes. Buttery/beef fat flavor was closely related with panelist overall flavor desirability ratings, indicating these two ketones likely play a

critical role in flavor desirability. Dimethyl sulfide content was found to have a negative effect on flavor desirability ratings. Moreover, numerous compounds identified from the headspace of cooked beef samples were found to relate to specific beef flavor traits. Several MUFA (C12:1, C14:1, C16:1 c9, and C18:1 c9) were identified as having a positive effect on sensory panel overall flavor desirability scores. Furthermore, multiple MUFA were associated with flavor traits having a positive effect on flavor desirability including beefy, browned, buttery, and roasted nut flavors. Conversely, stearic acid (C18:0) and several PUFA (C18:2t, C18:3 n-3, C20:1 c11, and C22:5 n-3) had a negative effect on flavor desirability scores and were found at a higher proportion in samples rating high for grassy, gamey, livery, fishy, and sour flavors. These results indicate that beef management practices resulting in beef with a higher proportion of PUFA, such as grass finishing, would have a negative effect on the flavor profile and desirability of these products, whereas practices that result in increased MUFA content, such as grain finishing, would have a positive effect on flavor desirability.

Table 4.1. Concentrations[1] of identified fatty acids in ground strip loin samples representing 12 beef treatments

	Treatment[2]													
Fatty acid	1	2	3	4	5	6	7	8	9	10	11	12	SEM[3]	*P*-value
C10:0	0.05^{abc}	0.06^{ab}	0.06^{a}	0.05^{abc}	0.05^{abc}	0.04^{c}	0.05^{abc}	0.05^{abc}	0.05^{bc}	0.04^{c}	0.05^{abc}	0.02^{d}	0.01	0.0040
C12:0	0.07	0.07	0.09	0.09	0.07	0.07	0.08	0.08	0.07	0.08	0.07	0.07	0.01	0.5773
C12:1	0.02^{ab}	0.01^{bcde}	0.02^{abcd}	0.03^{a}	0.02^{ab}	0.01^{bcde}	0.01^{abcd}	0.01^{cde}	0.02^{ab}	0.02^{abc}	0.00^{de}	0.00^{e}	0.00	0.0061
C14:0	3.41^{ab}	3.08^{abc}	3.08^{abc}	3.34^{ab}	3.19^{abc}	3.00^{bcd}	3.52^{a}	3.10^{abc}	3.26^{abc}	2.92^{cd}	2.81^{cd}	2.59^{d}	0.16	0.0251
C14:1	0.79	0.66	0.58	0.69	0.77	0.74	0.86	0.69	0.82	0.99	0.72	0.61	0.09	0.1563
C15:0	0.57^{bc}	0.59^{abc}	0.66^{a}	0.60^{ab}	0.66^{a}	0.51^{cd}	0.55^{bcd}	0.48^{d}	0.53^{bcd}	0.51^{bcd}	0.53^{bcd}	0.59^{abc}	0.03	0.0038
C16:0	29.41^{a}	27.51^{cd}	27.45^{cd}	27.49^{cd}	26.95^{d}	28.20^{bc}	29.06^{ab}	27.47^{cd}	27.61^{cd}	25.83^{e}	27.57^{cd}	27.24^{d}	0.32	< 0.0001
C16:1 c9	3.50^{bc}	3.04^{bcd}	2.62^{d}	3.33^{bc}	3.47^{bc}	3.35^{bc}	3.61^{ab}	3.01^{cd}	3.55^{bc}	4.13^{a}	3.49^{bc}	3.33^{bc}	0.20	0.0043
C17:0	1.50^{cd}	1.63^{bc}	1.76^{ab}	1.63^{bc}	1.87^{a}	1.44^{cde}	1.36^{def}	1.15^{f}	1.38^{de}	1.28^{ef}	1.43^{cde}	1.39^{de}	0.08	< 0.0001
C18:0	12.23^{cd}	12.95^{bcd}	13.89^{b}	12.26^{cd}	12.86^{bcd}	12.56^{bcd}	12.58^{bcd}	13.37^{bc}	13.05^{bcd}	12.32^{cd}	11.67^{d}	16.53^{a}	0.52	0.0002
C18:1 c11-15	3.01^{def}	5.18^{b}	7.99^{a}	7.29^{a}	4.24^{bc}	1.24^{g}	3.22^{cd}	3.11^{cde}	2.58^{def}	1.96^{efg}	1.71^{fg}	1.97^{efg}	0.42	< 0.0001
C18:1 c9	39.28^{bc}	38.29^{c}	34.19^{d}	35.54^{d}	39.26^{bc}	41.17^{ab}	38.30^{c}	38.61^{c}	40.15^{bc}	43.13^{a}	42.58^{a}	34.45^{d}	0.72	< 0.0001
C18:1t (total)	3.22^{f}	3.87^{def}	4.92^{c}	4.55^{cd}	3.46^{ef}	4.54^{cd}	3.78^{def}	5.85^{b}	4.17^{cde}	3.86^{def}	4.38^{cd}	6.91^{a}	0.31	< 0.0001
C18:2 Total	1.80^{bcde}	1.88^{abcde}	1.72^{de}	2.02^{ab}	2.01^{abc}	1.82^{abcde}	1.82^{abcde}	1.63^{e}	1.70^{de}	2.08^{a}	1.90^{abcd}	1.77^{cde}	0.09	0.0303
C18:2t[4]	0.62^{b}	0.56^{b}	0.39^{b}	0.46^{b}	0.51^{b}	0.65^{b}	0.64^{b}	0.77^{b}	0.61^{b}	0.47^{b}	0.57^{b}	1.36^{a}	0.12	0.0013
C18:3 n-3	0.29^{efg}	0.34^{cdef}	0.35^{cd}	0.38^{bc}	0.42^{b}	0.35^{cde}	0.30^{defg}	0.29^{fg}	0.28^{g}	0.20^{h}	0.26^{g}	0.73^{a}	0.02	< 0.0001
C20:1 c11	0.20	0.25	0.20	0.22	0.14	0.27	0.22	0.29	0.13	0.16	0.22	0.31	0.04	0.1127
C22:5 n-3	0.04^{cd}	0.03^{d}	0.03^{d}	0.04^{d}	0.03^{d}	0.06^{bc}	0.04^{cd}	0.07^{b}	0.04^{d}	0.03^{d}	0.04^{cd}	0.15^{a}	0.01	< 0.0001

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

[2] Treatments: 1 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 14 d; 2 = Low Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 14 d; 3 = Select, Angus, implanted, fed corn-based diet ≥ 100 d, wet-aged 14 d; 4 = Low Choice, calf-fed Holstein, implanted, fed corn-based diet ≥ 200 d, wet aged 14 d; 5 = Low Choice, Angus, implanted and supplemented with β agonists, fed corn-based diet ≥ 100 d, wet aged 14 d; 6 = Low Choice, Angus, implanted and supplemented with β agonists, fed barley-based diet ≥ 100 d, wet aged 14 d; 7 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 46 d; 8 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 9 = Prime, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 10 = Prime, American Wagyu, no growth enhancement, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 11 = Low Choice, Angus, no growth enhancement, fed corn-based diet ≥ 100 d, wet aged 14 d; 12 = Select, Angus, no growth enhancement, grass fed (no grain), wet aged 14 d.

[3] SE of the least squares mean.

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

^{abcdefgh} Least squares means in the same row lacking a common superscript differ ($P < 0.05$).

Table 4.2. Pearson correlation coefficients showing relationships between percentages of individual fatty acids and beef flavor attributes

Fatty Acid	Overall Flavor Desirability	Beefy/ Brothy	Browned/ Grilled	Buttery/ Beef Fat	Bloody/ Metallic	Grassy/ Hay Like	Gamey	Earthy/ Mushroom	Nutty/ Roasted Nut	Livery	Fishy	Sour	Sweet	Bitter
C10:0	0.06	0.05	-0.16	0.04	0.05	-0.24	-0.38*	-0.32	-0.11	-0.35*	-0.55**	-0.10	-0.05	-0.21
C12:0	-0.05	-0.17	-0.21	-0.02	0.39*	0.00	0.13	-0.03	-0.03	0.04	0.03	0.17	-0.05	0.14
C12:1	0.47**	0.51**	0.29	0.36*	-0.05	-0.44**	-0.44**	-0.14	0.17	-0.47**	-0.46**	-0.21	0.36*	-0.32
C14:0	0.15	0.12	0.05	0.17	0.13	-0.21	-0.24	0.14	0.09	-0.25	-0.35*	0.08	0.14	-0.01
C14:1	0.40*	0.34*	0.37*	0.40*	-0.36*	-0.29	-0.21	0.27	0.53**	-0.42*	-0.26	-0.16	0.40*	-0.20
C15:0	-0.28	-0.16	-0.48	-0.37*	0.48**	-0.11	0.16	-0.24	-0.50**	0.17	0.14	0.21	-0.19	0.14
C16:0	-0.28	-0.30	-0.29	-0.19	0.25	0.22	0.08	0.11	-0.22	0.18	0.04	0.33*	-0.16	0.32
C16:1 c9	0.35*	0.33	0.35*	0.36*	-0.31	-0.26	-0.12	0.36*	0.50**	-0.30	-0.06	-0.11	0.32	-0.12
C17:0	-0.20	-0.03	-0.45**	-0.33*	0.32	-0.23	-0.07	-0.45**	-0.52**	-0.02	-0.09	0.04	-0.16	0.01
C18:0	-0.44**	-0.51**	-0.28	-0.38*	0.40*	0.53**	0.61**	0.19	-0.17	0.64**	0.71**	0.35*	-0.22	0.45**
C18:1 c11-15	-0.06	-0.06	-0.32	-0.09	0.43**	-0.18	-0.08	-0.46**	-0.35*	-0.07	-0.23	-0.01	-0.09	-0.17
C18:1 c9	0.49**	0.52**	0.55**	0.45**	-0.76**	-0.31	-0.49**	0.11	0.46**	-0.55**	-0.45**	-0.41*	0.34*	-0.31
C18:1t (total)	-0.37*	-0.41*	-0.17	-0.36*	0.35*	0.48**	0.56**	0.07	-0.17	0.63**	0.61**	0.25	-0.32	0.22
C18:2 total	0.17	0.30	0.06	0.04	-0.12	-0.37*	-0.18	-0.12	-0.04	-0.24	-0.15	-0.08	-0.03	-0.14
C18:2t	-0.44**	-0.40*	-0.17	-0.38*	0.24	0.37*	0.56**	0.26	-0.15	0.64**	0.70**	0.37*	-0.34*	0.37*
C18:3n-3	-0.65**	-0.60**	-0.56*	-0.66**	0.62**	0.48**	0.73**	0.05	-0.47**	0.75**	0.85**	0.43**	-0.43**	0.44**
C20:1c11	-0.43**	-0.34*	-0.29	-0.42**	0.23	0.22	0.24	0.07	-0.32	0.52**	0.31	0.23	-0.45**	0.13
C22:5 n-3	-0.52**	-0.52**	-0.28	-0.47**	0.34*	0.50**	0.66**	0.32	-0.20	0.75**	0.83**	0.35*	-0.37*	0.37*

Table 4.3. Concentrations of identified volatiles isolated from cooked ground strip loin samples representing 12 beef treatments

	Treatment[1]													
Volatile (ng/g)	1	2	3	4	5	6	7	8	9	10	11	12	SEM[2]	*P*-value
Aldehydes														
Acetaldehyde	12.29^{bcd}	10.44^{d}	18.79^{ab}	23.12^{a}	13.34^{bcd}	11.26^{cd}	17.67^{abc}	18.20^{ab}	21.76^{a}	12.41^{bcd}	13.89^{bcd}	21.09^{a}	2.32	0.0027
Butanal	0.23	0.44	0.63	0.93	0.42	0.63	1.25	0.70	0.54	0.39	0.23	0.45	0.24	0.2267
2-Methylbutanal	92.02^{de}	233.20^{bcde}	166.23^{cde}	238.49^{bcde}	63.74^{e}	182.81^{bcde}	321.71^{bc}	361.52^{ab}	536.11^{a}	264.46^{bcd}	104.84^{de}	237.97^{bcde}	66.71	0.0027
3-Methylbutanal	5.60^{cd}	10.39^{bcd}	7.28^{bcd}	11.44^{bcd}	2.63^{d}	6.91^{bcd}	11.8^{bcd}	15.86^{b}	27.59^{a}	12.67^{bc}	9.25^{bcd}	7.62^{bcd}	4.10	0.0014
Pentanal	5.31	4.59	6.88	7.04	5.10	6.41	7.14	6.34	7.81	6.42	5.63	3.31	0.74	0.0657
Hexanal	168.85^{cde}	170.13^{cd}	273.27^{ab}	160.56^{de}	168.17^{cde}	197.71^{bcd}	375.41^{a}	276.83^{ab}	191.53^{bcd}	267.91^{bc}	158.97^{de}	66.84^{e}	35.27	0.0004
Heptanal	2.92	2.59	3.12	3.19	2.37	2.60	2.89	2.84	4.41	3.00	3.33	2.97	0.46	0.2078
Benzaldehyde	11.21	15.22	12.83	10.13	9.34	13.43	15.10	12.31	15.87	12.60	10.33	10.84	1.80	0.1525
Phenyl acetaldehyde	10.62	18.12	9.11	16.62	13.28	9.57	22.72	6.57	31.24	24.21	13.66	17.84	6.85	0.4072
Nonanal	16.72	15.38	14.99	21.43	12.55	13.32	13.33	19.09	28.82	23.29	21.72	23.70	5.76	0.6602
Octanal	10.71	12.13	11.30	13.76	8.47	10.40	10.85	11.27	13.77	13.22	15.52	19.24	3.04	0.5126
Decanal	1.45	1.18	1.34	2.53	0.81	1.34	1.44	2.40	2.09	3.05	1.75	2.37	1.14	0.8892
Cyclobutanal	5.83	5.39	6.16	6.21	4.71	3.61	6.45	5.50	6.60	2.99	5.35	2.38	1.47	0.5482
Ketones														
2-Propanone	204.97^{bc}	212.35^{bc}	177.64^{bc}	176.81^{bc}	145.04^{c}	159.99^{bc}	424.68^{a}	149.34^{bc}	248.25^{b}	148.54^{bc}	115.65^{c}	113.32^{c}	35.24	0.0002
2,3-Butanedione	148.65^{b}	204.92^{b}	205.94^{b}	203.58^{b}	181.13^{b}	143.42^{b}	120.30^{b}	533.55^{a}	691.17^{a}	529.45^{a}	125.49^{b}	55.34^{b}	79.08	< 0.0001
2-Butanone	1919.25^{bcd}	2620.16^{abc}	1515.81^{cd}	1989.30^{bcd}	1380.90^{d}	1694.81^{bcd}	3547.35^{a}	2096.05^{bcd}	2897.05^{ab}	1631.55^{cd}	1177.99^{d}	1495.64^{cd}	415.42	0.0160
3-Hydroxy-2-Butanone	532.21^{cdef}	827.84^{abc}	556.62^{bcdef}	622.25^{abcd}	606.36^{abcde}	398.41^{def}	241.32^{ef}	907.43^{ab}	930.09^{a}	594.58^{abcde}	585.57^{abcde}	200.15^{f}	127.74	0.0010
Sulfides														
Dimethyl sulfide	74.84^{abcd}	89.93^{abc}	92.12^{ab}	81.91^{abcd}	75.74^{abcd}	83.16^{abcd}	101.83^{a}	40.47^{ef}	63.05^{cde}	30.96^{f}	56.16^{def}	68.56^{bcd}	9.94	< 0.0001
Dimethyl disulfide	10.42	11.37	13.34	14.99	15.11	18.20	25.01	32.77	36.02	17.94	7.42	12.33	7.84	0.1810
Furans														
2-Pentyl furan	4.58^{cd}	6.50^{bc}	6.44^{bc}	3.83^{d}	5.96^{bcd}	7.78^{ab}	6.12^{bcd}	9.98^{a}	7.54^{b}	6.27^{bcd}	4.66^{cd}	3.73^{d}	0.99	0.0015
Pyrazines														
2,5-dimethyl-pyrazine	Undetected	549.97	87.46	116.55	Undetected	Undetected	238.15	29.70	143.78	45.22	27.31	83.11	204.92	0.4591
Trimethyl-pyrazine	12.81	1452.39	85.38	326.00	Undetected	Undetected	397.83	14.45	542.60	154.63	11.51	240.47	352.85	0.2932
Alkanes														
Heptane	6.74	6.79	7.35	6.98	5.25	4.13	7.27	8.35	6.16	3.36	6.39	2.34	1.59	0.3214
Octane	1.82	1.79	1.74	1.68	1.59	1.61	1.66	1.76	2.09	1.42	0.64	1.69	0.24	0.9242

[1] Treatments: 1 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 14 d; 2 = Low Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 14 d; 3 = Select, Angus, implanted, fed corn-based diet ≥ 100 d, wet-aged 14 d; 4 = Low Choice, calf-fed Holstein, implanted, fed corn-based diet ≥ 200 d, wet aged 14 d; 5 = Low Choice, Angus, implanted and supplemented with β agonists, fed corn-based diet ≥ 100 d, wet aged 14 d; 6 = Low Choice, Angus, implanted and supplemented with β agonists, fed barley-based diet ≥ 100 d, wet aged 14 d; 7 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 46 d; 8 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 9 = Prime, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 10 = Prime, American Wagyu, no growth enhancement, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 11 = Low Choice, Angus, no growth enhancement, fed corn-based diet ≥ 100 d, wet aged 14 d; 12 = Select, Angus, no growth enhancement, grass fed (no grain), wet aged 14 d.

[2] SE of the least squares mean.

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

Table 4.4. Pearson correlation coefficients showing relationships between quantities of various volatiles and beef flavor attributes

Volatile Compound	Overall Flavor Desirability	Beefy/ Brothy	Browned/ Grilled	Buttery/ Beef Fat	Bloody/ Metallic	Grassy/ Hay Like	Gamey	Earthy/ Mushroom	Nutty/ Roasted Nut	Livery	Fishy	Sour	Sweet	Bitter
Aldehydes														
Acetaldehyde	-0.12	-0.21	-0.06	-0.02	0.23	0.14	0.28	0.19	0.05	0.27	0.30	0.27	-0.02	0.20
Butanal	-0.18	-0.32	-0.17	-0.07	0.26	0.15	0.20	0.10	-0.04	0.12	0.08	0.51**	-0.22	0.44**
2-Methylbutanal	0.26	0.07	0.38*	0.33*	-0.30	0.22	0.04	0.33	0.46**	-0.14	-0.03	0.09	0.31	-0.01
3-Methylbutanal	0.43*	0.23	0.48**	0.53**	-0.41*	0.01	-0.13	0.13	0.46**	-0.34*	-0.15	-0.14	0.47**	-0.14
Pentanal	0.33*	0.21	0.24	0.37*	-0.12	-0.20	-0.24	0.05	0.26	-0.30	-0.40*	0.00	0.35*	-0.03
Hexanal	0.04	-0.07	0.08	0.11	-0.11	-0.06	-0.10	0.13	0.07	-0.12	-0.38*	0.23	0.04	0.12
Heptanal	0.20	0.12	0.15	0.30	-0.08	-0.02	0.08	0.28	0.36*	-0.06	0.07	0.01	0.26	0.00
Benzaldehyde	0.11	0.02	0.07	0.20	-0.04	0.24	0.07	0.31	0.18	0.03	-0.08	0.07	0.28	0.05
Phenyl acetaldehyde	0.06	-0.03	0.02	0.19	0.03	0.31	0.37	0.58**	0.40*	0.07	0.27	0.34	0.32	0.25
Nonanal	0.25	0.18	0.21	0.41*	-0.09	-0.10	0.13	0.15	0.39*	0.03	0.18	-0.11	0.48**	0.00
Octanal	-0.15	-0.16	-0.13	-0.03	0.21	0.10	0.38*	0.05	0.12	0.37*	0.47**	0.12	-0.01	0.22
Decanal	0.21	0.03	0.21	0.29	-0.11	-0.15	0.01	0.10	0.25	-0.01	0.15	0.00	0.22	0.24
Cyclobutanal	-0.01	-0.06	-0.11	0.11	-0.06	-0.11	0.01	-0.22	-0.04	-0.18	-0.22	0.19	0.02	0.11
Ketones														
2-Propanone	-0.14	-0.24	-0.11	0.01	0.01	0.29	0.12	0.27	0.04	-0.03	-0.11	0.56**	-0.06	0.38*
2,3-Butanedione	0.61**	0.49**	0.72**	0.62**	-0.54**	-0.38*	-0.42*	0.04	0.54**	-0.53	-0.36*	-0.36*	0.52**	-0.32
2-Butanone	0.01	-0.11	0.06	0.10	-0.05	0.30	0.09	0.30	0.15	-0.05	-0.07	0.40*	0.03	0.27
3-Hydroxy-2-Butanone	0.57**	0.57**	0.54**	0.49**	-0.42*	-0.38*	-0.47**	-0.31	0.17	-0.54**	-0.51**	-0.52**	0.36*	-0.57**
Sulfides														
Dimethyl sulfide	-0.47**	-0.42*	-0.59**	-0.52**	0.47**	0.25	0.19	-0.17	-0.53**	0.28	0.11	0.54**	-0.45**	0.47**
Dimethyl disulfide	0.24	0.10	0.39*	0.28	-0.22	0.03	0.01	0.26	0.38*	-0.16	-0.14	-0.09	0.24	-0.20
Furans														
2-Pentyl furan	0.16	0.11	0.34*	0.13	-0.31	-0.11	-0.24	-0.02	0.26	-0.18	-0.40*	-0.16	0.05	-0.11
Pyrazines														
2,5-dimethyl-pyrazine	-0.06	-0.08	-0.18	-0.05	-0.03	0.11	-0.02	-0.31	-0.21	-0.02	-0.03	0.21	-0.11	0.17
Trimethyl-pyrazine	0.05	0.13	-0.02	0.10	-0.10	0.12	-0.04	-0.11	-0.06	-0.09	-0.07	0.23	0.15	0.00
Alkanes														
Heptane	-0.05	-0.12	-0.11	0.07	-0.06	-0.13	0.00	-0.30	-0.08	-0.16	-0.28	0.10	-0.10	0.02
Octane	-0.02	-0.07	-0.05	0.09	-0.02	-0.11	0.14	-0.12	0.02	0.02	0.04	0.08	0.18	0.11

* Correlation coefficient differs from 0 ($P < 0.05$).
** Correlation coefficient differs from 0 ($P < 0.01$).

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APPENDIX A

Table A.1. Percentage of consumers who ranked overall flavor desirability as desirable[1] for beef samples by treatment

Treatment[2]	LS Mean	SEM[3]
1	55.40[b]	3.63
2	45.91[cd]	3.63
3	43.12[cd]	3.60
4	55.07[b]	3.63
5	40.69[d]	3.56
6	44.64[cd]	3.63
7	29.14[e]	3.20
8	48.87[bc]	3.64
9	72.51[a]	3.13
10	78.89[a]	2.78
11	47.30[bcd]	3.65
12	24.67[e]	2.97
P-value	< 0.0001	

[1] A sample was classified as desirable if the sample scored $\geq$ 5.0 on the 10 cm line scale for overall flavor desirability

[2] Treatments: 1 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 14 d; 2 = Low Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 14 d; 3 = Select, Angus, implanted, fed corn-based diet ≥ 100 d, wet-aged 14 d; 4 = Low Choice, calf-fed Holstein, implanted, fed corn-based diet ≥ 200 d, wet aged 14 d; 5 = Low Choice, Angus, implanted and supplemented with β agonists, fed corn-based diet ≥ 100 d, wet aged 14 d; 6 = Low Choice, Angus, implanted and supplemented with β agonists, fed barley-based diet ≥ 100 d, wet aged 14 d; 7 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 46 d; 8 = Premium Choice, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 9 = Prime, Angus, implanted, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 10 = Prime, American Wagyu, no growth enhancement, fed corn-based diet ≥ 100 d, wet aged 17 d, dry aged 30 d; 11 = Low Choice, Angus, no growth enhancement, fed corn-based diet ≥ 100 d, wet aged 14 d; 12 = Select, Angus, no growth enhancement, grass fed (no grain), wet aged 14 d.

[3] SE of the least squares mean.

[abcd] Least squares means lacking a common superscript differ ($P < 0.05$).

Table A.2. Pearson correlation coefficients among % lipid, moisture, protein, ash, and consumer flavor ratings

Flavor Trait	% Lipid	% Moisture	% Protein	% Ash
Overall Flavor Desirability	0.77**	-0.74**	0.12	0.27
Beefy/Brothy	0.64**	-0.62**	0.09	0.17
Browned/Grilled	0.81**	-0.84**	0.31	0.47**
Buttery/Beef Fat	0.85**	-0.84**	0.17	0.31
Bloody/Metallic	-0.72**	0.78**	-0.42*	-0.40*
Grassy/Hay Like	-0.34*	0.37*	-0.09	-0.16
Gamey	-0.47**	0.47**	-0.08	-0.08
Earthy/Mushroom	0.34*	-0.28	0.02	-0.00
Nutty/Roasted Nut	0.78**	-0.74**	0.17	0.33
Livery	-0.67**	0.68**	-0.19	-0.23
Fishy	-0.47**	0.48**	-0.11	-0.03
Sour	-0.34*	0.44**	-0.29	-0.34*
Sweet	0.77**	-0.70**	0.05	0.15
Bitter	-0.31	0.40*	-0.26	-0.26

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

** Correlation coefficient differs from 0 ($P < 0.01$)

Table A.3. Pearson correlation coefficients between volatile compounds and fatty acids

Volatile Compound	C10:0	C12:0	C12:1	C14:0	C14:1	C15:0	C16:0	C16:1 c9	C17:0	C18:0	C18:1 c11-15	C18:1 c9	C18:1t (total)	C18:2 Total	C18:2t	C18:3 n-3	C20:1c11	C22:5 n-3
Aldehydes																		
Acetaldehyde	-0.05	0.20	-0.04	0.12	-0.12	0.17	-0.01	-0.09	0.01	0.31	0.21	-0.44**	0.31	-0.10	0.21	0.29	0.13	0.25
Butanal	0.09	0.16	0.01	0.27	0.02	0.02	0.19	-0.08	-0.09	0.12	0.11	-0.21	0.02	-0.06	-0.08	-0.05	0.05	-0.02
2-Methyl Butanal	-0.01	0.07	-0.10	0.12	0.22	-0.40*	-0.03	0.08	-0.52**	0.15	-0.16	0.01	0.20	-0.33	0.08	-0.13	-0.03	0.07
3-Methyl Butanal	0.01	0.02	-0.05	0.05	0.20	-0.44**	-0.05	0.04	-0.45**	0.06	-0.16	0.18	0.02	-0.36*	-0.08	-0.28	-0.24	-0.13
Pentanal	0.29	0.21	0.14	0.43**	0.24	-0.07	0.10	0.16	-0.05	-0.32	0.06	0.15	-0.26	0.04	-0.36*	-0.50**	-0.16	-0.43**
Hexanal	0.24	0.11	-0.03	0.26	0.15	-0.17	0.08	0.01	-0.16	-0.23	0.06	0.14	-0.21	-0.02	-0.24	-0.50**	-0.01	-0.34*
Heptanal	0.03	0.14	0.00	0.21	0.09	0.17	0.04	0.24	0.03	-0.02	-0.16	0.06	-0.06	0.06	-0.04	-0.15	-0.04	0.01
Benzaldehyde	0.13	0.23	0.02	0.30	0.09	0.01	0.21	-0.02	-0.10	0.10	-0.04	-0.01	-0.18	-0.26	-0.16	-0.14	-0.13	-0.12
Phenylacetaldehyde	-0.36	0.13	-0.16	-0.16	0.02	0.07	-0.16	0.20	-0.04	0.24	-0.09	-0.19	0.29	0.09	0.46**	0.39*	0.16	0.33*
Nonanal	-0.16	0.28	0.00	0.15	0.38*	0.14	0.02	0.38*	-0.03	0.12	-0.19	0.05	-0.21	0.10	-0.03	0.12	-0.39*	0.00
Octanal	0.12	0.07	0.31	0.17	0.00	0.26	0.08	-0.05	0.18	-0.07	0.16	-0.11	-0.06	-0.02	0.02	0.02	0.06	-0.06
Decanal	-0.18	0.09	0.10	0.00	0.19	0.03	-0.12	0.25	-0.08	0.12	-0.13	0.01	0.03	-0.04	0.16	0.08	-0.07	0.11
Cyclobutanal	0.24	0.01	0.06	0.29	0.02	0.20	0.18	-0.01	0.23	-0.28	0.17	0.00	-0.23	0.16	-0.19	-0.27	0.01	-0.32
Ketones																		
2-Propanone	0.21	0.04	0.05	0.38*	0.15	-0.06	0.42*	0.01	-0.05	-0.09	0.02	-0.01	-0.33*	-0.08	-0.15	-0.24	-0.07	-0.25
2,3 Butanedione	0.03	-0.07	0.10	0.05	0.14	-0.32	-0.31	0.12	-0.35*	-0.08	-0.12	0.27	0.00	-0.10	-0.11	-0.42*	-0.20	-0.20
2 Butanone	0.21	0.08	0.03	0.39*	0.17	-0.14	0.33*	0.04	-0.20	-0.01	-0.07	-0.02	-0.15	-0.13	-0.05	-0.19	0.01	-0.14
3-Hydroxy-2-Butanone	0.29	-0.09	0.26	0.11	-0.02	-0.10	-0.23	-0.11	-0.03	-0.25	0.20	0.14	-0.08	-0.03	-0.20	-0.40*	-0.14	-0.38*
Sulfides																		
Dimethyl sulfide	0.33*	0.22	0.11	0.34*	-0.22	0.46**	0.48**	-0.26	0.47**	0.04	0.30	-0.40*	-0.13	0.03	-0.03	0.19	0.12	-0.11
Dimethyldisulfide	0.00	0.04	-0.08	0.22	0.38*	-0.39*	0.04	0.11	-0.53**	-0.01	-0.15	0.07	0.15	-0.39*	0.00	-0.24	-0.05	-0.01
Furans																		
2 Pentyl Furan	-0.17	0.17	-0.04	0.12	0.31	-0.14	-0.03	0.23	-0.32	0.16	-0.11	-0.02	0.01	-0.06	0.03	0.00	-0.05	0.08
Pyrazines																		
2,5-dimethyl Pyrazine	0.29	0.19	0.10	0.21	0.04	0.17	0.30	-0.11	0.14	0.00	0.24	-0.17	-0.17	-0.11	-0.01	0.02	-0.05	-0.12
Trimethylpyrazine	-0.20	-0.32	-0.11	-0.32	-0.53**	0.38*	-0.23	-0.38*	0.46**	0.33	0.14	-0.22	0.14	0.22	0.23	0.42*	0.33	0.25
Alkanes																		
Heptane	0.31	0.00	-0.07	0.21	-008	0.02	0.17	-0.18	0.08	-0.23	0.20	-0.01	-0.12	-0.03	-0.21	-0.35*	0.06	-0.32
Octane	0.06	0.03	-0.04	0.17	0.17	0.10	0.16	0.07	0.09	0.00	-0.02	-0.05	-0.11	-0.07	0.08	0.03	0.03	-0.06

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

** Correlation coefficient differs from 0 ($P < 0.01$)

Table A.4. Pearson correlation coefficients between percent lipid and fatty acid concentration

Fatty Acid	% Lipid
C10:0	-0.03
C12:0	-0.04
C12:1	0.30
C14:0	0.25
C14:1	0.63**
C15:0	-0.43**
C16:0	-0.06
C16:1 c9	0.53**
C17:0	-0.44**
C18:0	-0.37*
C18:1 c11-15	-0.35*
C18:1 c9	0.59**
C18:1t (total)	-0.44**
C18:2 Total	0.01
C18:2t	-0.30
C18:3n-3	-0.65**
C20:1c11	-0.45**
C22:5 n-3	-0.42*

* Correlation coefficient differs from 0 ($P < 0.05$)
** Correlation coefficient differs from 0 ($P < 0.01$)

Table A.5. Pearson correlation coefficients between percent lipid and volatile compound concentration

Volatile Compound	% Lipid
Aldehydes	
Acetaldehyde	-0.09
Butanal	-0.04
2-Methyl Butanal	0.40*
3-Methyl Butanal	0.54**
Pentanal	0.38*
Hexanal	0.34
Heptanal	0.24
Benzaldehyde	0.25
Phenylacetaldehyde	0.30
Nonanal	0.31
Octanal	-0.11
Decanal	0.31
Cyclobutanal	0.04
Ketones	
2-Propanone	0.19
2,3 Butanedione	0.60**
2 Butanone	0.22
3-Hydroxy-2-Butanone	0.29
Sulfides	
Dimethyl sulfide	-0.46**
Dimethyldisulfide	0.36*
Furans	
2 Pentyl Furan	0.26
Pyrazines	
2,5-dimethyl Pyrazine	-0.07
Trimethylpyrazine	0.04
Alkanes	
Heptane	-0.02
Octane	0.09

* Correlation coefficient differs from 0 ($P < 0.05$)
** Correlation coefficient differs from 0 ($P < 0.01$)

APPENDIX B

About Yourself

(Please circle the answer that best describes you for each item)

Gender

Male

Female

Age

Under 18

18-34

35-50

Over 50

How many times a week do you consume beef?

None 1 to 3 4 to 6 7 or more

Please rank the importance of the following (1 – 10) when purchasing meat:

_____ brand name of the product

_____ breed of the animal that produced the product

_____ marbling level (fresh meat)

_____ nutrient content

_____ taste/eating experience

_____ USDA grade of the product

_____visual appearance (fresh meat)

_____ where and how the animal was raised

_____ whether or not the animal received growth promotants and/or antibiotics

_____ whether or not the animal was raised exclusively on pasture or fed grain in a feedlot for any period of time

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Figure B.1. Demographic Questionnaire

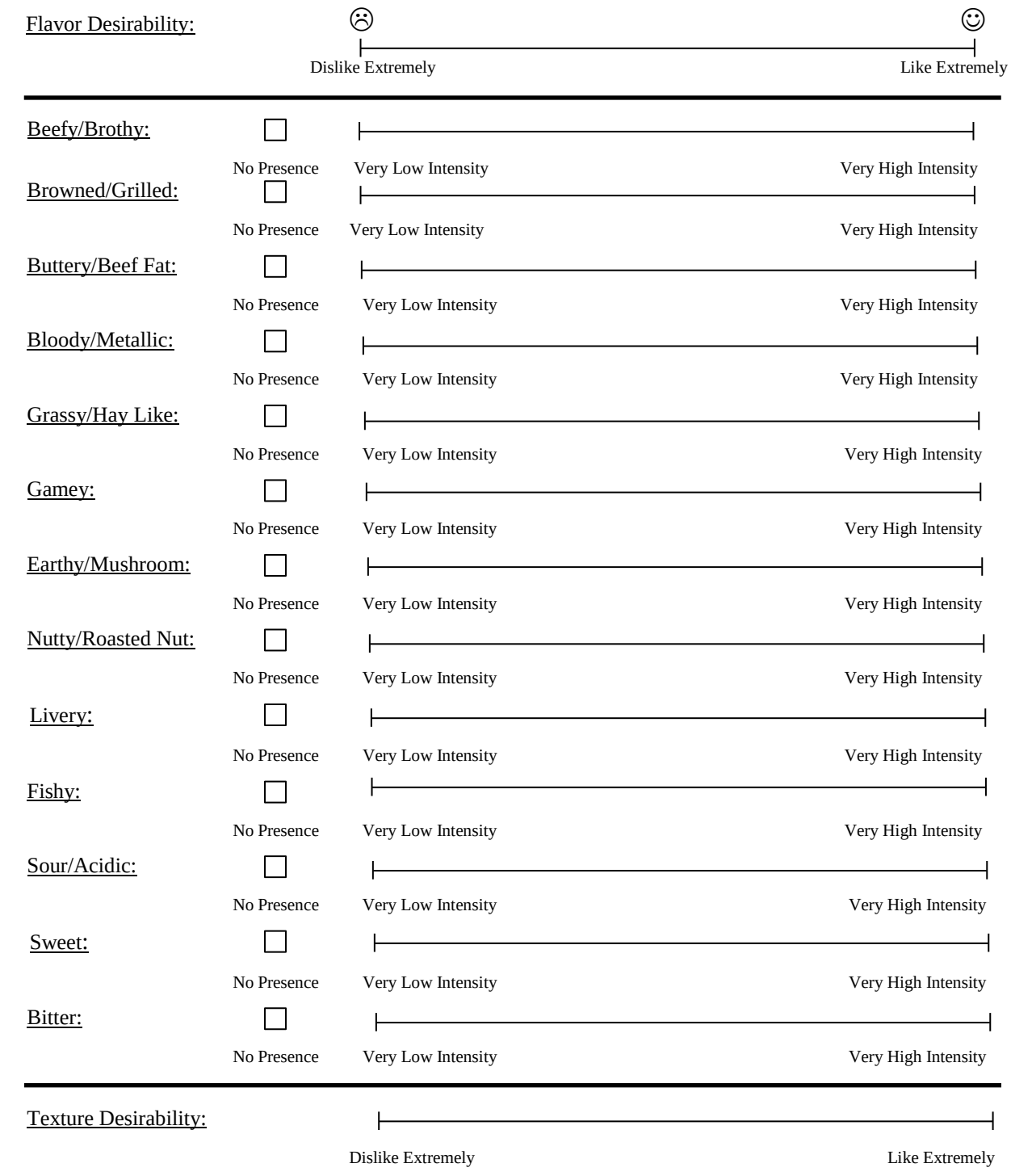

Figure B.2. Consumer Ballot