BEEF FLAVOR MYOLOGY

A Thesis

by

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ABSTRACT

It has been well established that cooking method, marbling level, and cooked internal temperature endpoint affect beef flavor, the most important driver of consumer acceptance. However, beef cuts respond differently to cooking method and cooked internal temperature endpoint based on their inherent chemical characteristics.

Treatments were: beef cuts (inside round, bottom round, and eye of round); USDA beef quality grade (upper two-thirds Choice and Select); cooking methods (pan grill, stir fry, stew no marinade, stew marinade, and roast); and internal cook temperature endpoints (58°C, 70°C, and 80°C). The pan grill cook method included 0.64 and 1.91 cm samples from each muscle type. The stir fry cook method treatment was limited to 0.64 cm cuts, which were cut into 2.54 cm strips prior to cooking. The marinated and non-marinated stew cook method treatments included 0.64 and 1.91 cm samples from each muscle. These samples were then cut into 0.64 x 2.54 x 2.54 cm and 1.91 x 2.54 x 2.54 cm samples prior to cooking. Stew marinated samples were marinated with 118 mL water, 90 mL lemon juice, 30 mL canola oil, 5 mL salt, and 2.5 mL pepper. 0.91 kg roasts were cut from bottom round, eye of round, and inside round subprimals prior to cooking. An expert descriptive beef flavor and texture attribute panel evaluated each sample using 16-point scales for flavor and texture attributes. Warner-Bratzler shear force (WBSF) were determined. The trained panel results and WBSF values were analyzed using Proc Means and Proc GLM procedures of SAS (version 9.4, SAS Institute, Cary, NC) with a predetermined alpha of 5%.

Quality grade impacted flavor for the inside round (*P*< 0.05). USDA quality grade had minimal effect on tenderness as expected, as beef round cuts are high use muscles and contain jigh amounts of connective tissue. Cooking method and internal cook temperature endpoint, or cooking time for the stewing cooking treatment impacted beef flavor to a greater extent (*P*< 0.05). When pan fried, thicker cuts resulted in more positive flavor attributes. For cuts that were roasted, cooking to higher internal temperatures resulted in higher levels of beef identity, roasted, and umami flavors and less serumy/bloody flavors, as well as decreased tenderness (*P*< 0.0001), especially in inside round roasts. Marinated round cuts were more tender than their non-marinated counterparts (*P* < 0.0001). Cuts that were thinner and had longer cooking times were more tender, but had more off-flavor attributes (*P* < 0.05). Cut thickness, cooking method, length of cooking or internal cook temperature endpoint, and presence of marinade affected flavor and texture of bottom round, eye of round, and inside round cuts. This data will be useful in providing consumer and food service personnel recommendations on how to maximize the flavor and texture of beef round cuts.

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CHAPTER I

INTRODUCTION

It has been well established that cooking method, marbling level and cooked internal temperature endpoint affect beef flavor, the most important driver of consumer acceptance. However, beef cuts respond differently to cooking method and cooked internal temperature endpoint based on their inherent chemical characteristics. Beef cuts differ in chemical characteristics based on muscle function in the live animal. Extensive work was conducted through the Beef Check-off to understand chemical and tenderness characteristics of beef cuts and is available on the Bovine Myology website. This website is used by university, industry and government entities to understand inherent characteristics of individual beef cuts and how to maximize their value as a protein source. However, an understanding of how to maximize flavor of individual cuts, the influence of cooking method, marbling level and cooked internal temperature endpoint across beef cuts has not been fully characterized. Recent Beef Check-off funded research has examined the relationship between different cooking methods, degree of doneness, cuts, and marbling scores on consumer, trained sensory descriptive sensory flavor, and aromatic volatile chemicals. In conducting these studies in 2013 to 2015, consumers in Pennsylvania, Oregon, Kansas and Georgia were recruited. Consumer evaluations were conducted in 2013 as a Central Location Test where beef from 20 different treatments were presented to 240 consumers. Consumers rated flavor and overall liking using 9-point hedonic scales and beef varied extensively in cook method, marbling level and internal cook temperature endpoint. The same samples were evaluated by a trained descriptive attribute sensory panel using methods defined by AMSA (2015) and Warner-Bratzler shear force was determined. A second study conducted similarly used beef top loin and beef bottom round roasts cooked to two internal cook temperature endpoints. Consumers (n=480) in the four aforementioned cities were served two chicken and pork cuts that differed in cook method and internal cook temperature endpoint at the same time. In a study conducted by researchers at Colorado State, consumers (n=307) rated top loin steaks that were variable in thickness and that were cooked to a common endpoint temperature using a variety of foodservice cooking methods. In this particular study, the cooking methods employed various types and rates of heat transfer and the addition of humidity. Steak thickness and cooking method influenced the flavor and tenderness of steaks. Additional data from a Beef Check-off funded project on foodservice cooking methods was conducted in the 1990's and while consumer data are not available, trained descriptive attribute flavor data similar to the Beef Lexicon were collected. These data sets provided a base for understanding the effect of cooking method, marbling level and internal cook temperature endpoint on beef flavor across cuts. However, new cooking methods have been developed that provide differences in heat transfer. With increases in technology in cooking devices, the foodservice industry has the ability to prepare and hold beef items differently than they ever have before. Specifically, combination ovens equipped with advanced computer systems a chef or cook to prepare a single beef item using multiple cookery methods in a cycle-like application. For example, a chef can grill/sear, braise, and hold or temper a steak in a single device and cooking cycle. This type of technology is currently being utilized to create various flavor profiles and eating experiences in foodservice. Additionally, beef fabrication procedures have changed so that individual muscles, especially from the round and chuck, are merchandized. There is a need to centralize information in a user-friendly manner for each beef cut, how flavor is impacted by cooking method, how marbling level impacts flavor, and how internal cooked temperature endpoint affects beef flavor. Additionally, there is a need to expand the information to include new cuts and new cooking methods. Data was collected for the first round of the Beef Flavor Myology project in order to begin the process of filling the void of available beef flavor data. However, the need for new beef flavor data was too large to incorporate into a single project. Therefore, the continuation of the Beef Flavor Myology project would incorporate existing data and generate new data to be used in the development of the Beef Flavor Myology tool for use by university, industry and government.

The objective of this study was to continue to develop a research, education and consumer resource that establishes flavor of major beef cuts as affected by cooking method, internal cooking endpoint, and steak thickness of bottom round, eye of round, and inside round cuts. Trained descriptive flavor attributes, volatile chemical compounds, and tenderness through Warner-Bratzler shear force will be determined.

CHAPTER II

LITERATURE REVIEW

Biological Response to Flavor

Flavor is defined as the impressions perceived via chemical senses from a product in the mouth. This includes aromatics caused by the volatile substances released from a product, tastes caused by soluble substances, and chemical feeling factors in the soft membranes of the buccal and nasal cavities which stimulate nerve ends (Meilgaard et al., 2007). Perceptions of flavor reflect information derived from sensory afferents including gustatory, olfactory, and somatosensory fibers (Small and Prescott, 2005). It is important to note flavor does not include appearance or texture, but visual and auditory cues of a food can contribute to the perceived flavor (Meilgaard et al., 2007). The gustatory, trigeminal, and olfactory systems are the main systems that play a role in flavor sensation. The combination of these three systems is regarded as flavor.

Gustation is a chemical sense. Signals begin in the taste buds that are stimulated by water-soluble compounds that come in contact with the apical tips of the epithelial cells of taste buds. Gustation, or taste, allows for the recognition of the five basic tastes: sweet, sour, salty, bitter, and umami. The five basic tastes are all contributors to meat flavor and have been found in various chemical compounds found in meat. Sweetness in meat is associated with glucose, fructose, ribose, and several amino acids and organic acids. Sourness is from aspartic acid, glutamic acid, organic acids, and carboxylic acids (MacLeod, 1994). Inorganic salts have played a large role in saltiness. Bitter flavors can be derived from hypoxanthine, anserine, carnosine, and particular amino acids (MacLeod, 1994). Umami, as defined by the beef lexicon as a flat, salty, somewhat brothy taste, can be described as the taste of glutamate, salts or amino acids and other molecules called nucleotides (Adhikari et al., 2011). Flavor enhancers such as monosodium glutamate (MSG), 5'-inosine monophosphate (IMP), 5'-guanosine monophosphate (GMP) and certain peptides help create umami (Macleod, 1994).

Olfactory signals are generated by neurons in a specialized patch of nasal epithelium and are triggered by volatile compounds (Meilgaard et al., 2007; Chaudhari and Roper 2010). Aromatics are the volatiles perceived by the olfactory system from a substance in the mouth via posterior nares. Aromatics will interact with the olfactory receptor neuron. Once this occurs, the axons arising from the receptor cells project directly to neurons in the olfactory bulb. This action causes a projection to the pyriform cortex in the temporal lobe of the brain. The olfactory system is unique from the other systems because it does not entail a thalamic delay in route to process information. Further processing in the various regions of the brain allows the aroma to be identified and initiates responses to the olfactory stimuli, thus characterizing a "smell" (Meilgaard et al., 2007). This system is able to discriminate among many different aromas and can identify a large number at a time (Breer, 2008).

Humans have natural differences in the olfactory system, creating large variation in flavor perception among people. There are thousands of odorous compounds that can be sensed by the olfactory system. Training panelists to detect these aromas can be difficult because of the vast number of aromas to identify and having a contact time that can be too brief to detect the aroma (Meilgaard et al., 2007).

Beef flavor

Beef flavor is not a single attribute, but is a combination of many different attributes, which makes it a dynamic topic. Beef flavor is a combination of substances that are present in raw beef steaks, as well as those created by chemical reactions occurring during the heating process (Glasscock, 2014). Flavors present in raw meat come from the juices and not in the muscle fiber, but once the meat is cooked, the fibers developed the meaty flavor. The main components were water soluble (Crocker, 1948). Wasserman (1972) described raw meat as having a salty, metallic, bloody taste and a sweet aroma resembling serum.

Proteins, lipids and carbohydrates play major roles in flavor developments because they play leading roles in flavor development because they include flavor precursors that are developed when heated. Flavor precursors can be divided into two categories: water-soluble components and lipids (Mottram,1998). The water-soluble precursors are amino acids, carbohydrates, nucleotides, and peptides, and nitrogenous compounds. Cysteine and ribose are the key water-soluble aromatic flavor compounds. Once cysteine, a sulfuric compound, is heated in the presence of ribose, glucose, or xylose, a meat-like flavor is produced (Morton, 1960). Cysteine plays a major role in the Maillard reaction and Strecker degradation. Ribose is a predominate sugar in muscle that is present in ribonucleotides such as adenosine triphosphate (ATP), ribonucleic acid (RNA), and deoxyribonucleic acid (DNA; Mottram, 1998). The two main reactions that occur during cooking and are largely responsible for flavor development in meat are the Maillard reaction and lipid degradation.

Flavor, tenderness, and juiciness are the major attributes that determine beef palatability. While consumers typically relate quality in terms of tenderness, juiciness, and flavor of a product, meat palatability largely depends on the mentioned factors as well as color, odor, and texture (Weir, 1960). Tenderness has most often been considered the defining trait of consumer acceptance of beef (Huffman et al., 1996; Miller et al., 2001; Platter et al., 2003). While tenderness is important in consumer acceptability of meat, the 2010 National Beef Tenderness survey have shown that over 94% of steaks from the rib and loin area were considered tender or very tender based on Warner-Bratzler shear force values (Guelker et al., 2013). With an increase in the availability of tender beef, recent consumer studies are revealing that consumers may consider beef flavor more important that tenderness. When asked, 50.8% of consumers said they considered flavor the most important factor, followed by tenderness (30.8%) and juiciness (18.4%) (Corbin et al., 2015). Thus, beef flavor has become the most important factor in consumers' assessments of eating quality and acceptability (Meinert et al., 2007; Dashdorj et al., 2015).

Miller and Kerth (2012) discussed the positive and negative beef flavor attributes that were identified in the beef lexicon (Adhikari at al., 2011). Positive beef flavors were identified as beefy, brown/roasted, bloody/serumy, fat-like, sweet, salty, and umami. The negative flavors were described as metallic, liver-like, sour, barnyard, musty-earthy/humus and bitter. Beefy, browned/roasted, bloody/serumy, sweet, salt and umami were associated with the lean portion of beef; whereas, fat-like, liver-like, metallic and bitter were associated with the lipid portion. Liver-like, metallic, and other off-flavors have been associated with beef with high myoglobin content, high pH and oxidized beef fat. Slightly higher levels of barnyard and musty-earthy/humus was found in roasts and when combined with beefy, brown/roasted and umami attributes can be perceived as positive (Miller and Kerth, 2012).

Beef Species Flavor

Beef and pork have been shown to have similar meaty flavors, hypothesizing that compounds within the lean portion interacted with amino acids, carbohydrates, and polypeptides to produce the flavor of cooked meat (Hornstein and Crowe, 1960). The lipid portion of the meat is what separates beef flavor from other species, such as pork. Species-specific flavors as seen by Horstein and Crowe (1960) develops from the different types of free fatty acids and carbonyls which produce various volatiles when heated. Batzer et al. (1960) used column chromatography and gel filtration to conclude unknown, low-molecular-weight, water-soluble compounds, basic amino acids, carbohydrates, peptides, and phosphates were precursors to beef aroma.

Maillard Reaction

The Maillard reaction, which was discovered by Louis-Camille Maillard in 1912, is a large contributor to flavor in cooked meat and meat products (Billaud and Adrian, 2003). This reaction is a type of non-enzymatic browning that involved the reaction of carbonyl groups with free amino acids when cooked at high temperatures (Kerth and Miller, 2015). The main flavors developed from this reaction are sweet and bitter but the

Maillard reaction provides multiple compounds that contribute to flavor, off-flavor, aroma, and odor (Hurrell, 1982). Other flavors that have been seen to be produced from this reaction can be described as roasted, browned, meaty, caramelized and various others (Kerth and Miller, 2015).

Maillard reactions occur when amino compounds condense with the carbonyl group of reducing sugar in the presence of heat (Calkins and Hodgen, 2007). This produces gylcosylamine which is rearranged and dehydrated to form furfural, furanone derivatives, hydroxyketones, and dicarbonyl compounds. All of these products contribute to flavor of meat. As the reaction advances, the intermediates can react with other amines, amino acids, aldehydes, hydrogen sulfide, and ammonia through the Amadori rearrangement, Strecker degradation, and Schiff bases pathways. Once the reaction has progressed through the Schiff base, Strecker degradation, or other pathways, the reactions can lead to melanoidins (Calkins and Hodgen, 2007; Fay and Brevard, 2005). The type of product produced, either acceptable or unacceptable aromas and flavors, depend on the various types of sugar and amino groups. Cysteine and glucose produce mainly sulfur compounds whereas cysteine and glucose under oxidized conditions produce more pyrazines and furans (Calkins and Hodgen, 2007; Tai and Ho, 1997).

The Strecker degradation is another part of the Maillard reaction that contributes to development of flavor. The Strecker degradation is the degradation of amino acids which are then decarboxylated and deaminated to form an aldehyde, while dicarbonyl is converted to an aminoketone or aminoalcohol (Mottram, 1998; Kerth and Miller, 2015).

The aldehydes are condensed to aldols that form furans, pyrazines, pyrroles, oxazoles, thiazoles and other heterocyclic odor compounds (Shahidi & Ho, 1998). The compounds produced during this reaction have been seen to be some of the most pungent produced during cooking (Mottram, 1998). If the amino acid is cysteine, the production of hydrogen sulfide, ammonia and acetaldehyde can result (Thorpe & Baynes, 2003). The sulfur-containing compounds that are derived from cysteine and ribose produce important aromatic characteristics of cooked meats (Shahidi et al., 2004). In meat, the main sources of ribose are inosine monophosphate and other ribonucleotides (Mottram, 1998).

Lipid Thermal Degradation

Fatty aromas in cooked meat and compounds which determine some of the aroma differences between meat from different species is lipid thermal degradation. Lipid thermal degradation products tend to contribute to flavor to a greater extent than Maillard reaction products due to the breakdown of lipids versus water-soluble compounds (Mottram, 1998). It has been shown that the lipid compounds tend to be more dominant in flavor development, unless high-heat cooking methods are used to cause large amounts of browning with more Maillard reaction products (Mottram, 1998). Lipid degradation may add to the desirable flavor of cooked meat in many ways including undergoing a thermal oxidative change, producing compounds that can contribute to meat aroma. They also can react with components from lean tissue to create different flavor compounds and act as a solvent for aroma compounds accumulated during production, processing and cooking of meat (Mottram & Edwards, 1983).

Several hundred volatile compounds are produced from lipid thermal degradation which contributes to development of meat flavor (Mottram, 1998). Aliphatic hydrocarbons, aldehydes, ketones, alcohols and carboxylic acids and esters are a few on that list. Long-term storage encourages lipid degradation and can result in rancid off-flavors, but in cooked products, the reactions occur quickly to provide a different profile of volatiles that produce more desirable flavors (Mottram, 1998) Lipid thermal degradation is the breakdown of polar phospholipids and neutral triglyceride because of the change in energy stabilization during cooking. Polar lipids are generally favored for degradation over neutral lipids because of their higher degree of unsaturation and the lack of fatty acid on the third glycerol carbon (Kerth & Miller, 2015).

Lipid-Maillard Reactions

Maillard reaction products may also interact with volatile products from thermal lipid degradation to produce volatile flavor compounds. As these lipid oxidation products enter the Maillard reaction, particularly the Strecker degradation, ending in other volatiles not formed by meat precursors. Phospholipids in meat generally contribute the fatty acids that interact with Maillard reaction products (Melton, 1999). The removal of triacylglycerols from lean beef caused no significant chemical or sensory aroma differences, but removal of both triacylglycerols and phospholipids resulted in a less meaty, more roasted aroma, lower concentrations of oxidation products and higher levels of heterocyclic compounds, predominantly alkyl pyrazines (Mottram et al. 1983). Kerth and Miller (2015) stated that it is possible for lipid and Maillard compounds to interact. These interactions result in mild volatiles compared to the intensity of each primary reaction. The interactions of Maillard and lipid degradation products have been confirmed and provide a mechanism, that enables both interaction products to be controlled by the cooking process (Elmore et al., 1999).

Muscle Comparison

It has been shown that various muscles in the body have different flavor profiles based on color, location, and function in the body (Xiong et al., 1999). Shackelford et al. (1995) studied 10 major muscles from *Bos indicus* and *Bos taurus* cattle. This study showed that the *M. Longissimus lumborum* (LM) had greater beef intensity when compared to the *M. Biceps femoris* (BF) and the BF was beefier than the *M. Gleteus medius* (GM). The perception of meat flavor is influenced by hundreds of compounds that contribute to meat aroma and flavor. Flavor of meat can be influenced by lipid content, oxidation, animal's diet, pH, and myoglobin (Calkins and Hodgen, 2007). Calkins and Hodgen (2007) stated, while all of these factors influence flavor, there is a relationship between certain muscles within a single carcass and flavor. Specific animal effect, and animal diet can contribute to an off-flavor presence.

The effect of myoglobin concentration has also been shown to alter flavors of different muscles. Yancey et al. (2006) studied the total iron, myoglobin, hemoglobin and lipid oxidation of the *Infraspinatus* (IN), GM, and *Psoas major* (PM). The GM had higher amounts of myoglobin in the muscle and a higher incidence for livery off-flavors than the other cuts.

Between 1993 to 1998 the wholesale value of chucks, rounds, and trimmings had decreased 25-26%, while the value of the beef rib and loin increased about 4-5%

(USDA, 2005). There is considerable value that was being underutilized in the majority of the meat from the carcass, with the round muscles making up between 22-25% of a carcass (Seggern et al., 2005; Huff-Lonergan, 2009). This realization prompted the muscle profiling research by the University of Nebraska and University of Florida. Warner-Bratzler shear (WBS) force and sensory characteristics (juiciness and tenderness) of 39 different muscles from the beef chuck and beef round were evaluated (Johnson et al., 2003). Warner-Bratzler shear force measurements of the beef muscles, *biceps femoris* and the *semitendinosus,* were an average of 4.68 and 4.73 kg, respectively. When ranked into categories for tenderness, both of these muscles were classified as tough, while the *adductor* was an intermediate toughness muscle with an average shear force of 4.57 kg (Johnson et al., 2003).

Muscles from the round are high use muscles and are used for locomotion. Locomotive muscles have been shown to have a higher amount of connective tissue (Neely et al., 1998). The *adductor* (AD) muscle was utilized in an in-home consumer study. Consumers found that the AD muscle was tougher and had fewer flavors present once cooked (Neely et al., 1998). Muscles high in connective tissue have been recommended to be cooked using a moist heat method to break down the collagen more effectively (Neely et al., 1999).

Quality Grade

It has been repeatedly seen that increased marbling level and USDA quality grade have repeatedly been associated with increased beef eating quality (Savell et al., 1987; Smith et al., 1985). Quality grades are determined by evaluating several factors that can influence tenderness, juiciness, flavor, and overall palatability of meat. Evaluating these factors, USDA quality grades can predict consumer palatability. Quality grades are determined based on the degree of marbling and degree of maturity. The overall quality grade is a composite evaluation of carcass maturity; firmness, texture, and color of lean; and the amount and distribution of marbling. Following evaluation of these factors, carcasses are designated into one of the eight USDA quality grades; Prime, Choice, Select, Standard, Commercial, Utility, Cutter and Canner.

Marbling is the intermingling or dispersion of fat with the lean. A marbling score is assigned to a carcass by evaluating the amount of intramuscular fat in the *M. Longissimus dorsi* (LD) muscle at the 12^{th}-13^{th} rib interface. Cuts with increased marbling are expected to be more tender, juicy and flavorful than cuts with lower levels of marbling (Tatum, 2007). Marbling can have more of an influence on meat palatability when beef is cooked to higher endpoint temperatures (Dikeman, 1987). Marbling has a large impact on beef flavor as well. It has been believed that marbling can affect flavor in two ways: oxidation products produced from fatty acids upon heating, and the fat may act as a storage depot for other volatile compounds released during cooking (Hornstein, 1971). As the amount of available fat increases, this allows for formation of flavor compounds. McBee and Wiles (1976) and Smith et al. (1983) found that as marbling score increased from practically devoid to moderately abundant, the desirable flavors present increased. Smith et al. (1983) concluded as well, that marbling score indirectly assessed concentrations of flavor and aroma in beef. These finding show that carcasses with higher marbling scores should in theory, produce meat with more beefy flavors present. While marbling increased the beefy flavor in meat, increased marbling also decreased incidence of undesirable flavors. As the marbling scores increased from practically devoid to moderately abundant, the undesirable ratings decreased from more than 55 percent to zero (Smith et al., 1983). Following this trend, Miller et al. (1997) found that Choice steaks had a higher flavor intensity rating than Select steaks. Beef flavor, tenderness, and juiciness are all impacted by marbling and levels of marbling present.

Tenderness

While flavor is the key driving attribute for consumer acceptability, tenderness is still an important factor for acceptance. As previously discussed, tenderness was the most important factor influencing consumer satisfaction for beef palatability (Dikeman 1987; Miller et al., 1995; Savell et al., 1987; Savell et al., 1999). Due to large variation in tenderness, it is a large concern for the meat industry (Smith et al., 1992). Several variables including: animal age, gender, rate of glycolysis, amount and solubility of collagen, amount of intramuscular fat, sarcomere length, ionic strength, and degradation of myofibrillar proteins all affect meat tenderness (Koohmaraie, 1992).

The beef industry utilizes the USDA quality grading system to predict tenderness using marbling and carcass maturity. While marbling has a large influence, it only accounts for a low amount of variability in beef tenderness (Blumer, 1963). There are four theories to help explain marbling's effect on tenderness: bulk density, lubrication, insulation, and the strain theory (Smith and Carpenter, 1974). The bulk density theory suggests that within a portion of cooked meat, the occurrence of marbling decreases the mass per unit volume, lowering the bulk density by replacing protein with lipid. Fat is much more resistant to shear force than is coagulated protein, the decrease in bulk density is accompanied by an increase in tenderness (Smith and Carpenter, 1974; Savell and Cross, 1988). The strain theory suggests, as marbling is deposited in the perivascular cells inside the walls of the perimysium or endomysium, the connective tissue walls on either side of the deposit are thinned, thereby decreasing their effective width, thickness, and strength (Smith and Carpenter, 1974; Savell and Cross, 1988). The lubrication theory suggests, intramuscular fats, present in and around the muscle fibers, lubricate the fibers and fibrils so in turn, make for a more tender and juicier product that potentiates the sensation of tenderness. This theory follows the assumption that tenderness is closely associated with juiciness (Smith and Carpenter, 1974; Savell and Cross, 1988). Lastly, the insurance theory suggests that higher presence of marbling allows the use of high-temperature, dry-heat methods of cooking and/or a greater degree of doneness without adversely affecting the palatability of the meat. Marbling thus provides some insurance that meat that is over cooked, cooked too rapidly, or cooked incorrectly will still be palatable (Smith and Carpenter, 1974; Savell and Cross, 1988).

Postmortem aging is essential for reaching peak tenderness in meat. Upon completion of rigor mortis, meat is the least tender due to the shortening of sarcomeres (Aberle et al., 2001). Tenderness tends to increase as postmortem storage time increases (Wilson, 1960). Post-mortem tenderization is caused by enzymatic degradation of key proteins (Koohmaraie, 1996). The calpain system has an essential role in postmortem muscle protein degradation. The calpain system has an essential role in postmortem muscle protein degradation. Calpain is a calcium–activated, cysteine- protease that is most active in the neutral pH range (Strasburg, 2008). Regulation of calpain is done by calpastatin, a calpain-specific protein inhibitor, along with calcium and phospholipids (Goll et al., 2003). The three capains that are present in muscle and help with muscle fiber degradation are *m*-calpain, μ-calpain, and calpain 3 (Bartoli & Richard, 2005). μ -calpain is mostly responsible for postmortem tenderization (Koohmaraie, 1996). Calpain 3 (also called p94 or CAPN3) is a skeletal muscle-specific calpain isoform that binds to certain regions of titin (Sorimachi et al., 1995). Unlike m- calpain and μ-calpain, calpain 3 is not inhibited by calpastatin suggesting that it does not aid in meat tenderness because animals with high calpastatin do not produce tender meat (Kemp et al., 2010).

Both *m*-calpain and μ-calpain are concentrated in the Z-discs and can cause complete loss of the Z-discs (Strasburg, 2008). As Ca^{2+} concentration increases postmortem, mostly *m*-calpains and μ-calpains are activated and start degradation of muscle proteins such as troponin-T, titin, nebulin, C-protein, desmin, filamin, vinculin, and synemin (Huff-Lonergan et al., 1996). Once the Z-disks and other structural proteins are disrupted, actin and myosin are released together with other proteins from the sarcomere and become substrates for other proteolytic enzymes (Strasburg, 2008). Autolysis of *m*- and μ-calpain will happen in the presence of sufficient calcium with the ultimate loss of activity (Koohmaraie, 1992).

Collagen is the most abundant connective tissue protein that is found throughout the body and it is a large factor in meat tenderness variation. It contributes significantly to the toughness of muscle and is an important functional ingredient in many foods such as gelatin (Strasburg, 2008). Collagen molecules are held together through intermolecular crosslinks to help provide structure and strength to the collagen molecule. The crosslinks over time stabilize and are replaced by mature, thermally-stable, less soluble crosslinks. There are two types of collagen crosslinks that determine collagen solubility: heat-labile and heat- stable. Heat-labile collagen melts or gelatinizes in the presence of heat increasing tenderness; whereas, heat-stable collagen does not melt, decreasing tenderness. As an animal matures and ages, the crosslinks slowly stabilize into the insoluble, heat-resistant type causing a reduction in tenderness (Hill, 1966).

Cooking can cause tenderization or toughening of meat. Generally, heat makes collagen more tender by converting it to gelatin, but heat coagulates and toughens the protein. Davey and Gilbert (1974) showed cooking toughening in two stages. The first stage, which occurred at 40 to 50°C, denatured the contractile proteins, actin and myosin and caused an initial loss of fluid. The second stage, at 64 to 68°C, caused the denaturation of collagen resulting in the shrinkage of the fibrils and more fluid loss.

Degree of Doneness

Raw meat has been described as weak, salty, and blood-like in flavor and as the degree of doneness increases, the desirable characteristic beefy flavor evolves (Crocker, 1948). The temperature of the heating element and the method of cooking affect the rate of cooking (Crocker, 1948). This, combined with the final degree of doneness, impacted the rate and extent of chemical reactions (Kerth, 2013). Cooking method and final temperature greatly affect what flavor volatiles may develop from the flavor compounds that are present in raw beef (Miller and Kerth, 2012). Luchak et al. (1998) studied sensory, chemical and cooking characteristics of retail beef cuts differing in intramuscular and external fat. The lower internal temperature endpoint showed steaks were juicier and more tender and had the lowest Warner-Bratzler Shear values.

The National Livestock and Meat Board described temperature endpoints for beef as very rare, 55°C; rare, 60°C; medium rare, 65°C; medium, 70°C; well done, 75°C; and very well done, 80°C (Bowers, 1987). Meat cooked to these various endpoint temperatures have different characteristics present. By varying cooking methods and internal temperatures, Calkins et al. (2007) created different flavors ranging from bland to strong meaty notes, some with high grill-like flavor, and others were noticeably roasted. Bowers et al. (1987) found that as endpoint temperatures increased, mouth-filling flavor blend and browned flavor increased, while bloody/serumy, metallic and sourness decreased. Juiciness declined linearly as the final temperature increased, as expected.

Belk et al. (1993) cooked beef roasts to four different internal temperatures to evaluate flavor differences. At lower temperatures, metallic and astringent mouth feel, and bitter, sour, bloody/serumy, painty, and soured aromatics were more highly detected. As the temperature increased, so did cooked beefy/brothy, cowy/grainy, cardboardy and livery flavors.

Cooking Method

Cooking significantly affects the flavor and tenderness of meat. Cooking method will affect both temperature and moisture content which controls chemical reactions such as lipid degradation and Maillard reactions (Aberle et al., 2001). Cooking is the most important extrinsic flavor that impacts volatile aroma compounds (Kerth and Miller, 2015). The type of cooking method, specifically the difference between moist-heat and dry-heat cookery, will drastically change flavor development (Aberle et al., 2001). Cooking meat in water in a closed or partially closed system such as braising, boiling, simmering or stewing are all examples of moist- heat cookery. Moist-heat cookery with lower temperatures prevents the beef from reaching sufficient surface temperature for the development of Maillard reaction products and inhibits dehydration of the surface to initiate the first step of the Maillard reaction (Kerth and Miller, 2015). Moist-heat cookery, as in cooking stews or boiling meat, around 100°C will have a significantly different odor and flavor from meat that is produced when cooking meat by dry heat such as roasting at 163°C (Rhee, 1989). Dry heat cookery, such as grill and oven methods, uses higher temperatures to cause dehydration of the surface and initiate the Maillard reaction and browning (Kerth & Miller, 2015). Wasserman (1972) observed that the aromas stewed, or braised meat heated at 100°C was different from the same meat roasted with dry heat at 190°C. It was also noted was that the internal temperature varied from about 60°C to 80°C thus, the flavor is derived from the surface. Neely et al. (1999) focused on the cooking methods of top round steaks and found that moist-heat cookery methods had higher liking ratings. Consumer liking of the top rounds steak was dependent on cooking method and city-specific attitudes

Cooking method used can also influence degree of doneness or internal temperature as a part of the process. As the degree of doneness and internal temperature increases, the length of time that you have to cook the meat will also increase. There will be a difference in flavor because of the difference in the physical characteristics of the inside of the product as well as the outside of the product because of the changes in flavor profile (Kerth and Miller, 2015).

Acid Marination

Marination is widely used by consumers to improve meat flavor and tenderness. Marination affects tenderness in three different ways, potentially: pH induced swelling of muscle fibers and/or connective tissue; accelerated or additional proteolytic weakening of muscle structure, and increased solubilization of collagen upon cooking (Offer and Trinick, 1983; Offer and Knight, 1988; Ertbjerg et al., 1999). Numerous studies have shown that with low pH marination, meat tenderness can increase (Wenham and Locker, 1976; Gualt, 1985; Gualt, 1991). Wenham and Locker (1976) found that marinating *sternomandibularis* muscles showed improvement, as recorded by a panel, for tenderness. In contrast, steaks from *longissimus dorsi* muscle showed only slight differences in tenderness. Marinating of poor quality meat has very real benefit, but there is marginal benefit to marinating higher quality cuts (Wenham and Locker, 1976).

Gas Chromatography and Mass Spectrometry

Flavor analysis has been conducted for many years using a variety of methods in order to develop new products, understand existing products, examine shelf-life, and to provide quality foods and other products (Chambers and Koppel, 2013). Sensory and instrumental methods are the two primary forms of flavor analysis used. Sensory descriptive methods that have been developed are highly reliable and able to determine the human perception of flavor (Chambers and Koppel, 2013). The GC reigns as the optimal method of separating volatile flavors and aromas into compounds, while the MS is the most powerful technique to identify unknown compounds which makes the GC/MS system the technique of choice for instrumental flavor and aroma analysis (Shahidi, 1994).

In foods and beverages, headspace analysis is an option for instrumental determination of volatile compounds in a sample as the headspace contains volatiles that are responsible for the odor sensation (Chambers and Koppel, 2013). The GC/MS system has four steps in determining the compounds: collection of volatiles, separation of volatile compounds, identification of each compound, and quantification of each compound (Chambers and Koppel, 2013). This technique is commonly accepted and routine in flavor studies of muscle foods (Shahidi, 1994). There are several options to isolate and concentrate the volatile compounds from the matrix, such as steam distillation/extraction, supercritical CO_2 extraction, or the solid phase microextraction (Chambers and Koppel, 2013). Solid phase microextraction is a popular technique used in flavor analysis due to this technique being simple, low-cost, solvent-free and sensitive for the analysis of volatile compounds with a wide boiling point range (Ma et al., 2013).

The volatiles are collected with a solid phase microextraction (SPME) in the headspace of a container. The SPME then is injected into the GC/MS and desorbed. The GC is able to separate the volatiles into individual compounds as the MS identifies the compounds. This system is able to identify thousands of compounds although some might not be aromatic (Laird, 2015). Mottram (1998) stated that there are indications that only small fractions of a large number of volatiles occurring in food contribute to odor and aroma. The peak profile obtained by any chemical detector does not always necessarily reflect the human identified aroma profile of a compound. This is due to low odor threshold values which allows the odor to have sensory relevance, but the odor is occurring at a very low concentration (Shahidi, 1994). GC-O technology is instrumental in identifying flavor compounds and aroma profiles in food products. Data collected with this technology has been correlated to trained sensory panel flavor rating and consumer liking.

CHAPTER III

MATERIALS AND METHODS

Sample Selection and Preparation

USDA upper two-thirds Choice and USDA Select bottom round, eye of round, and inside round subprimals were purchased from Ruffino's Meats in Bryan, Texas. The bottom and eye of rounds were sliced into 0.64 cm, 1.91 cm, and 0.91 kg steaks and inside rounds were sliced into 0.64 cm, 1.91 cm and 5.08 cm steaks. The steaks were randomly assigned to cooking and internal temperature endpoint treatments for trained panel sensory evaluation and Warner-Bratzler shear force (WBSF). Each treatment used a different subprimal. The steaks were vacuum-packaged (B2470, Cryovac Sealed Air Corporation, Duncan, SC) in film with an oxygen transmission rate of 3-6 cc at 4°C (m2, 24 h atm @ 4°C, 0% RH) and a water vapor transmission rate of 0.5-0.6 g at 38°C (100% RH, 0.6 m2, 24 h). The steaks were aged for 14 d, frozen and stored at -40°C until evaluated. For each analysis, individual steaks were randomly selected and thawed in refrigerated (4°C) storage for 48 h.

Cooking

The steaks were cooked using a stir fry (Signature Enameled Cast Iron Skillet, 11 ¾ in, Le Creuset of America, Inc., Early Branch, SC), pan grill (Signature Enameled Cast Iron Square Skillet Grill, Le Creuset of America, Inc., Early Branch, SC), stew (Outdoor Gourmet 10 in Dutch Oven) or roast (GE Profile Free-Standing Self Clean Gas Range, Rapid City, SD).

Stew samples both 0.64 cm and 1.91 cm cuts, were cut into 0.64 x 2.54 x 2.54 cm and 1.91 x 2.54 x 2.54 cm pieces prior to cooking. Stir fry samples were cut across the grain into 2.54 cm strips. Stew marinated samples were marinated with 118 mL water, 90 mL lemon juice, 30 mL canola oil, 5 mL salt, and 2.5 mL pepper. Samples were cut and marinated 12 hours prior to cook time.

Stewing is a cooking method that utilizes moisture, low heat, and time. High connective tissue cuts, like the bottom round, can be cooked using the stewing methods to assist in solubilizing connective tissue and improving meat tenderness. Bottom round cuts were stewed or marinated prior to stewing with a low pH lemon based marinade. For each stew or stew marinade treatment, 0.64 and 1.91 cm thick beef bottom rounds were cut into 0.64 x 2.54 x 2.54 cm and 1.91 x 2.54 x 2.54 cm pieces, respectively. Two cups of water were added to provide the moisture that is an important component of stewing. Cuts, both marinated and non-marinated, were then cooked either 30 minutes, 1.5 hours, or 3.0 hours.

The steaks assigned to stir fry, pan grill and roast were cooked to an internal temperature of either 58.3, 70 or 80°C to represent medium rare, medium and well done degrees of doneness. For stir fry and pan grill, pans were placed on copper diffusion plates to eliminate hot spots. Pans and oven were preheated to 177°C and monitored using an infrared meter. Samples that were stir fried were cooked with 14.8 mL of canola oil and strips were added and stirred for 1 to 2 minutes until final endpoint temperature was reached. Stewed samples were cooked with 29.6 mL of canola oil. The cubes were added and slowly browned on all sides. The drippings were discarded, and 3 cups of water were added. The Dutch oven was covered, and the meat cooked on low heat until cooked time was reached. Roasted samples were added to roasting pan and set on wire rack with 2 cups of water added to bottom of pan. Internal temperatures were monitored by iron-constantan thermocouples or probes (Omega Engineering, Stanford, CT) inserted into the cut geometric center of each steak. Sensory was conducted as defined by AMSA (2015) and Meilgaard et al. (2007). Sensory evaluations were approved by the Institutional Review Board for Use of Humans In Research at Texas A&M University (IRB2016-0609M).

Expert, Trained Descriptive Meat Flavor Analysis

Samples were evaluated by an expert trained meat descriptive attribute panel that helped develop and validate the beef lexicon. This panel (n = 5) was trained using the beef lexicon for 18 days (Adhikari et al., 2011). Panelists were retrained for one day between each cut to refamiliarize them with beef flavor lexicon attributes. Beef flavor attributes were measured using a 16-point scale (0 = none and 15 = extremely intense) defined in Table 1. After training was complete, panelists were presented fifteen samples per day. Testing occurred over a period of 61 days. Prior to the start of each trained panel evaluation day, panelists were calibrated using one orientation or "warm up" sample that was evaluated and discussed orally. After evaluation of the orientation sample, panelists were served the first sample of the session and asked to individually rate the sample for each beef flavor lexicon attribute. Double distilled water, sparkling water and unsalted saltine crackers were available for cleansing the palette between samples. During evaluation, panelists were seated in individual breadbox-style booths separated from the preparation area and samples were evaluated under red lights. In order to prevent taste fatigue, each evaluation day was divided into two sessions, with a ten-minute break between sessions. Samples were served so that there was at least four minutes after evaluation of a sample before the next sample was served.

After cooking, samples were cut for panelist evaluation. For 0.64 and 1.91 cm thick stewed samples the cubes were kept whole. For roasts, all visible browning was removed, and 1.27 cm cubes were cut. For all samples, three cubes per sample were served in 59 mL clear, plastic soufflé cups tested to assure that they did not impart flavors in the samples. Samples were identified with random three-digit codes and served in random order. Samples were cut and served immediately to assure samples were approximately 37˚ C upon time of serving.

Warner-Bratzler Shear Force

Tenderness was evaluated using WBSF as described by the American Meat Science Association guidelines (AMSA, 2015). Steaks were cooked as detailed above, then placed on a tray and overwrapped with polyvinyl chloride. Samples were stored at room temperature for at least 4 hours. Following cooling, with the 1.91 cm pan grill steaks and roasts, 4 to 6 cores (1.3-cm in diameter) were removed parallel to the muscle fiber orientation, randomly throughout the steak. Pan grill 0.64 cm steaks and stew method, 0.64 cm and 1.91 cm cubes were left as is. Individual cores and cubes were sheared once, perpendicular to the muscle fibers, on a United Testing machine (United

SSTM-500, Huntington Beach, CA) at a cross-head speed of 200 mm/min using a 500 kg load cell, and a 1.02 cm thick V-shape blade with a 60° angle and a half-round peak. The peak force was recorded for each core and cube, and all cores and cubes for each steak were averaged to determine the WBSF value of each sample.

Cooked Meat Volatile Flavor Evaluation

Volatiles were captured from the same steaks evaluated by the trained panelists. After samples were prepared for panelists, the remaining sample was placed in foil with a tag separated from the meat samples. Samples were placed in liquid nitrogen and frozen to -196°C. Samples were stored at -80°C until volatile analysis. Pooled samples, representative of all six samples in one treatment, were placed in heated glass jars (473 mL) with a Teflon lid under the metal screw-top to avoid off-aromas. Glass jars were set in a water bath at 60°C and thawed, then the headspace was collected with a Solid-Phase Micro-Extraction (SPME) Portable Field Sampler (Supelco 504831, 75 µm Carboxen/ polydimethylsiloxane, Sigma-Aldrich, St. Louis, Mo). The headspace above each meat sample in the glass jar was collected for 2 h for each sample after the sample reached 60°C. Upon completion of collection, the SPME was injected in the injection port of the GC, where the sample was desorbed at 280°C. The sample was then loaded onto the multi-dimensional gas chromatograph into the first column (30m X 0.53mm ID/ BPX5 (5% Phenyl Polysilphenylene-siloxane) X 0.5 µm, SGE Analytical Sciences, Austin, TX), which separates compounds based on boiling point. Through the first column, the temperature started at 40°C and increased at a rate of 7°C/minute until reaching 260°C.

Upon passing through the first column, compounds were sent to the second column ((30m X 0.53mm ID)(BP20- Polyethylene Glycol) X 0.50 µm, SGE Analytical Sciences, Austin, TX), which separates compounds due to polarity. The gas chromatography column then spilt into three different columns at a three-way valve with one going to the mass spectrometer (Agilient Technologies 5975 Series MSD, Santa Clara, CA). Volatile aromatic compounds were identified using the mass spectrometer and reported as area under the peak.

Statistical Analyses

The trained panel descriptive flavor attributes and the volatile compounds were analyzed using Proc GLM procedures of SAS (version 9.4, SAS Institute, Cary, NC) to understand treatment affects. A predetermined alpha of ($P < 0.05$) was used . Prelimenary analysis of trained descriptive data was conducted for each sensory attribute where panelist, panelist by Quality grade, panelist by treatment, and treatment were included as main effects. Sensory day and order were included as a random effect. This analysis was conducted to evaluate the efficacy of panelists while panelist effects were significant ($P < 0.05$) for some attributes, and interactions, leas square means did not differ more than 1.0, the trained sensitivity of the panel. Therefore, data was averaged across panelists and sensory day and order served were defined as random variables. For volatile category data, treatment was included as the main effect. Least squares means were calculated and the pdiff function of SAS was used to determine differences between least squares means when significance was defined by Analysis of Variance. If sensory attributes were not present or detected at very low levels (< 0.1), then attributes were not reported.

Principal component analysis (PCA) and partial least squares regression (PLS) were conducted using XLSTAT (v2013, Microsoft Corporation, Redmond, WA). Data were presented in bi-plots.

CHAPTER IV

RESULTS AND DISCUSSION

Expert, Trained Descriptive Meat Flavor Analysis

The beef flavor attributes, definition and reference standards are presented in Table 1 (Adhikari et al., 2011). The texture attributes for juiciness and tenderness were also included in Table 1 (AMSA, 2015). Descriptive sensory attributes were evaluated using a 16 point scale where 0 = none and 15 = extremely intense for flavor attributes and 0 = extremely dry, extremely tough, and abundant and 15 = extremely juicy, extremely tender and none for juiciness, overall tenderness, and connective tissue amount respectively.

Bottom Round

Least squares means for descriptive flavor and texture attributes for bottom round cuts are presented in Table 2. Quality grade affected fat-like ($P = 0.00$), green ($P = 0.03$), and buttery ($P = 0.03$) flavors. Choice bottom rounds had a slightly higher fat-like flavor than Select as expected, since beef cuts with high levels of marbling are expected to be more tender, juicy and flavorful than cuts with lower levels of marbling (Tatum, 2007; Philip, 2011). It is expected that positive flavor attributes would be more prevalent in the Choice quality grade cuts, as quality grade is a predictor for consumer palatability (tenderness, juiciness, flavor) according to Smith et al. (1983). Level of attributes, such as bloody/serumy, burnt, smokey charcoal, and roastedare more dependent on degree of doneness and cooking method than Quality grade (Glascock, 2014; Laird, 2015; Luckemeyer, 2015).

Cooking treatment affected flavor and texture attributes in bottom round. For pan grilled bottom rounds, thicker bottom round meat had higher levels ($P < 0.0001$) of beef identity, browned, bloody/serumy, fat-like, metallic, umami, and sweet flavor attributes, and lower levels ($P < 0.0001$) of roasted, liver-like, cardboardy, musty-earthy, and astringency. Additionally, 1.91 cm thick pan grilled bottom round cuts were juicier, more tender and had slightly less connective tissue present ($P < 0.0001$). As internal temperature increased within 0.64 cm and 1.91 cm thick bottom round products, browned, roasted, and umami flavor attributes increased ($P < 0.05$) and bloody/serumy, musty earthy, astringent, juiciness and tenderness flavor and texture attributes decreased ($P < 0.05$).

Roasted 0.91 kg bottom round cuts had lower ($P < 0.0001$) levels of brown, cardboardy, heated oil, and musty earthy flavor attributes, and higher ($P < 0.0001$) levels of roasted flavor attributes and connective tissue amount when compared to pan grilled bottom round cuts. As internal temperature increased for bottom round roasts, beef identity, browned, roasted, liver-like, umami, cardboardy, and astringent flavor attributes increased ($P < 0.0001$), and connective tissue amount was less detected ($P < 0.0001$). Bloody/serumy, metallic, sour, and salty flavor attributes, and juiciness and muscle fiber tenderness texture attributes decreased ($P < 0.0001$) as internal temperature increased. These results agree with Belk et al. (1993) who reported that beef roasts cooked to lower degree of doneness had higher metallic mouthfeel, and bloody/serumy, and sour flavors than roasts cooked to higher degrees of doneness. The method of roasting in this experiment was a moist heat cookery method, as water was added. McDowell et al.

(1982) stated that roasts cooked with a moist heat cookery method produced less tender and juicy roasts with more well done flavor, which follows the results presented here.

When 0.64 cm bottom round cuts were stir fried, flavor was similar to pan grilled, 0.64 cm cuts. Bottom round cuts that were stir fried to an internal temperature of 58°C and 80°C were higher in roasted, fat-like, cardboardy, and heated-oil flavor attributes, and lower in beef identity, browned, sweet, and salty flavor attributes compared to stir fried cuts cooked to 70°C ($P < 0.0001$). As internal temperature increased, tenderness was affected as juiciness and muscle fiber tenderness decreased ($P < 0.0001$), and connective tissue amount increased ($P < 0.0001$).

Stewed bottom rounds that were 1.91 cm thick and were not marinated had higher ($P < 0.0001$) levels of beef identity, browned, roasted, metallic, umami, sweet, and salty flavor attributes; and lower ($P < 0.0001$) levels of cardboardy, heated oil, and astringent flavor attributes; and were tougher than 0.64 cm thick pieces not marinated ($P < 0.0001$). When beef bottom round cuts were marinated, similar differences in flavor between 0.64 cm and 1.91 cm pieces were observed. However, marination impacted flavor and texture of beef bottom round pieces, especially for 0.64 cm pieces. Most likely, the low pH lemon based marinade was able to penetrate the surface of the 0.64 cm pieces more effectively. The 0.64 cm marinated beef bottom round pieces had lower ($P < 0.0001$) beef identity, browned, fat-like, umami, sweet, cardboardy, heated oil, peppery, and astringent flavor attributes; higher ($P < 0.0001$) metallic, sour, salty, and bitter flavor attributes; and were juicier and more tender with less connective tissue ($P < 0.0001$). As lemon juice, salt and pepper were components of the marinade, differences in sour, salty and peppery would be expected. These results indicate that for 0.64 cm bottom round pieces, marination improved juiciness, tenderness and connective tissue, especially in thinner cut beef bottom round pieces. Increased cook time for marinated and non-marinated bottom round pieces for both thicknesses improved tenderness, both sensory tenderness and Warner-Bratzler shear force (Table 5). The cooking times could have provided more opportunity for connective tissue solubilization, but also may have provided more opportunities for development of off flavors associated with lipid oxidation.

Interactions for quality grade by cooking method were significant for bottom round cuts for roasted (Figure 1) and buttery flavor attributes. Roasted flavor attribute was higher in the Select 0.64 cm pan grilled treatments than in Choice 0.64 cm cut, but was shown to have lower roasted than Choice in the 1.91 cm pan grilled steaks. The roasted flavor in choice bottom round cuts roasted was more intense than Select counterparts. For Choice stew treatments, without marinade present, roasted flavor was higher and as cooking temperature increased roasted flavor attribute levels increased. In the Select roasts, the same trend was not observed. Adding the marinade to the stew treatments, showed as internal temperature increased in the Select steaks, roasted flavor increased, and roasted flavor did not increase in the Choice steaks of the same treatment.

A partial least squares regression for trained descriptive flavor attributes and treatments is shown in Figure 2. For bottom rounds, beef identity, umami, brown, sweet, and fat-like flavors were clustered and negatively associated with astringent, muscle fiber tenderness, bitter, salty, sour and peppery. Bloody/serumy, juiciness and buttery flavor attributes were closely related and positively related to beef identity, umami, brown, sweet and fat-like. Interestingly, 1.91 cm pan grilled bottom round cuts and roasted bottom rounds were related to bloody serumy, smoky charcoal, and juiciness. The thinner pan grilled bottom round cuts and thicker non-marinated stewed bottom round cuts, and 0.64 cm stir fried cuts were related to beef identity, umami, liver-like and browned flavor attributes. Heated oil, cardboardy, roasted and musty earthy humus flavor attributes were clustered and negatively related to smoky charcoal, burnt, green and metallic flavor attributes. The marinade treatments were clustered with muscle fiber tenderness, astringent, peppery, bitter, burnt, green, sour and salty sensory attributes and non-marinade treatments were more closely associated with cardboardy, heated oil, roasted and musty earthy humus flavor attributes. As lemon juice, salt and pepper were used in the marinade, differences in flavor were expected.

Eye of Round

Least squares means for descriptive flavor and texture attributes for bottom rounds are presented in Table 3. Quality grade only affected the buttery flavor attribute ($P = 0.05$). As with bottom round, cooking treatment affected flavor and tenderness attributes. Cooking treatment affected all flavor and texture attributes except green, and astringency flavor attributes.

For pan grilled eye of rounds, thicker steaks had higher bloody/serumy, fat-like, metallic, and sweet flavor attributes. Thicker steaks as well were juicier, and had more connective tissue present than the thinner cuts ($P < 0.0001$). Thinner eye of round steaks that are pan grilled showed higher off flavors present, with increased liver-like, cardboardy, burnt, heated oil, and musty earthy flavor attributes. As internal temperature increased with the 1.91 cm steaks, there was an increase in beef identity, browned, and roasted flavor attributes ($P < 0.0001$). These results were expected, as internal cooked temperature increased, there was additional time for Maillard reactions to occur and therefore, potential for more brown and roasted flavors. With the same 1.91 cm steaks, as temperature increased there was a decrease in sour, bitter, astringent, and muscle fiber tenderness attributes ($P < 0.0001$). As internal temperature increased with the 0.64 cm steaks liver-like, musty/earthy, astringent flavor attribute, and connective tissue amount increased ($P < 0.0001$). Looking at both 0.64 cm and 1.91 cm steaks, umami, and sweet flavors increased while bloody/serumy and juiciness decreased when internal endpoint temperature increased ($P < 0.0001$).

Roasted eye of rounds had lower beef identity, browned, metallic, and sweet flavor attributes and were higher in juiciness, muscle fiber tenderness, and connective tissue amount when compared to pan grilled eye of round steaks ($P < 0.0001$). As internal temperature increased, eye of round roasts were higher in beef identity, browned, roasted, umami, and cardboardy flavor attributes, while bloody/serumy, fat-like, metallic, sour, and bitter flavor attributes decreased ($P < 0.0001$). As internal temperature increased, juiciness of roasts decreased ($P < 0.0001$). According to Adhikari et al. (2011), metallic and bloody/serumy are closely related. These results also agree with research that has shown steaks cooked to lower internal cook temperature endpoints will tend to have higher bloody flavors (Glascock, 2014; Laird, 2015; Luckemeyer, 2015).

When eye of round steaks were stir fried, similar results to the pan grilled 0.64 cm steaks were reported. As internal temperature increased, there was an increase ($P < 0.0001$) in beef identity, roasted, liver-like, and green flavors, and a decrease ($P < 0.0001$) in fat-like, sour, cardboardy, and heated oil flavor attributes. Internal temperature affected texture attributes as well. As temperature increased from 58°C to 80°C juiciness decreased. These results agree with Lorenzen et al. (1999) that stated as degree of doneness increased, juiciness decreased.

Stewed 1.91 cm eye of round pieces that were not marinated had higher ($P < 0.0001$) levels of beef identity, browned, roasted, fat-like, umami, sweet, and salty flavor attributes, and lower ($P < 0.0001$) levels of metallic, cardboardy, burnt, musty/earthy, and astringent flavor attributes. As cooking time increased, there was an increase ($P < 0.0001$) in beef identity, browned, fat-like, umami, and salty flavor attributes in the 1.91 cm pieces. However, there was a decrease ($P < 0.0001$) in the same flavors in the 0.64 cm pieces as cooking time increased. Heated oil flavor increased ($P < 0.0001$) in intensity as cut thickness as cooking temperature increased. Tenderness attributes followed the same trend as with bottom round cuts. As cooking time increased in thicker cuts, tenderness increased and the amount of connective tissue decreased ($P < 0.0001$). For thinner pieces, little difference in tenderness attributes was seen. Eye of round pieces that were stewed following marination, had similar results as the eye of round pieces that were not marinated. For thicker pieces that were marinated, there was higher ($P < 0.0001$) beef identity, browned, roasted, fat-like, umami, sweet, salty, and peppery flavor attributes, and decreased ($P < 0.0001$) metallic, sour, bitter, cardboardy, burnt, and astringent flavor attributes. Juiciness and muscle fiber tenderness texture attributes were lower in thicker pieces and thicker pieces had more connective tissue ($P < 0.0001$). As discussed, the salt and pepper were components of the marinade so differences in these attributes would be expected. Marination largely affected tenderness and connective tissue amount in the thinner cuts. As cooking time increased beef identity, browned, roasted, umami, heated oil, and tenderness increased ($P < 0.0001$). As cooking time increased there was a decrease ($P < 0.0001$) in fat-like, salty, bitter, and juiciness attributes.

A partial least squares regression for trained descriptive flavor attributes and treatments is shown in Figure 3. For eye of rounds, similar trends were present as with bottom round cuts. Beef identity, umami, brown, sweet, and fat-like flavors were clustered and negatively associated with astringent, muscle fiber tenderness, bitter, salty, sour and peppery. Bloody/serumy and juiciness were closely related and positively related to beef identity, umami, brown, sweet and fat-like flavors. Pan grilled 0.64 cm and 1.91 cm eye of round cuts were related to bloody/serumy, browned, smoky charcoal, and beef identity flavor attribute. Heated oil, cardboardy, roasted and musty earthy humus were clustered and negatively related to smoky charcoal, burnt, green and metallic flavors. The marinade treatments were clustered with muscle fiber tenderness, astringent, peppery, bitter, sour and salty and non-marinade treatments were more closely associated with cardboardy, heated oil, roasted and musty earthy humus.

Inside Round

Least squares means for descriptive flavor and texture attributes for inside rounds are presented in Table 3. Quality grade affected sweet ($P = 0.02$), cardboardy ($P = 0.05$), juiciness (P = 0.00), and muscle fiber tenderness (P = 0.03) attributes. Choice inside round steaks had slightly higher sweet flavor and Select steaks had slightly more intense cardboardy flavor. Choice steaks were juicier and were more tender than Select inside steaks. Cooking method affected all flavor and texture attributes.

For pan grilled inside round cuts, thicker steaks had higher ($P < 0.0001$) beef identity, browned, bloody/serumy, fat-like, metallic, umami, sweet, and salty flavors, and lower ($P < 0.0001$) roasted, liver-like, bitter, cardboardy, heated oil, musty earthy, and smoky charcoal flavors. Pan grilling is a form of dry cookery and has been associated with higher positive beef flavor attributes (Hood et al., 1995). Hood et al. (1995) stated that dry heat cookery has been observed to produce cuts with greater desirability and aroma. Thicker steaks were less tender and juicy than the thinner 0.64 cm steaks ($P < 0.0001$). As internal temperature increased liver-like, salty, and astringent increased ($P < 0.0001$), and sour and muscle fiber tenderness decreased ($P < 0.0001$). This was expected as increased internal temperature has been related to tougher beef (Luchak et al., 1998). It has been shown that cooking method significantly affects the flavor and tenderness of muscle since it will affect temperature and moisture content (Aberle et al., 2001). With 1.91 cm steaks, as internal temperature increased there was a decrease ($P < 0.0001$) in bloody/serumy, but the same effect was not reported for thinner steaks.

Roasting impacted inside round roasts similarly to bottom round and eye of round roasts. Compared to pan grilled inside round steaks, there was slightly less connective tissue present ($P < 0.0001$) in inside round roasts. As internal temperature increased there was an increase ($P < 0.0001$) in beef identity, browned, roasted, umami, cardboardy, and connective tissue amount. As temperature increased bloody/serumy, fat-like, metallic, sweet, sour, bitter, juiciness, and muscle fiber tenderness decreased ($P < 0.0001$). These results agree with Bamsey (2016) that found, steaks cooked for a longer period of time to a higher internal temperature endpoint, had more intense umami flavor ($P < 0.0001$).

Stir fried inside round steaks had lower browned than pan grilled eye of rounds steaks. This would be expected as cook times were less for stir fried inside round steaks than pan grilled eye of round steaks. Less time would decrease the rate of Maillard reactions. As internal temperature increased, there was an increase in beef identity, roasted, umami, and salty flavors ($P < 0.0001$). Inside rounds cooked to 58°C and 80°C were more closely related in flavor and texture attributes than the inside rounds cooked to 70°C.

Thicker stew pieces, both marinade and non-marinade, had more intense ($P < 0.0001$) beef identity, browned, roasted, fat-like, umami, sweet, and salty flavors and lower ($P < 0.0001$) bitter, cardboardy, and musty/earthy, peppery flavors. As cooking time increased, non-marinated cuts had less intense roasted, metallic, and heated oil flavors ($P < 0.0001$). Marinated 1.91 cm pieces had more intense ($P < 0.0001$) beef identity, browned, roasted, umami, sweet, and bitter attributes. The 0.64 cm inside round pieces had lower intensity of these same attributes. The 1.91 cm inside round marinated pieces had lower levels ($P < 0.0001$) of metallic, sour, musty/earthy, and astringent flavor attributes; whereas these same attributes increased in the 0.64 cm pieces ($P < 0.0001$). Stewed treatments, both marinade and non-marinade, were more tender and with less detectable connective tissue amount as cook time increased ($P < 0.0001$).

A partial least squares regression for trained descriptive flavor attributes and treatments is shown in Figure 4. Inside rounds showed similar clusters as with bottom and eye of rounds previously discussed. Beef identity, bloody/serumy, umami, brown, sweet, and fat-like flavors and juiciness attributes were clustered and negatively associated with astringent, muscle fiber tenderness, bitter, salty, sour and peppery attributes. Pan grilled eye of round cuts 0.64 cm and 1.91 cm were related to bloody serumy, browned, smoky charcoal, and beef identity. Heated oil, cardboardy, roasted and musty earthy humus flavors were clustered and negatively related to smoky charcoal, burnt, green and metallic flavors. The marinade treatments were clustered with muscle fiber tenderness, astringent, peppery, bitter, sour and salty attributes and non-marinade treatments were more closely associated with cardboardy, heated oil, roasted and musty earthy humus attributes.

Cooked Meat Volatile Flavor Evaluation

Bottom Round

Volatile aromatic compounds are reported in Table 5. Sixty seven total volatile aromatic compounds were reported for the different cuts. A partial least squares regression biplot is presented in Figure 2 to understand the relationships between volatile aromatic compounds and descriptive sensory attributes for the bottom round. Only volatiles with a variable importance in the projection (VIP) of greater than 0.80 were reported in the PLS. Stew no marinade treatments were closely related to 2,4-decadienal (oily, chicken fat, sweet, orange aromas; Burdock, 2010), 3-dodecen-1-al, cyclooctane, 1-heptanol (floral, fruity, apple, citrus aromas), 2-pentyl-furan (green, waxy, caramel aromas), 2-ethyl-furan, 2-hexenal (green apple, bitter, almond aromas), 2-heptenal (brassy, herbaceous, green aromas), 2,4-hexadienal (sweet, green aromas), 2,3-octanedione (warmed over flavor), decanal (orange and citrus aromas; Kerth and Miller, 2015), and 2-decanal.The majority of the compounds that were closely related to the stew treatments were a part of the aldehyde functional group. These aldehyde compounds are shown to be associated with lipid oxidation (Kerth and Miller, 2015). The pan grill and roasted treatments was shown to be antagonistic to the stew no marinade treatment. There are no compounds that were reported that are closely related to these treatments. Compounds that would be expected to be related to the pan grill treatment would be compounds associated with the Maillard reaction such as pyrazines, which are a common intermediate of the reaction (Wall, 2017). Stew marinade treatments were closely related to L-limonene (lemon-like, citrus aroma), and 2-docecen-1-al (soapy, waxy, citrus, orange flavor).

Eye of Round

For eye of rounds, a partial least squares regression biplot is presented in Figure 3. Majority of volatile compounds reported were closely associated with the stew treatments. The pan grill and roast treatments were not shown to be closely related to any compounds presented. These treatments are closely related to the browned, smoky charcoal flavor attributes, which would likely be associated with compounds produced form the Maillard reaction.

Stew marinade treatments were shown to be closely related to cyclooctane, 3-ethyl-benzaldehyde, tetradecanal, sulfur dioxide, copaene, linalyl propionate, and heptenal. Tetradecanal is described as a fatty aroma, and linalyl propionate is described as being a sweet, floral aroma. Heptenal is described as having a very strong, fatty, pungent odor, and an unpleasant, fatty taste (Burdock, 2010).

Inside Round

For inside rounds, a partial least squares regression biplot is presented in Figure 3. Pan grill treatments of both 0.64 cm and 1.91 cm were closely related to 3-ethyl-2,5-dimethyl- pyrazine, 2,5-dimethyl-pyrazine, 3-methyl-butanal, 2-butanone, and 1,1-dodecanediol-diacetate. 3-eithyl-2,5-dimethyl-pyrazine is described as peanut, caramel, coffee, popcorn aroma, 2,5-dimethyl-pyrazine is a meaty, musty, potato, cocoa aroma, 3-methyl-butanal is malty aroma, 2-butanone is a chemical-like, fruity-green aroma (Kerth and Miller, 2015). Pyrazines are a product of the Maillard reaction and have a distinct roasted aroma (Glascock, 2014). The pan grilled treatments are closely related to the browned, smoky charcoal flavor attributes, so it is expected that they would be clustered with the pyrazine volatile compounds present.

Stew marinade treatments were closely related to benzoic acid (faint urine and almond odor), linalyl propionate (sweet, floral aroma), tetradecanal (fatty aroma), dimethyldisulfide (onion aroma; Burdock, 2010), and 1,4-cyclohexadiene,1-methyl-4-(1-

methylethyl)-. Stew non-marinade treatments were closely related to hexanal, pentadecane, 4-ethyl-benzaldehyde, and pentanal. Hexanal is described as a green, grassy aroma, and pentanal is described as a winey, fermented, bready aroma (Kerth and Miller, 2015). Hexanal is known to be a product of lipid oxidation (Mottram, 2007).

Warner-Bratzler Shear Force

WBSF values (Table 5) for beef bottom, eye of round and inside round cuts showed similar trends as reported for sensory tenderness, but the magnitude of differences were more apparent. Quality grade did not affect WBSF for bottom and eye of round cuts, but Select inside round cuts were slightly tougher ($P = 0.04$) than Choice inside round cuts. Pan grilling thinner cuts had higher shear force values for bottom round cuts ($P < 0.0001$), but pan grilled 1.91 cm inside round cuts were more tender than the thinner pan grilled inside round cuts ($P < 0.0001$). Thickness did not impact WBSF values for eye of round pan grilled cuts. As internal temperature increased from 58°C to 80°C for pan grilled bottom and inside round cuts, WBSF values increased ($P < 0.0001$). For eye of round 0.64 cm thick cuts, as internal temperature increased, WBSF values decreased ($P < 0.0001$), or thin eye of round cuts were more tender.

As internal temperature endpoint increased for bottom round roasts, bottom round roasts were tougher ($P < 0.0001$), but internal temperature endpoint did not affect WBSF values for eye of round roasts ($P < 0.0001$). However, inside round roasts increased in WBSF to a greater extent as internal temperature increased for inside round roasts compared to bottom round roasts ($P < 0.0001$).

Stir fried bottom round cuts had higher WBSF values, regardless of internal temperature endpoint, then stir fried eye of round or inside round cuts ($P < 0.0001$). Interesting, stir fried eye of round cuts did not differ in WBSF as internal temperature increased, but as internal temperature increased for bottom and inside round stir fried cuts, WBSF values increased ($P < 0.0001$).

The 1.91 cm thick non-marinated round cuts were substantially tougher than the 0.64 cm thick non-marinated round cuts ($P < 0.0001$). Regardless of cut thickness, as stew time increased from 30 minutes to 3 hours, cuts were more tender for bottom round and eye of round cuts ($P < 0.0001$). However, 1.91 cm thick non-marinated inside round cuts did not appreciably change in tenderness with increased cooking time. Marinating thinner cuts resulted in lower WBSF values for the three round cuts ($P < 0.0001$), but marination did not improve tenderness of 1.91 cm thick round cuts ($P < 0.0001$). Whereas cook time for 1.91 cm thick cuts did not improve tenderness for non-marinated round cuts, marinated 1.91 cm thick round cuts had lower WBSF values with increased cooking time ($P < 0.0001$). This effect was most pronounced for bottom round and eye of round cuts. Marination and increased cook time greatly impacted tenderness of all cuts ($P < 0.0001$). Marination would be recommended to impact flavor profile. Marination did improve tenderness as cook time increased for 1.91 cm thick eye of round and inside round cuts.

CHAPTER V

CONCLUSIONS

Cut thickness, cooking method, length of cooking or internal cook temperature endpoint, and marination affected flavor and texture of bottom round, eye of round and inside round cuts. Quality grade impacted flavor for inside rounds. As beef round cuts are high use muscles in the animal and contain higher amounts of connective tissue it is not surprising that USDA Quality grade had minimal effect. Cooking method and internal cook temperature endpoint or cooking time for the stewing cooking treatment tended to impact beef flavor to a greater extent. For pan frying, thicker cuts resulted in beef that had more positive flavor attributes. When roasting round cuts, cooking to higher internal temperatures resulted in more beef identity, roasted, and umami flavors and less serumy/bloody flavors, but tenderness decreased, especially in inside round roasts. Marination of round cuts was most effective in improving tenderness of cuts that were thicker and increased cooking time improved tenderness, but increased levels of off-flavor development. This data will be useful in predicting consumer liking for these cuts for the Beef Flavor Myology tool.

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APPENDIX A

TABLES

Table 1. Definition and reference standards for beef descriptive flavor aromatics and basic taste sensory attributes and their intensities where 0 = none and 15 = extremely intense from Adhikari et al. (2011).

Attributes	**Definition**	**References**
Flavor		
Beef Flavor ID	Amount of beef flavor identity in the sample.	Swanson's beef broth = 5.0 80% lean ground beef = 7.0 Beef brisket (160 °F) = 11.0
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% caffeine solution = 2.0 0.02% caffeine solution = 3.5
Bloody/Serumy	The aromatics associated with blood on cooked meat products. Closely related to metallic aromatic.	USDA Choice strip steak (60° C internal) = 5.5 Beef brisket = 6.0
Browned	Aromatic associated with the outside of grilled or broiled meat; seared but not blackened or burnt.	Steak cooked at high temperature (internal 137° F, seared on outside)
Burnt	The sharp/acrid flavor note associated with over roasted pork muscle, something over baked or excessively browned in oil.	Arrowhead Mills Puffed Barley Cereal= 3.0
Buttery	Sweet, dairy-like aromatic associated with natural butter.	Land O'Lakes Unsalted butter = 7.0
Cardboardy	Aromatic associated with slightly oxidized fats and oils,	Dry cardboard (1 in. square) = 5.0 (a) Wet cardboard (1 in. square and 1

	reminiscent of wet cardboard packaging.	cup water) = 7.0 (a)
Fat-Like	The aromatics associated with cooked animal fat.	Hillshire farms Lit'l beef smokies = 7.0 Beef suet = 12.0
Green	Sharp, slightly pungent aromatics associated with green/plant/vegetable matter such as parsley, spinach, pea pod, fresh cut grass etc.	Hexanal (50 mL) in propylene glycol (10 mL) at 5000ppm = 6.5 (a) Fresh parsley water (25 g) steeped in water for 15 min then drained) = 9.0
Heated Oil	The aromatics associated with oil heated to a high temperature.	Wesson Vegetable Oil (1/2 cup, 3 min microwaved) = 7.0 Lay's Potato Chips (4 chips in medium snifter) = 4.0 (a)
Liver-Like	Aromatics associated with cooked organ meat/liver.	Beef Liver (broiled) = 7.5(a)(f) Brauschweiger liver sausage 10.0 (a)(f)
Metallic	The impression of slightly oxidized metal, such as iron, copper, and silver spoons.	0.10% Potassium Chloride solution = 1.5 Select strip Steak (cooked to 60 ^{o} C internal) = 4.0 Dole Canned Pineapple Juice = 6.0
Musty-Earthy/Humus	Musty, sweet, decaying vegetation.	Mushrooms = 10 1000 ppm of 2,6-Dimethylcyclohexanol = 9.0 (a)
Roasted	Aromatic associated with roasted meat.	
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% sodium chloride solution = 1.5 0.64% sodium chloride solution = 3.5
Smoky Charcoal	An aromatic associated with meat juices and fat dripping on hot coals, which can be acrid, sour, burned, etc.	Wright's Natural Hickory seasoning (1/4 tsp. in 100 ml of water) = 9.0 (a)

Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Sweet	The fundamental taste factor associated with sucrose.	2.0% sucrose solution = 2.0
Umami	Flat, salty, somewhat brothy flavor. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% Accent Flavor Enhancer solution = 7.5
Tenderness		
Juiciness	The amount of perceived juice that is released from the product during mastication.	Carrot = 8.5 Mushroom = 10.0 Cucumber = 12.0 Apple = 13.5 Watermelon = 15.0 Choice top loin steak cooked to 58°C = 11.0 Choice top loin steak cooked to 80°C = 9.0
Muscle Fiber Tenderness	The ease in which the muscle fiber fragments during mastication.	Select eye of round steak cooked to 70°C = 4.0 Select tenderloin steak cooked to 70°C = 14.0
Connective Tissue	The structural component of the muscle surrounding the muscle fiber that will not break down during mastication.	Cross cut beef shank cooked to70°C= 4.0 Select tenderloin cooked to 70°C = 14.0

Table 2. Bottom round least squares means flavor and texture attributes not possessing interactions.

	Beef Identity	Brown	Bloody/ Serumy	Fat- Like	Metallic	Liver- Like	Green	Umami	Sweet	Sour	Salty
Quality Grade	0.85	0.80	0.33	0.00	0.47	0.57	0.03	0.62	0.88	0.28	0.67
Choice	6.6	3.2	1.4	1.9	2.2	0.3	0.0	2.5	1.3	2.8	2.2
Select	6.6	3.1	1.3	1.7	2.3	0.3	0.0	2.5	1.3	2.9	2.2
Treatments	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.50	<0.0001	<0.0001	<0.0001	<0.0001
Pan Grill, 0.64 cm, 58°C	6.2	3.0	1.6	1.9	2.3	0.6	0.1	2.3	1.2	2.3	1.9
Pan Grill, 0.64 cm, 70°C	6.6	3.2	1.5	2.1	2.0	0.7	0.0	2.7	1.3	2.1	2.2
Pan Grill, 0.64 cm, 80°C	6.4	4.4	1.1	2.1	2.0	0.7	0.0	2.9	1.5	2.2	2.1
Pan Grill, 1.91 cm, 58°C	7.0	3.7	3.8	2.6	2.7	0.3	0.0	2.7	1.6	2.3	2.0
Pan Grill, 1.91 cm, 70°C	7.6	4.7	3.4	2.4	2.7	0.2	0.0	3.1	1.8	2.0	2.1
Pan Grill, 1.91 cm,80°C	7.4	4.6	2.7	2.3	2.4	0.2	0.0	3.1	1.8	2.1	2.2
Roast, 0.91 kg, 58°C	6.4	1.5	3.4	2.1	2.6	0.3	0.0	2.1	1.7	2.3	2.0
Roast, 0.91 kg, 70°C	6.8	2.1	2.3	1.7	2.4	0.5	0.0	2.6	1.5	2.3	2.1
Roast, 0.91 kg, 80°C	7.8	3.0	1.3	1.8	2.0	0.5	0.0	3.0	1.7	1.9	2.0
Stir Fry, 0.64 cm, 58°C	6.2	3.1	1.7	2.2	2.3	0.5	0.0	2.5	1.2	2.2	2.0
Stir Fry, 0.64 cm, 70°C	6.6	3.7	1.5	2.1	2.3	0.4	0.0	2.5	1.4	2.4	2.2
Stir Fry, 0.64 cm, 80°C	6.4	3.5	1.5	2.2	2.2	0.7	0.0	2.7	1.2	2.5	1.9
Stew No Marinade, 0.64 cm, 30 minutes	6.0	3.2	0.2	1.9	1.7	0.3	0.0	1.8	0.9	1.5	1.5
Stew No Marinade, 0.64 cm, 1.5 hours	6.5	3.0	0.4	1.4	1.7	0.1	0.0	2.2	0.9	1.6	1.4
Stew No Marinade, 0.64 cm, 3 hours	6.2	2.6	0.5	1.5	1.9	0.2	0.1	2.0	0.9	1.8	1.4
Stew No Marinade, 1.91 cm, 30 minutes	7.0	3.2	1.1	1.8	2.2	0.2	0.0	2.6	1.1	2.0	1.6
Stew No Marinade, 1.91 cm, 1.5 hours	7.7	3.0	0.5	1.7	2.0	0.1	0.0	3.1	1.6	1.8	2.0
Stew No Marinade, 1.91 cm, 3 hours	8.2	3.6	0.3	1.6	1.7	0.1	0.0	3.5	1.6	1.6	1.7
Stew Marinade, 0.64 cm, 30 minutes	4.8	2.0	0.4	1.1	2.7	0.2	0.1	1.2	0.6	6.2	3.6
Stew Marinade, 0.64 cm, 1.5 hours	5.2	1.9	0.4	1.1	2.7	0.1	0.0	1.5	0.6	5.5	3.1
Stew Marinade, 0.64 cm, 3 hours	4.7	2.3	0.5	0.9	2.9	0.3	0.0	1.1	0.4	6.6	2.4
Stew Marinade, 1.91 cm, 30 minutes	6.0	3.2	0.7	1.4	2.3	0.2	0.0	2.6	1.1	4.7	4.4
Stew Marinade, 1.91 cm, 1.5 hours	7.1	3.2	0.6	1.6	2.2	0.2	0.0	3.1	1.3	4.1	3.4
Stew Marinade, 1.91 cm, 3 hours	8.1	3.9	0.4	1.5	2.3	0.1	0.1	3.3	1.3	4.0	2.8
Root Mean Square Error	0.90	1.17	0.55	0.50	0.43	0.39	0.08	0.67	0.33	1.91	0.53

Table 2 cont. Bottom round least squares means flavor and texture attributes not possessing interactions.

	Bitter	Card-boardy	Burnt	Heated-Oil	Musty Earthy	Smoky Charcoal	Peppery	Astringent	Juiciness	Muscle Fiber Tenderness	Connective Tissue
Quality Grade	0.12	0.76	0.94	0.36	0.95	0.58	0.90	0.38	0.33	0.49	0.20
Choice	2.2	1.9	0.0	0.6	1.6	0.0	0.4	1.3	7.9	9.5	8.6
Select	2.3	1.9	0.1	0.5	1.6	0.0	0.4	1.5	7.8	9.7	9.0
Treatments	<.0001	<.0001	0.05	<.0001	0.00	0.19	<.0001	<.0001	<.0001	<.0001	<.0001
Pan Grill, 0.64 cm, 58°C	2.0	2.0	0.0	0.2	1.9	0.1	0.1	0.7	8.6	9.3	6.9
Pan Grill, 0.64 cm, 70°C	2.0	2.2	0.0	0.3	1.7	0.2	0.1	0.7	7.9	8.4	7.4
Pan Grill, 0.64 cm, 80°C	2.0	2.2	0.1	0.4	2.0	0.2	0.1	0.5	7.2	7.9	6.8
Pan Grill, 1.91 cm, 58°C	2.0	1.1	0.0	0.2	1.5	0.0	0.1	0.6	10.6	9.2	6.0
Pan Grill, 1.91 cm, 70°C	2.0	1.0	0.0	0.2	1.5	0.1	0.2	0.3	10.6	9.0	6.3
Pan Grill, 1.91 cm, 80°C	2.0	1.1	0.4	0.4	1.2	0.1	0.2	0.4	9.3	8.1	6.0
Roast, 0.91 kg, 58°C	1.9	1.0	0.0	0.1	1.3	0.0	0.2	0.4	9.9	10.3	7.8
Roast, 0.91 kg, 70°C	2.0	1.7	0.0	0.1	1.4	0.0	0.1	0.5	8.3	8.1	7.2
Roast, 0.91 kg, 80°C	1.7	1.8	0.0	0.1	1.4	0.0	0.1	0.6	7.9	8.9	8.2
Stir Fry, 0.64 cm, 58°C	2.1	2.4	0.0	1.2	1.8	0.0	0.1	0.3	8.8	9.3	7.9
Stir Fry, 0.64 cm, 70°C	2.0	2.1	0.0	1.0	1.7	0.0	0.1	0.7	8.8	8.7	7.1
Stir Fry, 0.64 cm, 80°C	2.2	2.5	0.0	1.1	1.9	0.0	0.0	0.9	8.0	7.8	6.0
Stew No Marinade, 0.64 cm, 30 minutes	1.8	2.9	0.0	1.4	1.9	0.0	0.1	1.0	6.0	6.6	7.8
Stew No Marinade, 0.64 cm, 1.5 hours	1.8	2.7	0.0	0.8	1.9	0.0	0.3	0.9	6.4	9.8	10.4
Stew No Marinade, 0.64 cm, 3 hours	2.0	2.8	0.0	1.2	1.7	0.0	0.2	1.3	6.5	10.5	13.1
Stew No Marinade, 1.91 cm, 30 minutes	1.9	2.3	0.1	0.7	1.6	0.1	0.1	0.5	6.6	7.5	5.6
Stew No Marinade, 1.91 cm, 1.5 hours	1.9	2.0	0.0	0.6	1.7	0.0	0.3	0.8	6.4	9.3	8.0
Stew No Marinade, 1.91 cm, 3 hours	1.6	1.4	0.0	0.7	1.4	0.0	0.2	1.1	6.8	12.1	12.7
Stew Marinade, 0.64 cm, 30 minutes	3.7	1.7	0.0	0.3	1.6	0.0	1.6	4.1	7.7	11.7	12.4
Stew Marinade, 0.64 cm, 1.5 hours	3.4	1.7	0.0	0.3	1.8	0.1	1.2	3.7	7.9	12.3	13.8
Stew Marinade, 0.64 cm, 3 hours	4.2	1.8	0.3	0.4	1.6	0.0	1.0	6.4	7.0	13.5	13.9
Stew Marinade, 1.91 cm, 30 minutes	2.6	1.7	0.0	0.5	1.7	0.0	2.0	2.2	7.9	8.4	6.3
Stew Marinade, 1.91 cm, 1.5 hours	2.4	1.7	0.0	0.5	1.4	0.0	0.8	2.5	6.9	11.4	10.9
Stew Marinade, 1.91 cm, 3 hours	2.5	1.4	0.2	0.2	1.4	0.1	1.2	2.7	6.9	12.7	13.4
Root Mean Square Error	0.47	0.58	0.64	0.47	0.46	0.16	0.50	1.01	1.09	1.65	2.80

Table 3. Eye of round least squares means flavor and texture attributes not possessing interactions.

	Beef Identity	Brown	Roasted	Bloody/ Serumy	Fat-Like	Metallic	Liver-Like	Green	Umami	Sweet	Sour	Salty
Quality Grade	0.68	0.61	0.48	0.87	0.30	0.76	0.06	0.16	0.34	0.21	0.94	0.63
Choice	6.0	2.5	5.0	1.0	1.7	2.3	0.2	0.0	1.7	1.1	2.8	1.9
Select	5.9	2.4	5.1	1.0	1.8	2.3	0.1	0.0	1.6	1.0	2.8	2.0
Treatments	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.17	<0.0001	<0.0001	<0.0001	<0.0001
Pan Grill, 0.64 cm, 58°C	6.3	3.8	3.7	1.1	1.8	2.3	0.6	0.0	1.9	1.0	2.2	1.7
Pan Grill, 0.64 cm, 70°C	6.5	4.2	4.6	1.0	2.0	2.1	0.7	0.0	2.1	1.1	2.0	1.8
Pan Grill, 0.64 cm, 80°C	6.4	3.9	4.4	0.9	1.9	2.2	0.7	0.0	2.1	1.1	2.1	1.7
Pan Grill, 1.91 cm, 58°C	6.2	3.5	2.2	2.5	2.1	2.7	0.0	0.0	1.9	1.3	2.3	1.7
Pan Grill, 1.91 cm, 70°C	6.4	3.7	2.7	2.4	2.4	2.4	0.4	0.1	2.2	1.5	2.3	1.8
Pan Grill, 1.91 cm, 80°C	6.4	4.0	2.9	2.2	2.1	2.6	0.0	0.0	2.2	1.5	2.1	1.7
Roast, 0.91 kg, 58°C	4.9	0.7	2.3	3.0	2.2	3.0	0.1	0.0	1.0	1.3	2.4	1.6
Roast, 0.91 kg, 70°C	5.9	1.3	4.2	1.8	1.8	2.5	0.0	0.0	1.6	1.3	2.2	1.7
Roast, 0.91 kg, 80°C	6.4	1.6	5.7	0.9	1.7	2.1	0.1	0.0	2.1	1.2	1.9	1.7
Stir Fry, 0.64 cm, 58°C	5.7	2.2	4.1	0.9	2.1	2.2	0.2	0.0	1.5	0.9	2.2	1.6
Stir Fry, 0.64 cm, 70°C	6.2	3.3	4.7	0.9	2.0	2.1	0.4	0.1	1.8	1.0	2.0	1.8
Stir Fry, 0.64 cm, 80°C	6.1	2.2	4.5	0.9	1.9	2.1	0.4	0.1	1.7	1.2	2.0	1.7
Stew No Marinade, 0.64 cm, 30 minutes	5.6	2.4	4.8	0.6	1.5	2.3	0.2	0.0	1.4	0.8	2.4	1.5
Stew No Marinade, 0.64 cm, 1.5 hours	5.8	1.9	5.5	0.3	1.4	2.0	0.0	0.0	1.3	0.9	1.8	1.2
Stew No Marinade, 0.64 cm, 3 hours	5.2	1.7	5.1	0.2	1.3	1.9	0.0	0.0	0.6	0.7	1.6	1.1
Stew No Marinade, 1.91 cm, 30 minutes	5.9	1.8	6.8	0.7	1.8	1.9	0.1	0.0	1.8	1.2	2.0	1.6
Stew No Marinade, 1.91 cm, 1.5 hours	7.1	2.6	8.4	0.3	1.6	1.6	0.0	0.0	2.6	1.3	1.5	1.7
Stew No Marinade, 1.91 cm, 3 hours	7.6	3.1	8.5	0.3	2.1	1.9	0.1	0.0	2.6	1.2	2.1	1.9
Stew Marinade, 0.64 cm, 30 minutes	4.8	1.2	4.7	0.5	1.1	2.9	0.0	0.0	0.6	0.5	5.8	3.0
Stew Marinade, 0.64 cm, 1.5 hours	4.9	1.6	5.0	0.5	1.1	3.0	0.0	0.0	0.6	0.3	5.8	1.9
Stew Marinade, 0.64 cm, 3 hours	4.4	1.4	4.5	0.5	1.1	2.9	0.1	0.1	0.3	0.4	5.9	1.8
Stew Marinade, 1.91 cm, 30 minutes	5.5	2.1	6.6	0.7	1.6	2.3	0.0	0.0	1.6	0.8	4.3	4.9
Stew Marinade, 1.91 cm, 1.5 hours	6.2	2.7	7.7	0.4	1.5	2.4	0.1	0.0	2.0	0.8	4.1	3.0
Stew Marinade, 1.91 cm, 3 hours	6.7	2.6	7.8	0.7	1.4	2.3	0.0	0.0	2.2	1.0	3.4	2.9
Root Mean Square Error	0.83	1.04	1.05	0.46	0.37	0.43	0.34	0.07	0.60	0.29	0.77	0.43

Table 3 cont. Eye of round least squares means flavor and texture attributes not possessing interactions.

	Bitter	Card boardy	Burnt	Heated Oil	Musty Earthy	Peppery	Astringent	Juiciness	Muscle Fiber Tenderness	Connective Tissue
Quality Grade	0.69	0.63	0.91	0.45	0.58	0.86	0.99	0.79	0.09	0.10
Choice	2.1	1.6	0.1	0.3	1.3	0.2	1.1	7.6	9.0	7.8
Select	2.1	1.6	0.1	0.4	1.3	0.2	1.1	7.6	8.3	7.1
Treatments	<0.0001	<0.0001	0.01	<0.0001	0.00	<0.0001	0.17	<0.0001	<0.0001	<0.0001
Pan Grill, 0.64 cm, 58°C	2.0	1.8	0.1	0.2	1.3	0.0	0.0	7.8	7.9	6.1
Pan Grill, 0.64 cm, 70°C	2.0	1.6	0.3	0.3	1.4	0.1	0.3	7.5	8.0	6.3
Pan Grill, 0.64 cm, 80°C	2.0	1.9	0.1	0.1	1.7	0.0	0.3	7.4	7.9	6.4
Pan Grill, 1.91 cm, 58°C	2.0	0.6	0.1	0.0	1.1	0.0	0.3	9.7	8.1	5.9
Pan Grill, 1.91 cm, 70°C	2.0	0.8	0.0	0.0	1.2	0.0	0.1	9.4	7.7	5.3
Pan Grill, 1.91 cm, 80°C	1.9	0.8	0.1	0.1	1.2	0.1	0.0	9.1	7.6	5.6
Roast, 0.91 kg, 58°C	2.1	0.9	0.0	0.0	1.1	0.0	0.1	9.5	9.4	6.6
Roast, 0.91 kg, 70°C	1.7	0.9	0.0	0.0	1.1	0.0	0.1	8.4	7.8	6.0
Roast, 0.91 kg, 80°C	1.6	1.3	0.0	0.1	1.2	0.0	0.0	7.6	8.3	7.1
Stir Fry, 0.64 cm, 58°C	2.0	2.0	0.0	1.3	1.7	0.1	0.1	7.7	7.9	6.5
Stir Fry, 0.64 cm, 70°C	1.9	1.8	0.0	1.2	1.5	0.1	0.1	7.8	7.7	6.0
Stir Fry, 0.64 cm, 80°C	1.9	1.5	0.0	1.0	1.5	0.0	0.2	7.7	7.7	6.1
Stew No Marinade, 0.64 cm, 30 minutes	2.0	2.3	0.2	0.4	1.3	0.0	1.1	6.8	8.1	8.0
Stew No Marinade, 0.64 cm, 1.5 hour	1.7	2.6	0.1	0.4	1.4	0.0	0.7	5.5	8.8	8.6
Stew No Marinade, 0.64 cm, 3 hours	1.7	3.1	0.0	0.7	1.5	0.0	0.3	6.1	8.0	8.1
Stew No Marinade, 1.91 cm, 30 minutes	1.7	2.3	0.0	0.3	1.4	0.0	0.2	6.3	5.9	4.5
Stew No Marinade, 1.91 cm, 1.5 hours	1.3	1.6	1.0	0.4	1.0	0.0	0.1	6.4	9.3	8.4
Stew No Marinade, 1.91 cm, 3 hours	1.7	2.0	0.0	1.0	1.1	0.1	0.5	7.2	9.8	8.5
Stew Marinade, 0.64 cm, 30 minutes	3.1	1.5	0.0	0.1	1.1	0.6	4.2	8.0	10.1	10.0
Stew Marinade, 0.64 cm, 1.5 hour	3.5	1.6	0.2	0.0	1.1	0.2	6.2	7.9	12.8	12.5
Stew Marinade, 0.64 cm, 3 hours	3.3	1.6	0.2	0.3	1.7	0.2	6.3	7.3	12.2	11.9
Stew Marinade, 1.91 cm, 30 minutes	2.5	1.1	0.0	0.0	1.4	0.9	1.7	7.3	12.2	11.9
Stew Marinade, 1.91 cm, 1.5 hours	2.4	1.1	0.0	0.2	1.4	0.7	2.4	7.0	9.7	9.0
Stew Marinade, 1.91 cm, 3 hours	2.1	1.3	0.0	0.4	1.2	0.6	1.9	7.1	10.4	9.8
Root Mean Square Error	0.42	0.58	0.22	0.48	0.48	0.30	1.12	0.98	1.71	1.81

Table 4. Inside round least squares means flavor and texture attributes not possessing interactions.

	Beef Identity	Brown	Roasted	Bloody/ Serumy	Fat-like	Metallic	Liver-Like	Green	Umami	Sweet	Sour	Salty
Quality Grade	0.19	0.06	0.73	0.92	0.87	0.61	0.90	0.00	0.06	0.02	0.09	0.66
Choice	6.4	1.9	4.8	0.7	1.4	2.2	0.1	0.0	1.6	0.7	2.6	2.0
Select	6.2	1.7	4.7	0.7	1.4	2.2	0.1	0.0	1.4	0.6	2.7	2.0
Treatments	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.00	0.05	<0.0001	<0.0001	<0.0001	<0.0001
Pan Grill, 0.64 cm, 58°C	6.7	2.5	3.5	0.8	1.5	2.1	0.4	0.1	1.6	0.8	2.3	1.5
Pan Grill, 0.64 cm, 70°C	7.0	3.5	4.2	0.8	1.7	2.1	0.5	0.0	1.9	0.8	2.0	1.8
Pan Grill, 0.64 cm, 80°C	6.7	3.9	3.2	0.9	1.6	2.1	0.5	0.0	1.9	0.8	2.1	1.8
Pan Grill, 1.91 cm, 58°C	7.0	3.6	2.0	2.7	2.0	2.7	0.0	0.0	2.2	1.4	2.4	1.8
Pan Grill, 1.91 cm, 70°C	7.6	4.1	2.0	2.1	2.1	2.4	0.2	0.0	2.1	1.4	2.4	2.0
Pan Grill, 1.91 cm, 80°C	7.2	3.7	2.8	1.4	1.9	2.1	0.2	0.0	2.3	1.0	2.0	2.0
Roast, 0.91 kg, 58°C	5.4	0.9	1.0	3.1	1.7	3.2	0.0	0.0	0.9	1.0	2.7	1.8
Roast, 0.91 kg, 70°C	5.8	1.1	3.5	1.2	1.5	2.3	0.1	0.0	1.3	0.7	2.3	1.8
Roast, 0.91 kg, 80°C	6.8	1.2	6.4	0.2	1.2	1.7	0.1	0.0	1.6	0.8	1.8	1.8
Stir Fry, 0.64 cm, 58°C	6.1	2.2	3.4	0.9	1.8	2.1	0.2	0.1	1.3	0.6	2.1	1.6
Stir Fry, 0.64 cm, 70°C	6.0	2.3	3.5	0.6	1.5	1.8	0.3	0.2	1.5	0.7	2.0	1.7
Stir Fry, 0.64 cm, 80°C	6.5	2.0	4.6	0.7	1.7	2.0	0.3	0.0	1.6	0.6	2.1	1.9
Stew No Marinade, 0.64 cm, 30 minutes	5.6	1.1	5.0	0.0	1.2	1.8	0.1	0.0	1.0	0.6	1.6	1.3
Stew No Marinade, 0.64 cm, 1.5 hour	5.6	1.0	5.0	0.0	1.2	1.8	0.1	0.0	0.8	0.5	1.7	1.1
Stew No Marinade, 0.64 cm, 3 hours	5.7	0.6	5.3	0.1	1.2	1.9	0.0	0.0	0.8	0.4	1.6	1.2
Stew No Marinade, 1.91 cm, 30 minutes	6.2	1.0	6.1	0.3	1.5	1.6	0.3	0.0	1.7	0.5	1.9	1.6
Stew No Marinade, 1.91 cm, 1.5 hours	6.9	0.9	7.4	0.1	1.2	1.6	0.1	0.0	2.1	0.8	1.6	1.6
Stew No Marinade, 1.91 cm, 3 hours	6.5	1.1	7.5	0.1	1.3	1.8	0.0	0.0	1.6	0.6	1.6	1.5
Stew Marinade, 0.64 cm, 30 minutes	5.7	1.1	5.1	0.3	0.7	2.4	0.1	0.0	1.0	0.2	5.1	3.6
Stew Marinade, 0.64 cm, 1.5 hour	5.1	1.0	4.5	0.1	0.9	3.0	0.0	0.0	0.4	0.2	5.3	2.3
Stew Marinade, 0.64 cm, 3 hours	5.2	0.8	3.9	0.1	0.4	3.5	0.0	0.0	0.2	0.1	6.7	1.6
Stew Marinade, 1.91 cm, 30 minutes	6.2	0.9	6.8	0.3	1.1	2.3	0.0	0.0	1.7	0.4	3.8	4.5
Stew Marinade, 1.91 cm, 1.5 hours	6.6	1.0	8.1	0.1	1.1	1.9	0.1	0.0	2.1	0.5	3.7	3.3
Stew Marinade, 1.91 cm, 3 hours	7.3	1.2	8.7	0.3	1.2	1.9	0.0	0.0	2.3	0.6	3.2	3.4
Root Mean Square Error	0.76	0.88	1.20	0.43	0.42	0.41	0.31	0.09	0.61	0.29	0.59	0.46

Table 4 cont. Inside round least squares means flavor and texture attributes not possessing interactions.

	Bitter	Card boardy	Burnt	Heated Oil	Musty Earthy	Smoky Charcoal	Peppery	Astringent	Juiciness	Muscle Fiber Tenderness	Connective Tissue
Quality Grade	0.38	0.05	0.55	0.49	0.16	0.20	0.21	0.16	0.00	0.03	0.73
Choice	2.4	1.3	0.1	0.3	1.2	0.2	0.2	1.5	7.7	8.6	7.5
Select	2.4	1.4	0.1	0.4	1.3	0.2	0.2	0.9	7.4	8.1	7.4
Treatments	<0.0001	<0.0001	0.00	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Pan Grill, 0.64 cm, 58°C	2.2	1.3	0.1	0.3	1.1	0.5	0.0	0.1	7.9	8.8	6.2
Pan Grill, 0.64 cm, 70°C	2.2	1.1	0.2	0.0	1.5	0.8	0.0	0.3	8.0	8.5	6.4
Pan Grill, 0.64 cm, 80°C	2.2	1.2	0.1	0.2	1.3	0.6	0.0	0.3	7.9	8.5	6.7
Pan Grill, 1.91 cm, 58°C	2.0	0.5	0.1	0.1	1.0	0.3	0.1	0.4	9.4	8.4	6.6
Pan Grill, 1.91 cm, 70°C	2.2	0.5	0.2	0.1	0.8	0.5	0.0	0.2	9.6	8.0	5.9
Pan Grill, 1.91 cm, 80°C	2.0	0.8	0.0	0.1	1.0	0.1	0.1	0.5	7.9	7.8	6.5
Roast, 0.91 kg, 58°C	2.2	0.6	0.0	0.0	0.7	0.0	0.0	0.2	9.2	10.0	7.5
Roast, 0.91 kg, 70°C	2.1	1.0	0.0	0.0	0.9	0.1	0.1	0.2	7.6	8.1	7.1
Roast, 0.91 kg, 80°C	1.7	1.2	0.0	0.1	0.7	0.1	0.0	0.2	6.3	7.3	6.9
Stir Fry, 0.64 cm, 58°C	2.1	1.6	0.0	1.3	1.7	0.2	0.0	0.3	7.9	8.2	6.8
Stir Fry, 0.64 cm, 70°C	2.0	1.4	0.0	1.4	2.0	0.1	0.0	0.2	7.6	7.6	6.3
Stir Fry, 0.64 cm, 80°C	2.2	1.6	0.1	1.1	1.6	0.1	0.1	0.2	7.8	8.0	6.7
Stew No Marinade, 0.64 cm, 30 minutes	1.9	2.3	0.1	0.5	1.3	0.1	0.0	0.9	6.5	6.7	6.3
Stew No Marinade, 0.64 cm, 1.5 hour	1.9	2.8	0.0	0.5	1.4	0.1	0.0	0.6	6.2	6.8	7.1
Stew No Marinade, 0.64 cm, 3 hours	1.7	2.6	0.1	1.1	1.7	0.1	0.0	1.0	5.9	7.3	8.1
Stew No Marinade, 1.91 cm, 30 minutes	1.8	1.6	0.0	0.4	1.5	0.1	0.1	0.3	7.5	6.5	5.0
Stew No Marinade, 1.91 cm, 1.5 hours	1.7	1.5	0.1	0.3	0.9	0.1	0.0	0.7	6.4	8.1	7.6
Stew No Marinade, 1.91 cm, 3 hours	1.6	1.9	0.1	0.9	1.2	0.1	0.1	0.1	6.6	7.5	7.6
Stew Marinade, 0.64 cm, 30 minutes	3.7	1.0	0.0	0.1	1.0	0.1	1.0	3.8	7.4	9.5	9.0
Stew Marinade, 0.64 cm, 1.5 hour	4.4	1.4	0.2	0.0	1.3	0.1	0.5	5.8	7.1	11.0	11.0
Stew Marinade, 0.64 cm, 3 hours	5.5	1.2	0.3	0.1	1.5	0.1	0.3	7.4	8.1	13.0	13.2
Stew Marinade, 1.91 cm, 30 minutes	2.4	0.8	0.0	0.1	1.1	0.1	1.1	5.6	7.3	6.3	5.4
Stew Marinade, 1.91 cm, 1.5 hours	2.6	0.9	0.0	0.0	1.0	0.1	0.7	2.1	7.1	9.0	8.8
Stew Marinade, 1.91 cm, 3 hours	2.7	0.9	0.2	0.2	1.1	0.0	0.8	2.0	7.6	10.6	10.0
Root Mean Square Error	0.59	0.55	0.18	0.56	0.56	0.24	0.37	3.20	0.85	1.87	1.93

Table 4. Warner-Bratzler shear force (kg) least square means.

	Bottom Round	Eye of Round	Inside Round
<u>Quality grade</u>	0.36	0.09	0.04
Choice	4.9	4.1	5.0
Select	4.6	4.8	5.4
<u>Treatments</u>	<.0001	<.0001	<.0001
Pan Grill, 0.64 cm, 58°C	5.4	4.0	4.0
Pan Grill, 0.64 cm, 70°C	5.5	3.5	3.7
Pan Grill, 0.64 cm, 80°C	6.1	3.4	4.1
Pan Grill, 1.91 cm, 58°C	3.8	3.3	3.1
Pan Grill, 1.91 cm, 70°C	3.4	4.1	3.0
Pan Grill, 1.91 cm, 80°C	4.0	3.5	3.7
Roast, 0.91 kg, 58°C	2.7	3.2	2.9
Roast, 0.91 kg, 70°C	3.5	3.8	4.4
Roast, 0.91 kg, 80°C	3.7	3.5	5.3
Stir Fry, 0.64 cm, 58°C	5.3	3.9	3.7
Stir Fry, 0.64 cm, 70°C	6.4	4.0	3.9
Stir Fry, 0.64 cm, 80°C	6.1	3.6	4.3
Stew No Marinade, 0.64 cm, 30 minutes	5.5	3.4	4.0
Stew No Marinade, 0.64 cm, 1.5 hours	3.7	1.7	3.9
Stew No Marinade, 0.64 cm, 3 hours	4.0	2.5	2.7
Stew No Marinade, 1.91 cm, 30 minutes	7.9	8.9	11.6
Stew No Marinade, 1.91 cm, 1.5 hours	6.5	9.3	10.1
Stew No Marinade, 1.91 cm, 3 hours	4.8	7.1	11.6
Stew Marinade, 0.64 cm, 30 minutes	2.9	1.8	2.8
Stew Marinade, 0.64 cm, 1.5 hours	2.8	1.0	1.4
Stew Marinade, 0.64 cm, 3 hours	2.0	1.9	1.0
Stew Marinade, 1.91 cm, 30 minutes	9.4	10.3	12.0
Stew Marinade, 1.91 cm, 1.5 hours	5.0	7.9	9.3
Stew Marinade, 1.91 cm, 3 hours	4.1	6.7	8.0
Root Mean Square Error	1.90	1.51	1.78

APPENDIX B

FIGURES

Figure 1. Bottom round main effect and cut by cooking treatment least squares means for roasted flavor descriptive attribute.

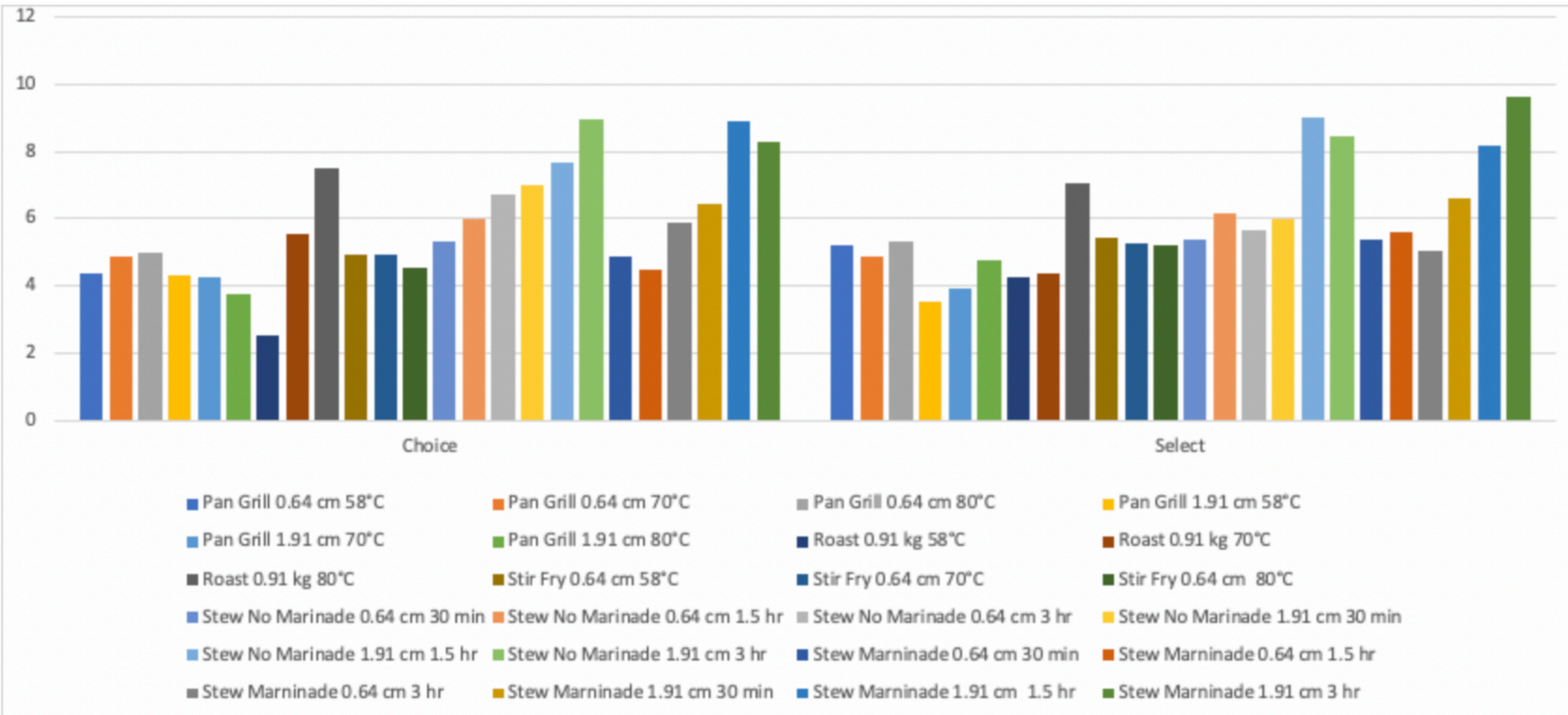

Figure 2. Bottom round partial least squares regression biplot for trained descriptive flavor (•), volatile aromatic compounds (•), and steak treatments (•).

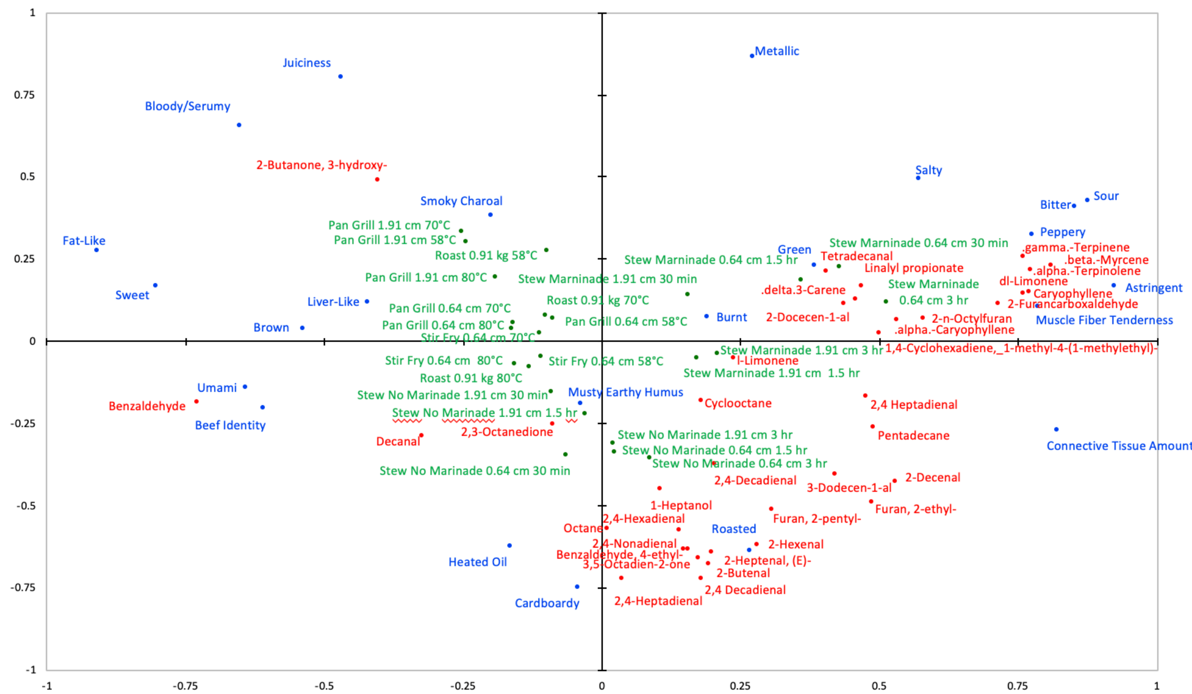

Figure 3. Eye of round partial least squares regression biplot for trained descriptive flavor (•), volatile aromatic compounds (•), and steak treatments (•).

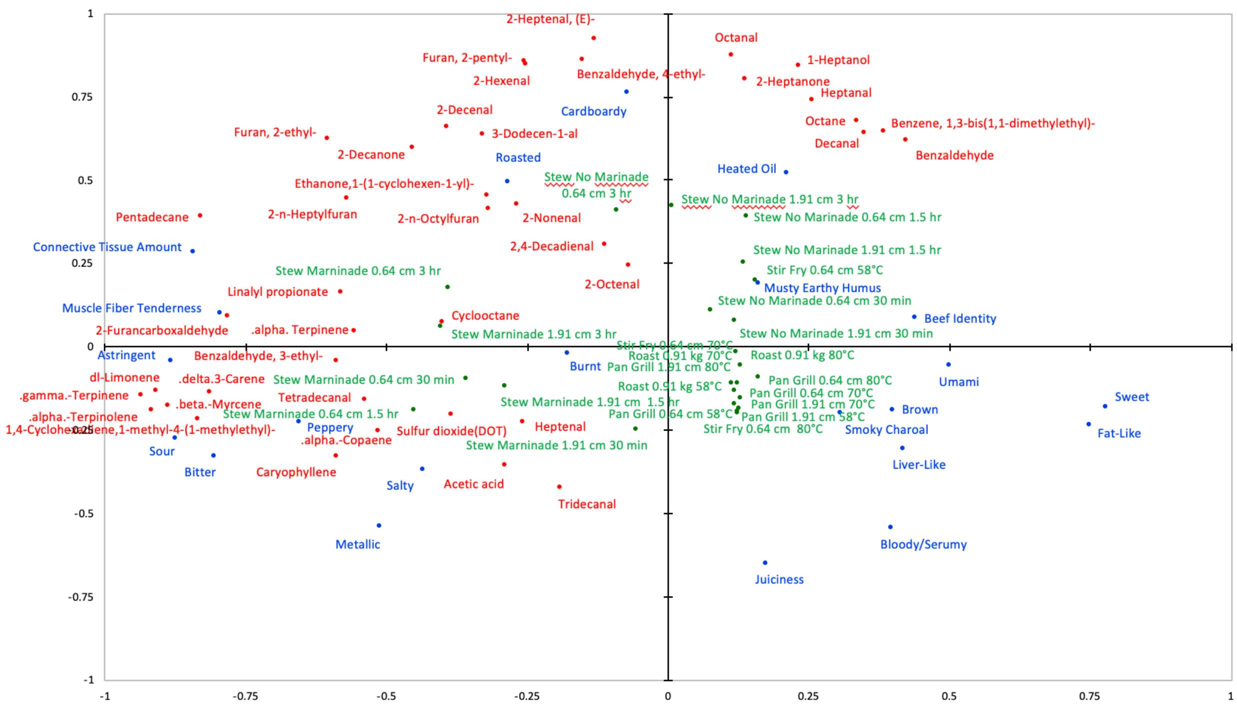

Figure 4. Inside round partial least squares regression biplot for trained descriptive flavor (•), volatile aromatic compounds (•), and steak treatments (•).