FLAVOR IN GROUND BEEF AND PORK TENDERNESS

A Dissertation

by

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ABSTRACT

The restaurant industry has been trying to produce a better hamburger utilizing different formulations and grind treatments to affect flavor and texture attributes in ground beef patties. With each hamburger chain claiming their hamburger is the best because of a premium type of meat or processing characteristic they use, this research will help determine the legitimacy of their marketing claims by understanding how different meat sources, grind methods, form methods, patty thickness, cooking methods, and holding temperatures affect the flavor, texture, and consumer perception of the final hamburger. Hamburger production and consumption in America is a huge industry and all processing measures impact the flavor and texture of ground beef patties. From this study, the positive and negative flavor and texture attributes of different ground beef patty processing were found. In the second study, 16 treatments were utilized, including four meat sources, two fat percentages, and two grind treatments to better understand consumer attitudes and preferences of ground beef in a home use test. Consumers were recruited from 4 cities and given ground beef samples in chubs and patty forms. In this home-use study, when consumers prepared the meat themselves, they preferred patties or chubs that were 10% fat, chuck or sirloin meat source, and traditionally ground to 6.4 mm plate size.

Consumer research has consistently shown that traditionally consumers over-cook pork creating a subpar eating experience. Understanding the relationship between loin color, cut thickness, cooking method, water-holding capacity and tenderness from chops and roasts cooked to 62.8°C is crucial. Pork boneless chops, blade chops, bone-in chops, tenderloin roast and boneless roasts from both National Pork Board color score 2 and 4. The chops and roasts were then cooked to 62.8°C either by baking, grilling, pan frying, or pan-sautéing. Cooking method and chop thickness affected (*P* < 0.05) cook yield and cook time. Baking took the longest cooking time, pan-sauté had the greatest yield (*P* < 0.05) and grilling had the most (*P* < 0.05) cook loss. Thickness had minimal effect. Although the baking method had the longest cooking time, it produced the most (*P* < 0.05) tender bone-in and boneless chops. Overall, this study revealed that color, cooking method, and thickness impacted drip loss, cook yield, cook time, cooked color, and tenderness on blade, boneless, and bone-in chops, tenderloins, and roasts.

DEDICATION

This work is dedicated to my family, friends, and colleagues who have helped me develop into the person I am today.

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This work was supervised by a dissertation committee consisting of Dr. Rhonda Miller [advisor] and Dr. Chris Kerth of the Department of Animal Science, Dr. Christine Alvarado of the Department of Poultry Science, Dr. Andreea Botezatu of the Department of Horticulture, and Dr. Koushik Adhikari of the University of Georgia Griffin, Department of Food Science and Technology. Another collaborator to these projects is Dr. Edgar Chambers of Kansas State University. All work for the dissertation was completed independently by the student.

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NOMENCLATURE

TRC	Taste receptor cells
USDA	United States Department of Agriculture
FSIS	Food Safety and Inspection Service
PSE	Pale, soft, and exudative
DFD	Dark, firm, and dry
RN	Rendement Napole gene
pI	Isoelectric point
ATP	Adenosine triphosphate
CIE	Commission International de l'Eclairage
CLT	Central Location Test
GC/MS/O	Gas chromatograph/mass spectrophotometer system with olfactory
HUT	Home Use Test
IMPS	Institutional Meat Purchase Specifications
WBSF	Warner-Bratzler Shear Force

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1. INTRODUCTION

Flavor and tenderness are major factors in meat consumption and contribute the most to desirability. A great deal of knowledge exists about both flavor and tenderness and the factors that affect them, but little is known about how to drive factors to create a desirable product. Since flavor and tenderness play a large role in meat consumption, it is important to gain a better understanding of the factors that influence flavor and tenderness in muscle foods.

1.1. Beef Flavor

Ground beef has long been a traditional, convenient, and versatile food. As hamburger's popularity in the United States has grown over the past decade and Approximately 62% of the beef sold and consumed in the United States is in the ground form (Close, 2014). It is one of the most popular protein sources due to its affordability and versatility. Over the past several years, consumers have moved to consuming most of their beef in the ground form. Cost and convenience are major driving forces in this change. Ground beef is a quick-prepare meal and does not require consumers to pre-plan meals. Since most consumers do not pre-plan, ground beef becomes a protein that can be prepared in a short amount of time with little preparation skills. As the price increases for all beef, the price differentiation between steaks and ground beef drives consumers to downgrade their beef purchase to the less expensive ground beef (Close, 2014).

Most retailers and restaurants offer some form of ground beef or hamburger on their menu causing an increase in the variety of ground beef offered. Upscale burger chains have led a new emphasis on serving premium ground beef at higher prices. Traditionally, ground beef is thought of as an industry by-product but over the last several years, has become a premium market. More research into ground beef sources and type of processing is needed to determine what is driving consumers to eat more ground beef.

The fast-food industry has dominated the burger industry for years, but as the culture shifts, so has the options for a good burger. Premium, fast-casual burger chains are increasing all over the country with chains like Smashburger, Five Guys, Shake Shack, BurgerFi, In-and-Out, and Whataburger. These growing burger chains offer expanded choices through premium cuts of meat along with specialized toppings. The popularity of premium hamburger chains continues to increase the demand for "better burgers". Each chain has their own specialty grinds which include a variety of different muscles and grind types. According to the 2015 Canadian Burger Consumer Trend Report, consumers reported the two most important burger attributes being the quality and taste of the meat and the price and value for the money. For the hamburger industry, it is essential to discover how source and processing characteristics influence the taste of the hamburger and the consumer drivers of the product. Little scientific data has been collected about the flavor of ground beef and how processing characteristics affect the consumers perception of the final product. With each hamburger chain claiming their hamburger is the best because of a "premium" type of meat or processing characteristic they use, this research will help determine the legitimacy of their marketing claims by understanding how different sources, grind methods, form methods, patty thickness, cooking methods, and holding temperatures affect the flavor, texture, and consumer perception of the final hamburger.

Most ground beef is manufactured using beef trimmings from either traditionally-raised beef; lean trimmings from older, mature cows and bulls; or imported lean beef (grain fed and non-fed; Speer et al., 2015). The source of raw material is used to affect final lipid content and the subsequent flavor of the final product. Additionally, ground beef is commonly consumed at home and in the foodservice industry and cooking and preparation varies. Beef flavor is comprised principally from aromas generated from either thermal lipid degradation or Maillard browning reactions. Formulation, grinding procedures and cooking methods affect how heat transfers through ground beef and ultimately impact beef flavor.

Flavor is incredibly important to the long-term success of beef products and serves as the “guard rails” to beef quality. Sitz et al. (2005) found that flavor was the most important factor affecting consumers’ buying habits and preferences when tenderness was held constant. Recent research conducted has shown that beef flavor is more closely related to overall consumer liking than beef tenderness and juiciness (Glascock, 2014; Kerth and Miller, 2015; Laird, 2015; Luckemeyer, 2015). Consumers often rate taste attributes as the most important purchasing motivators. It is apparent that multiple factors impact flavor in ground beef. Flavor of food is complex, multi-dimensional and more than the taste perceived on the tongue. The perception of flavor is comprised of the aroma detected by the olfactory system, the chemical feeling sensations, the taste perceived by the tongue and an interaction of these sensations. The visual and auditory cues of a food also contribute to the perceived flavor (Meilgaard et al., 2015). Flavor has been defined as the sum of perceptions resulting from stimulation of the senses that are grouped together at the entrance of the alimentary and respiratory tracts (Meilgaard et al., 2015). Flavor, as a whole, describes the combination of taste, aroma, and other sensations within the mouth (Meilgaard et al., 2015).

Beef flavor is composed of several attributes and hundreds of volatile compounds that create a particularly complex and dynamic sensory experience. These flavors are an important component of beef demand. The combination of taste and aroma make up meat flavor, but mouthfeel and juiciness of meat can also influence flavor perception (Farmer, 1992). In 2011, the whole-muscle beef flavor lexicon was developed to identify the major and minor flavor components in beef and now beef flavor can be quantified by trained panelists (Adhikari et al., 2011). Many antemortem and postmortem factors alter the development of meat flavor including animal age, sex, composition, handling, cook method, and storage conditions (Imafidon and Spanier, 1994; Kerth and Miller, 2015; Melton, 1999).

1.2. Pork Quality

Pork quality can be defined by four primary measurements: color, ultimate pH, water-holding capacity and intramuscular fat. Color, ultimate pH, and water-holding capacity is largely influenced by the rate of pH decline in muscles after slaughter.

Ultimate pH has been found to have a large effect on the eating quality of pork. The rate and extent of the pH decline influence meat quality in terms of color and water-holding capacity. During the conversion of muscle to meat, the rate and extent of the drop of pH have a great impact on meat paleness, softness and exudation. Normal muscle starts at a physiological pH of 7.2 and drops to between 5.5 and 5.8 after slaughter due to the increase of hydrogen ion concentration because of the dissociation of lactic acid in pork (Lonergan, 2012). After slaughter, muscle is no longer receiving oxygen and converts from aerobic metabolism to anaerobic metabolism. As the muscle tries to maintain homeostasis, the only available energy source is glycogen. During anaerobic metabolism, the by-product of glycogen breakdown is lactic acid. The extent of the pH decline is determined mostly by the amount of glycogen in the muscle at the time of slaughter. The rate of pH decline and ultimate pH are key factors in pork quality.

Water-holding capacity is the ability of meat to retain naturally occurring or added moisture during the application of any external force (Aberle et al., 2012). Color, texture, firmness of raw meat, along with tenderness and juiciness of cooked meat are all affected by water-holding capacity. Myofibrillar proteins, more specifically myosin and actin, are responsible for binding water in meat and are generally affected by pH. A rapid decline in pH during the onset of rigor will cause a combination of low pH and high temperatures, denaturing the myosin. Since this condition denatures myosin, there is less functional proteins and less protein to bind water. As the pH nears the isoelectric point (5.1 in meat), the point where positive and negative ions are neutral, water-holding capacity is at its lowest. Low pH in pork will cause a greater drip loss, greater cooking losses, and less water-holding capacity.

Meat color is the first impression consumers have at the meat counter. Consumers expect raw meat to have an appealing color and make most of their purchasing decisions based on color and the appearance of meat. Several studies have identified color as the most important characteristic consumers consider when buying pork (Barbut, 2001; Font-i-Furnols et al.; 2012; Glitsch, 2000; Tan et al., 2000). A consumer study by Small Insights (2014), looked at purchase criteria for fresh pork and showed that quality, freshness, and color were key factors in fresh pork purchases. The consumers associated a darker color to a higher quality product. In another consumer study, Lusk et al., (2018) found that the majority of consumers used color to assess quality and that color is more important than marbling. Also, a significant percentage of consumers perceived the whiter, lower quality pork chops to be preferable, suggesting that consumer perceptions of quality does not line up with actual pork color quality information (Lusk et al., 2018).

Consumer research has consistently shown that traditionally consumers over-cook pork creating a subpar eating experience (Detienne and Wicker, 1999). With over-cooking, pork is drier, tougher, and not as flavorful. In the extensive consumer study conducted, consumers evaluated pork cooked to four internal temperatures (62.8, 68.3, 73.9 and 79.4°C; Moeller et al., 2010). In that study, consumers responded positively to pork loin chops cooked to 62.8°C. Through a series of research projects, the National Pork Board has shown that there will be essentially no risk from a food safety standpoint in eating pork cooked to 62.8°C and suggested that the minimum cooked internal temperature endpoint of pork be changed to 62.8°C for whole-muscle cuts. In 2011, the USDA/FSIS changed the internal doneness temperature from 71.1°C to 62.8°C with a three-minute rest time after cooking to improve the pork eating experience (FSIS, 2013). However, how tenderness and water-holding capacity is affected in pork chops differing in thickness and color score cooked to 62.8°C is unknown.

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2. LITERATURE REVIEW

2.1. Biological Response to Flavor

Flavor is a multidimensional perception that is more than just the taste on the tongue. The complete flavor experience depends on both the response of our senses and the cognitive processing of these inputs. Flavor can be defined as the combined perceptions from stimulation of the senses that are grouped together at the entrance of the alimentary and respiratory tracts (Meilgaard et al., 2015). The entirety of flavor describes the combination of taste, aroma, and other sensations inside the mouth (Meilgaard et al., 2015). Flavor includes gustatory, oral-somatosensory (trigeminal), and retronasal olfaction signals and the combination of these signals in the brain. Visual and auditory cues also influence how flavor is perceived.

The detection of the basic tastes creates gustation by receptors on the tongue and ultimately by the brain (Meilgaard et al., 2015). The basic tastes elicitors are solubilized in water, oil or saliva in order to be detected. The sense of taste or gustation initiates at the taste buds. Taste is perceived by approximately 5,000 onion-shaped taste buds in the oral cavity mostly on the tongue and also on the pharynx, epiglottis, larynx, and soft palate (Briand and Salles, 2016). Each taste bud is composed of 50-150 specific taste receptor cells (TRCs) (Chaudhari and Roper, 2010). The TRCs are arranged like bananas such that their tips form a taste pore. Microvilli extend from the taste pore and contain the taste receptor (Chaudhari and Roper, 2010). At this site, the interaction of food and the taste receptor, the sensory signal is a taste. Within a taste bud, there can be some taste receptor cells for sweet and others for sour, bitter, salty, and umami tastes

(Chaudhari and Roper, 2010). The taste receptors then send signals to the sensory nerves. Three nerves relay the gustatory impulses including the chorda tympani branch of the facial nerve, the glossopharyngeal, and the vastus nerves (Chaudhari and Roper, 2010). The nerves communicate sensory input to the brain stem and ultimately to the thalamus and forebrain (Reed and Xia, 2015).

From a physiological perspective, the sense of taste allows for the ability to assess food quality by evaluating the caloric content, the presence of salt, and to protect us from toxic chemicals. The gustatory system is responsible for the perception taste of the five basic tastes: salty, sour, sweet, bitter and umami. Also, several other tastes have been suggested including the taste of water, fat, calcium, starch and carbon dioxide (Mattes, 2009).

The olfactory system is responsible for the detection of aroma and smells. The olfactory neurons detect volatile compounds and are responsible for the aromatic sensation perceived by the brain (Meilgaard et al., 2015). Humans can detect, identify and discriminate between thousands of odorant compounds via the olfactory system (Breer, 2008). During the chewing and swallowing of foods, volatiles are released from the food matrix into the mouth and travel through the posterior nares to the olfactory epithelium (Meilgaard et al., 2015). Olfactory epithelium, located on the room of the nasal cavity can sense odorants (Meilgaard et al., 2015). Only a small portion of the volatiles reaches the olfactory epithelium from the nasal cavities or the back of the mouth (Maruniak and Mackay-Sim, 1988). On the olfactory epithelium, there are as many as 1,000 olfactory neurons that connect the olfactory epithelium with the olfactory bulb (Buck and Axel, 1991). Each neuron has one receptor protein and terminates at two glomeruli (Buck and Axel, 1991). There are approximately 2,000 glomeruli on the olfactory bulb of the brain (Buck and Axel, 1991). The perception of smell occurs when signals are sent from the olfactory bulb to the olfactory cortex (Young and Trask, 2002).

The concentration of the compound and the odor threshold are believed to control the impact of the aroma (Farmer, 1994). The American Society for Testing and Materials (ASTM) defines thresholds as, "the concentration range below which the odor or taste of a substance will not be detectable under any practical circumstances, and above which individuals with a normal sense of smell or taste would readily detect the presence of the substance" (ASTM E-679-04, 2011). Determining the threshold of an aroma can determine the perception of intensity. When the concentration of an odor in food is higher than its threshold concentration, it is safe to assume that the aroma would have a significant impact of flavor (Shahidi et al., 1986).

Humans exhibit natural differences in the olfactory system allowing the perception of flavor to be different among individuals. Individuals have also shown different sensitivity to aromas depending on hunger, satiety, mood, concentration, the presence or absence of respiratory infections, and in women, menstrual cycle and pregnancy (Maruniak and Mackay-Sim, 1988).

Trigeminal or tactile sensations are the chemical feeling factors that are sensed in the mouth such as spice, heat, astringency, metallic and cooling (Meilgaard et al., 2015). Other somatosensory cues such as texture, auditory and visual characteristics of food products contribute to flavor perception (Small and Prescott, 2005; Spence and Zampini, 2006). Tastes combine with smells and tactile sensations to ultimately form flavor. Signals from the gustatory and olfactory systems are mixed in the orbitofrontal and other areas of the cerebral cortex to generate flavors and mediate food recognition (Rolls and Baylis, 1994). Ultimately, the gustatory and olfactory senses complement each other to enhance flavor. Flavor is a multisensory perception.

2.2. Beef Flavor Development

Flavor is essential to the long-term success of beef products and serves as the guard rails of beef quality. Sitz et al. (2005) found that flavor was the most crucial factor affecting consumers' buying habits and preferences when tenderness was held constant. Additionally, Huffman et al. (1996) reported that flavor had the most substantial relationship ($r = 0.67$) to overall steak palatability ratings when consumers prepared steaks at home. Recent research has shown that beef flavor is more closely related to overall consumer liking than beef tenderness and juiciness (Berto, 2015; Glascock, 2014; Laird, 2015; Luckemeyer, 2015). Consumers often rate taste attributes as being the most important purchasing motivators.

Beef flavor is composed of several attributes and hundreds of volatile compounds that create a particularly complex and dynamic sensory experience. These flavors are an essential component of beef demand. The combination of taste and aroma form meat flavor, but mouthfeel and juiciness of meat can also influence flavor perception (Farmer, 1992). In 2011, the beef lexicon was developed to identify the major and minor flavor components in beef (Adhikari et al., 2011). With the addition of the beef lexicon, beef flavor can be quantified by trained panelists. Many antemortem and postmortem factors alter the development of meat flavor including animal age, sex, composition, handling, cook method, and storage conditions (Imafidon and Spanier, 1994; Kerth and Miller, 2015; Melton, 1999).

Raw meat has little to no aroma and has a salty, metallic, bloody taste and a sweet smell resembling serum (Wasserman, 1972). However, meat is a reservoir for compounds that contribute to flavor. Precursors to flavor development found in the components of meat are water, protein, lipids, carbohydrates, minerals, and vitamins. Flavor precursors are divided into two categories - water soluble components and lipids (Mottram, 1998).

Historically, Crocker (1948) reported that flavors present in raw meat are in the juices of the muscle, but once cooked, the muscle fibers developed the meaty flavor suggesting that the main flavor constituents were water-soluble. The main water-soluble precursors are free sugars, sugar phosphates, nucleotide-bound sugars, free amino acids, peptides, nucleotides and other nitrogenous components (Mottram, 1998). Ribose, ribose phosphates, glucose, fructose, mannose, glucose-6-phosphate, and fructose-6-phosphate are found in beef (Koutsidis et al., 2008a). These sugars are a product of post-mortem changes, for instance, the degradation of ribonucleotides to produce ribose and the depletion of glycogen to form glucose (Koutsidis et al., 2008b).

Meat flavor is believed to originate from the lean portion of meat and the species-specific flavor from the lipid portion. Hornstein and Crowe (1960) discovered that extracted water from cooked beef, pork, and lamb all had similar flavors, but when the fats were heated, species-characteristic aromas developed. This discovery suggested that the lean tissues contained precursors for the meaty flavor and the fatty tissues provided the species characteristics (Hornstein and Crowe, 1960). Hundreds of lipid-derived volatiles linked to cooked meat flavor include aliphatic hydrocarbons, aldehydes, ketones, alcohols, carboxylic acids and esters (Calkins and Hodgen, 2007). The lipid-derived volatiles tends to have high odor thresholds, particularly when compared to Maillard reaction products (Mottram, 1998).

Taste precursors tend to be large, water-soluble molecules, while aroma compounds are low molecular weight volatile compounds (Farmer, 1994). These components not only act as precursors to flavor but also have taste properties. MacLeod (1994) suggested that, in beef, sugars such as glucose, fructose, and ribose may contribute to sweetness, while organic, glutamic, carboxylic and aspartic acids provide a sour taste. Inorganic salts may play a significant role in saltiness, while bitter tastes may come from hypoxanthine, anserine, carnosine, and particular amino acids (MacLeod, 1994). Flavor enhancers such as monosodium glutamate (MSG), 5'-inosine monophosphate (IMP), 5'-guanosine monophosphate (GMP) and specific peptides help create umami (MacLeod, 1994).

Volatile compounds developed during cooking produce most of the characteristic flavors of meat. Heterocyclic volatile compounds containing sulfur compounds contribute the most to savory, meaty, roasty, and boiled flavor characteristics of meat (Van Ba et al., 2012). They mostly occur at low concentrations but also have a low odor threshold (Mottram, 1985). Other heterocyclic compounds linked to roast flavors are pyrazines, thiazoles, and oxazoles (Mottram, 1998).

Flavor development primarily relies on two factors. The first being flavor precursors that are inherently present in meat including fatty acids, amino acids, reducing sugars, and nucleotides and the second factor refers to the reaction conditions or cooking (Kerth and Legako, 2015). During the cooking process, unique flavor profiles are developed from two principle reactions - the Maillard reaction and lipid thermal degradation (Wood et al., 2004). Individually, these reactions create their own flavor profiles, but together they make the characteristic flavor of beef (Farmer, 1994).

2.2.1. Maillard Reactions

One of the most significant contributors to the flavor of cooked meat and meat products is the Maillard reaction. The Maillard reaction is a non-enzymatic browning reaction that results from a chemical reaction between an amino acid and a reducing sugar usually with heat. The reaction between one amino acid and one sugar will create numerous volatile compounds through a complex network of reactions (Farmer and Mottram, 1994). These volatiles are critical contributors to the overall flavor of the meat. The odor is dependent on the primary amino acid, while the sugar dictates the rate of reaction (Kiely et al., 1960). During the cooking process, most proteins denature between 55 and 80°C, and browning begins around 90°C (Maillard, 1912).

The mechanism of this reaction is still not completely understood, but the mechanism proposed by Hodge (1953) offers a basic understanding. The Maillard reaction is described in seven reactions: (1) Amine-sugar condensation; (2) Amadori rearrangement; (3) Sugar dehydration; (4) Sugar fragmentation; (5) Strecker degradation of amino acids; (6) Adol condensation; and (7) Aldehyde-amine condensation (Nursten, 2005). In the initial stages of the reaction, the presence of heat causes the condensation of the carbonyl group of the reducing sugar with the amino compounds to produce glycosylamine (Mottram, 1998). The glycosylamine is then rearranged and dehydrated to form furfural, furanone-derivatives, hydroxyketones, and dicarbonyl compounds (Calkins and Hodgen, 2007). As the reaction continues, the Amadori rearrangement occurs. The intermediates can react with other amines, amino acids, aldehydes, hydrogen sulfide, and ammonia.

One of the more essential reactions for flavor development is Strecker degradation. In this reaction, the amino acids are degraded by dicarbonyl compounds to form aldehydes (Shahidi, 1998). The amino acid is decarboxylated and deaminated creating an aldehyde (Resconi et al., 2013). This Strecker aldehyde contains one less carbon atom than the original amino acid, and carbon dioxide is formed (Shahidi, 1998). The dicarbonyl forms an α-aminoketone or aminoalcohol. These intermediates will go on to produce many of the desirable compounds including furans, pyrazines, pyrroles, oxazoles, thiazoles, thiophenes and other heterocyclic compounds. If this amino acid is a cysteine, it will lead to the production of hydrogen sulfide, ammonia, and acetaldehydes (Shahidi, 2004). These compounds produce pungent aromas that are created during cooking and have been shown to be the most important flavor compounds in meat flavor (Mottram, 1998; Shahidi, 1998).

Different sugars and amino groups can influence the Maillard reaction products and ultimately the flavor. One group, in particular, ribose and cysteine play an essential role in meat flavor (Kiely et al., 1960; Morton et al., 1960). Sulfur-containing volatiles such as thiophenes, thiazoles, thiazolines, dithianes, dithiolanes, trithiolanes, and trithianes have all been identified in cooked meat (Shahidi et al., 1986). The thermal degradation of sulfur-containing amino acids and vitamins have been proposed to be a precursor to many of the sulfur-containing volatile compounds (Gasser and Grosch, 1990).

2.2.2. Lipid Thermal Development

During cooking, lipids are degraded resulting in numerous aromatic compounds. These volatiles may contribute to the desirable and characteristic flavor of meat. Intramuscular lipids are mostly composed of triglycerides from marbling fat, and phospholipids from structural or membrane lipids (Shahidi, 1998). Lipid-derived compounds tend to be less impactful than Maillard reaction products because their odor thresholds are usually much higher than the volatiles produced from the Maillard reaction (Mottram, 1998). Higher concentrations of these compounds are needed to influence cooked flavor, but since all meat contains lipids in the form of intramuscular fat and phospholipids, lipids are a dominant contributor to cooked meat flavor (Mottram, 1998). However, when meat is prepared under severely high temperatures, lipid degradation products can be overpowered by the Maillard reaction products like pyrazines.

Hundreds of lipid-derived volatiles found in cooked meat include aliphatic hydrocarbons, aldehydes, ketones, alcohols, carboxylic acids and esters (Mottram, 1998). Lipid oxidation starts in raw beef and during cooking the reaction speeds up. During long-term storage, lipid oxidation products could lead to rancid off-flavors, but during cooking, the reactions happen quickly and create a different profile of volatiles producing more desirable flavors (Mottram, 1998). Lipids contribute both desirable and undesirable flavors in meat.

The oxidation and degradation of saturated and unsaturated fatty acids generally produce the aromatic volatile compounds associated with lipid degradation (Shahidi, 1998). Lipid thermal degradation is the breakdown of polar phospholipids and neutral triglyceride because of the change in energy stabilization during cooking (Kerth and Miller, 2015). Unsaturated fatty acids are more rapidly oxidized and act as the regulators of shelf life (Wood et al., 2004). Polar lipids are usually preferred over neutral lipids for degradation since polar lipids have a higher degree of unsaturation and lack of fatty acid on the third glycerol carbon (Kerth and Miller, 2015). Mottram et al. (1982) showed that the addition of adipose tissue to lean beef and pork did not proportionally increase lipid-derived volatiles, concluding that intramuscular lipids are the primary source of volatiles. Mottram and Edwards (1983) revealed that when triglycerides from intramuscular and intermuscular fat were removed there were no significant chemical or sensory aroma differences. However, the removal of all lipids (triglycerides and phospholipids) caused a less meaty, more roasted aroma, lower concentrations of oxidation products and higher levels of heterocyclic compounds, predominantly alkyl pyrazines. Thus, in beef, lipids may inhibit the formation of some heterocyclic compounds specially produced from the Maillard reaction (Mottram and Edwards, 1983). Since phospholipids have a higher degree of unsaturation and are more susceptible to oxidation, they are vital for meat flavor development (Mottram, 1998). It is important to note that lipid oxidation and the Maillard reaction do not occur separately but work together to create a wide range of effects on the volatile compounds produced.

2.2.3. Thiamine Degradation

Apart from the other precursors, thiamine appears to be a central precursor to meat flavor. Model systems have shown that when thiamine thermally degrades a multitude of sulfur compounds such as thiols, furanthiols, sulfides and disulfides are produced (Grosch, 2001; MacLeod, 1994; Van den Ouweland and Peer, 1975). Farmer (1994) reported that thiamine produced odor-causing flavor compounds such as bis2-methyl-2-furyldisulfide and 2-methyl-3-furyl-2-furfuryl-disulfide. Two other significant compounds produced by thiamine degradation were methyl-3furanthiol and 2(3)-mercapto-3(2)-pentanone (Guntert et al., 1990). It is important to note that these compounds can be derived from other pathways including the Maillard reaction between cysteine and ribose or during the Strecker reactions of sulfur amino acids and the interactions between them (Guntert et al., 1990).

2.3. Factors affecting Flavor and Tenderness

2.3.1. Lipid Percentage

Many studies have shown a certain level of fat is necessary to assure flavor, texture, mouthfeel, tenderness, appearance, and overall acceptability on whole-muscle and ground beef products (Cole et al., 1960; Cross et al., 1980; Miller et al., 1983). The amount of fat plays a vital role in how flavor is perceived. Mottram (1998) reported that the amount and types of fat might interfere with the Maillard reaction products and it is possible that higher concentrations of fat could block the formation of some lipid-derived volatiles. Unique lipid and Maillard derived volatiles were shown in patties made with different lean sources, but as fat percentages increased, there was an interference with the development of lipid and Maillard derived volatiles (Blackmon et al., 2015). Another hypothesis was suggested by Troutt et al. (1992), who proposed that fat can help protect the meat from overcooking by the consumer. Egbert et al. (1991) reported overall acceptability decreased as fat level decreased. Flavor intensity, juiciness, and tenderness were directly correlated to fat content (Egbert et al., 1991).

Higher fat content in ground beef has been shown to be more tender compared to lower-fat formulations (Berry and Leddy, 1984; Cross et al., 1980; Garzon et al., 2003; Kregel et al., 1986). Cross et al. (1980) evaluated the effects of the source and level of fat on sensory characteristics of ground beef and found that increasing fat from 16% to 28% increased tenderness and juiciness. In a similar study, Kregel et al. (1986) showed that texture and juiciness increased as fat increased in ground beef patties with 9.5 %, 21 %, and 28.5 % fat. Troutt et al. (1992) evaluated the chemical, physical and sensory characteristics ground beef patties at 5, 10, 15, 20, 25, and 30%. The lower fat (5 and 10%) patties had a darker red color; lower cooking losses; denser cooked physical structure; less juiciness, moisture release, beef flavor, and oily coating of the mouth; and greater patty firmness, cohesiveness, and crumbliness compared to the 20 and 30% fat patties (Troutt et al., 1992). Patties formulated with 20-30% fat were rated juicier and more flavorful (Troutt et al., 1992). Egbert et al. (1991) reported that flavor intensity, juiciness, and tenderness directly correlate with fat content, and the overall acceptability of beef patties was highest in the patties with 19% fat.

In a home-use test, consumers in Dallas and Houston, TX, preferred ground beef containing 20% fat over ground beef containing 15, 25 and 30% based on flavor, tenderness, juiciness, and general liking (Glover, 1964). Law et al. (1965) examined ground beef of varying fat levels (15, 25, and 25%) in a home-use study in Baton Rouge, LA. Five packages of frozen patties and five samples of frozen ground beef were sent home with 122 families asked to rate color before cooking, shrinkage, general cooking qualities, juiciness, flavor, and general acceptability. Consumers preferred the 15% fat percentage over the other two levels for all attributes except juiciness. There were no significant differences in juiciness between the three fat levels. The consumers rated the bulk ground beef higher than the patty form in all attributes except for shrinkage and general cooking qualities (Law et al., 1965).

In a more recent study, Lusk and Parker (2009) asked consumers whether they preferred 10% fat or 20% fat in their ground beef. The majority of consumers indicated that they preferred the lower fat level indicating that although consumers were willing to buy lower fat ground beef, higher fat ground beef was more palatable (Lusk and Parker, 2009). However, ground beef with 10 % fat has often led to a cooked product that is bland and dry with a hard, rubbery texture (Keeton, 1994; Youssef and Barbut, 2011). Similarly, Troutt et al. (1992) stated that low-fat patties (5% and 10%) were crumblier, less juicy and flavorful, firmer, and caused less mouth coating than patties with 20% or 30% fat.

In one consumer study, Wilfong et al. (2016) found that tenderness, flavor, texture, and overall liking were not affected by the fat level, but the fat level was shown to affect juiciness. The two 90/10 ground beef treatments used in this study were rated lower for juiciness than two 80/20 treatments and one 73/27 ground beef (Wilfong et al., 2016). Highfill (2012) used ground knuckles and chuck rolls from USDA Select and Top Choice carcasses and evaluated the effects of quality grade on sensory panel scores.

Ground beef patties formulated from Select and Top Choice knuckles had similar scores for cohesiveness, juiciness, beef flavor, off-flavor, and desirability (Highfill, 2012). However, ground beef patties from the Select chuck rolls were firmer and had less mouth coating then the Top Choice chuck rolls (Highfill, 2012).

2.3.2. Fatty Acid Profile

The fatty acid composition is an important factor in the sensory quality attributes and nutritional value of beef (Wood et al., 2004). Previous studies have related positive and negative flavor attributes to fatty acids. Since fatty acids are precursors for different volatile compounds, a variation in volatile aromatics produced could change the overall perception of beef flavor. The concentration of oleic acid in beef accounts for about one-third of total fatty acid content in beef and has been positively correlated with overall palatability (Rule et al., 2002; Waldman et al., 1968; Westerling and Hedrick, 1979). Oleic acid has also been positively correlated with beef/brothy and beef fat beef flavor attributes (Baublits et al., 2009). Thus, as oleic acid increased, beef flavors increased.

Blackmon et al. (2015) examined the fatty acid profile from ground beef prepared from the brisket, flank, and plate. Brisket patties contained higher proportions of monounsaturated fatty acids and the patties produced from the flank had less saturated fatty acids. Similarly, Gredell et al. (2018) examined the fatty acid content of seven ground beef blends of various whole-muscle cuts and 81/19 ground chuck trimmings. They found that brisket had increased concentrations of monounsaturated fatty acids. Blackmon et al. (2015) reported that linoleic acid reduced the intensity of beef identity; myristoleic acid decreased salty basic tastes; and stearic acid increased umami, overall sweet, sweet, and heated oil flavor and basic taste attributes (Blackmon et al., 2015). In this study, stearic acid was highly correlated to beef flavors instead of oleic acid contrary to Melton et al. (1982). Melton et al. (1982) reported that palmitoleic acid and oleic acid positively correlate with beef flavor and stearic acid was negatively correlated.

Kerth et al. (2015) compared the fatty acid concentrations between ground beef patties made with the lean from brisket, chuck, round, and flank. Stearic acid was shown to be lower in brisket patties when compared to the chuck and flank. Patties made from the flank had a higher percentage of total saturated fatty acids when compared to patties made from the round (Kerth et al., 2015). However, consumer sensory traits were not affected by the difference in fat sources (Kerth et al., 2015).

2.3.3. Young versus Mature

A significant source of meat for the beef industry comes from mature cows. In 2017, 18.2% of all cattle slaughtered in the U.S. were from mature animals (USDA, 2018). Decreased productivity, efficiency, and profitability result in older animals culled from the beef cattle herd. Many consumers believe that all cow beef ends up as ground beef and becomes the source for hamburgers in fast food restaurants (Woerner, 2010). Although a large portion of meat used for ground beef formulations is from mature cattle, most cow meat facilities also produce whole-muscle cuts. Market cows do not qualify for the traditional USDA quality grades of Prime, Choice, Select, and Standard because they are most likely older than 42 months of age but are eligible for USDA quality grades of Commercial, Utility, Cutter, and Canner. In most cow plants, carcasses are sorted by company personnel (not USDA) based on carcass quality characteristics such as fat color, lean color, amount of muscling and degree of marbling (Woerner, 2010). When compared to conventionally-produced beef from grain-finished steers and heifers, the majority of meat produced from market cows is tougher, leaner, less juicy, and has a higher incidence of undesirable flavors (Woerner, 2010). As maturity increases, consumers have reported finding the beef tougher and had more instances of off-flavors (Hilton et al. 1998; Stelzleni et al., 2007). Smith et al. (1983) also showed that flavor decreased as maturity increased. Since the majority of market cow beef sold is as ground beef, a common practice among processors has been to blend cow lean with fat trimmings from conventionally-produced beef or fed cows. It is imperative to understand how meat from mature cattle could influence flavor and texture abilities. Two key factors that affect the flavor and tenderness of mature beef are animal diet and amount of heat-soluble collagen.

In one study by Hilton et al. (1998), as physiological age increased from youthful to mature, sensory panel scores for off-flavor also increased. The off-flavors and the variation in flavor have been attributed to the animal on a forage-based maintenance diet its entire life (Bruce et al., 2005). Several studies have shown that beef from cattle finished on low-energy diets with high-forage contents produce an undesirable flavor (Brown et al., 1979; Dolezal et al., 1982; Hedrick et al., 1983; Larick et al., 1987; Melton et al., 1982; Schroeder et al., 1980). Grass-fed beef has undesirable flavor characteristics such as grassy, gamey, intense milky-oily, sour and fishy (Berry et al., 1980; Brown et al., 1979; Larick et al., 1987; Melton et al., 1982; Schroeder et al., 1980). Several studies have shown that by feeding high concentrate diets to market cows before harvest, flavor and tenderness improved (Cranwell et al., 1996; Schnell et al., 1997; Stelzleni et al., 2007). In another study, Miller et al. (1983) reported that by keeping marbling scores constant across maturity groups, palatability and shear force values were not different. A high-energy diet also significantly increased ribeye area and marbling scores of mature carcasses (Boleman et al., 1996; Stelzleni et al., 2007).

The concentrations of precursors have also been found to vary with the type of feeds. Koutsidis et al. (2008a) showed that total reducing sugars were higher in beef from the concentrate feeding group as compared to the group that was fed grass silage; whereas, animals fed grass silage had higher levels of free amino acids. The higher glycogen content in concentrate-fed cattle could produce more lactic acid and increase sourness (Larick and Turner, 1990).

As cattle age, the cartilaginous buttons of the vertebrae ossify and become hard bone, indicating a mature carcass (USDA, 2016). As this occurs, the beef becomes tougher due to the decrease in collagen solubility and the increase in collagen cross-bridges (Herring et al., 1967). The amount of collagen does not increase, but there is an increase in diameter and in the amount of collagen that matures to form heat-stable crosslinks (Purslow, 2005). As an animal matures and ages, the crosslinks slowly mature and stabilize and become insoluble, this concept is the basis for the maturity-beef tenderness relationship (Miller et al., 1983). This relationship was seen in Herring et al. (1967) who reported that as each maturity group increased, the collagen solubility significantly decreased in both the m. *Longissimus dorsi* and m. *semimembranosus*. This relationship is why cattle are harvested at a young age in the United States (Herring et al., 1967). Another factor that affects the meat quality of mature cattle is the myoglobin concentration in muscle increases with animal age leading to a darker red beef color (Clydesdale and Francis, 1971).

Xiong et al. (2007) looked at how animal age affects the overall quality of postmortem meat. m. *Semitendinosus* and m. *Semimembranous* muscles from animals in three different age groups, 2 to 4 yr, 6 to 8 yr, and 10 to 12 yr, were ground and made into patties to evaluate lipid and myoglobin oxidation. Although they did not notice any myoglobin oxidation, they discovered a substantial difference in lipid oxidation between the different age groups. In raw and cooked patties of both muscles from the 10 to 12 yr cows were the most susceptible to lipid oxidation, followed by the 6 to 8 yr, and the 2 to 4 yr group was least susceptible. Xiong et al. (2007) suggested that since humans have been shown to have decreased plasma antioxidants with age, 10 to 12 yr cow muscle might have less endogenous antioxidants, thus, enhancing the oxidative susceptibility of the lipids. The increased lipid oxidation in older animals could affect flavor.

Cross et al. (1976) compared young quality grades (Prime, Choice, and Select) with the mature quality grades (Utility and Cutter) on the palatability of ground beef patties. Ground beef patties formulated from USDA Cutter carcasses were tougher then patties from youthful carcasses. USDA Prime and Choice patties were also found to have less connective tissue and had higher overall acceptability compared to the patties made from USDA Utility and Cutter carcasses (Cross et al., 1976). Similarly, Berry and Abraham (1996) found that ground beef patties from young carcasses (< 24 mo) were more tender for initial and final tenderness and had less connective tissue then the ground beef patties formulated with mature carcasses (> 24 mo). However, panelists did not find differences for juiciness and flavor (Berry and Abraham, 1996).

2.3.4. Muscle Source

With new emerging trends in the gourmet burgers industry, several restaurant chains believe their signature blend of raw material leads to a better tasting burger. Different muscles in the animal will have different flavor profiles based on color, location, and function in the body (Xiong et al., 1999). Several studies have assessed the effects of different primal and sub-primal sourced blends on ground beef palatability. Several factors including the impact of fat source, marbling, maturity levels, and muscle-specific blends affect the overall flavor and texture of ground beef (Blackmon et al., 2015; Highfill, 2012; Kerth et al., 2015)

Fruin and Van Duyne (1961) examined palatability differences in ground beef prepared from the chuck and round of U.S. Commercial or Standard carcasses. Quality grade was shown to not affect palatability, but panelists preferred ground beef from chucks over ground beef prepared from rounds.

Gredell et al. (2018) evaluated the differences in flavor and texture across seven different ground beef products including chuck shoulder clods, chuck boneless short ribs, briskets, tenderloin tips, top sirloin caps, knuckles, and 81/19 chuck sourced trimmings. Using trained panel evaluations, Gredell et al. (2018) found that ground beef patties formulated from the chuck trimmings were more desirable in flavor attributes as compared to ground beef formulations containing brisket or sirloin cap. The brisket and sirloin caps were rated similarly high with the chuck sourced trimmings for beefy/brothy, browned/grilled, and buttery/beef fat flavor attributes and lower in livery and sour acidic off-flavor attributes (Gredell et al., 2018). In another study, Wilfong et al. (2016) found no difference in consumer palatability between in 80/20 ground chuck, 80/20 Certified Angus Beef ground chuck and 80/20 ground beef. The 90/10 ground beef and 90/10 Certified Angus Beef ground sirloin was rated similarly for juiciness, flavor, texture and overall acceptability; however, the 90/10 ground beef was rated lower for tenderness than the 90/10 Certified Angus Beef ground sirloin (Wilfong et al., 2016).

Ground beef patties made from the brisket, plate, and flank have been shown to possess unique flavor, and Maillard derived volatiles (Blackmon et al., 2015). Blackmon et al. (2015) showed that ground beef patties produced from the brisket had less 2-heptenal, decane, nonane, 2-octanone, dodecane, nonenal, heptanal, pentanal, octane, and octanal, but more butanoic (butyric) acid and 2-nonenal than those from the plate. As the premium hamburger chains want specialty blends, more flavor research on the different muscle sources and blends of various muscles is needed.

2.3.5. Texture Influences

Brewer (2012) defined texture as the combination of kinesthetic sensory characteristics to include those perceived before mastication (particle size and oiliness), those observed during mastication (tenderness and juiciness), and those perceived after mastication (fibrous residue and mouth coating). Consumers recognize texture as an essential characteristic of satisfaction for chewing and the pleasure of eating (Bourne and Szczesniak, 2003). Since muscle foods have natural texture characteristics like muscle fibers, fluid/fat exudation, and connective tissue, texture becomes an essential characteristic of meat palatability and consumer acceptability (Brewer, 2012).

Muscle fibers contain about 75% water. Meats ability to hold water is a vital component of texture perception. Therefore, increasing temperature or decreasing pH can substantially increase the loss of water and decrease juiciness and overall acceptability of ground beef (Brewer and Novakofski, 1999; Offer and Knight, 1988; Siegel and Schmidt, 1979). In ground beef, the processing characteristics such as grind size, grind method, and forming method will all affect the flavor and tenderness attributes.

2.3.5.1. Grind Method

The grinding process is designed to reduce particle size and extract soluble proteins in ground beef. Particle size reduction for ground beef occurs through several methods including grinding, flaking, chopping, chunking or slicing. Grinding method of comminuting beef has been related to tenderness, juiciness and overall acceptability (Cross et al., 1980). In this method, traditional plate grinders reduce particle size by squeezing and extruding meat through perforated plates.

Another method, flake-cutting or flaking is where meat is forced across the cutting edge by a high-speed impeller, producing thin, cut flakes without crushing the meat particles (Chesney et al., 1978). Lin and Keeton (1994) used different particle size reduction methods including, flaked, coarse ground, and a mixture of flaked and fine ground to formulate 10% fat beef patties in order to conduct sensory, instrumental and compositional evaluations. Patties made with the flaker were rated juicier and less hard, dense and cohesive then patties that were coarse ground (Lin and Keeton, 1994). Similarly, Randall and Larmond (1977) also looked at the effect of grinding and flaking on ground beef patties. Panelists found that the ground beef had a finer texture, increased tenderness, were less rubbery, juicier, and greasier (Randall and Larmond, 1977). The panelists indicated the flaked patties were tough and dry, pressed too tight, too firm, and spongy while the ground patty was tender and moist, smoother, and lighter (Randall and Larmond, 1977). In pork, Chesney et al. (1978) found that flaked products were rated lower in juiciness and cohesiveness but were rated higher in overall acceptability compared to ground products.

Historically, the bowl-chopper has been primarily used to form meat batters but is now commonly used to reduce the particle size of meat and fat and for mixing ingredients (Aberle et al., 2012). The bowl-chopping method uses rotating knives to finely cut the meat and mix the product at the same time. Although there are limited amounts of research on the effect of bowl-chopping on ground beef patties, several premium hamburger chains have started to employ this method as their choice of particle size reduction

2.3.5.2. Grind Size

In the ground beef system, the size of meat from the different systems will influence the sensory and texture attributes. Roth et al. (1999) formulated ground beef at three different grinder plate sizes (2, 3, and 5 mm) to examine sensory and instrumental texture attributes. Grinding beef through a 2 mm plate size produced lower cook loss, hardness, and Kramer shear force patties than did the patties with the larger plate sizes (3 and 5 mm; Roth et al., 1999). Also, rubberiness was shown to increase as plate size increased (Roth et al., 1999). Roth et al. (1999) hypothesized that the decrease in cook loss from the smaller plate size might be related to an increase in heat transfer rate because of the smaller particles.

Wells et al. (1980) reported that mechanical desinewing through a 0.19 cm aperture resulted in improved tenderness compared to the use of the 0.25 cm aperture grind plate in cow meat beef patties. Similarly, Suman and Sharma (2003) reported that ground buffalo patties prepared at 3 mm grind size were rated higher in juiciness, texture, and overall acceptability as compared to patties made with the 4- and 6-mm grind size plates. They hypothesized that the increase in sensory attributes could be due to smaller particle sizes that allowed for increased binding in ground buffalo meat patties (Suman and Sharma, 2003). In another study, McHenry (2013) used two different grind sizes, 1.6 and 3.2 mm, to determine differences in flavor and texture attributes in ground beef patties. The smaller grind size patties were rated softer, more tender, had less connective tissue, and smaller particle size than patties from the larger grind size. Conversely, overall palatability and tenderness of ground beef patties were shown to decrease by final grinding through 0.32 cm compared to a larger (0.48 cm) plate (Egbert et al., 1991).

2.3.5.3. Forming Method

Forming methods are designed to create the proper shape, size, and weight of a ground beef patty. In recent years, the hamburger trend is evolving from cookie-cutter, perfect hamburger shapes to home-made style hamburger because consumers perceive them as being of higher value (Salvage, 2008). There are several different types of filling and molding methods that all have advantages and disadvantages. While the research on forming methods is limited, the forming process has been shown to affect flavor and texture (Liu and Berry, 1998; MeHenry, 2013; Roth et al., 1999) .

Liu and Berry (1998) examined two different patty filling methods, a gravity fill, and an alternative filling method. The gravity fill method forced meat into a mold by gravity; whereas, in the alternative method, meat was twisted with less pressure through small holes into a mold (Liu and Berry, 1998). The alternative method created patties that were softer, had a faster rate of breakdown, and lower yield and more chewed pieces than gravity-filled patties.

McHenry (2013) used a vacuum stuffer with a portioning device and a Formax F6. The Formax patties were more cohesive, but had lower hardness, tenderness, connective tissue, and particle size values as compared to patties formed using a vacuum stuffer with a portioning device (McHenry, 2013). Patties made with the Formax were softer and more cohesive, while patties made with the vacuum stuffer were crumblier (McHenry, 2013). The vacuum-stuffer method had higher scores for moisture content and fat mouthcoating (McHenry, 2013).

Roth et al. (1999) used different formation pressures of 50, 100, or 150 kg on 10% and 25% fat ground beef patties. Patties formed at 50 kg were significantly less cohesive than the patties formed using the other two pressures (Roth et al., 1999). Twenty-five percent fat patties formed at 50 kg had the lowest breaking strength compared to patties from the other fat and pressure combinations (Roth et al., 1999). Patties formed at 150 kg of pressure minimized rubbery texture, hardness, shear and break force (Roth et al., 1999).

2.3.6. Thickness

Kerth (2016) observed the effects of different thickness of steaks and cook surface temperatures on Maillard reaction products. As a result, the aromatic volatiles associated with beef flavor were altered (Kerth, 2016). Thinner steaks (1.3 cm) and lower cooking temperatures favored the production of lipid-degradation products including 2-decenal (tallow), 1-hexanol (woody), 1-octanol (soapy), 2-heptanone (fruity), 2-pentyl-furan (green bean), octanal (fatty), and styrene (sweet; Kerth, 2016). The thicker (3.8 cm) steaks had more Maillard reaction products including 2-ethyl-5-methyl-pyrazine (roasted), 2-ethyl-6-methyl-pyrazine (fruity), 2-methyl-butanal (burnt), butanedione (buttery), 2,5-dimethyl-pyrazine (roasted), 3-methyl-butanal (sickly), and methyl-pyrazine (roasted; Kerth, 2016). Berto (2018) examined the differences of steak thickness and cook surface temperatures on expert trained flavor and texture descriptive attributes and consumer liking attributes. USDA Top Choice and Select beef top loin steaks cut to 1.3 cm or 3.8 cm were cooked on a commercial flat top grill with a surface temperature of 177°C and 232°C. This study suggested that consumers liked the beef flavor of the thick steaks cooked at the lower temperature. However, the thick steaks cooked on a high temperature had higher levels of smoky charcoal, bitter, burnt, and metallic descriptive flavor attributes that were negative consumer attributes.

Thickness has been shown to be an important consideration for consumers when purchasing steaks; however, preferences differed among consumers (Leick et al., 2011; Leick et al., 2012). Liu and Berry (1998) reported that increasing patty thickness from 0.95 cm to 1.27 cm in low-fat ground beef patties decreased sensory firmness and increased initial juiciness. The hypothesis was that the thicker patties might have higher fat retention than the thinner patties due to a lower external surface to volume ratio and less surface contact with the griddle since the thicker patties had smaller diameters (Liu and Berry, 1998).

Clarke et al. (1983) determined that consumers preferred pork chops between 1.3 cm and 2.5 cm when shown pictures of chops attached to foam slices of varying thickness. Holmes et al. (1966) compared tenderness between 1.3 and 1.9 cm pork chops broiled to 77°C. Flavor and tenderness were not affected, but the 1.9 cm chops were juicier. Weir et al. (1963) examined pork rib chops cut to 1.9 and 3.8 cm thick and cooked by braising or broiling. The thicker (3.8cm) broiled rib chops were less juicy than the 1.9 cm chops. However, the flavor was more fully developed in the thicker chops from both cooking methods, but the thicker chops had more flavor intensity in the broiled cooking method. The thin chops were more tender and juicier, but less flavorful. The broiled chops had higher juiciness and tenderness scores than braising. Kersh (1978) investigated the relationship between cooking method and chop thickness on the palatability of pork loin chops. Chops were cut to either 0.7, 1.3 1.9 or 2.5 cm thick and cooked either by broiling, pan frying or microwave to an internal temperature of 77°C. Chop thickness had no effect on tenderness, juiciness or overall acceptability scores of the chops. Broiling produced the most tender chops. Simmons et al. (1985) evaluated the effects of chop thickness, internal temperature, and cooking method. For chops cut to 1.27, 1.90, and 2.54 cm, tenderness and juiciness sensory panel values did not differ across thickness of the grilled and oven prepared chops, but the grilled 1.27 cm chops had higher WBSF values.

2.3.7. Cooking Method

Cooking is one of the last factors that influence the eating quality of meat before consumption. The meat industry has little control over this step when meat is taken home by the consumer, but this is one of the most critical factors that influence meat eating quality. Differences in beef flavor are dramatically affected by different cooking methods. Cooking method changes the volatile compounds formed and the overall flavor of the meat. Three main factors differ among difference cooking techniques: the temperature on the surface of the meat, the temperature profile through the meat and the method of heat transfer (Bejerholm and Aaslyng, 2004). Cooking can cause a wide variety of heating conditions in meats. During frying a steak or chop, the internal temperature might reach 60°C in only a few minutes, while the outer surface might reach 120°C. The center of a roast might reach 75°C after an hour in the oven, but the surface is at 190°C. In a stew, meat might be at 100°C for several hours (Van den Ouweland and Swaine, 1980).

Surface temperature is essential for the development of odor, flavor, and color of the meat. Surface temperatures above 110°C facilitate Maillard reactions which aide in the development of flavor and aromas (Whitfield and Mottram, 1992). The temperature profile through the meat will influence the rate and extent of protein denaturation. Davey and Gilbert (1974) showed heat induced by cooking caused meat to toughen in two stages. The first stage, occurred at 40 to 50°C, denatured the contractile proteins, actin, and myosin and caused an initial loss of fluid (Davey and Gilbert, 1974). The second stage, at 64 to 68°C, resulted in the denaturation of collagen and there was additional shrinkage of the fibrils and more fluid loss (Davey and Gilbert, 1974).

The method of heat transfer affects the aromas, flavor, and color, especially in the presence of humidity. The moist cooking method will prevent Maillard reactions and will create a different flavor (Kerth and Miller, 2015). Cooking meat in a moist environment with water or a partially closed method such as using a clamshell type cooking apparatus will trap moisture allowing the meat to cook using steam. 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 and Miller, 2015).

Low temperature, moist-heat cookery prevents beef from reaching a sufficient surface temperature for the development of Maillard reaction products and also inhibits dehydration of the surface to initiate the Maillard reaction (Kerth and Miller, 2015). Moist-heat cooking around 100°C will have significantly different flavor attributes from meat cooked with a dry heat method (Rhee, 1989). MacLeod et al. (1981) divided all of the cooking methods into two heated beef flavors typed: boiled and roasted. They summarized the volatile compounds from boiled and roasted aromas of beef and found that carboxylic acids, amines, thiols, dithianes, dithiolanes, trithianes, and trithiolanes were identified more often in boiled beef aromas than roasted aromas; while, hydrocarbons, benzenoids, alcohols, aldehydes, ketones, lactones, esters, sulfides, furans, thiophenes, pyrroles, pyridines, pyrazines, thiazoles, thiazolines, oxazoles, and oxazolines were found more frequently in roasted aromas than boiled aromas (MacLeod et al., 1981).

Berry and Leddy (1984) looked at six different dry cooking methods on ground beef patties including broiling on open hearth electric grills; charbroiling on an open, slated grill; conventional oven roasting; convection oven roasting; frying on flat grills with no oil; and microwave to understand how flavor and texture attributes were affected using a trained descriptive attribute sensory panel. Conventional and convection oven roasting along with broiling produced the highest ratings for initial tenderness followed by char-broiling, frying and finally microwave (Berry and Leddy, 1984). Frying, convection oven roasting, and broiling had the highest rating for flavor intensity (Berry and Leddy, 1984). Connective tissue was not affected by the cooking methods (Berry and Leddy, 1984). Berry and Leddy (1984) suggested that the lower tenderness scores seen for the frying cooking method were most likely the result of the thicker crust formation.

The cooking method of pork has a dramatic effect on the juiciness and tenderness of pork. Several studies have shown a variety of pork cuts and different cooking methods, such as roasting, grilling, and frying. They have demonstrated that juiciness is most affected by cooking conditions (Heymann et al., 1990; Prestat et al., 2002; Simmons et al., 1985). Davey and Gilbert (1974) suggested that the reduction in juiciness and tenderness as cooking temperature increased was due to myofibrillar protein denaturation and structural changes in the muscle that caused water to expel from the tissue. Bailey (1988) proposed that at higher temperatures the denaturation and shrinkage of endomysial and perimysial collagen sheaths cause a loss of water and increased toughness.

Bejerholm and Aaslyng (2004) used five different cooking techniques to determine the sensory impact of cooking technique on pork. Cooking treatments consisted of minced meat patties pan-fried at 155°C, steaks pan-fried at 155°C, pot roasts prepared with water, oven roasts cooked in a roasting bag at 140°C, and oven roasts cooked at 90°C. The low-temperature cooking generally resulted in more tender, juicy, and less hard meat as compared to the pan-fried methods. The pan-fried methods produced more roasted flavor (Bejerholm and Aaslyng, 2004).

Bennett et al. (1973) reported that deep fat frying toughened all pork chops when compared to broiling. Broiled chops were rated higher in tenderness by a sensory panel with no differences in juiciness or flavor and lower in WBSF values (Bennett et al., 1973). Simmons et al. (1985) looked at differences between grilling on an inside grill versus baking. The oven-baked loin chops cooked to 80°C had the highest WBSF values and the sensory panel also ranked these chops as being the toughest (Simmons et al., 1985).

2.3.8. Internal Temperature

Consumer research has consistently shown that traditionally consumers over-cook pork creating a subpar eating experience (Detienne and Wicker, 1999). Due to concerns about a parasite, *Trichina spiralis*, and the potential health threat, consumers tend to over-cook pork. Webb et al. (1961), Weir et al. (1963), Carlin et al. (1965), and Pengilly and Harrison (1966) observed that as pork loin roasts decreased in internal doneness temperature, the juiciness and cooking yields increased. Simmons et al. (1985) noticed a significant decrease in sensory panel tenderness of chops grilled to 80°C as compared to chops grilled to 60°C and 70°C. The grilled chops did not present differences in WBSF values between the 60°C, 70°C and 80°C internal temperatures, but the baking cooking method resulted in increased WBSF values at 80°C (Simmons et al., 1985). As the internal temperature increased in the pork chops, the cooking loss significantly increased for both cooking methods. Simmons et al. (1985) concluded that reduced internal doneness temperature had favorable effects on juiciness, tenderness and cooked yield of chops. In a similar study, Berjerholm and Aaslyng (2004) discovered that regardless of cooking method, juiciness decreased as internal temperature increased.

2.3.9. Hold Time

Most foods are cooked for immediate consumption. However, the food service and retail food industries might prepare and cook meat products in advance. The conventional food service method consists of cooking and serving or cooking and holding (Klein et al., 1984). Hot-holding is a method where a food product is cooked and then held above 60°C until consumed. Hot-holding occurs in cafeterias or buffet lines where the meat may be placed in steam tables or other types of hot-holding equipment to maintain temperature. Bengtsson and Dagersbog (1978) reported that hot-holding is an efficient means of destroying the sensory quality of food products. Storage of cooked meat has been known to cause flavors like old, stale, oxidized, warmed-over, rancid or painty flavors and odors produced by oxidation of unsaturated fatty acids (Rhee, 1989).

Karlstrom and Jonsson (1977) examined the effects of hot holding and internal degree of doneness on hamburgers. There was significant deterioration for cooked ground beef patties in sensory quality after warm-holding for 3 h for 70 and 90°C internal temperature endpoints (Karlstrom and Jonsson, 1977). The hamburgers cooked to 90°C were firmer, drier, had less yield, and more sensory deterioration in flavor and aroma then the hamburgers cooked to 70°C (Karlstrom and Jonsson, 1977). However, Paulus et al. (1978) found that hot-holding meat entrees, such as sauerbraten, chicken fricassee, meatloaf, beef goulash, and fried sausage, could be hot-held for at least 3 h without any significant decreases in sensory quality.

James and Calkins (2007) studied the influence of holding time on beef chuck and round steaks on flavor. There were no tenderness differences between the 0 h and 1 h holding times but the 0 h hold time had higher juiciness ratings. Liver-like, metallic, sour, charred, rancid, fatty or other off-flavors were not different between holding times but oxidized off-flavor was impacted by holding time for m. *Vastus medialis*. James and Calkins (2007) concluded that the longer hold time reduced intensity of off-flavors.

Berry and Liu (1988) examined the effect of cook and hold methods on the properties of low-fat beef patties. Ground beef patties at 10% fat were either immediately evaluated after cooking or held at 63°C for 90 min (Berry and Liu, 1998). The held patties had reduced total cooked weight, increased fat content, reduced moisture content, and lowered juiciness values, but had a slightly faster breakdown during chewing and had increased ground beef flavor intensity (Berry and Liu, 1998). The holding procedure also decreased the presence of pink/red color. The use of thicker patties was advised in cook and hold systems. This study indicated that a cook and hold system might not be too detrimental to the eating quality of low-fat ground beef patties (Berry and Liu, 1998).

2.4. Pork Quality

2.4.1. Conversion of Muscle to Meat

After death, a complex series of changes within the muscle occur that can dramatically influence meat quality. The initiation of the conversion of muscle to meat is the cessation of blood circulation leading to the depletion of muscle oxygen. Muscles are trying to synthesize and use adenosine triphosphate (ATP) in order to maintain homeostasis. Oxygen quickly depletes from the muscle, and since the animal is no longer receiving oxygen, the muscle metabolism converts from aerobic to anaerobic. As the muscle is trying to produce more ATP, glycogen stored within the muscle will begin to break down through glycogenolysis. The glucose molecules enter the glycolytic pathway to produce ATP through glycolysis. Pyruvate, an end product of glycolysis, is broken down into lactate and hydrogen ions by the enzyme lactate dehydrogenase. While the muscle is trying to maintain function, glycolysis is producing ATP at a minimal rate. Once the ATP is diminished, muscles contract and permanent cross-bridges between actin and myosin forms.

The accumulation of lactate and hydrogen ions will reduce the pH from a physiological pH of approximately 7.2 to between 5.5 and 5.8 after slaughter (Lonergan, 2012). The rate and extent of the pH decline are related to the type of muscle, the temperature of chilling, and preslaughter stress. Hambrecht et al. (2005) reported that oxidative muscle fiber type has a lower glycolytic potential and higher final pH than glycolytic muscle fiber types. Pork muscles chilled at higher temperatures were shown to have a steeper pH decline early postmortem (Briskey and Wismer-Pedersen, 1961). Antemortem stress can lead to changes in the pH decline and the development of pale, soft, and exudative (PSE) or dark, firm, and dry (DFD) pork. Rosenvold and Anderson (2003) reported the average pH of pork m. *Longissimus dorsi* measured at 45 min postmortem of pigs stressed by exercise and non-stressed pigs. The average pH at 45 min of pigs stressed was 6.3 compared to non-stressed pigs with an average pH of 6.45

(Rosenvold and Andersen, 2003). When long-term stress occurs in the animal before harvest, glycogen reserves are used to respond to the stressor. When glycogen reserves are limited, higher ultimate pH is observed because of restricted glycolysis postmortem (Hambrecht et al., 2005). Myofibrillar proteins, more specifically myosin and actin, are responsible for binding water in meat and are also affected by pH. A rapid decline in pH will cause a combination of low pH and high temperatures, denaturing a component of the myosin. Since this condition denatures myosin, there are fewer functional proteins to bind water.

Huff-Lonergan et al. (2002) found significant correlations between ultimate pH and color, marbling, firmness, percent drip loss, percent cook loss, and sensory characteristics of tenderness, juiciness, flavor and off-flavor. In another study Moeller et al. (2010b), reported that an ultimate pH near 5.4 reduced consumers' satisfaction, however, increasing pH incrementally from 5.4 to 6.4 improved juiciness, tenderness and flavor. The higher pH values have been shown to predict more tender and juicy pork (Moeller et al., 2010a). Moeller et al. (2010b) concluded that ultimate pH had a significant effect on consumer perceptions and satisfaction. Consumer satisfaction decreased for products that were near pH 5.4, but incremental improvements in juiciness, tenderness, and flavor attributes were observed as pH increased to 6.4 (Moeller et al., 2010b). The rate of pH decline and ultimate pH are critical factors in pork quality and will affect water-holding capacity and color (Pearce et al., 2011).

2.4.2. Water-holding Capacity

Water-holding capacity is the ability of meat to retain naturally occurring or added moisture during the application of any external force (Aberle et al., 2012). Color, texture and firmness of raw meat along with tenderness and juiciness of cooked meat are all affected by water-holding capacity. There are two main reasons why water-holding capacity is vital to meat quality: first, economics as meat is sold by weight; and second, customer satisfaction as losses during cooking reduce the size of meat, number of servings, juiciness, and tenderness. Excessive purge creates an unattractive appearance (Offer and Trinick, 1983). Drip loss or purge is a measure of water-holding capacity in meat. It is estimated that as much as 50% or more of pork produced has a high drip loss or purge (Kauffman et al., 1992; Stetzer and McKeith, 2003). Weight loss from drip loss can average as much as 1 to 3% in fresh cuts and as high as 10% in PSE (Melody et al., 2004; Offer and Knight, 1988). The Pig Improvement Company (2003) suggested that more than a 5% drip loss, 35% cook loss and 3% purge in whole loin packages creates a pork quality problem. In addition to the loss in weight, purge also contains water-soluble, sarcoplasmic proteins (Savage et al., 1990).

Meat is composed of about 75% water, approximately 20% protein, about 5% lipids, approximately 1% carbohydrates and other vitamins and minerals (ash) are about 1%. The majority of water is held within the structure of the muscle. Water is a dipolar molecule with positive and negative charged ends that are naturally attracted to charged species like protein (Huff-Lonergan and Lonergan, 2005). Some water is bound so tightly to the proteins it has limited mobility and is called bound water (Offer and Knight, 1988). Bound water does not freeze and stays intact during heating (Aberle et al., 2012). The next layer of water is held within the spaces of myofibrils by either steric effects or by attraction to bound water, this is called immobilized water (Huff-Lonergan and Lonergan, 2005). During the early stages of rigor, this water does not flow from the tissues but can be removed by drying and can be frozen during freezing. This water is most affected by the conversion of muscle to meat because by lowering the pH and changing the muscle cell structure this water will eventually flow freely as purge (Offer and Knight, 1988). The final layer of water or free water is held by weak forces and flows freely from the tissues. In pre-rigor meat, free water is not observed but as the conversion of muscle to meat occurs, the immobilized water moves to the surface to become free water (Fennema, 1996).

Postmortem pH plays a significant role in water-holding capacity. During the conversion of muscle to meat, an increase in positively charged ions reduces the pH and causes a reduction in net charge in the muscle proteins (Aberle et al., 2012). At the isoelectric point (5.1 in meat), the proteins have no excess net charge and have limited ability to bind water. As the pH nears the isoelectric point, the water-holding capacity will decrease. Once the pH reaches the isoelectric point (pI), the net charge is zero. The positive and negative charges on the proteins are attracted to each other creating a decrease in the amount of water held in the proteins (Aberle et al., 2012). Furthermore, the negative charge on the protein creates a repulsive action around the protein, as more and more positive ions bind with the negative binding sites, the proteins begin to collapse onto themselves and aggregate with other proteins (Aberle et al., 2012). As a result, the structure of the protein is more compact and less capable of binding water (Aberle et al., 2012). Low pH in pork will cause greater drip loss, greater cooking losses and less water-holding capacity. The opposite reaction happens when the ultimate pH remains high as in DFD meat. A higher ultimate pH produces a darker color and reduced drip loss in fresh pork (Huff-Lonergan et al., 2002).

In fresh meat, the drop in pH only accounts for approximately one-third of the loss of water-holding capacity, and steric effects account for the rest (Aberle et al., 2012). Myofibrils make up a large proportion of the muscle cell, and the myofibril contains much of the water found in muscles (Huff-Lonergan and Lonergan, 2005). The myofibrils are thought to hold more than 80% of water in muscle. Changes in the myofibril can considerably change the water-holding capacity. As muscles go into rigor, a tight bond between actin and myosin occur once ATP disappears postmortem, compressing the structure of the sarcomere. Structural changes in the muscle create a lack of space that impacts the ability of the proteins to bind water. Steric effects are defined as the physical characteristics that create space within the muscle fiber and facilitate areas for water to occupy (Aberle et al., 2012). Hoinkel et al. (1986) reported an increased drip loss with decreasing sarcomere length. Along with the loss of space pushing water out of the sarcomere, after rigor, the cellular membranes start disintegrating leading to water transferring from the myofibril to the extracellular space (Bertram et al., 2002).

2.4.3. Color

Meat color is the first impression consumers have at the meat counter of meat. Consumers expect raw meat to have an appealing color and make most of their purchasing decisions based on color and the appearance of meat. Several studies have identified color as the most critical characteristic consumers consider when buying pork (Barbut, 2001; Font-i-Furnols et al., 2012; Glitsch, 2000; Tan et al., 2000). A consumer study by Small Insights (2014), looked at purchase criteria for fresh pork and showed that quality, freshness and color were crucial factors in fresh pork purchases. The consumers associated a darker color to a higher quality product. In another consumer study, Lusk et al., (2018) found that a majority of consumers used color to assess quality and that color is more important than marbling. Also, a significant percentage of consumers perceived the whiter, lower quality pork chops to be preferable, suggesting that consumer perceptions of quality do not line up with actual pork color quality information (Lusk et al., 2018). Color is a major inconsistency in fresh pork today.

Consumers evaluate the quality of pork from individual expectations of the product and experience (Brewer, 2001). Ultimately, if a consumer is dissatisfied from a poor eating experience of pork, they might not repurchase pork and switch to a different protein source. Consumers prefer pork that is lean, consistent in color and has a little amount of water on the cut surface or in the package (Mabry and Baas, 1998). Consumers use discoloration and water loss as a determination of freshness (Mancini and Hunt, 2005).

Myoglobin accounts for 80 to 90% of the total pigment of muscles (Aberle et al., 2012). The concentration and chemical state of myoglobin will determine the color of meat and accounts for the variability between species, age, sex, muscle, and physical activity (Aberle et al., 2012). Myoglobin's function in muscle is to store and deliver oxygen required for the generation of energy, and the concentration of myoglobin in meat reflects the muscle's need for oxygen storage and delivery (Wittenberg and

Wittenberg, 2003). The structure of myoglobin is fundamental in the understanding of pork color. Myoglobin has two primary components to its structure, an apoprotein, and heme (Suman and Joseph, 2013). The apoprotein has a tertiary protein structure with three subunits. Heat-induced denaturation of the myoglobin occurs during cooking. This process does not happen at a single temperature but occurs slowly as the tertiary structure diminishes. The heme portion is responsible for the red color in meat. In muscle, the heme group binds to oxygen and allows for storing and transporting oxygen, and in meat, the heme group remains active to bind oxygen. In the center of the heme ring is an iron molecule that has six binding sites (Suman and Joseph, 2013). Four connect to the heme ring, one connects to the apoprotein, and the final one can reversibly bind with several molecules to change the chemical state of the iron (Suman and Joseph, 2013). In fresh meat, there are three main chemical states of the iron: oxygenated (oxymyoglobin), reduced (deoxymyoglobin), or oxidized (metmyoglobin). Myoglobin in muscle is purplish, but when exposed to oxygen, it produces a bright red color. If removed from oxygen, myoglobin converts to deoxymyoglobin, a purplish red color. This state occurs in vacuumed-packaged meat. Myoglobin can go back and forth between oxymyoglobin and deoxymyoglobin until the eventual oxidation of the iron to the ferric state. This state causes the dissociation of oxygen and the iron to bind to water forming metmyoglobin, a brown color.

Ultimate pH, water-holding capacity, myofibrillar matrix, and the level of protein denaturation influences color. In fresh meat, color is also affected by the amount of water present in or on the surface of the meat. A low ultimate pH (< 5.4) in meat, causes the proteins to not bind water very tightly creating more free water on the surface. The free water on the surface of the tissues reflects or scatters light making the meat appear lighter in color and pale. As the pH increases, the proteins can bind water more tightly causing the color to become darker. Homm et al. (2006) observed the influence of chop location on color and found that color was consistent with the central portions of the loin, but there was more variability in the anterior and posterior regions. The anterior chops were generally darker, and the posterior chops were generally lighter (Homm et al., 2006).

The NPB Color Standards (National Pork Board, 2011) are used to evaluate color subjectively by an experienced grader. The scale ranges from one to six with a one appearing pale, pinkish-gray to white in appearance and a six appearing dark, purplish-red. According to these guidelines, pork with excellent eating quality should be in the color range of three to five. The 2015 National Retail Benchmarking audit indicated that the range of color scores for center-cut loin chops in the retail store were from one to six with the average being 2.85 (± 0.79; Bachmeier, 2016). Norman et al. (2003) gave consumers the opportunity to cook and evaluate fresh pork chops from different color groups based on the National Pork Boards color standards. Consumers rated a higher liking of tenderness and juiciness for the darker colored pork chops (NPB color scores 5 and 6) than the paler chops. Although a difference in overall liking did not occur, when consumers were given a choice to select the pork themselves, the majority chose the darker pork chops.

Color can also be evaluated objectively by a colorimeter (e.g., the Minolta CR series) or spectrophotometer (e.g., the HunterLab Ultrascan, ColorQuest, and LabScan series). A colorimeter can quantify color by measuring the three primary colors of light (red, green, and blue), while a spectrophotometer measures color through light wavelengths. Minolta colorimeters measure CIE (Commission International de l'Eclairage) L* (lightness to darkness), a* (red to green), and b* (blue to yellow) color space values. The L* score measures the amount of light reflection on the surface of the meat. This scale was designed to correlate with the way that humans perceive color (Morgan et al., 1997). The CIE L*a*b* color space allows color to be expressed in a three-dimensional space where a* values are represented on the X axis, the b* values on the Y axis and the L* values on the Z axis (American Meat Science Association, 2012). The Pig Improvement Company (2003) reported that the preferred L* scores range from 42 to 46. National Pork Board (2011) reported that an L* of 53 represented a subjective color score of 3. Light reflectance scores can be correlated to WBSF values in pork (Davis et al., 1975; Hodgson et al., 1991).

2.4.4. Pale, Soft and Exudative (PSE)

The potential of PSE starts early in life from the selection of genetics to handling before slaughter. PSE is a quality defect in pork that describes meat that has an abnormally light color, soft texture, and excessive purge. This defect is typically caused by a rapid metabolism following slaughter when the carcass temperature is still warm (Matarneh et al., 2017). Forrest (1998) estimated that 99% of pork would be PSE if the ultimate pH is 5.5 or below. In PSE meat, the pH drops rapidly and achieves normal ultimate pH within an hour postmortem (Matarneh et al., 2017). Since the pH is rapidly dropping and the muscle temperature is still high, extreme denaturation of the proteins in the muscle occurs. The occurrence of PSE occurs from genetic factors and preslaughter stressors. In stressful conditions, the fight or flight mechanism activates in the nervous system, initiating a series of biochemical reactions designed to mobilize energy (Matarneh et al., 2017). The activation of the sympathetic nervous system causes the secretion of epinephrine from the adrenal medulla (Matarneh et al., 2017). Epinephrine binds with β-adrenergic receptors on the muscle activating cAMP-dependent protein kinase A, which phosphorylates and activates phosphorylase kinase (Matarneh et al., 2017). Once phosphorylase kinase is activated, it activates glycogen phosphorylase b (a low activity with low substrate affinity) into the more active form increasing glycogen degradation (Matarneh et al., 2017). Furthermore, the activation of protein kinase A activates the ryanodine receptor causing a rapid release of Ca^{2+} from the sarcoplasmic reticulum and thus, accelerating glycolysis (Matarneh et al., 2017).

Two genetic mutations can alter the pH decline in pork and cause poor pork quality. The first gene is the Halothane gene referred to as the porcine stress syndrome gene caused by a single point mutation on the ryanodine receptor (RYR1 gene; Fujii et al., 1991). This defect, triggered by stress, causes a leaky ryanodine receptor, allowing large amounts of calcium to be released into the sarcoplasmic reticulum causing increased rate of metabolism in the muscle, ultimately, causing a more rapid pH decline than usual. The rapid pH decline and relatively high carcass temperatures causes greater protein denaturation and results in pale, soft and exudative pork (Bendall and Wismer-Pedersen, 1962; Briskey, 1964; Offer and Knight, 1988). The second genetic abnormality is the Rendement Napole (RN) gene identified in the Hampshire breed. This mutation causes high muscle glycogen stores and a prolonged pH decline post-mortem. This defect is caused by a mutation in the regulatory γ subunit of adenosine monophosphate-activated protein kinase (Milan et al., 2000). The mutation causes a 70% increase in muscle glycogen in RN homozygous and heterozygous pigs (Huff-Lonergan and Lonergan, 2005). Higher production of lactate is produced; thus, a lower ultimate pH. Compared to the Halothane gene, the RN gene had a less dramatic effect on water-holding capacity and only increased drip loss by approximately one percent (Bertram et al., 2000).

2.4.5. Dark, Firm and Dry (DFD)

Dark, firm and dry (DFD) meat has an abnormally dark color, firm texture, and dry or sticky surface caused by long-term stress. During long-term stress, muscle glycogen depletes, and harvest occurs before there is enough time to replenish (Matarneh et al., 2017). Postmortem metabolism is stopped prematurely due to the lack of glycogen stores, limiting the pH drop and ultimately causing a high pH of 6.1 or higher, dark color, and a high-water-holding capacity. The high pH allows for more available binding sites, and DFD meat is sticky or dry because it has an excellent ability to bind water (Matarneh et al., 2017). In DFD meat, the pH is favorable for bacterial growth and shortens the shelf life.

2.4.6. Factors Influencing Pork Tenderness

Meat tenderness is a vital meat quality trait and affects the palatability of a meat product. Tenderness affects the palatability and acceptability of meat to consumers. Generally, consumers prefer pork to be tender, and some researchers consider tenderness to be the most important factor associated with palatability of pork (Koohmaraie, 1996).

Tenderness based on the ease of chewing relies on several factors. Pork m. *Longissimus* has been considered relatively tender over the last several decades, but there has been significant animal-to-animal variation in pork tenderness (DeVol et al., 1988). Reducing this variation is essential for the pork industry in order to give the consumer a consistent and satisfactory eating experience. During the conversion of muscle to meat, the muscle undergoes three stages of chemical changes that contribute to toughness. The pre-rigor phase during which collagen content mainly contributes to toughness, the rigor stage during which muscle shortening causes more toughening and finally during aging when the muscle begins to tenderize (Bhat et al., 2018).

Tenderness can be measured subjectively by consumer panelists or by using objective mechanical measures or trained panelists. The objective mechanical measures are generally cheaper, less time-consuming and remove the subjective nature of sensory testing (Shorthose and Harris, 1991). Warner-Bratzler Shear Force (WBSF) is one objective measurement of tenderness. This method measures the force that is necessary to shear across entire muscle fibers. Moeller et al. (2010b) observed consumers preferred WBSF values below 24.5 N for overall like, tenderness like tenderness level, juiciness like, and juiciness level but for every 4.9 N increase in WBSF values, the overall like decreased by 4%.

2.4.6.1. Collagen

The intramuscular connective tissue is a complex network of proteins that maintain muscle structure. Many factors that affect meat tenderness such as animal age, muscle location, and sex are caused from differences in connective tissue. Connective tissue is primarily composed of fibers of collagen and elastin proteins surrounded by a proteoglycan matrix (Purslow, 2005). Collagen is the most abundant protein in connective tissue and a significant factor in tenderness variation. Connective tissue is arranged in three layers that provide structure to the muscle. The outer layer, epimysium, surrounds entire muscles. Perimysium, the second layer, separates each muscle into muscle fiber bundles, and the innermost layer, endomysium is a very thin connective tissue separating individual muscle fibers (Purslow, 2005). In pork, endomysium and perimysium contribute to tenderness during aging (Nishimura et al., 2008; Nishimura et al., 2009). The thickness of perimysium and the amount of total collagen are significantly correlated to the shear-force of various pork muscles (Fang et al., 1999; Nishimura et al., 2009).

Immature collagen is heat liable and will solubilize or gelatinize in the presence of heat, increasing tenderness; however, as the animal ages and collagen matures, collagen becomes heat-stable and tougher. This occurs because collagen molecules are held together by intermolecular crosslinks, and over time, the crosslinks stabilize into a mature, thermally stable, less soluble crosslink (Aberle et al., 2012). Wheeler et al. (2000) reported a weak but significant correlation between collagen content, tenderness, and connective tissue. Nishiumi et al. (1995) reported a significant correlation between heat-solubility of collagen and toughness of raw pork. Conversely, Nishimura et al. (2009) reported that the heat-solubility of collagen and shear force values were not significantly correlated (r = -0.077). McCormick (1999) concluded that mature crosslinks and collagen concentration have an additive effect on the toughening of meat. Avery et al. (1996) compared textural differences in pork m. *Longissimus dorsi* with reducible and nonreducible collagen crosslinking. No relationships were found between texture and the type or concentration of collagen crosslinks (Avery et al., 1996). One hypothesis was that the low collagen concentrations in the porcine m. *Longissimus dorsi* contributed to the lack of a relationship (Avery et al., 1996). However, when both collagen and crosslink concentrations were elevated, meat was tougher, but if either collagen or crosslink concertation was reduced, the effect on the remaining factor minimized the effect on texture (Avery et al., 1996).

2.4.6.2. Sarcomere Length

Muscles contract during the conversion of muscle to meat causing the sarcomeres to shorten. Shorter sarcomere lengths can create more overlap of thin and thick filaments causing an increase in toughness. Extreme shortening can result in the loss of the I-band, and since the I-band holds a large proportion of water, this causes an increase in drip loss. Temperature is a significant factor in sarcomere length during the rigor process. Cold shortening can occur if the carcasses are chilled too quickly before the onset of rigor mortis (Savell et al., 2005). Feldhusen and Kühne (1992) observed the effects of cold shortening on tenderness of pork m. *Longissimus* chilled to -5°C before the onset of rigor. Sarcomere lengths were shortened by 33.5% as compared to the control treatment (Feldhusen and Kühne, 1992). The shorter sarcomere lengths significantly correlated with WBSF indicating an increase in toughness as sarcomere lengths shortened (Feldhusen and Kühne, 1992).

Wheeler et al. (2000) showed that differences in tenderness between unaged muscles were largely accounted for by differences in sarcomere lengths. m.

Semitendinosus and m. T*riceps brachii* were toughest when grilled to 70°C followed by the m. *Longissimus*, then m. *Semimembranosus.* The m. *Biceps femoris* ranked the lowest in mean tenderness ratings. At sarcomere lengths > 2 μm, both collagen content and desmin degradation are related to tenderness. Seventy-two percent of the variation in tenderness was attributed to the importance of sarcomere length to tenderness in unaged muscle (Wheeler et al., 2000).

2.4.6.3. Proteolysis

After rigor is complete, meat is very tough due to the contractile state of the muscle and the shortened sarcomeres. As the meat ages, tenderness gradually improves. Enzymatic degradation of myofibrillar and cytoskeletal proteins cause tenderness improvements (Huff-Lonergan et al., 1996; Koohmaraie, 1996). Proteolysis is the breakdown of proteins into smaller units of polypeptides or amino acids. During aging, proteolysis occurs from an enzymatic action on proteins by endogenous muscle proteases such as the calpain system.

The calpain system plays a key role in postmortem proteolysis and is thought to be the primary protease responsible for postmortem tenderization. Currently, calpains have three isoforms identified, μ-calpain (calpain-1), m-calpain (calpain-2) and calpain-3. Calpastatin is an inhibitor of μ-calpain and m-calpain. Calpastatin does not inhibit calpain-3 suggesting that it does not participate in meat tenderization because animals with high calpastatin do not produce tender meat (Kemp et al., 2010). μ-Calpain and m-calpain are named after the amount of calcium required to activate each enzyme with μM of calcium needed to activate μ-calpain and mM of calcium for m-calpain (Matarneh et al., 2017).

Both m- and μ- calpains are heavily concentrated in the Z-discs and cause complete loss of the Z-discs (Strasburg, 2008). As Ca^{2+} concentration increases postmortem, calpains are activated and start degradation of proteins such as troponin-T, titin, nebulin, C-protein, desmin, filamin, vinculin, and synemin (Huff-Lonergan et al., 1996). Disruption of the structural proteins causes actin and myosin to be released with other proteins from the sarcomere and become substrates for other proteolytic enzymes (Strasburg, 2008). Lametsch et al. (2004) reported the degradation of desmin, troponin-T, myosin heavy chain, myosin light chain I, actin, and tropomyosin isoforms of purified porcine myofibrils incubated with μ-calpain. In pork muscles, desmin degradation has explained 25% and 38% of the variation in tenderness between m. *Semimembranousus* and m. *Biceps femoris* (Wheeler et al., 2000).

Calpains can be affected by pH as well. In a study examining the activity of purified μ-calpain, μ-calpain had the highest activity at pH 6.5 when compared to pH at 6.0 and 7.5 (Carlin et al., 2006). μ-Calpain at 6.5 pH also did not lose activity as quickly as the other pH treatments (Carlin et al., 2006). In another study, Bee et al. (2007) reported a lesser amount of degradation of desmin and talin in pork with a faster pH decline suggesting that μ-calpain autolysis occurred earlier in pork that had a faster pH decline.

2.5. Consumer Response

2.5.1. Home Use Test versus Central Location Test

Central location tests (CLT) and home use tests (HUT) are quantitative testing methods used to assess subjective evaluations of consumers based on their perception of different attributes and opinions. The CLT has been a common method because researchers are allowed to control the environment and products tested, however, HUT creates a more realistic environment of product evaluation with less control. The CLT allows the researcher to collect consumer data during the same period and in the same serving method (Lawless and Heymann, 2010). Compared to HUT, a CLT can be significantly cheaper, take less time, and be easily controlled under standardized testing conditions with comparatively smaller samples. One drawback for the CLT is the preparation of the samples might not be consistent with the way consumers would prepare the products themselves.

Although HUT usually cost more, they allow consumers to evaluate products in the most realistic situation (Lawless and Heymann, 2010). The HUT method usually lets consumers prepare and evaluate the product at home under natural circumstances that closely mimic real-life conditions usually over several days. The HUT has less standardization and control than the CLT. Thus, the HUT could cause difficulty in managing the results because of the differences in sample preparation, time of consumption and other products or ingredients consumed with the test products (Meilgaard et al., 2015). The most common differences between CLT and HUT are the testing conditions. Other studies have indicated that test conditions such as consumption amount, time of day, along with combining other foods and social context can impact consumer acceptability (Birch et al., 1984; Hersleth et al., 2003; King et al., 2007; King et al., 2004; Petit and Sieffermann, 2007). Several researchers have stated that HUT has a better ability to predict long-term consumption than CLT because of HUT long-term and natural testing environment (Boutrolle et al., 2007; Lawless and Heymann, 2010; Meilgaard et al., 2015; Porcherot and Issanchou, 1998).

Many studies compared the two approaches, CLT and HUT, but there is still not a consensus of what methodology is better. Consumer panelists tend to give higher acceptability scores in HUT when compared to the CLT (Boutrolle et al., 2005; Boutrolle et al., 2007; Daillant-Spinnler and Issanchou, 1995; Hellemann et al., 1993; King et al., 2007; King et al., 2004; Kozlowska et al., 2003; Laird, 2015; Murphy et al., 1958). Boutrolle et al. (2007) suggested when using HUT, consumers are allowed to choose when they consume the products emulating their real consumption and this may improve overall satisfaction. The consumers also have prolonged contact time with the product which could potentially increase satisfaction (Boutrolle et al., 2007). De Graaf et al. (2005) suggested that the relatively larger sample size and consumption amount could play a role in the increase in acceptability. Meiselman (1992) proposed that a laboratory environment could cause the consumer not to react the same way in real life. However, the natural environment of the HUT and the potential to not follow instructions as closely could make the consumers feel less involved in evaluating samples which could cause the consumer to be less critical than with the CLT (Pound et al., 2000).

In one study by Sosa et al. (2008), the authors performed a CLT and HUT on concentrated chocolate milk and diluted chocolate milk. Overall, the HUT had higher acceptability scores than in the CLT. In the CLT, the concentrated chocolate milk had higher acceptability scores than the diluted chocolate milk in any presentation order, but in the HUT the acceptability was influenced by sample order. This could indicate that the CLT consumers were more critical and paid more attention than the HUT consumers (Sosa et al., 2008). Boutrolle et al. (2007) suggested that CLT reinforced the idea of a formal experiment where subjects are placed in an analytical mindset and are more likely to analyze the samples. Boutrolle et al. (2007) used three types of products: fermented milk beverage, salted crackers, and sparkling water to determine the differences between the CLT and HUT. For each test, different consumers were used. The results revealed that the HUT received higher liking scores than the CLT.

Providing consumers context has been shown to increase acceptability but sometimes has adverse effects. King et al. (2007) suggested that if differences between products were not significant enough, consumers might need to be able to taste the products back to back in order to detect differences. In a difference test on cod, consumers could tell differences between two samples in the CLT but did not do so in the HUT. The results from this test suggested that the CLT had higher discriminating power (Sveinsdottir et al., 2010). King et al. (2004, 2007), proposed that scores for well-liked and familiar foods were less affected by the standardized context. Herselth et al. (2005) used familiar foods - semi-hard, and hard cheeses - to test this hypothesis. No significant difference was found in the hedonic scores from both the CLT and HUT (Hersleth et al., 2005). The consumers' familiarity could explain these results to specific cheese categories, the similarity of expectations and the lack of a natural meal context for these products (Hersleth et al., 2005).

The standardized situation of a CLT tends to underestimate product acceptance as compared to tests using a more natural setting. Posri and MacFie (2008) compared different consumer tests with alternative contexts in CLT and used HUT as a benchmark using a tea bag product. This study examined a traditional CLT and two specialized CLT where each consumer was allowed to choose different lengths of brewing time and to add different condiments to the tea. A traditional CLT used a controlled procedure. In the dosing CLT, consumers were served selected portions of condiments, and a free CLT was used to mimic a realistic environment by providing all the condiments and allowing consumers to control the brew time. HUT consumers were allowed to choose their preferred preparation style. The traditional CLT did not detect as many differences in liking between the teas as the other dosing and free CLT. Internal preference mapping showed that among the different testing methods, the freer choices the consumer had, the higher the liking score dispersion with the liking scores from HUT being the most dispersed. However, the dosing CLT was the only test correlated to the HUT results. The study suggested that consumers could be good at focusing on a few factors in deciding preferences, but if too many factors were involved, it could be distracting and increase the difficulty for consumers to reveal their actual preferences. Ultimately, the dosing CLT appeared to be the best CLT method to predict long-term acceptability (Posri and Macfie, 2008).

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3. THE FLAVOR AND TEXTURE ATTRIBUTES OF GROUND BEEF DESCRIPTIVE ANALYSIS

3.1. Materials and Methods

Descriptive panelist training and testing procedures were approved by the Texas A&M Institutional Review Board (IRB2015-0507M).

3.1.1. Sample Selection

Commercial coarse ground beef was purchased from a major, commercial beef processor at 7% and 20% chemical lipid (IMPS 136). Mature beef 90% lean trimmings (IMPS 138) and white fat trimmings were collected from a cow processing plant, H & B Packing Co. in Waco, TX. Raw material was obtained on three different processing days for each raw material source to represent three replicates. Commercial coarse ground beef lipid levels were assumed to be what the supplier specified. The coarse ground beef for the two lipid levels (7 and 20%) within replicate were segmented into three treatments for further processing: chopped in a bowl-chopper to approximately 6.4 mm grind (Model K64 Vacuum Cutter, Seydelmann, Stuttgart, Germany); final grind using a 9.5 mm grind plate; and final grind using a 6.4 mm grind plate (Meat Grinder Model 1056, Biro Manufacturing Company, Marblehead, OH). Mature raw material trimmings were estimated by the supplier to be 90% lean and additional cow fat trimmings were used to determine the two lipid levels (7 and 20%). Within each replicate the trimmings were coarse ground (12.7 mm) and then tested to determine fat percentage. Three random samples from the mature lean and fat coarse ground batches were taken to determine starting fat percentage of each source. Samples were homogenized in a food processor. Three replicates of each sample were used to determine the fat and moisture (Smart System[5] Moisture/Solids Analyzer and SMART Trac Fat Analysis System, CEM Corporation, Matthews, NC). After three readings for each source were taken, fat and moisture percentages were averaged and utilized when calculating for 7 and 20% final fat content for the four meat sources. A Pearson square was utilized to calculate how much lean source and how much fat trim were needed for fat percentages (± 2%) for each batch.

After fat analysis, the mature coarse ground beef was formulated and tested again to determine final fat percentage. The mature coarse ground beef was then segmented into three treatments: chopped in a bowl-chopper to approximately 6.4 mm particle size; final grind using a 9.5 mm grind plate; and final grind using a 6.4 mm grind plate.

After the final grind/chop, patties were formed into 2.54 cm and 6.4 mm thick ground beef patties by either hand forming (07-0310-W, Weston, Southern Pines, NC) or machine forming into final patties (Supermodel 54 Food Portioning Machine, Hollymatic Corporation, Countryside, IL). Patties were randomly assigned to Texas A&M or Kansas State University trained panels. Once patties were labeled, they were placed with patty paper on top and bottom in a single layer on trays, placed in a -40°C freezer and crust-frozen for 20 minutes, and then vacuum-packaged. Patties were individually placed in vacuum package bags (B2470, Cryovac Sealed Air Corporation, Duncan, SC) with an oxygen transmission rate of 3 to 6 cc at 4°C (m^2, 24 h at 4°C, 0% RH) and a water vapor transmission rate of 0.5 to 0.6 g at 38°C (100% RH, 0.6 m^2, 24 h) and individually sealed. An equal number of patties were segmented for use at Texas A&M University and at

Kansas State University. Patties were stored at -10°C until testing. Testing occurred within two months of manufacture. Frozen patties were transported to Kansas State University and Texas A&M University where they were used for trained descriptive flavor and texture attribute evaluation using expert sensory panels using the Beef Lexicon (Adhikari et al., 2011) and AMSA (2015).

3.1.2. Expert, Trained Descriptive Beef Flavor Analysis

Patties were evaluated by an expert trained beef flavor descriptive attribute panel that helped develop and validate the beef lexicon (Adhikari et al., 2011). This panel was retrained for 22 d leading up to testing using the beef lexicon. For sensory evaluation, patties were thawed in a cooler (4°C) for approximately 24 h prior to testing. Patties were cooked using a commercial flat top grill heated to 176.7°C (Star Max 536TGF Countertop Electric Griddle with Snap Action Thermostatic Controls, Star International Holdings Inc. Company, St. Louis, MO) and a clam-shell grill with a surface heat of 176.7°C, (George Foreman Precision Clamshell Grill-Model GRP99, George Foreman/Applica Consumer Products Inc., Miramar, FL) to an internal cook temperature endpoint of 70°C. Internal temperatures were monitored using thermocouple probes (Model SCPSS-040U-6, Type T thermocouple, Omega Engineering, Stamford, CT) by probing into the geometric center of the patty periodically throughout cooking and were displayed using a thermometer (Omega HH501BT Type T, Omega Engineering, Stanford, CT). Raw weight, initial temperature, and time the patties started cooking were recorded. After patties finished cooking and the final weight was recorded, patties were wrapped in foil and placed in a holding oven (Model 750-TH-II, Alto-Shaam, Menomonee Falls, WI) for up to 20 min, until served. Patties (n = 288) were served to an expert flavor and texture descriptive sensory panel at Texas A&M University in College Station, TX. The panel was trained to evaluate beef flavor using the Beef Flavor Lexicon and texture attributes as defined in Meilgaard et al. (2015) for initial juiciness, sustained juiciness, hardness, springiness, cohesiveness of mass, and particle size. The trained descriptive attributes, definitions and references are presented in Tables 1 and 2. Flavor and texture attributes were measured using a 16-point scale with 0 = none and 15 = extremely intense. Panelists evaluated up to 12 samples per day for 24 evaluation days per panel. Panelists were provided palate cleansers of salt-less saltine crackers (Premium Unsalted Tops Saltine Crackers, Nabisco, East Hanover, NJ) and double-distilled, deionized water between samples. During evaluation, panelists were seated in individual breadbox-style booths separated from the preparation area and samples were evaluated under red lights (44.2 lux). Samples were served at least four minutes apart.

After cooking, patties were cut into 6-wedges as defined by AMSA (2015) and panelists received 3 wedges per sample for evaluation. Three wedges per sample were served in clear, plastic 59 mL soufflé cups (translucent plastic 2 oz. portion cups, Georgia-Pacific, Asheboro, North Carolina) 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 randomly assigned to sensory session by source, fat formulation, thickness, grind size or method, and cooking treatment. Samples were cut and served immediately to assure samples were approximately 37°C upon time of serving.

For the second phase of this study, a subset of the aforementioned treatments (n = 216) were sent to Kansas State University to be evaluated. The treatments included two meat sources (commercial, 20% fat and mature, 7% fat), three final grind methods (6.4 mm, 9.7 mm, and bowl-chop), two thicknesses (6.4 mm and 2.54 cm), one forming method (machine) and two cooking methods (grill and clam-shell), and three holding times (0, 1, and 3 h) were used. Each of the treatments were held for 0, 1 or 3 h in a steam table (EP302, Duke Manufacturing, St. Louis, MO) set so that the internal environment of the steam table was 60°C. Sensory analysis was completed as previously defined at the Sensory Analysis Center at Kansas State University in Manhattan, KS.

3.1.3. Volatile Aromatic Compounds

Volatiles were captured from the same patties evaluated by the panelists at Texas A&M University and Kansas State University (3 h hold only) by freezing two ground beef wedges from each sample wrapped in foil in liquid nitrogen and frozen to -196°C. Samples were stored at -80°C until volatile analysis. Volatiles were evaluated using an Agilent gas chromatograph/mass spectrophotometer system with dual sniff ports for characterization of aromatics. This technology provided the opportunity to separate individual volatile compounds, identify their chemical structure, and identify an aroma event. Samples were placed in heated glass jars (473 mL) with a Teflon lid under the metal screw-top to avoid off-aromas and then set in a water bath at 60°C and thawed for 1 h. A Solid-Phase Micro-Extraction (SPME) Portable Field Sampler (Supelco 504831, 75 µm Carboxen/ polydimethylsiloxane, Sigma-Aldrich, St. Louis, MO) was inserted through the lid in order to collect the headspace of the meat sample in the glass jar for 2

h. Upon completion of collection, the SPME was injected in the injection port of the gas chromatograph (GC; Agilent Technologies 7920 series GC, Santa Clara, CA) where the sample was desorbed at 280°C for 3 min. The sample was then loaded onto the multi-dimensional gas chromatograph into the first column (30 m X 0.53 mm ID/ BPX5 (5% Phenyl Polysilphenylene-siloxane) X 0.5 µm, SGE Analytical Sciences, Austin, TX). Through the first column, the temperature started at 40°C and increased at a rate of 7°C/min until reaching 260°C. Upon passing through the first column, compounds were sent to the second column (30 m X 0.53 mm ID) [BP20 - Polyethylene Glycol] X 0.50 µm, SGE Analytical Sciences, Austin, TX). The gas chromatography column then split into three different columns at a three-way valve with one going to the mass spectrometer (Agilient Technologies 5975 Series MSD, Santa Clara, CA) and two going to the two humidified sniff ports that were heated to a temperature of 115°C with glass nose pieces. The sniff ports and software for determining flavor and aroma were a part of the AromaTrax program (MicroAnalytics-Aromatrax, Round Rock, TX). Up to two technicians were present per sample to record aromatic events (AromaTrax) via the olfactory port. Chemicals present during an aroma event and exceeding a quality report from the MS of 80 were used for analysis.

3.1.4. Raw Chemical Analysis

Chemical lipid, moisture and fatty acids were determined on the four meat source treatments in the raw state (n = 12). Fat and moisture analyses were determined in triplicate on the powdered meat samples according to the AOAC (1990) procedures using the ether extraction and air-drying oven methods.

Fatty acid methyl esters (FAME) were prepared from the lipid extracts as described by Morrison and Smith (1964). Approximately, 3-5 g of powdered meat was combined with 1 mL of 0.5 KOH in MeOH and heated at 70 °C for 10 min. After cooling, 1 mL of boron trifluoride (BF3; 14%, wt/vol) was added to each sample, which was flushed with N_2, loosely capped, and heated at 70 °C for 30 min. The samples were removed from the bath, allowed to cool to room temperature, and 2 mL of HPLC grade hexane and 2 mL of saturated NaCl were added to the samples and vortexed. After phase separation, the upper phase was transferred to a tube containing 800 mg of Na_2SO_4 to remove moisture from the sample. An additional 2 mL of hexane was added to the tube with the saturated NaCl and vortexed again. The upper layer was transferred into the tube containing the Na_2SO_4. The hexane extract was transferred to glass scintillation vials. The sample was evaporated to dryness at 60 °C under N_2 gas, subsequently reconstituted with HPLC grade hexane, and analyzed using a Varian gas chromatograph (model CP-3800 fixed with a CP-8200 auto- sampler, Varian Inc., Walnut Creek, CA; Chung et al., 2006). Separation of FAME was accomplished on a fused silica capillary column CP-Sil88 (100 m x 0.25 mm (i.d.); Chrompack Inc., Middleburg, The Netherlands), with helium as the carrier gas (flow rate = 1.2 mL/min). After 32 min at 180 °C, oven temperature increased at 20 °C/min to 225 °C and held for 13.75 min. Total run time was 48 min. Injector and detector temperatures were at 270 °C and 300 °C, respectively. Standards from Nu-Check Prep, Inc. (Elysian, MN) were used for identification of individual FAME. Individual FAME were quantified as a percentage of total FAME analyzed. All fatty acids normally occurring in beef lean and fat trim, including isomers of conjugated linoleic acid, were identified by this procedure.

3.1.5. Statistical Analyses

Data were analyzed using Analysis of Variance for treatment effects in a factorial arrangement using the Generalized Linear Model procedure of SAS (v9.4, SAS Institute, Inc., Cary, NC) with an $\alpha < 0.05$. The main effects of 4 meat sources (commercial, 7% fat; commercial, 20% fat; mature, 7% fat; and mature, 20% fat) and by 2 thickness (6.4 mm and 2.54 cm) by 3 grinds (bowl-chop, 9.5 mm and 6.4 mm) by 2 cooking methods (grill and clam-shell) and their interactions were included in the model. Three and four-way interactions were not included in the model. Replicate was included as a fixed effect and sensory day and order were included as a random effect in the model. Least squares means were calculated for main effects and significant two-way interactions. Two-way interactions that were not significant ($P > 0.05$) were not included in the final model. Post-hoc mean separation was done using Fisher's least significant difference ($P < 0.05$). Chemical data were analyzed as previously described. The second phase sensory data was analyzed similarly.

To understand relationships between treatments of ground beef, descriptive sensory attributes and volatile aromatic chemical compounds, principle component analysis (PCA, correlation matrix) and partial least squares regression analysis (PLS; XLSTATS; Addinsoft, New York, NY) were used. Data are presented in bi-plots. Variables used in partial least squares regression equations to predict overall liking were selected to have variable importance in the projection (VIP) $\geq$ 0.5. Since phase two volatiles were only collected from samples that were held for 3 h, only the 3 h held treatments were included in the PLS model.

3.2. Results and Discussion

3.2.1. Phase One

3.2.1.1. Expert, Trained Descriptive Beef Flavor Analysis

Six sensory panelists were trained to identify the attributes as indicated in Table 1; however, sour aromatic, animal-hair, apricot, asparagus, barnyard, beet, chemical, chocolate/cocoa, cumin, fishy, floral, nutty, medicinal, musty, painty, petroleum-like, rancid, smoky/wood, soapy and spoiled putrid flavor aromatics were not present and data is not presented. Two-way interactions are not present for sour, salty, buttery, leather, refrigerator stale, sour milk and particle size. Two-way interactions were reported for beef identity, brown/roasted, bloody/serumy, fat-like, metallic, liver-like, green hay-like, warmed over flavor, fat mouth-feel, umami, overall sweet, sweet, sour, bitter, burnt, cardboard, dairy, heated oil, smoky/charcoal, springiness, hardness, initial juiciness and cohesiveness of mass flavor aromatics, basic tastes, and texture attributes (Figure 1 to 6). The difference in fat percentage between the commercial and mature, 7% fat patties was included as a covariate but did not affect any attribute and was removed.

Beef identity and brown/roasted flavor aromatics were lowest ($P < 0.0001$) in ground beef with 7% fat, regardless of source (commercial or mature) when compared to the 20% fat patties. Whereas, ground beef with 20% fat was highest ($P < 0.05$) in overall sweet, burnt, and buttery flavor aromatics. Commercial ground beef patties with 20% fat were highest ($P <0.0001$) in fat-like flavor and sweet basic tastes. Commercial ground beef patties containing 7% fat were highest ($P < 0.0001$) in bloody/serumy. Mature ground beef patties containing 7% fat were lowest ($P < 0.05$) in fat-like and smoky/charcoal flavor, umami and sweet basic taste and highest ($P < 0.05$) in metallic, liver-like, leathery, refrigerator/stale, sour milk, cardboard, warmed over, flavors, sour and bitter basic tastes. Beef identify is a species-specific flavor that originates in the lipid portion of the meat. The lower fat levels would be expected to have lower levels of beef identity. Woerner (2010) reported that most of the meat produced from market cows is tougher, leaner, less juicy, and has a higher incidence of off-flavors. Hilton et al. (1998) and Stelzleni et al. (2007) reported that as maturity increased, consumers reported tougher beef with more off-flavors. Egbert et al. (1991) reported similar findings that flavor intensity, juiciness, and tenderness directly correlated with fat content. In this study, the positive flavor attributes were seen in the commercial, 20% ground beef patties and closely followed by the mature, 20% fat patties. The lower fat patties emphasized the negative attributes especially in the mature meat source.

Ground beef patty texture attributes were also affected by meat source (Table 4). Ground beef patties from mature lean had a larger particle size ($P = 0.0002$). Across lean sources, ground beef containing 20% fat were juicier ($P < 0.0001$) and had higher amounts of fat mouth coating ($P < 0.0001$) than ground beef patties that contained 7% fat. Previous studies have shown that higher fat content in ground beef was more tender compared to lower-fat formulations (Berry and Leddy, 1984; Cross et al., 1980; Garzon et al., 2003; Kregel et al., 1986). Ground beef patties from mature lean with 7% fat were the driest, hardest, springiest, and had the lowest amount of fat mouth-coating ($P < 0.0001$). Similarly, Troutt et al. (1992) reported that low-fat patties (5% and 10%) were crumblier, less juicy and flavorful, firmer, and caused less mouth coating than patties with 20% fat. They also found that fat-level significantly affected moistness, juiciness, beef flavor intensity, firmness, and cohesiveness of mass in ground beef patties. Abraham

(1996) also found that ground beef patties from young carcasses (< 24 mo) were more tender for initial and final tenderness and had less connective tissue then the ground beef patties formulated with mature carcasses (> 24 mo).

Patty thickness impacted flavor and texture attributes of ground beef patties. Thinner ground beef patties (6.4 mm thick; Table 3) had lower levels ($P < 0.05$) of beef identity, brown/roasted, bloody/serumy, fat-like, metallic, burnt, buttery, and smoky/charcoal flavor aromatics and umami, and bitter basic tastes; and slightly higher levels ($P < 0.05$) of green hay-like, refrigerator/stale, cardboard, and warmed-over flavor than 2.54 cm thick patties. The thicker patties required significantly ($P < 0.0001$; Table 5) longer cook times than the thinner patties that could have resulted in more Maillard reaction products resulting in more desirable flavors. Additionally, thin ground beef patties had slightly smaller ($P < 0.0001$; Table 4) particle size, were drier ($P < 0.0001$), had more cohesiveness of mass ($P < 0.0001$), were springier ($P < 0.0001$) and harder ($P < 0.0001$) than thick ground beef patties. Similarly, Liu and Berry (1998) reported an increase in initial juiciness and decreased firmness in 1.27 cm thick ground beef patties as compared to 0.95 cm thick patties. One hypothesis suggested that thicker patties could have a higher fat retention than the thinner patties due to a lower external surface to volume ratio and less surface contact with the griddle since the thicker patties had smaller diameters (Liu and Berry, 1998). In this study, patties were the same dimensions.

Final grind size or method also affected ground beef flavor, but not as extensively as the aforementioned treatments. Texture attributes were affected by final grind size and method to a great extent. Ground beef patties where particle size reduction was accomplished using a bowl-chopper had less fat-like flavor, and slightly more liver-like and leathery flavor than ground beef patties manufactured using either 6.4 mm or 9.7 mm grinder plates ($P < 0.05$; Table 3). Particle size was largest ($P < 0.0001$) in ground beef patties manufactured using a 9.7 mm final grind plate and ground beef patties manufactured using a bowl-chopper were the smallest (Table 4). Since the 9.7 final grind size was the largest particle size, this was expected. Ground beef patties ground using a 6.4 mm grinder plate were less springy and softer than ground beef patties manufactured either using a bowl-chopper or a 9.7 mm grinder plate ($P < 0.0001$). Although the grind sizes were smaller as compared to the current study, McHenry (2013) reported similar results when reducing grind size. The smaller grind size (1.6 mm) was softer, more tender, less connective tissue, and smaller particle size when comparted to the larger grind size (3.2 mm) (McHenry 2013). However, Egbert et al. (1991) reported a decrease in overall palatability and tenderness when grinding though a 0.32 cm plate as compared to the larger, 0.48 cm plate.

Forming method impacted ground beef patty flavor and texture attributes. Hand-formed ground beef patties were higher ($P < 0.05$) in beef identity, brown/roasted, bloody/serumy, fat-like, overall sweet, burnt, buttery, and smoky/charcoal flavor aromatics and umami, sweet, and sour basic tastes; and lower ($P < 0.05$) in green hay-like, refrigerator/stale, cardboard, and warmed-over flavor aromatics than machine-formed ground beef patties. Hand-formed patties had larger ($P < 0.05$) particle size, were juicier, had less cohesiveness of mass, had less fat mouth coating, were less ($P < 0.05$) springy, and were softer than machine-formed patties. The hand-formed patties had higher amounts of the positive flavor attributes and lower amounts of the negative flavor attributes. The restaurant industry is moving towards hand-formed patties because consumers view hand-formed patties as higher quality when compared to machine-formed patties (Salvage, 2008). Although the machine-formed patties are the most efficient forming method for hamburger patties, hand-formed patties created more positive flavor attributes. Hand-formed patties had a less cook yield (*P* = 0.01) and the hand-formed patties took longer (*P* < 0.0001) to cook than the machine-formed patties (Table 5). As hand-formed patties have lower compaction during forming, lower cook yields and longer cook times, it is reasonable to suggest that heat transfer differs during cooking that may have affected flavor development.

Ground beef patties cooked using a flat grill were higher (*P* < 0.05) in beef identity, brown/roasted, overall sweet, burnt, buttery, and smoky/charcoal flavor aromatics, and umami basic tastes; and lower (*P* < 0.05) in liver-like, green hay-like, leathery, refrigerator/stale, sour milk, cardbardy, warmed over and heated oil flavor aromatics and sour and bitter basic tastes than patties cooked using a clam-shell style grill. Texture attributes were minimally affected by cooking method, but ground beef patties cooked using a flat grill were slightly more (*P* = 0.004; Table 4) juicy, lower (*P* = 0.0004) in cohesiveness of mass and not as springy (*P* = < 0.0001) as ground beef patties cooked on a clam-shell style grill. Moist heat cooking as in the clam-shell method has been shown to reduce Maillard reaction products and limit the production of positive flavor

Beef identify (*P* = 0.01), brown/roasted (*P* = 0.005) and umami (*P* < 0.0001) flavor and basic taste attributes were highest for thick patties cooked on a flat-top grill (Figure 1). When comparing thickness by forming method, the thicker patties were higher in bloody/serumy (*P* < 0.0001), initial juiciness (*P* = 0.008), and umami (*P* = 0.04); and lower in warmed-over flavor (*P* = 0.03; Figure 2). Thick, machine-formed patties were higher in liver-like (*P* = 0.0009) and fat mouthcoating (*P* = 0.01). Thin, machine-formed patties had higher amounts of green-hay-like (*P* = 0.03) and lower amounts of fat-like (*P* = 0.0001).

As previously discussed, patties cooked on the clam-shell grill were lower in beef identity, brown/roasted, and umami flavors. For patties cooked on a flat-top grill, forming method affected beef identity (*P* = 0.0008), brown/roasted (*P* = 0.0005), and umami (P < 0.0001; Figure 3). Grilled, hand-formed patties were higher in beef identity, brown/roasted, fat-like and umami descriptive attributes (*P* < 0.05). The hand-formed, grilled patties had longer cooking time that could have led to development of more positive flavors, especially those associated with Maillard reaction products (Table 6). While interactions for final grind method by forming method were significant, a defined trend was not apparent (Figure 4). Additionally, least squares means difference were slight and, while consistent, may not be practically different for the meat industry to act on. These results indicate that dry heat cooking, thicker patties and bowl-chopped patties tended to have more positive flavor attributes.

When comparing meat sources and grinding methods, initial juiciness differed (*P* = 0.01; Figure 5). Commercial and mature, 7% fat bowl-chopped patties, commercial 7% fat 6.4 mm grind, and mature, 7% fat 9.7 mm grind were lowest (*P* = 0.01) in initial juiciness. Umami was the only attribute with a meat source by cooking method and meat source by patty thickness interaction (Figure 6). Thicker, 20% fat patties regardless of the source were higher in umami (*P* = 0.01). Patties with 20% fat that were cooked on a grill had the highest umami (*P* =0.03) basic taste regardless of meat source. Umami is a basic taste associated with brothy-type tastes. Higher fat patties, especially those cooked on a grill or dry heat cooking, provided opportunity for more extensive lipid heat denaturation reactions. As products of lipid heat denaturation also interact with Maillard reaction products, conditions where Maillard reaction products can be developed (dry heat in combination with higher lipid content) most likely resulted in higher umami basic taste. Generally, the grilled, high fat, hand-formed, thick patties displayed the most positive flavor and texture attributes.

Principal component analyses (PCA) were used to show relationships between descriptive attributes and treatments (Figure 7). Meat source was shown to be the main driving factor in flavor and texture development and the interactions between the other treatments were chosen to show relationships. Meat source by forming method (a), meat source by patty thickness (b), meat source by grinding method (c) and meat source by cooking method (d) biplots are displayed in Figure 7. In the meat source by forming method PCA (Figure 7, a), both machine and hand-formed patties for all meat sources are clustered closely together, but the hand-formed patties were closer to the more positive flavor attributes. This trend shows that hand-formed patties tend to have more positive flavor attributes regardless of the muscle source. This may explain why food service companies have been successful in marketing hand-formed ground beef patties. Mature, 7% fat source patties were closely clustered with metallic, liver-like, cardboardy, refrigerator stale, warmed over, sour, and bitter flavor attributes and springiness texture attribute. Commercial and mature, 20% fat meat source from hand-formed patties were closely related to beef identity, umami, initial juiciness, heated oil, smoky charcoal, fat mouthcoating, sweet, fat-like, buttery, brown/roasted descriptive flavor and texture attributes. Machine and hand-formed, commercial, 7 % fat patties were closely related to cohesiveness of mass and bloody/serumy descriptive attributes. Overall, the hand-formed, 20% fat patties from both commercial and mature were associated with the most positive flavor attributes.

The relationships between meat source by patty thickness and descriptive attributes are presented in Figure 7, b. There are three large clusters; the cluster on the right side of the biplot contained the 2.5 cm thick, commercial and mature, 20% fat patties. These patties were closely associated with beef identify, smoky charcoal, burnt, umami, brown/roasted, initial juiciness, overall sweet, buttery, sweet, fat-like, and fat mouthcoating descriptive attributes. The cluster in the bottom center of the graph contained the thinner patties from both commercial sources and mature, 20% fat patties from these treatments clustered closely with cohesiveness of mass. Buttery, sweet, fat-like, fat mouthcoating, and heated oil flavor attributes, while related, were not as closely related. The third cluster contained the mature, 7% fat patties at both thicknesses. More negative descriptive attributes such as metallic, bitter, liver-like, sour, refrigerator stale, cardboardy, warmed over, springiness and hardness flavor and texture attributes were closely clustered with the aforementioned treatments. Overall, the thick, high-fat patties were more closely associated with positive descriptive attributes, where the thinner, low-fat patties were associated with more negative flavors.

Grinding method had little effect on descriptive attributes of patties as previously reported (Figure 7, c). Treatments within grind size clustered indicating that within meat source, grinding method did not influence patty showing that they all had similar flavor attributes. Commercial patties at both fat levels and mature, 20% fat patties clustered in a triangle with the bowl-chop patties at the farthest left point of all the clusters. This could be a trend indicating that bowl-chop patties had more negative flavors because it is pulling to the left but since there was little to no significant differences within the means, this is doubtful. One thing to point out is that liver-like did show significant differences ($P = 0.002$) between the grinding method and bowl-chop had the highest amount. Liver-like is one of the most left points on this biplot and could be pulling the bowl-chop towards the left. This effect was not seen in the mature, 7% fat patties as the 9.7 mm ground patties were at the most left point closely associated with liver-like. The sources were clustered with the commercial and mature high-fat patties closest to the positive attributes and the mature low-fat patties clustered with more negative flavors and the commercial low-fat patties clustered at the bottom of the biplot being pulled by texture attributes.

Cooking method was shown to have a large effect on the descriptive flavor attributes (Figure 7, d). All of the grill cooking method patties for each source clustered on the right-hand side of the biplot with the more positive attributes. The grilled commercial and mature, 20% fat patties were closely clustered with buttery, sweet, overall sweet, umami, brown/roasted, burnt, smoky charcoal, salty, and beef identity descriptive attributes. The commercial, 7% fat patties were loosely related to the positive attributes. The mature, 7% fat patties cooked on the grill were closely associated with heated oil flavor attribute. The clam-shell cooking method for patties from all meat sources pulled to the left-hand side of the biplot towards the negative attributes. The clam-shell, mature 7% fat patties were closely associated with cohesiveness of mass, warmed over, cardboardy, and refrigerator stale descriptive attributes. The other three sources were clustered with liver-like, springiness, sour, metallic, bloody/serumy, particle size, and hardness descriptive attributes. Overall, the grill cooking method produced the most positive flavor attributes.

3.2.1.2. Cook yield and time

Cook yield and cook time are reported in Table 5 for main effects. The 20% fat patties had lower ($P < 0.0001$) cook yield then the 7% fat patties, as expected. Berry 1994 and Cross et al., 1980 reported higher yields for lower-fat (4%) patties when compared to higher fat (20%) patties. The higher fat patties had more fat loss during cooking. There were no differences in cook time between the meat and fat sources. The 2.54 cm thick patties had lower cook yield and longer cook time then the 6.4 mm thick patties. There was no difference in cook yield due to the final grind method treatments contrary to Roth et al. (1999) when hypothesized that a decrease in cook loss from patties made with a smaller plate size might be related to an increase in heat transfer rate.

Interactions of the main effects for cook yield and cook time are reported in Table 6. Patty thickness by cooking method interaction was present for cook yield and cook time. Patties from both thicknesses cooked on the clam-shell style grill had similar ($P = 0.0009$) cook yields but the 6.4 mm thick, grilled patties had a higher yield than the thicker grilled patties. The thicker patties from both cooking methods had longer cook times ($P < 0.0001$) than the thin patties. A cook time interaction was present for forming method by cooking method where the hand-formed patties had longer ($P < 0.0001$) cook times than the machine-formed for both cooking methods.

Cook yield displayed a meat source by cooking method and patty thickness by final grind method interactions. As expected, the 20% fat patties had a lower yield (P = 0.02) than the 7% fat patties but the clam-shell cooked patties for all meat sources had a higher yield. While interactions for patty thickness by final grind method were significant for cook yield, a defined trend was not apparent.

3.2.1.3. Raw Chemical Analysis

Raw proximate and fatty acid analyses were determined to understand if these attributes explained differences in trained sensory attributes. Proximate and fatty acid attributes differed by meat source (Table 7). Both the mature and commercial, 20% fat patties had similar fat concentrations. The mature and commercial, 7% fat patties were also similar in fat levels. Percentage moisture differed by meat source and fat level. As fat increased, moisture decreased. However, within fat level, commercial patties had lower moisture content. Polyunsaturated fatty acids did not differ in patties that differed in meat source and fat level. However, monounsaturated and unsaturated fatty acids did differ in patties due to meat source and fat level. Of the major fatty acids in beef, palmitic, stearic, and oleic, patties from the 20% fat mature meat source were lowest (P < 0.05) in oleic and highest in palmitic and stearic. Additionally, these patties were lower (P < 0.05) in palmitoleic and trans-vaccenic.

In a review, Van Elswyk and McNeill (2014) summarized that the majority of the fatty acids in beef are saturated fatty acids (37.8-48.8%) and mono-unsaturated fatty acids (33.8-46.2%) and a small portion of poly-unsaturated fatty acids (3.4-6.0%). Changes in fatty acid composition from commercial and mature cattle is mostly likely from the differences in feeding systems between the animals. Commercial animals are on high concentrate grain-based diets and mature animals are commonly fed grass-based diets. Leheska et al. (2008) found that grass-finished beef had greater amounts of saturated fatty acids, lower amounts of mono-unsaturated fatty acids and did not differ in poly-unsaturated fatty acids. These results are similar as reported in this study.

To examine the relationships between sensory descriptive attributes and raw chemical composition, simple correlation coefficients were calculated (Table 8). Palmitic and stearic fatty acids, cooked milk, dairy, burnt and cohesiveness of mass flavor and texture attributes were not correlated and were not included in the table. Moisture and lipid percentages, while inverse in their relationships to sensory attributes, were moderately related to fat-like and slightly related to bloody/serumy, liver-like, umami, sweet, sour, buttery, heated oil, sour milk, initial juiciness and fat mouthcoating. Most of the correlation coefficients between the descriptive flavor and texture attributes and the fatty acid concentrations were low and not strong relationships. Myristic (14:0) fatty acid and warmed over and heated oil descriptive attributes were slightly related. Myristoleic (14:1) exhibited a slight negative correlation with brown/roasted. Umami and sweet basic tastes were slightly correlated with palmitoleic (16:1). Oleic (18:1) was moderately correlated with fat-like and fat mouthcoating descriptive attributes and moderately negatively correlated with metallic, sour, sour milk, springiness, and hardness descriptive attributes. Green was slightly negatively correlated with trans-vaccenic 18:1 (n-11). Mono-unsaturated fatty acids have been shown to be associated in increases in beef-like flavor attributes (Larick and Turner, 1990). Fat-like was moderately and negatively correlated and liver-like, sour, and refrigerator stale were moderately and positively correlated with arachidonic (20:4) fatty acid. Generally, increased polyunsaturated fatty acids resulted in increased off-flavors, and decreased beef flavor (Calkins and Hodgen, 2007). Similar results were found in this study.

3.2.1.4. Volatile Aromatic Compounds

Volatile aromatic chemicals defined for ground beef patties are presented in Table 9. One hundred and eighty-two volatile aromatic compounds were reported. The volatiles were not quantified between treatments but used as qualitative data to show relationships. In order to understand how the volatiles impacted the flavor and treatments, a PLS biplot was presented (Figure 8). Since meat source, cooking method and thickness affected descriptive attributes for ground beef patties, forming method and grinding method were not included in the final model. Volatile aromatic compounds that had a variable importance projection (VIP) < 0.5 were excluded from the model. The VIP showed which variables were contributing the most to the overall regression. Volatile compounds and trained panel attributes that contributed to flavor are mainly segmented by the first factor that is shown on the Y-axis with attributes that positively impacted flavor on the right, and attributes that negatively impacted flavor on the left. The second factor segmented mainly for attributes that impacted texture on the X-axis with attributes that positively impacted texture above the X-axis and attributes that negatively impacted texture below the X-axis.

The positive descriptive attributes such as sweet, buttery, overall sweet, umami, beef identify, brown/roasted, burnt, smoky charcoal, salty, and bitter descriptive attributes were clustered on the right side of the plot and the negative descriptive attributes such as refrigerator stale, warmed over, cardboardy, and liver-like flavors were seen in the lower left-hand quadrant. Maillard reaction products were clustered with positive flavor attributes. The pyrazines, 2-ethyl-6-methylpyrazine, 2,3-dimethypyrazine, 2-methylpyrazine, 2-ethyl-5-methypyrazine, 3-ethyl, 2,5-dimethlypyrazine, trimethylpyrazine, 2,5 dimehtlypyrazine, 2-ethyl-3-methlypryazine, and 2-ethyl-2,5-dimeythlpyrazine were clustered with the positive flavor attributes such as umami, beef identity, brown/roasted, smoky charcoal, salty, and bitter descriptive flavor attributes. Pyrazines have a characteristic cooked, roasted or toasted flavor. More specifically each pyrazine has their own flavor. 2,3-dimethypyrazine has a 2.5 ppm odor detection threshold and 2,5- dimethylpyrazine has a 1.7 ppm odor detection threshold and both have been described as meaty, musty, potato and cocoa-like (Burdock, 2016; Buttery et al., 1988; Kerth and Miller, 2015; Macleod and Ames, 1986). 3-ethyl-2,5-dimethylpyrazine has been associated with peanut, caramel, coffee, and popcorn flavors. Laird (2015) reported 3-ethyl-2,5-dimethyl pyrazine was closely clustered with brown/roasted flavor attribute and overall liking, grilled flavor liking, overall liking and grilled flavor liking consumer attributes. Trimethylpyrazine has a 0.009 ppm odor detection threshold detection and has a raw, musty, potato-like flavor (Burdock, 2016; Leffingwell and Leffingwell, 1991). The pyrazines predominantly create positive aroma compounds. Pyrazines are formed during the Maillard reaction from intermediate reactions including from Amadori rearrangement products, Heyns rearrangement products, or via the Strecker degradation mechanism (Jousse et al., 2002). Other heterocyclic, Maillard reaction product aromatics were shown close to the positive attributes such as pyrroles, furanones, furans, and thiophenes. Pyrrole and 1H-pyrrole-2-carboxaldehyde were clustered closely with brown/roasted, beef identify, umami, burnt, smoky charcoal descriptive attributes. Another pyrrole, 2-acetylepyrrole, was still clustered on the right-hand side but in the bottom right-hand quadrant. One furanone, 2(5H)-Furanone was closely clustered on the right side with the positive flavor attributes. Several furans, furfural, 2-ethylfuran, and 2-furanmethanol. Furfural has a brown, sweet, woody, bready, nutty, and caramel flavor (Burdock, 2016).

Benzeneacetaldehyde was located close to salty along with octane,3-dodencen-a-al and 2-octanone. Benzene and compounds containing benzene are commonly found in beef and have been described as distinct, pleasant aroma characteristics (Calkins and Hodgen, 2007). Benzaldehyde has been associated with almond oil and bitter almond while benzenacetaldehyde is sweet and honey-like (Calkins and Hodgen, 2007; Van Ba et al., 2012).

Aldehydes can be produced through either the Maillard reaction or lipid degradation (Kerth and Miller, 2015). Since the clam-shell cooking method produces little to no Maillard reaction products (Kerth and Miller, 2015), it was expected that patties cooked on the clam-shell grill clustered with the negative flavor attributes and mostly lipid oxidation products. Miller and Kerth (2015) reported that Maillard reaction products were not produced from moist heat cookery since the first step in the Maillard reaction is dehydration. Hexanal, pentanal, and dodecanal were aldehydes and are lipid oxidation products. Hexanal has a green grassy flavor, pentanal is winey, fermented, and bready, and dodecanal has a soapy, waxy, citrus, orange rind flavor (Kerth and Miller, 2015). Hexanal is derived from the degradation of linoleic acid and has been associated with cattle finished on concentrate diets (Elmore et al., 2004). The aldehydes on the right side that were closely associated with the positive descriptive attributes were 2-decenal, undecanal, 2,4-decadieal, 2-dodecen-a-al, and nonenal. Undecanal was most closely associated with bitter basic taste and is related to waxy, buttery, soapy, and laundry detergent flavors (Burdock, 2016; Leffingwell and Leffingwell, 1991). In general, aldehydes give a meaty, tallow aroma that contribute to positive flavor perception (Brewer, 2006). Strecker aldehydes, 2-methylbutanal, 3-methylbutanal and 3-methylthioproanal were found in the bottom right hand corner. These types of compounds are believed to contribute to the roasted flavor of beef (Liebich et al., 1972). These compounds are formed during the Strecker degradation of amino acids with 2-methlybutanal from leucine, 3-methylbutanal from isoleucine, and 3-methylthiopropanal from methionine (Resconi et al., 2013; Van Ba et al., 2012).

1-Octen-3-ol was most closely related to liver-like flavor. Werkhoff et al. (1996) reported flavor volatiles associated with livery flavor included thiols, sulfides, thiazoles, and sulfur-substituted furans. Some studies have indicated that sulfur-containing compounds might interact with carbonyl compounds to produce the livery flavor attribute (Yancey et al., 2006). In this study, carbon disulfide was the closest sulfur containing compound to liver-like flavor.

Of the carboxylic acids, heptanoic acid was closely clustered with the positive flavor attributes. Heptanoic acid has a cheesy, fruity, dirty aroma and an odor threshold of 3.0 ppm (Burdock, 2016; Kerth and Miller, 2015; Leffingwell and Leffingwell, 1991). Slightly farther away from the positive flavor attributes were butanoic, nonanoic, octanoic, and decanoic acids. Butanoic and hexanoic acids are related to lipid oxidation products and have been reported to increase with aging of beef muscles (Stetzer et al., 2008). Kerth (2016) reported that butanoic acid can have a strong, unpleasant odor, but can be beneficial to aroma balance at lower concentrations. Pentanoic acid is in the top left quadrant; whereas, acetic acid is in the bottom left quadrant clustered closely with cohesiveness of mass descriptive texture attribute. Larick et al. (1987) reported that heptanoic acid, pentanoic acid, nonanoic acid and decanoic acid were positively correlated with grassy flavor in ground beef.

These results indicate that volatile aroma compounds are related to trained descriptive sensory flavor attributes. Aroma chemical attributes can be used to predict beef flavor attributes. Although it is not practical to measure every volatile aroma compound for every hamburger, by examining and increasing the production of positive sensory attributes such as beef identity, browned/roasted, sweet, buttery, and fat-like, and umami descriptive attributes and therefore the volatile aromatic compounds associated with those attributes, positive flavor attributes can be increased.

3.2.2. Phase Two

3.2.2.1. Expert, Trained Descriptive Beef Flavor Analysis

Ground beef patties from two meat sources, patty thickness, final grind method, cooking method and holding time in a steam table were evaluated for ground beef flavor and texture attributes (Tables 10 and 11). Flavor aromatics not present in the cooked ground beef patties were sour aromatic, animal hair, apricot, asparagus, beet, chocolate/cocoa, cumin, fishy, floral, nutty, medicinal, musty, painty, petroleum-like, rancid, smoky wood, smoky charcoal, soapy and spoiled putrid. The two-way interactions were present for beef identity, cardboardy, initial juiciness, brown/roasted, warmed over, springiness, salt, burnt, fat-like, umami, refrigerator stale, barnyard, liver-like, burnt particle size, cohesiveness of mass, bloody/serumy, and hardness descriptive attributes.

Ground beef patties manufactured with commercial lean with 20% lipid had higher levels of brown/roasted, fat-like, overall sweet, burnt, and warmed-over flavor attributes and lower levels of bloody/serumy, metallic, liver-like, sour, and barnyard. Additionally, these patties were juicier, more cohesive, and had higher fat mouthcoating. The effect of patty thickness, final grind size and method, and cooking method were similar are those reported in samples previously discussed.

Holding time affected flavor of ground beef patties. Ground beef patties held for 1 h differed in some flavor attributes. The major effect of holding time was an increase in cardboard flavor. This was expected as increased levels of cardboardy flavor are due to increased lipid oxidation (Angelo et al., 1987). Storage of cooked meat has been known to cause flavors like old, stale, oxidized, warmed-over, rancid or painty flavors and odors produced by oxidation of unsaturated fatty acids (Rhee, 1989). Holding time impacted initial juiciness, fat-mouth coating, and springiness texture attributes. Patties that were held for 0 h had the highest ($P < 0.0001$) amount of initial juiciness and patties held for 1 h had the least. Patties held for 0 h and 3 h had the highest amount of fat-mouth coating ($P = 0.0006$) and springiness ($P = 0.001$). Fat-like flavor attribute was affected as reported for fat mouthcoating. The 3 h hold time resulted in patties with higher fat-like and fat mouthcoating descriptive attributes. Due to the increased loss of moisture in patties held at 60°C, fat content could have increased causing higher fat-like flavor and fat mouthcoating texture values. Changes in weight due to hold time was not calculated. Similarly, Berry and Liu (1998) reported that ground beef patties held for 90 minutes also had increased fat content, reduced moisture content, lowered juiciness values, a slightly faster breakdown during chewing, and had increased ground beef flavor intensity (Berry and Liu, 1998).

Patty thickness by cooking method interaction is reported in Figure 9 for beef identity ($P < 0.0001$), cardboardy ($P = 0.004$), initial juiciness ($P = 0.03$), brown/roasted ($P < 0.0001$), warmed over ($P = 0.01$), springiness ($P = 0.02$), salty ($P = 0.0001$), and burnt ($P < 0.0001$) descriptive attributes. Grilled, thick patties were highest in beef identity, brown/roasted, and initial juiciness flavor and texture attributes. The thinner patties regardless of cooking method were higher in warmed over flavor,

Fat-like ($P < 0.0001$), umami ($P = 0.01$), cardboardy ($P = 0.02$), and initial juiciness ($P = 0.01$) descriptive attributes exhibited a cooking method by holding time interaction reported in Figure 10. Grilled patties regardless of holding times were highest in fat-like flavors. Initial juiciness was highest for the grilled patties that were held for 0 h and 3 h and umami basic taste tended to be higher in the grilled patties held of 1 h when compared to the clam-shell cooked patties held for 1 h. Cooking method by final grind interaction was also present for barnyard and hardness descriptive flavor and texture attributes (Figure 11). Although barnyard flavor attribute was significant ($P = 0.04$) for cooking method by final grind method, there was not any differences between the grind sizes, but barnyard was higher for the clam-shell cooking method. The grilled, 6.4 mm plate size ground beef patties were softer ($P = 0.03$) than the other cooking methods and grind methods.

Meat source by patty thickness interaction was present for beef identity ($P < 0.0001$), warmed over ($P < 0.0001$), barnyard ($P = 0.005$), refrigerator stale ($P < 0.0001$), liver-like (P = 0.002), brown/roasted (P < 0.0001), burnt (P = 0.006), and umami (P = 0.004) descriptive attributes (Figure 12). Commercial, 20% fat, thick patties were highest in beef identity, brown roasted, burnt, and umami and lowest in warmed over and refrigerator stale. Mature patties from both thicknesses were highest in liver-like, barnyard and liver-like showing that the thicker patties did not aide in eliminating these off flavors. These results indicate that thicker patties made from commercial meat with 20% fat content had higher levels of positive flavor attributes and lower levels of flavors associated with lipid oxidation.

Final grind size/method by meat source interaction was present for particle size (P = 0.03), cohesiveness of mass (P = 0.03), and bloody/serumy (P = 0.01) flavor and texture attributes (Figure 13). Bowl-chopped, commercial, 20% fat patties were higher in particle size and cohesiveness of mass than the bowl-chopped, mature, 7% fat patties. The other grinds had comparable particle size and cohesiveness of mass for both the commercial and mature sources. Mature meat source patties had slightly higher levels of bloody/serumy than other patties. As meat from mature animals has higher myoglobin content (Clydesdale and Francis, 1971), this is not surprising. The looser structure of the bowl-chopped patties from the mature meat source most likely contributed to less myoglobin heat denaturation during cooking that could have contributed to slightly higher bloody/serumy levels. An interaction for meat source by cooking method is reported in Figure 14. Grilled, commercial, 20% fat patties were higher in brown/roasted (P = 0.007) and burnt (P = 0.006) than the clam-shell cooked and the grilled mature patties. Patties cooked on the grill using dry heat would expectantly have higher brown/roasted flavor. The higher fat content in the commercial patties may have contributed to slightly higher levels of brown/roasted and burnt.

Cardboardy (*P* = 0.03) was higher in grilled mature, 7% patties when compared to the other patty treatments. While differences in cardboardy were slight, differences were consistent and resulted in an interaction. These results indicate that low fat ground beef patties made with mature meat sources cooked with dry heat may be more conductive to development of lipid oxidation. Particle size and hardness texture attributes displayed a patty thickness by final grind size/method interaction (Figure 15). Particle size (*P* = 0.002) was higher in the thick patties ground to 6.4 and 9.7 mm when compared to the thin patties. As there was more meat to evaluate particle size in thicker patties, particle size may have been more identifiable. Differences in particle size were minimal. Thin patties ground with the 6.4 mm plate were hardest. Final grind size/method and holding time interaction for cohesiveness of mass is reported in Figure 16. As hold time increased to 3 h, patties were more cohesive with bowl-chopped patties tending to be slightly less cohesive at 0 h compared to patties with the smallest grind size.

Principal component analysis (PCA) were used to show relationships between descriptive attributes and the holding treatments (Figure 18). Meat source and holding time treatments affected descriptive flavor and texture attributes. Patties manufactured using commercial meat source containing 20% fat and held for 0 or 1 hours were closely associated with positive flavor and texture attributes. These results indicate that holding these patties for 1 h did not affect texture and flavor attributes. As previously discussed, patties from mature meat sources differed in flavor and were closely associated with bitter, sour, bloody/serumy, liver-like and metallic flavors. Additionally, mature patties had more defined particle size. As for commercial patties, holding for 0 and 1 h did not affect these flavor and texture attributes. Patties held for 3 h were associated with negative flavors/ For commercial patties, patties held for 3 h were associated with refrigerator stale and warmed-over flavors; whereas patties from mature meat sources were harder and clustered with barnyard and cardboardy flavors. Therefore, holding ground beef patties regardless of meat source and fat level, induced development of negative flavors and harder patties.

The 0 and 1 h, mature, 7% fat treatments are in the lower right quadrant closely clustered with particle size, bloody/serumy, metallic, sour, bitter, and liver-like descriptive attributes. Mature 7% fat, 0 h and 1 h hold patties were not drastically different this could have occurred because lipid oxidation is the main concern in holding time and since there was reduced lipids and only one hour of holding time, this could have limited the amount of lipid oxidation products. The 3 h hold from the mature, 7% fat was closely related to cardboardy, barnyard and hardness. The mature, 7% source was not as affected by 1 h of holding but the 3 h hold was detrimental to the sensorial quality of the patties. This could be caused from the limited fat in the patties that limited lipid oxidation products. On the other side, the commercial samples were dramatically affected by holding time. The 0 h hold is clustered with cohesiveness of mass, springiness, overall sweet, fat mouthcoating, and fat-like descriptive attributes. Cohesiveness of mass is measured after 10 to 15 chews and is the amount that the food holds together. The 1 h hold for commercial, 20% fat is farther from cohesiveness of mass. Berry and Liu (1998) reported similar results for the 1 h holding that the meat broke down faster when chewed. The 3 h hold, commercial, 20% fat treatment was closest to refrigerator stale and warmed over. The 3 h hold treatment from the commercial meat source were on the same level of the y-axis with the 3 h hold of the mature, 7% fat meat source indicating that they had similar flavors but different textures. The mature was harder and the commercial was springier and more cohesive. Karlstrom and Jonsson (1977) reported significant deterioration for cooked ground beef patties in sensory quality after warm-holding for 3 h. In the current study, the 3 h hold time for both sources was unfavorable for the flavor and texture of the patties.

3.2.2.2. Cook yield and time

Cook yield and cook time for patties are reported in Table 12. The mature, 7% fat patties had a higher ($P < 0.0001$) yield than the commercial, 20% fat. This is likely because of the differences in fat level. The 2.54 patty thickness had a lower ($P < 0.0001$) yield than the thin patties. This could be due to the longer ($P < 0.0001$) cook times led to more water loss in the thicker patties. There were no differences in yield of cook time between the different grind sizes or methods and holding times. Cooking method was significantly different for cook time as the grill took longer ($P = 0.003$) to cook than the clam-shell method. This could be due to the clam-shell method cooks on two sides; whereas, the grill only cooks on one side. Cook time had an interaction for patty thicknesses by cooking methods. The thick patties cooked by grill took significantly longer ($P < 0.0001$) to cook than the other methods. The thin patties cooked by the clam-shell took the shortest amount of time.

3.2.2.3. Raw Chemical Analysis

To examine the relationships between sensory descriptive attributes and raw chemical composition, simple correlation coefficients were calculated (Table 13). Beef identity brown/roasted, umami, and salty descriptive flavor and taste attributes were not significantly correlated with chemical attributes and were not included. Moisture and lipid percentages had inverse relationships to sensory attributes, but they were highly related to fat-like, liver-like and fat mouthcoating and moderately related to initial juiciness, sour, and metallic descriptive attributes ($P < 0.05$). Fat like and fat-mouthcoating was moderately correlated ($P < 0.05$) with myristic (14:0), myristoleic (14:1), palmitic (16:0), palmitic (16:1), oleic (18:1), and trans-vaccenic (18:1 n-11) fatty acids and negatively correlated to stearic (18:0) fatty acid. Liver-like had an inverse relationship with fat-like and fat-mouthcoating and was negatively correlated ($P < 0.05$) with myristic (14:0), myristoleic (14:1), palmitic (16:0), palmitic (16:1), oleic (18:1), and trans-vaccenic (18:1 n-11) fatty acids and positively correlated with stearic (18:0) and arachidic (20:0) fatty acids. Yancey et al. (2006) suggested that liver-like and metallic flavors are more common in muscles with higher concentrations of myoglobin and heme iron. Since meat from mature animals has higher myoglobin content (Clydesdale and Francis, 1971), this might have led to the moderate to strong relationship between liver-like and metallic flavors and the fatty acids. Trans-vaccenic (18:1 n-11) fatty acid was moderately correlated ($P < 0.05$) with warmed-over flavor and refrigerator stale and negatively correlated ($P < 0.05$) to bloody/serumy, metallic, liver-like, sour, and barnyard with acid but were not related ($P > 0.05$) in the first study. Similar to this study, Camfield et al. 1997 reported that trans-vaccenic fatty acid was negatively related to livery, sour, and metallic flavors and was implicated in several in off-flavors including cowy.

Dannenberger et al. (2005) reported that in grass fed animals, Δ^9-desaturase activity decreased. This desaturase along with trans-vaccenic acid is responsible for the synthesis of conjugated linolenic acid cis-9, trans-11 (Dannenberger et al., 2005). With the reduction in Δ^9-desaturase activity, flavor changes might occur because of unused trans-vaccenic acid creating more off flavors (Dannenberger et al., 2005). However, in this study, the mature, 7% fat ground beef had lower ($P = 0.0003$) amounts of trans-vaccenic than the commercial, 20% fat ground beef (Table 7). The fatty acid and descriptive attributes correlations were very different from the first study as holding treatments were added. The first study had mostly low and not strong relationships, whereas this study showed moderate to strong relationships between the fatty acids and descriptive attributes.

3.2.2.4. Volatile Aromatic Compounds

Volatile aromatic compounds were evaluated in ground beef patties that where held for 3 hours. One hundred and thirty-one volatile aromatic compounds were reported (Table 14). To understand relationships between treatments, sensory attributes and volatile aromatic compounds, partial least squares regression was used and biplots are reported in Figure 18. Only the 3 h hold treatments and volatiles are presented.

The volatiles were grouped similarly in the first study but were associated with different descriptive flavor attributes. As this analysis only included patties held for 3 h holding would be expected to increase lipid oxidation products. The aforementioned positive volatiles, such as the pyrazines and pyrroles, are now associated with the mature, 7% fat meat source cooked on the grill as well as, barnyard, sour, bitter, and cardboardy descriptive attributes. The clam-shell cooked mature patties of both thicknesses are clustered with bloody/serumy and metallic descriptive flavor attributes and several lipid oxidation products. Since the Maillard reaction was limited in the clam-shell cooking method, it was expected to have more lipid oxidation products than patties from the grilled cooking method. The commercial source patties cooked using the clam-shell are loosely clustered with positive flavor attributes of umami, beef identify and overall sweet flavor attributes. The commercial, 20% fat patties cooked on the grill for both thicknesses were clustered with brown roasted, burnt, fat-like, fat mouth coating and initial juiciness. Additionally, these patty treatments are clustered with many lipid oxidation volatile compounds. This is opposite of what was reported in the first study. It is hypothesized that this occurred because of the higher fat content in the commercial patties allowed for more lipid oxidation products to develop. As the time increased during holding, the lipid oxidation products continued to increase in concentration as the Maillard reaction would have decreased and/or were stopped after cooking. In the grilled, mature, 7% fat patties, the Maillard reaction would have been initiated but as these patties had low lipid content, fewer lipid oxidation products would have been expected. Overall, the commercial 20% fat patties from both the clam-shell and grill cook methods were still associated with the positive flavor attributes but were also related to more lipid-oxidation products and the grilled, mature, 7% patties were related to the negative flavors and the Maillard reaction products. The 3 h hold time for the mature, 7% fat patties were detrimental for the flavor and texture regardless of cooking method of the patties but was less damaging for the commercial, 20% fat patties.

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3.4. Figures and Tables

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

Attributes	Definition	Reference
Apricot	Fruity aromatics that can be described as specifically apricot.	Sun sweet dried apricot = 7.5 (F)
Asparagus	The slightly brown, slightly earthy green aromatics associated with cooked green asparagus	Asparagus water =6.5 (F); 7.5 (A)
Animal hair	The aromatics perceived when raw wool is saturate with water.	Caproic acid = 12.0
Barnyard	Combination of pungent, slightly sour, hay-like aromatics, associated with farm animals and the inside of a horn.	White pepper in water = 4.0 (F); 4.5 (A) Tincture of civet = 6.0 (A)
Beef identity	Amount of beef flavor identity in the sample.	Swanson's beef broth = 5.0 80% lean ground beef = 7.0 Beef brisket = 11.0
Beet	A dark damp-musty-earthy note associated.	Food Club sliced beets juice with 1-part juice with canned red beets to 2 parts water = 4.0 (F)
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 = 5.5 Beef brisket = 6.0
Brown/roasted	A round, full aromatic generally associated with beef suet that has been broiled.	Beef suet = 8.0 80% lean ground beef = 10.0
Buttery	Sweet, dairy-like aromatic associated with natural butter	Land O'Lakes unsalted butter = 7.0
Burnt	The sharp/acrid flavor note associate with over-roasted beef muscle, something over-baked or excessively browned in oil.	Alf's red wheat Puffs = 5.0
Chemical	The aromatics associated with garden hose, hot Teflon pan, plastic packaging and petroleum-based product such as charcoal	Zip-Loc sandwich bag =13.0 Clorox in water = 6.5

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

Attributes	Definition	Reference
Chocolate/ Cocoa	The aromatics associated with cocoa beans and powdered cocoa and chocolate bars. Brown, sweet, dusty, often bitter aromatics.	Hershey's cocoa powder in water = 3.0 Hershey's chocolate kiss = 8.5
Cooked milk	A combination of sweet, brown flavor notes and aromatics associated with heated milk.	Mini Babybel original Swiss cheese = 2.5 Dillon's whole milk = 4.5
Cumin	The aromatics commonly associated with cumin and characterized as dry, pungent, woody a slightly floral	McCormick ground cumin = 7.0 (F); 10.0 (A)
Dairy	The aromatics associated with products made from cow's milk, such as cream, milk, sour cream or butter milk.	Dillon's reduced fat milk (2%) = 8.0
Fat-like	The aromatics associated with cooked animal fat.	Hillshire farms Lit'l beef smokies = 7.0 Beef suet = 12.0
Floral	Sweet light, slightly perfume impression associated with flowers	Welch's white grape juice in water = 5.0 Geraniol = 7.5 (A)
Green	Sharp, slightly pungent aromatics associated with green/plant/ vegetable matters such as parsley, spinach, pea pod, fresh cut grass, etc.	Hexanal in propylene glycol (5,000 ppm) = 6.5 (A) Fresh parsley water = 9.0
Green-hay like	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley and tea leaves.	Dry parsley in medium snifter = 5.0 (A) Dry parsley in ~30-mL cup = 6.0
Heated Oil	The aromatics associated with oil heated to a high temperature.	Wesson Oil, microwaved 3 min = 7.0 Lay's Potato Chips = 4.0 (A)
Leather	Musty, old leather (like old book bindings).	2,3,4-Trimethoxybenzaldehyde= 3.0(A)
Liver-like	The aromatics associated with cooked organ meat/liver.	Beef liver = 7.5 Oscar Mayer Braunschweiger liver sausage = 10.0

Table 1 Continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste where 0 = none; 15 = extremely intense adapted from Adhikari et al. (2011).

Attributes	Definition	Reference
Medicinal	A clean sterile aromatic characteristic of antiseptic like products such as Band-Aids, alcohol and iodine	Band-Aid = 6.0 (A)
Metallic	The impression of slightly oxidized metal, such as iron, copper and silver spoons.	0.10% potassium chloride solution = 1.5 USDA choice strip steak = 4.0 Dole canned pineapple juice = 6.0
Musty/earthy/ Humus	Musty, sweet, decaying vegetation.	Sliced button mushrooms = 3.0 (F & A) 1000 ppm of 2,6-Dimethcycyclohexanol in propylene glycol = 9.0 (A)
Overall sweet	A combination of sweet taste and sweet aromatics. The aromatics associated with the impression of sweet.	Post-shredded wheat spoon size=1.5 (F) Hillshire farms Lit'l beef smokies = 3.0
Petroleum-like	A specific chemical aromatic associated with crude oil and it's refined products that have heavy oil characteristics	Vaseline petroleum jelly = 3.0 (A)
Rancid	The aromatics commonly associated with oxidized fat and oils. These aromatics may include cardboard, painty, varnish and fishy	Microwaved Wesson vegetable oil (3 min) = 7.0 Microwaved Wesson vegetable oil (5 min) = 9.0
Refrigerator stale	Aromatics associated with products left in refrigerator for an extended period of time and absorbing a combination of odors (lack of freshness/flat)	80% lean ground beef, stored overnight and served at room temperature = 4.5 (F); 5.5 (A)
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5

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

Attributes	Definition	Reference
Smoky Charcoal	An aromatic associated with meat juices and fat drippings on hot coats which can be acrid, sour, burned, etc.	Wright's Natural Hickory seasonings in water = 9.0 (A)
Smoky wood	Dry, dusty aromatic reminiscent of burning wood	Wright's Natural Hickory seasoning in water = 7.5 (A)
Soapy	An aromatic commonly found in unscented hand soap	Ivory bar soap in water = 6.5 (A)
Sour aromatics	The aromatics associated with sour substances.	Dillon's buttermilk = 5.0
Sour milk/ Sour dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream.	Laughing cow light Swiss cheese= 7.0 Dillon's buttermilk = 9.0
Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Spoiled-putrid	The presence of inappropriate aromatics and flavors that is commonly associated with the products. It is a foul taste and/or smell that indicates the product is starting to decay and putrefy.	Dimethyl disulfide in propylene glycol 10,000 ppm) = 12.0 (aroma)
Sweet	The fundamental taste factor associated with sucrose.	2.0% sucrose solution = 2.0
Umami	Flat, salty, somewhat brothy. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% accent flavor enhancer solution = 7.5
Warmed-over	Perception of a product that has been previously cooked and reheated.	80% lean ground beef (reheated) = 6.0

Table 2. Definition and reference standards for meat descriptive texture attributes and their intensities where 0 = none, 15 = extremely intense adapted from Meilgaard et al. (2016).

Attributes	Definition	Reference
Cohesiveness of Mass	The degree to which chewed sample holds (at 10 – 15 chews) together in a mass.	Licorice = 0.0 Carrots = 2.0 Mushrooms = 4.0 Frankfurter = 7.0 American Process Cheese = 9.0 Soft Brownie = 13.0; Pillsbury Biscuit dough = 15.0
Mouthcoating	A sensation of having a slick/fatty coating on the tongue and other mouth surfaces.	Half and Half = 4.5 Whipping cream = 8.0
Hardness	The force to attain a given deformation, such as: force to compress with the molars; force to compress between tongue and palate; force to bite through with incisors.	Cream Cheese = 1.0 Egg White = 2.5 Yellow American Cheese = 4.5 Olives = 6.0 Hebrew National Frankfurter = 7.0 Planters Peanut = 9.5 Life Savers = 14.5
Initial Juiciness	The amount of perceived juice that is released from the product during the initial 2 – 3 chews.	Carrot = 8.5 Mushroom = 10.0 Cucumber = 12.0 Apple = 13.5 Watermelon = 15.0
Particle Size	The degree to how large or small the particle is.	Small pearly tapioca = 4.0 Boba tea tapioca = 8.0
Springiness	The degree to which sample returns to original shape or the rate with which sample returns to original shape.	Cream Cheese = 0.0 Frankfurter = 5.0 Marshmallow = 9.5 Gelatin dessert = 15.0

Table 3. Flavor and basic tastes descriptive attributes least squares means for ground beef patties segmented by main effects of meat source, patty thickness, final grind size/method, patty forming method, and cooking method where 0 = none and 15 = extremely intense.

Treatment	Beef identity	Brown/ roasted	Bloody/ serumy	Fat-like	Metallic	Liver-like	Basic Tastes Umami	Sweet	Sour	Salty	Bitter
Meat Source[a]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.01
Commercial, 7% fat	8.1[b]	8.3[c]	1.9[d]	3.1[c]	2.6[b]	0.6[b]	2.0[b]	1.6[c]	2.1[b]	1.7[b]	2.3[b]
Commercial, 20% fat	8.7[c]	8.7[d]	1.4[bc]	3.6[e]	2.5[b]	0.4[b]	2.5[c]	1.8[d]	2.2[c]	1.8[c]	2.3[b]
Mature, 7% fat	8.2[b]	7.9[b]	1.6[c]	2.6[b]	2.8[c]	1.1[c]	1.9[b]	1.5[b]	2.6[d]	1.8[c]	2.5[c]
Mature, 20% fat	8.6[c]	8.4[cd]	1.3[b]	3.3[d]	2.6[b]	0.4[b]	2.4[c]	1.6[c]	2.3[c]	1.8[c]	2.4[b]
Patty Thickness[a]	<0.0001	<0.0001	<0.0001	<0.0001	0.01	0.11	<0.0001	0.001	0.87	0.03	0.001
6.4 mm	8.1[b]	8.0[b]	1.3[b]	3.0[b]	2.6[b]	0.6	1.9[b]	1.6[b]	2.3	1.8[b]	2.3[b]
2.54 cm	8.7[c]	8.6[c]	1.8[c]	3.3[c]	2.7[c]	0.7	2.5[c]	1.6[c]	2.3	1.8[c]	2.5[c]
Final Grind Method[a]	0.12	0.54	0.62	0.01	0.65	0.002	0.26	0.61	0.21	0.83	0.43
6.4 mm grind	8.5	8.3	1.6	3.2[c]	2.6	0.5[b]	2.2	1.6	2.3	1.8	2.4
9.7 mm grind	8.4	8.4	1.5	3.2[c]	2.6	0.6[bc]	2.3	1.6	2.3	1.8	2.4
Bowl-chop	8.3	8.3	1.5	3.0[b]	2.6	0.8[c]	2.1	1.6	2.4	1.8	2.4
Forming Method[a]	<0.0001	<0.0001	<0.0001	0.04	0.22	0.32	<0.0001	0.001	0.04	0.55	0.66
Hand-formed	8.6[c]	8.6[c]	1.7[c]	3.2[c]	2.6	0.6	2.3[c]	1.6[c]	2.3[b]	1.8	2.4
Machine-formed	8.2[b]	8.1[b]	1.4[b]	3.1[b]	2.6	0.7	2.1[b]	1.6[b]	2.3[c]	1.8	2.4
Cooking Method[a]	<0.0001	<0.0001	0.64	0.08	0.44	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Grill	9.2[c]	9.7[c]	1.5	3.2	2.6	0.4[b]	2.8[c]	1.7[c]	2.2[b]	1.9[c]	2.3[b]
Clam-shell	7.6[b]	6.9[b]	1.6	3.1	2.6	0.9[c]	1.6[b]	1.5[b]	2.4[c]	1.7[b]	2.5[c]
RMSE[f]	0.64	0.90	0.48	0.42	0.30	0.65	0.54	0.21	0.28	0.18	0.36

Table 3 Continued. Flavor and basic taste descriptive attributes least squares means for ground beef patties segmented by main effects of meat source, patty thickness, final grind size/method, patty forming method, and cooking method where 0 = none and 15 = extremely intense.

Treatment	Overall Sweet	Green hay	Burnt	Buttery	Leathery	Refrigerator/ Stale	Sour Milk	Card-boardy	Warmed Over	Heated Oil	Smoky/ Charcoal
Meat Source[a]	<0.0001	0.02	0.03	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
Commercial, 7% fat	0.9^{bc}	0.1^{b}	0.7^{bc}	0.6^{c}	0.1^{b}	0.7^{b}	0.1^{b}	2.1^{b}	0.6^{b}	0.3^{c}	0.9^{bc}
Commercial, 20% fat	1.1^{d}	0.1^{bc}	0.9^{c}	0.7^{d}	0.1^{b}	0.7^{b}	0.1^{b}	2.1^{b}	0.6^{b}	0.6^{e}	1.1^{d}
Mature, 7% fat	0.8^{b}	0.2^{bc}	0.5^{b}	0.4^{b}	0.2^{c}	1.0^{c}	0.4^{c}	2.7^{c}	0.9^{c}	0.1^{b}	0.7^{b}
Mature, 20% fat	1.0^{cd}	0.2^{c}	0.8^{c}	0.6^{cd}	0.1^{b}	0.7^{b}	0.2^{b}	2.3^{b}	0.7^{b}	0.4^{d}	1.0^{cd}
Patty Thickness[a]	<0.0001	0.005	<0.0001	<0.0001	0.74	<0.0001	0.14	<0.0001	<0.0001	0.55	<0.0001
6.4 mm	0.9^{b}	0.2^{c}	0.5^{b}	0.5^{b}	0.1	0.8^{c}	0.2	2.5^{c}	0.8^{c}	0.4	0.8^{b}
2.54 cm	1.0^{c}	0.1^{b}	0.9^{c}	0.6^{c}	0.1	0.6^{b}	0.2	2.1^{b}	0.6^{b}	0.3	1.1^{c}
Final Grind Method[a]	0.81	0.63	0.64	0.53	0.004	0.30	0.57	0.25	0.22	0.73	0.90
6.4 mm grind	1.0	0.2	0.7	0.6	0.1^{b}	0.7	0.2	2.2	0.6	0.4	0.9
9.7 mm grind	1.0	0.1	0.7	0.6	0.1^{b}	0.8	0.2	2.3	0.7	0.3	1.0
Bowl-chop	1.0	0.2	0.8	0.6	0.2^{c}	0.8	0.2	2.4	0.7	0.3	1.0
Patty Forming Method[a]	0.0005	0.001	0.03	0.04	0.23	0.0002	0.11	<0.0001	<0.0001	0.69	<0.0001
Hand-formed	1.0^{c}	0.1^{b}	0.8^{c}	0.6^{c}	0.1	0.7^{b}	0.2	2.0^{b}	0.6^{b}	0.3	1.1^{c}
Machine-formed	0.9^{b}	0.2^{c}	0.6^{b}	0.5^{b}	0.1	0.8^{c}	0.2	2.6^{c}	0.8^{c}	0.4	0.8^{b}
Cooking Method[a]	<0.0001	0.04	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.01	<0.0001
Grill	1.1^{c}	0.1^{b}	1.4^{c}	0.7^{c}	0.1^{b}	0.4^{b}	0.1^{b}	1.7^{b}	0.4^{b}	0.3^{b}	1.8^{c}
Clam-shell	0.8^{b}	0.2^{c}	0.5^{b}	0.2^{b}	0.2^{c}	1.1^{c}	0.3^{c}	2.9^{c}	1.1^{c}	0.4^{c}	0.1^{b}
RMSE[f]	0.26	0.29	0.72	0.23	0.20	0.39	0.24	0.65	0.38	0.33	0.56

[a]P-value from Analysis of Variance table.

[bcde] Mean values within a column and interaction followed by the same letter are not significantly different ($P < 0.05$).

[f]RMSE = Root Meat Square Error.

Table 4. Texture descriptive attributes least squares means for ground beef patties segmented by main effects of meat source, patty thickness, patty forming method, final grind size/method and cooking method where 0 = none and 15 = extremely intense.

Treatment	Particle Size	Initial Juiciness	Cohesiveness of Mass	Fat Mouth Coating	Springiness	Hardness
Meat Source[a]	0.0002	<0.0001	0.12	<0.0001	<0.0001	<0.0001
Commercial, 7% fat	5.4[b]	9.3[c]	6.9	3.1[c]	5.2[b]	5.8[b]
Commercial, 20% fat	5.5[b]	9.8[e]	6.8	3.9[e]	5.3[bc]	6.1[c]
Mature, 7% fat	5.7[c]	9.0[b]	6.7	2.5[b]	5.5[d]	6.3[d]
Mature, 20% fat	5.8[c]	9.6[d]	6.8	3.6[d]	5.3[c]	6.2[cd]
Patty Thickness[a]	<0.0001	<0.0001	<0.0001	0.14	<0.0001	0.004
6.4 mm	5.4[b]	9.2[b]	6.9[c]	3.2	5.5[c]	6.2[c]
2.54 cm	5.9[c]	9.7[c]	6.7[b]	3.4	5.2[b]	6.0[b]
Final Grind Method[a]	<0.0001	0.14	0.16	0.29	<0.0001	<0.0001
6.4 mm grind	5.7[c]	9.5	6.8	3.3	5.2[b]	6.0[b]
9.7 mm grind	6.0[d]	9.5	6.8	3.4	5.4[c]	6.2[c]
Bowl-chop	5.2[b]	9.3	6.8	3.2	5.4[c]	6.1[c]
Patty Forming Method[a]	<0.0001	0.001	0.0004	0.16	<0.0001	0.0003
Hand-formed	6.0[c]	9.5[c]	6.7[b]	3.2[b]	5.2[b]	6.0[b]
Machine-formed	5.3[b]	9.3[b]	6.9[c]	3.4[c]	5.4[c]	6.2[c]
Cooking Method[a]	0.49	0.004	0.04	0.86	<0.0001	0.69
Grill	5.6	9.5[c]	6.8[b]	3.3	5.2[b]	6.1
Clam-shell	5.6	9.3[b]	6.9[c]	3.3	5.4[c]	6.1
RMSE	0.57	0.55	0.35	0.84	0.33	0.35

[a]P-value from Analysis of Variance table.
[bcde] Mean values within a column and interaction followed by the same letter are not significantly different ($P < 0.05$).
[f]RMSE = Root Meat Square Error.

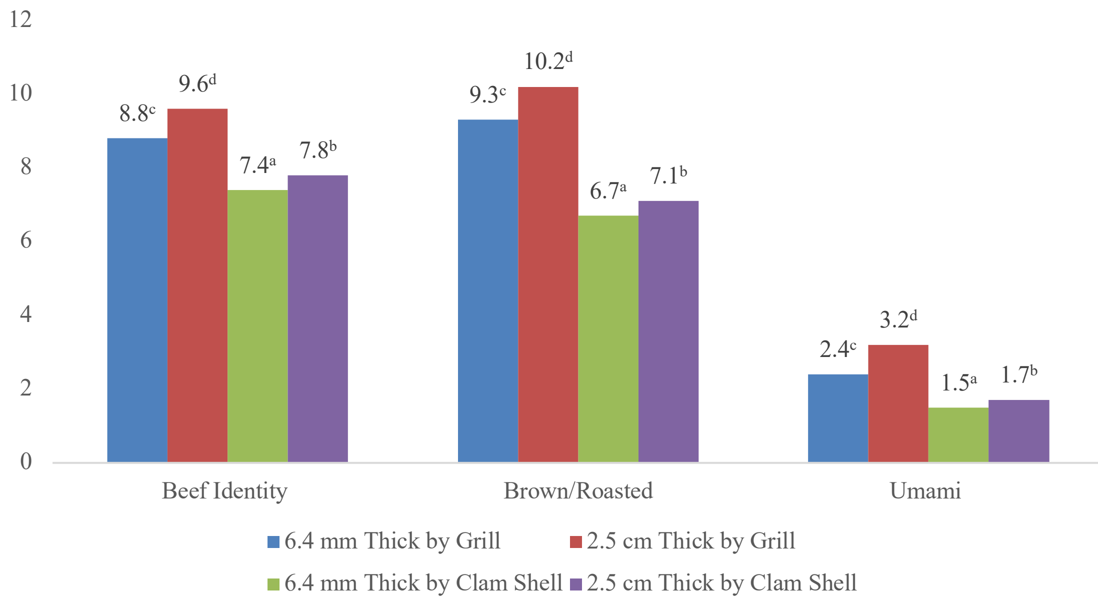


Figure 1. Patty thickness by cooking method interaction least squares mean for beef identity (*P* = 0.01), brown roasted (*P* = 0.005) and umami (*P* < 0.0001) descriptive flavor and taste attributes where 0 = none and 15 = extremely intense.

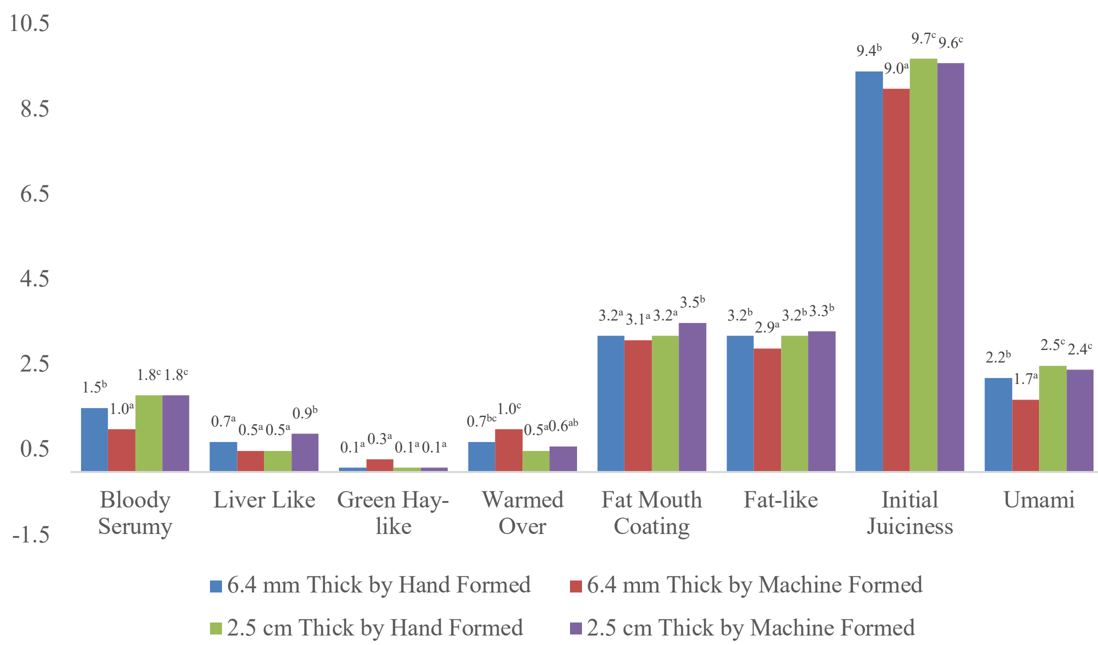


Figure 2. Patty thickness by forming method interaction least squares mean for bloody/serumy (*P* < 0.0001), liver-like (*P* = 0.0009), green hay-like (*P* = 0.03), warmed over (*P* = 0.03), fat mouthcoating (*P* = 0.01), fat-like (*P* = 0.0001), umami (*P* = 0.04), and initial juiciness (*P* = 0.008) descriptive flavor, taste, and texture attributes where 0 = none and 15 = extremely intense.

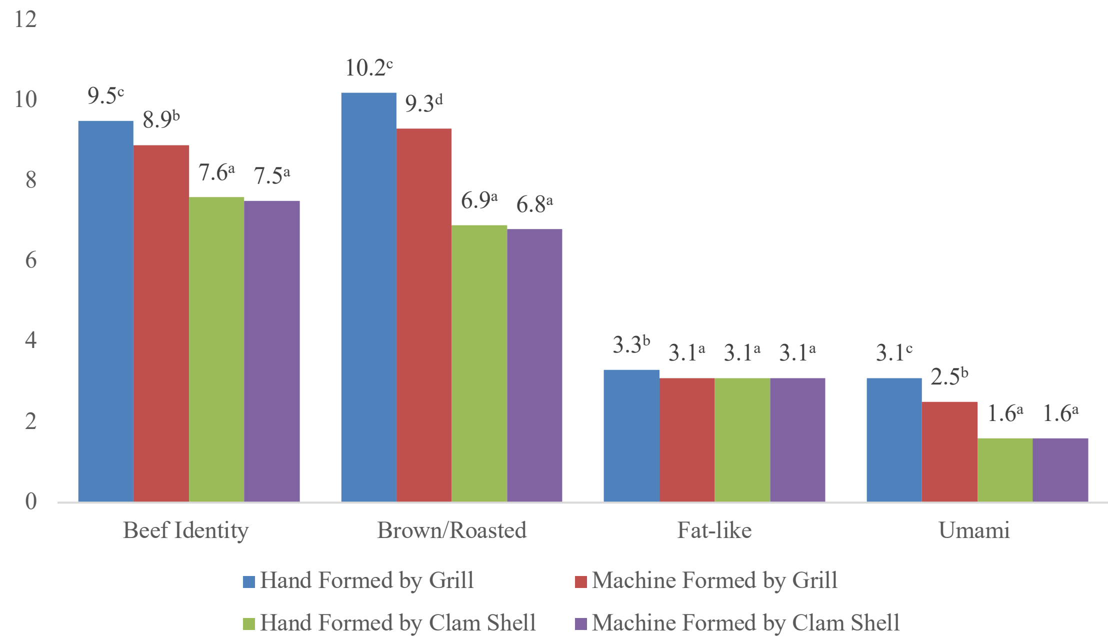


Figure 3. Forming method by cooking method interaction least squares mean for beef identity ($P = 0.0008$), brown roasted ($P = 0.0005$), fat-like ($P = 0.007$), and umami ($P < 0.0001$) descriptive flavor and basic taste attributes where 0 = none and 15 = extremely intense.

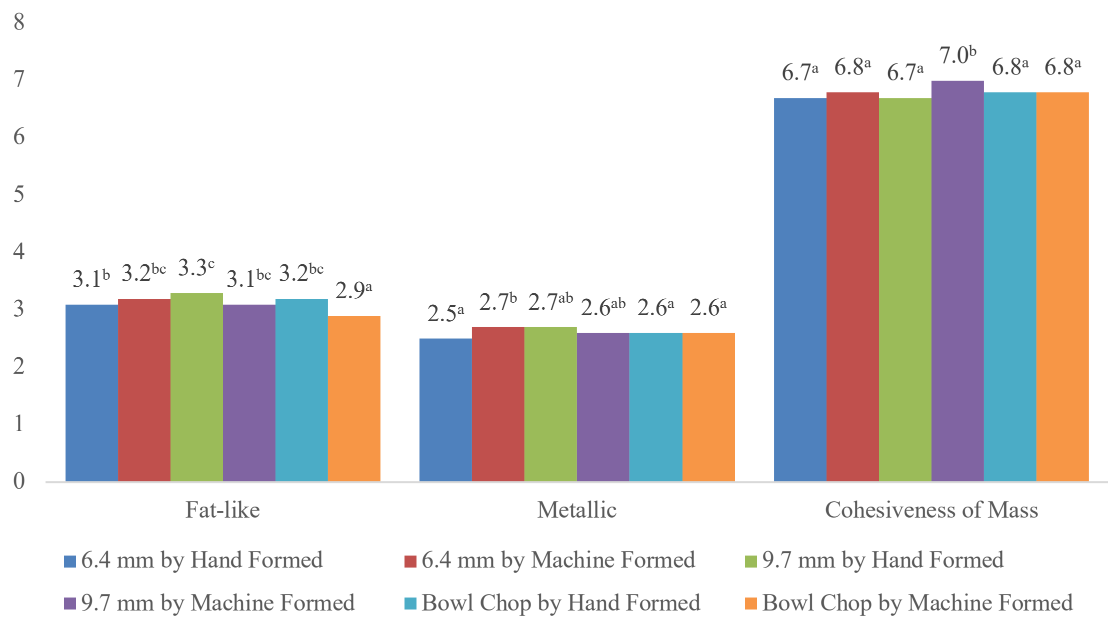


Figure 4. Final grind method by forming method interaction least squares mean for fat-like ($P = 0.01$), metallic ($P = 0.01$), and cohesiveness of mass ($P = 0.04$) descriptive flavor and texture attributes where 0 = none and 15 = extremely intense.

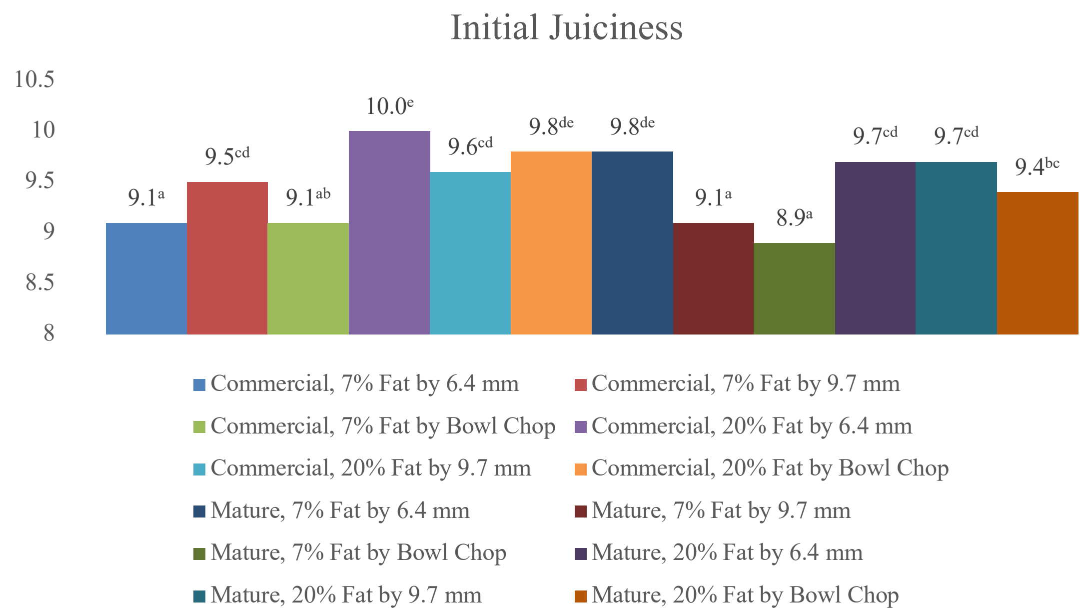
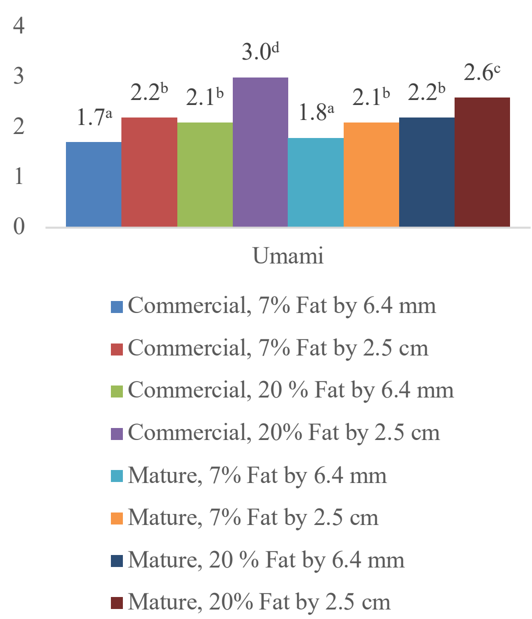


Figure 5. Meat source by final grind method interaction least squares mean for initial juiciness (*P* = 0.01) descriptive texture attribute where 0 = none and 15 = extremely intense.



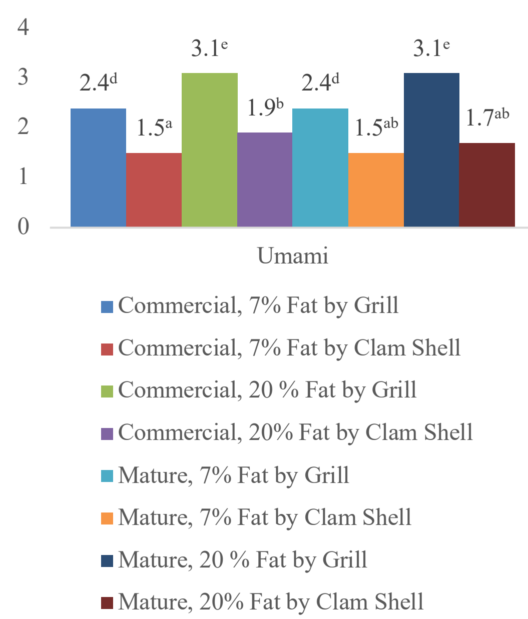


Figure 6. Meat source by patty thickness (*P* = 0.01) and meat source by cooking method (*P* = 0.03) interactions least squares mean for umami basic taste attributes where 0 = none and 15 = extremely intense.

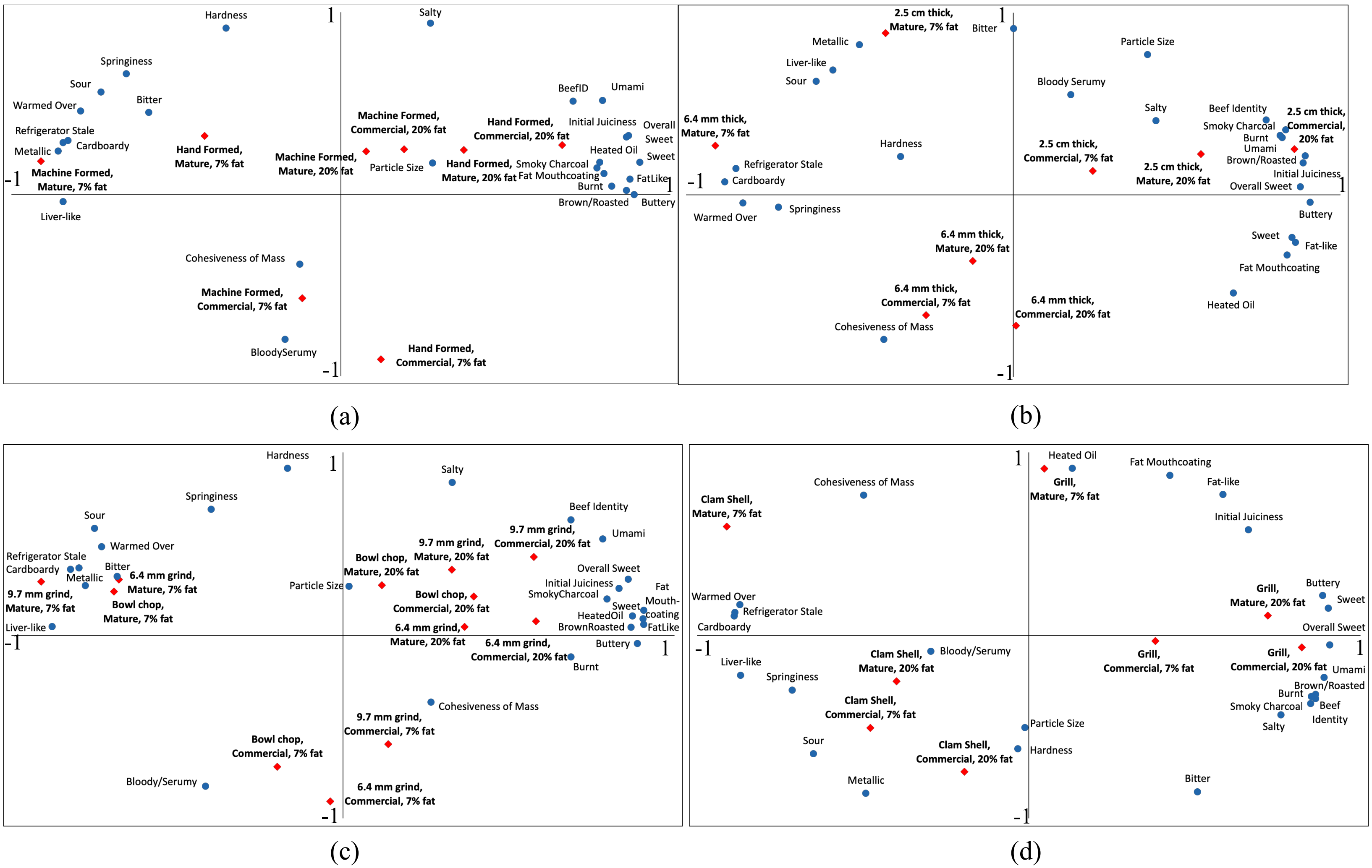


Figure 7. Principal component analysis of (a) meat source by forming method (F1 accounted for 61.84% of the variation and F2 accounted for 17.91%), (b) meat source by patty thickness (F1 accounted for 59.23% of the variation and F2 accounted for 22.42%), (c) meat source by grinding method (F1 accounted for 59.97% of the variation and F2 accounted for 18.72%), (d) meat source by cooking method (F1 accounted for 59.49% of the variation and F2 accounted for 21.51%), and descriptive flavor and texture attributes.

Table 5. Cook yield and cook time least squares means for ground beef patties segmented by main effects of meat source, patty thickness, patty forming method, and cooking method.

Treatment	Cook Yield, %	Cook Time, min.
Meat Source[d]	<0.0001	0.75
Commercial, 7% Fat	75.4[c]	10.7
Commercial, 20% Fat	66.3[a]	10.5
Mature, 7% Fat	72.7[b]	10.5
Mature, 20% Fat	66.9[a]	10.1
Patty Thickness[d]	0.0003	<0.0001
6.4 mm	71.2[b]	6.2[a]
2.54 cm	69.5[a]	14.7[b]
Final Grind Method[d]	0.63	0.004
6.4 mm	70.4	10.2[a]
9.7 mm	70.1	9.8[a]
Bowl-chop	70.6	11.4[b]
Patty Forming Method[d]	0.01	<0.0001
Hand-formed	69.8[a]	12.5[b]
Machine-formed	70.9[b]	8.4[a]
Cooking Method[d]	<0.0001	<0.0001
Grill	68.3[a]	13.7[b]
Clam-shell	72.4[b]	7.2[a]
RMSE[e]	3.87	3.31

[abc] Mean values within a column and interaction followed by the same letter are not significantly different ($P < 0.05$).
[d]P-value from Analysis of Variance table.
[e]RMSE = Root Meat Square Error.

Table 6. Cook yield and cook time least squares means for ground beef patties segmented by the interactions of meat source, patty thickness, patty forming method, and cooking method.

Treatment	Cook Yield, %	Cook Time, min.
Patty Thickness by Cooking Method[f]	0.0009	<0.0001
6.4 mm by Grill	69.9[b]	7.6[b]
6.4 mm by Clam-shell	72.5[c]	4.8[a]
2.5 cm by Grill	66.6[a]	19.8[d]
2.5 cm by Clam-shell	72.4[c]	9.6[c]
Forming Method by Cooking Method[f]	-	<0.0001
Hand-formed by Grill	-	17.0[d]
Hand-formed by Clam-shell	-	8.0[b]
Machine-formed by Grill	-	10.4[c]
Machine-formed by Clam-shell	-	6.4[a]
Meat Source by Cooking Method[f]	0.02	-
Commercial, 7% Fat by Grill	73.2[cd]	-
Commercial, 7% Fat by Clam-shell	77.6[e]	-
Mature, 7% Fat by Grill	71.6[c]	-
Mature, 7% Fat by Clam-shell	73.9[d]	-
Commercial, 20% Fat by Grill	63.1[a]	-
Commercial, 20% Fat by Clam-shell	69.5[b]	-
Mature, 20% Fat by Grill	65.1[a]	-
Mature, 20% Fat by Clam-shell	68.7[b]	-
Patty Thickness by Final Grind Method[f]	0.03	-
6.4 mm by 6.4 mm	71.6[bc]	-
6.4 mm by 9.7 mm	70.0[ab]	-
6.4 mm by Bowl-chop	72.0[c]	-
2.5 cm by 6.4 mm	69.1[a]	-
2.5 cm by 9.7 mm	70.1[abc]	-
2.5 cm by Bowl-chop	69.3[a]	-
RMSE[g]	3.87	3.31

[abcde] Mean values within a column and interaction followed by the same letter are not significantly different ($P < 0.05$).
[f]P-value from Analysis of Variance table.
[g]RMSE = Root Meat Square Error.

Table 7. Raw chemical components least squares means for ground beef treatments.

Chemical Measurement	P-value[d]	Mature, 20% Fat	Commercial, 20% Fat	Mature, 7% Fat	Commercial, 7% Fat	RMSE[e]
Proximate Analysis (% of total)						
Fat Content	<0.0001	20.4[b]	20.1[b]	4.2[a]	9.2[a]	1.04
Moisture Content	<0.0001	61.9[b]	59.7[a]	73.8[d]	70.0[c]	0.52
Fatty Acid Composition (% of total)						
Myristic (14:0)	0.01	3.0[b]	2.9[b]	2.6[a]	2.6[a]	0.10
Myristoleic (14:1)	0.0002	0.4[a]	0.9[c]	0.5[ab]	0.6[b]	0.07
Palmitic (16:0)	0.004	25.4[b]	23.6[a]	23.0[a]	23.2[a]	0.43
Palmitoleic (16:1)	0.0006	2.4[a]	3.9[c]	3.1[b]	3.3[b]	0.17
Stearic (18:0)	0.0002	23.2[c]	12.9[a]	15.9[b]	15.2[b]	0.99
Oleic (18:1)	<0.0001	32.7[a]	39.3[c]	33.7[b]	38.6[c]	0.37
Trans-vaccenic (18:1 n-11)	0.0003	1.2[a]	1.9[c]	1.7[b]	1.7[b]	0.08
α-Linolenic (18:3)	0.93	0.3	0.2	0.3	0.2	0.11
Arachidic (20:0)	0.005	0.2[c]	0.0[a]	0.1[b]	0.0[a]	0.04
Arachidonic (20:4)	0.65	0.3	0.2	0.5	0.3	0.16

[abc] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[d] P-value from Analysis of Variance table.
[e] RMSE = Root Mean Square Error

Table 8. Simple correlation coefficients[a] between chemical measures and trained descriptive sensory panel flavor attributes.

Descriptive Attributes	Lipid %	Moisture %	Fatty Acids 14:0	14:1	16:1	18:1	18:1 (n-11)	20:0	20:4
Beef Identity	0.20	-0.20	-0.08	-0.10	0.09	0.02	-0.02	0.03	-0.07
Brown/Roasted	0.14	-0.14	-0.09	-0.13	0.09	0.09	0.03	-0.04	-0.05
Bloody/Serumy	-0.24	0.24	0.02	0.04	0.00	0.11	0.09	-0.15	0.00
Fat-Like	0.52	-0.52	0.01	0.04	0.03	0.30	0.09	-0.08	-0.29
Metallic	-0.25	0.25	0.00	-0.05	0.01	-0.20	-0.04	0.09	0.09
Liver-Like	-0.32	0.32	0.04	-0.04	-0.04	-0.12	0.03	-0.07	0.28
Green Hay-like	0.03	-0.02	0.12	0.04	-0.05	-0.14	-0.10	0.15	-0.01
Umami	0.26	-0.26	-0.05	-0.10	0.13	0.03	-0.04	0.05	-0.06
Overall Sweet	0.29	-0.29	-0.02	-0.10	0.10	0.09	0.00	0.03	-0.13
Sweet	0.35	-0.36	-0.09	-0.03	0.14	0.18	0.04	-0.05	-0.12
Sour	-0.30	0.30	0.07	-0.07	-0.06	-0.37	-0.07	0.17	0.25
Salty	0.16	-0.16	-0.08	-0.07	-0.01	-0.13	-0.11	0.17	-0.06
Bitter	-0.13	0.12	-0.05	-0.11	0.07	-0.09	0.01	-0.01	0.16
Buttery	0.29	-0.30	-0.04	0.04	0.07	0.14	-0.03	0.01	-0.18
Cardboardy	-0.17	0.17	0.12	-0.04	-0.08	-0.15	-0.03	0.05	0.15
Green	0.04	-0.04	-0.01	0.00	-0.03	-0.15	-0.18	0.16	0.02
Heated Oil	0.35	-0.36	0.17	-0.06	-0.06	0.16	0.03	-0.04	-0.09
Leather	-0.18	0.18	0.12	0.09	-0.06	-0.12	-0.01	0.06	-0.01
Refrigerator Stale	-0.20	0.19	0.13	0.03	-0.04	-0.10	0.05	-0.06	0.23
Smoky Charcoal	0.12	-0.12	-0.08	-0.12	0.11	0.06	0.01	-0.0	-0.07
Sour Milk	-0.24	0.24	0.06	0.01	-0.06	-0.26	-0.05	0.13	0.13
Warmed Over	-0.13	0.13	0.13	0.02	-0.06	-0.13	0.00	0.03	0.14
Springiness	-0.09	0.10	0.02	-0.03	0.02	-0.20	-0.06	0.09	0.17
Hardness	0.03	-0.03	0.01	-0.06	0.00	-0.29	-0.10	0.20	0.13
Initial Juiciness	0.39	-0.40	-0.01	-0.04	0.10	0.15	0.01	-0.02	-0.15
Particle Size	-0.01	0.01	-0.04	0.03	0.07	-0.13	-0.09	0.13	0.00
Fat Mouth-coating	0.38	-0.39	0.03	0.07	0.07	0.21	0.05	-0.06	-0.17

[a] Simple correlation coefficients > 0.12 are significant ($P < 0.05$).

Table 9. Overall list of volatile aromatic compounds in samples.

Variable	Compound	Mean	Standard Deviation
C1	1-Octen-3-ol	78267	87063
C2	1-Octanol	25786	36451
C3	1-Pentanol	33566	52962
C4	1,1-Dodecanediol, diacetate	3335	11453
C5	Indole	227	1458
C6	2-Decenal	47420	90103
C7	2-Dodecanone	751	2767
C8	2-Heptanone	19807	29566
C9	2-Nonanone	4130	11094
C10	2-Octanone	2030	8821
C11	2,3-Octanedione	25022	51824
C12	Acetaldehyde	8284	9113
C13	Benzaldehyde	669046	556587
C14	3-Ethylbenzaldehyde	203	1445
C15	Benzeneacetaldehyde	14853	24093
C16	Carbon disulfide	22686	42855
C17	Decanal	54943	44854
C18	2-Methyldodecane	368	2115
C19	2-(Hexyloxy)ethanol	106888	217491
C20	2-Acetylpyrrole	11950	21064
C21	2-Acetyl-2-thiazoline	2254	6388
C22	2-Pentylfuran	52319	58282
C23	Heptanol	16493	33209
C24	Hexanal	859388	1050691
C25	Heptanal	258269	357476
C26	Nonacosane	990	1952
C27	Nonanal	756037	539252
C28	Nonenal	28813	47696
C29	Octacosane	910	2166
C30	Octadecanal	3600	13813
C31	Octanal	303920	314020
C32	2-Octenal	25738	38571
C33	Pentanal	38815	58565
C34	Butylated hydroxytoluene	3973	16966
C35	2-Ethyl-5-methylpyrazine	12329	24521
C36	2,5-Dimethylpyrazine	62388	105869
C37	3-Ethyl-2,5-dimethylpyrazine	18679	37279
C38	Trimethylpyrazine	13052	37377
C39	Styrene	8685	19291
C40	Tridecane	4160	10043
C41	Undecanal	8753	23426

Table 9 Continued. Overall list of volatile aromatic compounds in samples.

Variable	Compound	Mean	Standard Deviation
C42	Undecenal	34516	69051
C43	3-Hydroxy-2-butanone	32824	62908
C44	2-Propanol	9004	97736
C45	3-Dodecen-1-al	12468	42870
C46	Acetic acid	12198	25536
C47	Cyclooctanol	2446	8064
C48	Decanoic acid, ethyl ester	3238	18559
C49	Hexadecane	737	3133
C50	Hexanoic acid	14246	28192
C51	Ethenyl hexanoate	7207	28158
C52	Octane	37002	82747
C53	Tridecanal	3302	8110
C54	1-Hexanol	9171	22028
C55	1,3-Octadiene	2244	8979
C56	2-Acetyl thiazole	1024	5028
C57	2-Butanone	15000	27747
C58	2-Decanone	3930	10457
C59	2-Heptenal	2584	10982
C60	2-Hexenal	418	2242
C61	4-Hydroxy-4-methyl-2-pentanone	877	6640
C62	2,3-Dimethylbenzaldehyde	216	1182
C63	2,4-Decadienal	3335	7580
C64	2,4-Nonadienal	319	1622
C65	5-Pentyloxolan-2-one	207	1669
C66	Benzenemethanol	128	533
C67	Cyclooctane	6282	29485
C68	Eicosane	708	3907
C69	Heptane	11699	36434
C70	Heptanoic acid	899	4126
C71	Methanethiol	648	2381
C72	Nonanoic acid	731	4383
C73	Octanoic acid	2086	14001
C74	Phenol	445	1561
C75	Tetradecanal	6542	15504
C76	Toluene	23361	55504
C77	2-Decen-1-ol	343	3034
C78	2-Nonenal	13917	38659
C79	Dodecanal	12516	27015
C80	2(5H)-Furanone	6016	18070
C81	2-Methylbutanal	4920	22450
C82	3-Methylbutanal	8329	24612

Table 9 Continued. Overall list of volatile aromatic compounds in samples.

Variable	Compound	Mean	Standard Deviation
C83	4-(2-Propenyl)-1H-imidazole	154	613
C84	2-Docecen-1-al	3228	15383
C85	Butanoic acid	1325	7852
C86	Hexadecanal	12049	30460
C87	2-Ethyl-6-methylpyrazine	4858	22138
C88	2,5-Octanedione	3274	14292
C89	Decane	1097	4472
C90	Dimethyl sulfide	1472	2812
C91	Hentriacontane	1677	3502
C92	Nonahexacontanoic acid, methyl ester	316	1314
C93	Pentadecane	539	3366
C94	2-Methylpropanal	4197	12802
C95	2-(Ethenyloxy)propane	262	1411
C96	Thiourea	13860	44250
C97	6,10-Dimethyl-2-undecanone	604	2173
C98	2,3-Butanedione	1854	11224
C99	Butyrolactone	1317	7571
C100	Cycloheptane	284	1759
C101	Dodecane	1117	6445
C102	2-Methylpyrazine	16503	37402
C103	2-Propanone	28013	53618
C104	Butanal	646	3632
C105	Formic acid, hexyl ester	796	5500
C106	Octyl Formate	13072	34247
C107	Hexanoic acid, pentyl ester	75	679
C108	Nonadecane	1235	4036
C109	Nonane	1171	5720
C110	Oxalic acid, isobutyl nonyl ester	290	1661
C111	1,2-Dimethylbenzene	567	3248
C112	Octanoic acid, ethyl ester	5066	36096
C113	Undecane	487	3215
C114	2-Nonen-1-ol	583	3763
C115	2-Octen-1-ol	734	3900
C116	2,4-Undecadienal	140	850
C117	2-Furanmethanol	130	1161
C118	3-Methylthiopropanal	538	2069
C119	2-Dodecenal	1662	8288
C120	3,6-Dimethyl-2-pentylpyrazine	77	553
C121	Decanoic acid	404	1965
C122	Heneicosane	14108	166444
C123	Furfural	574	2873

Table 9 Continued. Overall list of volatile aromatic compounds in samples.

Variable	Compound	Mean	Standard Deviation
C124	3-(1,3-Benzoxazol-2-yl)phenol	105	590
C125	1-Undecanol	414	2763
C126	1,4-Dimethylbenzene	1064	4605
C127	1-Phenylethanone	389	2122
C128	Pentafluoropropionic acid, octyl ester	796	5854
C129	Heptenal	573	3842
C130	1-Butanol	2880	20489
C131	2-Cyclohexen-1-ol	6443	39393
C132	2-Ethyl-3,5-dimethylpyrazine	2005	8736
C133	Dodecamethylpentasiloxane	1535	11513
C134	1-Dodecanol	277	2239
C135	3-Heptanol	1228	4847
C136	2,3-Dimethylpyrazine	1997	10420
C137	2-Dodecen-1-ol	783	4747
C138	2-Methylphenol	130	1042
C139	1-Octene	880	6116
C140	Aloxiprin	319	3134
C141	D-Limonene	1069	7212
C142	Styrene Oxide	1565	8831
C143	3-Methyl-1-pentanol	61	540
C144	Pyrrole	165	1163
C145	1H-Pyrrole-2-carboxaldehyde	25	194
C146	Octadecane	9036	133056
C147	2-Heptadecyloxirane	1944	12816
C148	2,6,10-Trimethyltetradecane	168	1066
C149	2-Methyldecane	114	1143
C150	Pentane	574	4236
C151	2-Ethyl-3-methylpyrazine	1703	15622
C152	2-Pentanone	1482	9491
C153	Hexane	252	1927
C154	1-Nonen-3-ol	1549	13164
C155	Heptacosane	157	987
C156	2-Hexadecyloxirane	1893	15776
C157	Pentadecanal	1226	10875
C158	Oxalic acid, decyl isohexyl ester	447	4171
C159	4-Methylphenol	347	2338
C160	5-Methyl-2-hexanone	254	1465
C161	2-Tridecenal	2653	20250
C162	2-Methyloxolan-3-one	495	3812
C163	2-Undecanone	448	3319
C164	1,3-Dimethylbenzene	3341	21893

Table 9 Continued. Overall list of volatile aromatic compounds in samples.

Variable	Compound	Mean	Standard Deviation
C165	Chavicol	137	1282
C166	2-Heptene	502	3688
C167	Acetic acid, decyl ester	673	3570
C168	1,3-Bis(1,1-dimethylethyl)-benzene	3456	17763
C169	3-Methylheptane	207	1402
C170	Sulfur dioxide	1140	13163
C171	Acetylpyrrole	473	3316
C172	Heptadecane	119	988
C173	Oxalic acid, dodecyl isohexyl ester	191	2184
C174	2-Undecenol	726	4920
C175	2-Propyl-1-heptanol	52	537
C176	Tetradecane	341	2263
C177	Cyclodecane	246	2524
C178	2-Ethylfuran	104	930
C179	1-Decanol	361	2075
C180	3-Furaldehyde	133	1009
C181	Pentanoic acid	157	1518
C182	1,3-Pentadiene	99	812

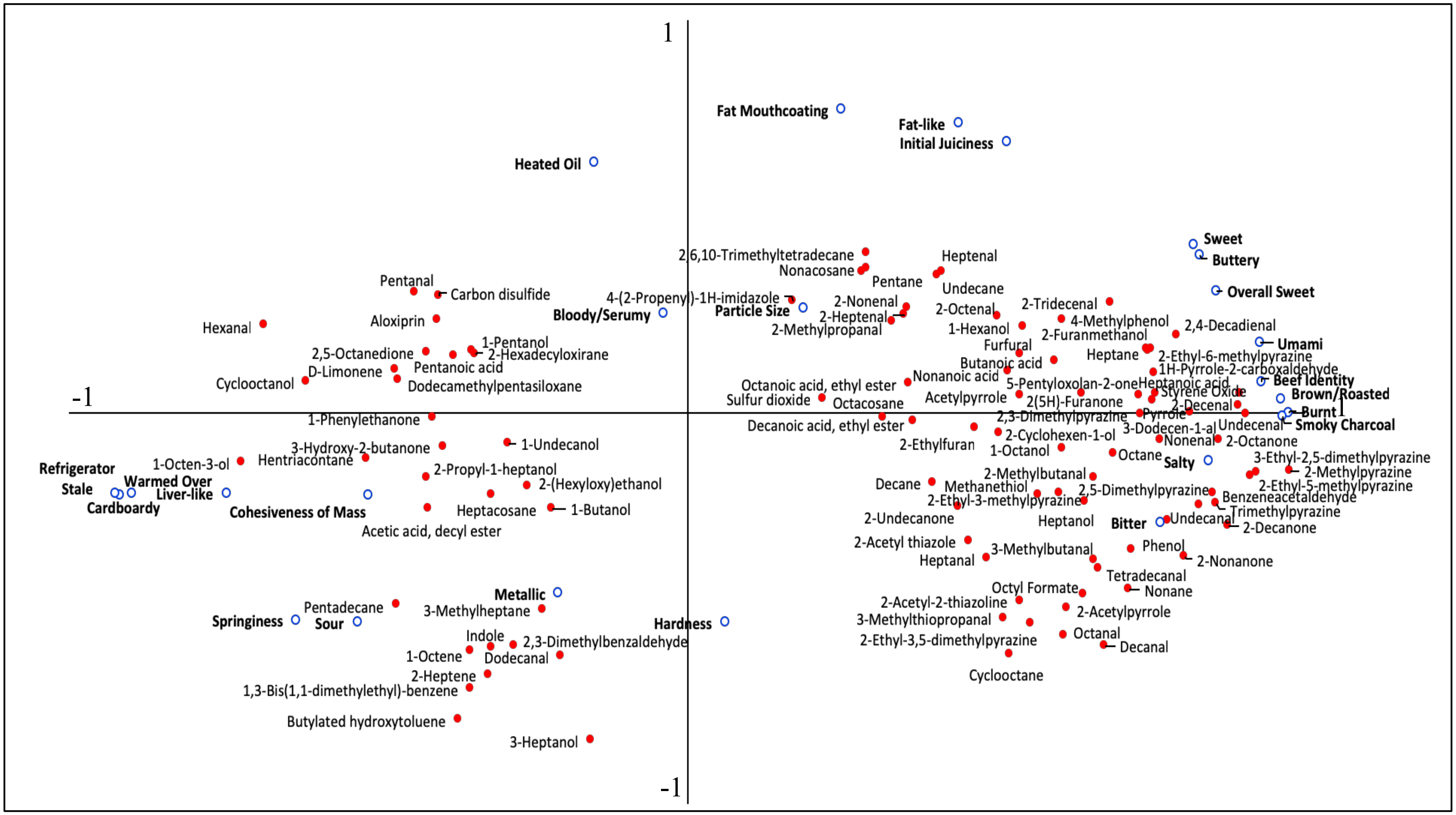


Figure 8. Partial least squares regression biplot for descriptive attributes (°) and volatile aromatic compounds (•) for meat source, patty thickness, and cooking method. Treatments not included. Correlations on X and Y with Y accounting for 66.2% of the variation in X and X accounting for 44.0% of the variation in Y.

Table 10. Flavor, basic tastes and texture attributes least squares means for machine-formed ground beef patties segmented by main effects of meat source, patty thickness, final grind size/method, cooking method and holding time where 0 = none and 15 = extremely intense.

Treatment	Beef identity	Brown/ roasted	Bloody/ serumy	Fat-like	Metallic	Liver-like	Chemical	Overall Sweet
Meat Source[a]	0.73	0.005	<0.0001	<0.0001	<0.0001	<0.0001	0.91	0.01
Commercial, 20% Fat	2.2	1.1[c]	0.8[b]	2.6[c]	1.6[b]	0.7[b]	0.4	0.7 [c]
Mature, 7% Fat	2.2	0.8[b]	1.3[c]	1.0[b]	1.8[c]	1.6[c]	0.4	0.6 [b]
Patty Thickness[a]	<0.0001	<0.0001	<0.0001	0.99	0.22	<0.0001	0.95	0.0005
6.4 mm	1.8[b]	0.5[b]	0.6[b]	1.8	1.7	1.0[b]	0.4	0.6[b]
2.54 cm	2.5[c]	1.4[c]	1.5[c]	1.8	1.7	1.3[c]	0.4	0.7[c]
Final Grind Method[a]	0.84	0.75	0.005	0.37	0.59	0.08	0.86	0.88
6.4 mm	2.2	0.9	1.1 [c]	1.9	1.7	1.0	0.4	0.7
9.7 mm	2.2	0.9	1.2 [c]	1.7	1.6	1.2	0.4	0.7
Bowl-chop	2.2	1.0	0.8 [b]	1.8	1.7	1.2	0.4	0.7
Cooking Method[a]	0.0004	0.01	0.19	<0.0001	0.10	0.67	0.09	0.74
Grill	3.1 [c]	1.6 [c]	1.4	3.5 [c]	1.5	1.0	0.2	0.7
Clam-shell	1.3 [b]	0.3 [b]	0.7	0.1 [b]	1.8	1.2	0.6	0.6
Holding Time[a]	0.31	0.47	0.98	<0.0001	0.14	0.91	0.50	0.08
0 h	2.3	1.1	1.0	2.3 [c]	1.6	1.2	0.5	0.7
1 h	2.0	0.8	1.0	0.7 [b]	1.6	1.2	0.5	0.5
3 h	2.3	0.9	1.1	2.4 [c]	1.9	1.0	0.3	0.8
RMSE[d]	0.50	0.54	0.65	0.58	0.22	0.53	0.27	0.26

Table 10 Continued. Flavor, basic tastes and texture attributes least squares means for ground beef patties segmented by main effects of meat source, patty thickness, final grind size/method, patty forming method, cooking method, and holding time where 0=none and 15=extremely intense.

Treatment	Basic Tastes: Umami	Basic Tastes: Sour	Basic Tastes: Salty	Basic Tastes: Bitter	Burnt	Barnyard	Refrigerator/ Stale	Card-boardy	Warmed Over
Meat Source[a]	0.31	0.0003	0.71	0.62	<0.0001	<0.0001	0.98	0.6	0.01
Commercial, 20% fat	0.5	1.5[b]	0.7	2.6	0.6[c]	1.7[b]	1.4	3.3	1.8[c]
Mature, 7% fat	0.4	1.6[c]	0.8	2.6	0.1[b]	2.0[c]	1.4	3.4	1.6[b]
Patty Thickness[a]	<0.0001	0.78	<0.0001	0.007	<0.0001	0.42	<0.0001	<0.0001	<0.0001
6.4 mm	0.3[b]	1.6	0.6[b]	2.6[b]	0.1[b]	1.9	1.7[c]	3.5[c]	2.0[c]
2.54 cm	0.6[c]	1.6	0.9[c]	2.7[c]	0.6[c]	1.8	1.2[b]	3.1[b]	1.4[b]
Final Grind Method	0.53	0.45	0.22	0.99	0.73	0.15	0.66	0.45	0.97
6.4 mm grind	0.5	1.6	0.8	2.6	0.4	1.8	1.5	3.3	1.7
9.7 mm grind	0.5	1.6	0.7	2.6	0.3	1.9	1.4	3.3	1.7
Bowl-chop	0.4	1.5	0.7	2.6	0.4	1.8	1.4	3.4	1.7
Cooking Method[a]	0.01	0.30	0.67	0.24	0.60	0.02	0.25	0.94	0.21
Grill	0.9[c]	1.7	0.8	2.7	0.5	1.5[b]	1.2	3.3	1.4
Clam-shell	0.1[b]	1.5	0.7	2.5	0.2	2.2[c]	1.7	3.3	2.0
Holding Time[a]	0.05	0.04	0.95	0.81	0.73	0.54	0.80	0.03	0.54
0 h	0.7	1.6[c]	0.7	2.6	0.4	1.8	1.5	3.1[b]	1.5
1 h	0.3	1.4[b]	0.8	2.6	0.2	2.0	1.4	3.1[b]	1.7
3 h	0.4	1.8[c]	0.8	2.7	0.5	1.7	1.4	3.8[c]	1.8
RMSE	0.37	0.21	0.24	0.23	0.54	0.35	0.51	0.36	0.49

[a] P-value from Analysis of Variance table.
[bc] Mean values within a column and interaction followed by the same letter are not significantly different ($P < 0.05$).
[d]RMSE = Root Meat Square Error.

Table 11. Texture attributes least squares means for ground beef patties segmented by main effects of meat source, patty thickness, patty forming method, final grind size/method, cooking method and holding time where 0=none and 15=extremely intense.

Treatment	Particle Size	Initial Juiciness	Cohesiveness of Mass	Fat Mouth Coating	Springiness	Hardness
Meat Source[a]	0.72	<0.0001	0.001	<0.0001	0.23	0.07
Commercial, 20% fat	5.3	2.4[c]	5.4[c]	3.3[c]	1.9	6.3
Mature, 7% fat	5.2	1.6[b]	5.0[b]	1.9[b]	1.8	6.6
Patty Thickness[a]	<0.0001	0.0007	0.0003	0.66	<0.0001	0.07
6.4 mm	5.0[b]	1.9[b]	5.4[c]	2.6	1.6[b]	6.3
2.54 cm	5.5[c]	2.2[c]	5.0[b]	2.5	2.1[c]	6.5
Final Grind Method[a]	<0.0001	0.01	0.01	0.11	0.14	<0.0001
6.4 mm grind	5.2[c]	2.2 [c]	5.3[c]	2.7	1.8	6.1[b]
9.7 mm grind	5.5[d]	2.1[bc]	5.3[c]	2.5	1.9	6.6[c]
Bowl-chop	5.0[b]	1.9[b]	5.0[b]	2.5	1.9	6.6[c]
Cooking Method[a]	0.67	<0.0001	0.58	0.0002	0.53	0.31
Grill	5.1	3.0[c]	5.4	3.5[c]	1.7	6.1
Clam-shell	5.4	1.0[b]	5.0	1.6[b]	2.0	6.8
Holding Time[a]	0.69	<0.0001	0.08	0.0006	0.001	0.15
0 h	5.1	2.5[c]	4.9	2.8[c]	2.2[c]	6.0
1 h	5.3	1.4[b]	4.7	1.8[b]	1.3[b]	6.3
3 h	5.4	2.2[bc]	6.0	3.0[c]	2.1[c]	7.0
RMSE	0.68	0.51	0.78	0.56	0.51	0.80

[a] P-value from Analysis of Variance table.
[bcd] Mean values within a column and interaction followed by the same letter are not significantly different ($P < 0.05$).
[d]RMSE = Root Meat Square Error.

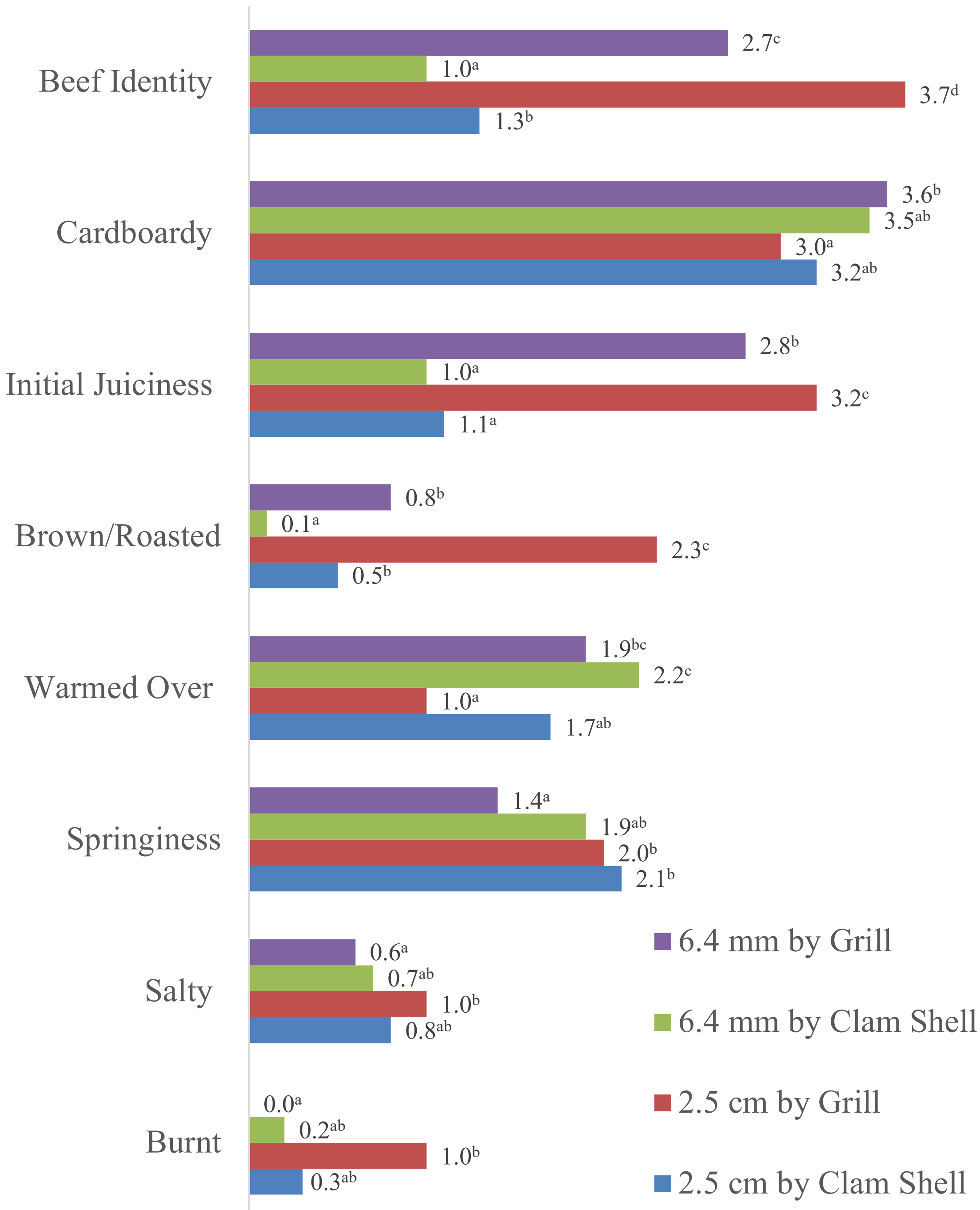


Figure 9. Patty thickness by cooking method interaction least squares mean for beef identity ($P < 0.0001$), brown/roasted ($P < 0.0001$), warmed over ($P < 0.0001$), burnt ($P = 0.006$), salty ($P = 0.0001$), cardboardy ($P = 0.02$), initial juiciness ($P = 0.03$), and springiness ($P = 0.02$) descriptive taste, flavor and texture attributes where 0 = none and 15 = extremely intense.

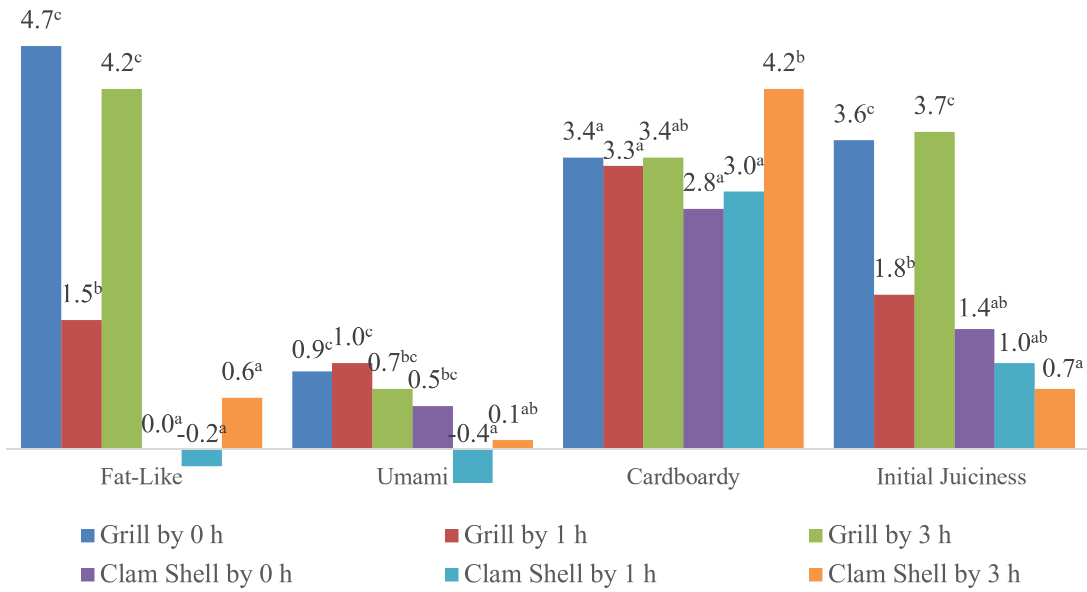


Figure 10. Cooking method by holding time interaction least squares mean for fat-like ($P < 0.0001$), umami ($P = 0.01$), cardboardy ($P = 0.02$), and initial juiciness ($P = 0.01$) descriptive flavor, basic taste, and texture attributes where 0 = none and 15 = extremely intense.

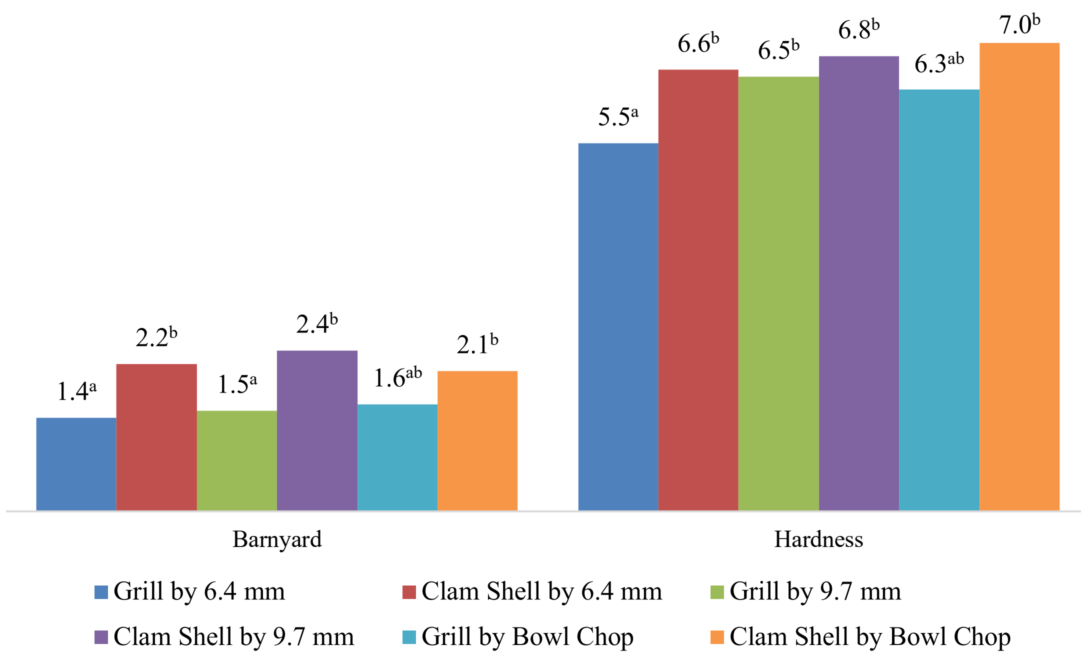


Figure 11. Cooking method by final grind method interaction least squares mean for barnyard ($P = 0.04$) and hardness ($P = 0.03$) texture attributes where 0 = none and 15 = extremely intense.

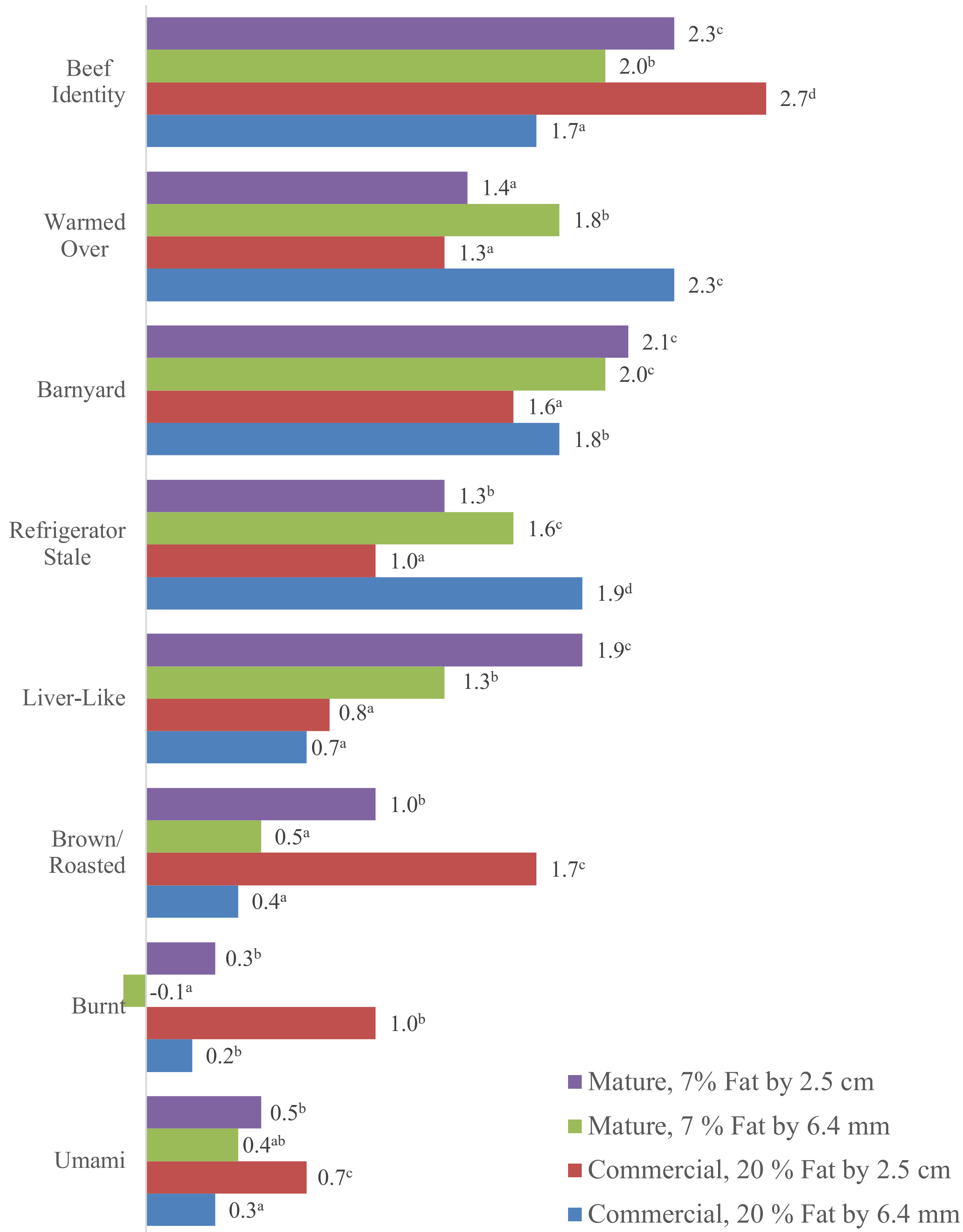


Figure 12. Meat source by patty thickness interaction least squares mean for beef identity ($P < 0.0001$), warmed over ($P = 0.01$), barnyard ($P = 0.005$), refrigerator stale ($P < 0.0001$), liver-like ($P = 0.002$), brown/roasted, burnt and umami ($P = 0.004$), descriptive flavor and basic taste attributes where 0 = none and 15 = extremely intense.

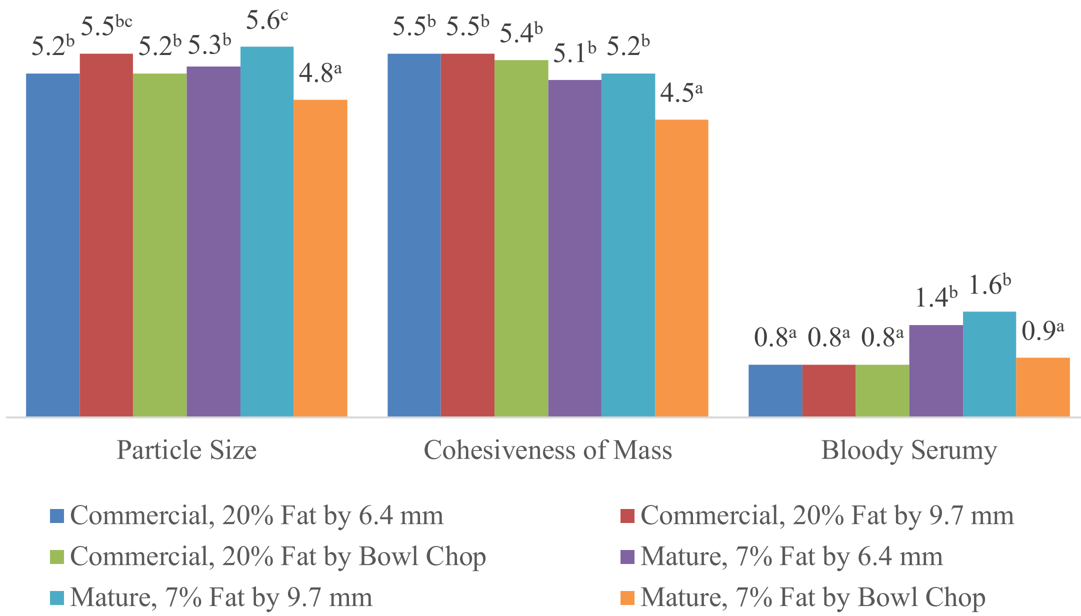


Figure 13. Meat source by final grind method interaction least squares mean for particle size ($P = 0.03$), cohesiveness of mass ($P = 0.03$), and bloody/serumy ($P = 0.01$), descriptive texture and flavor attributes where 0 = none and 15 = extremely intense.

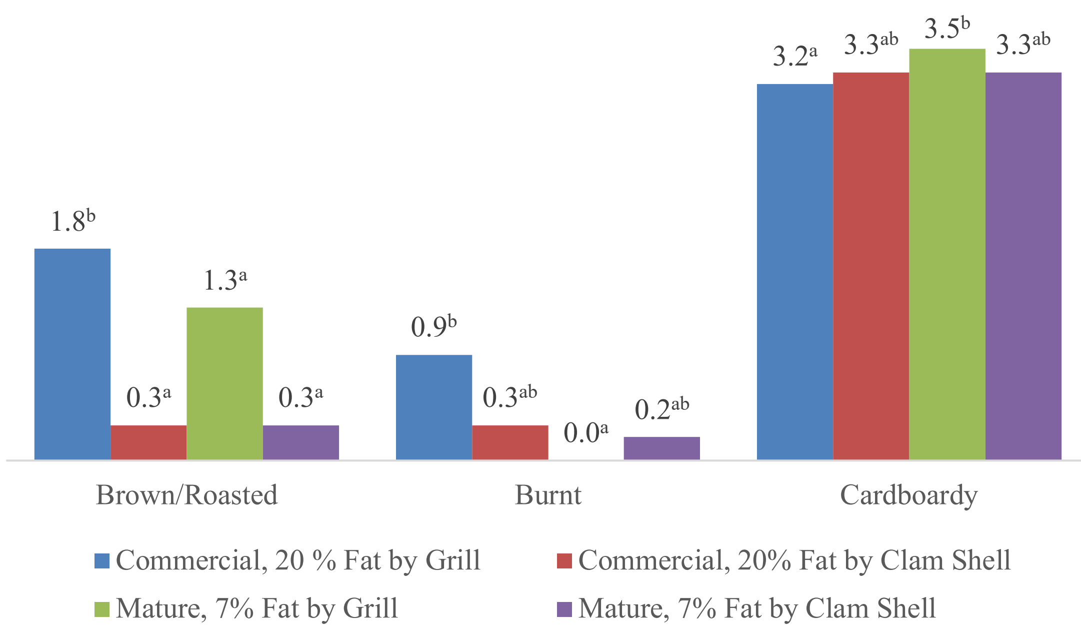


Figure 14. Meat source by cooking method interaction least squares mean for brown/roasted ($P = 0.007$), burnt ($P = 0.0007$), and cardboardy ($P = 0.03$) descriptive flavor attributes where 0 = none and 15 = extremely intense.

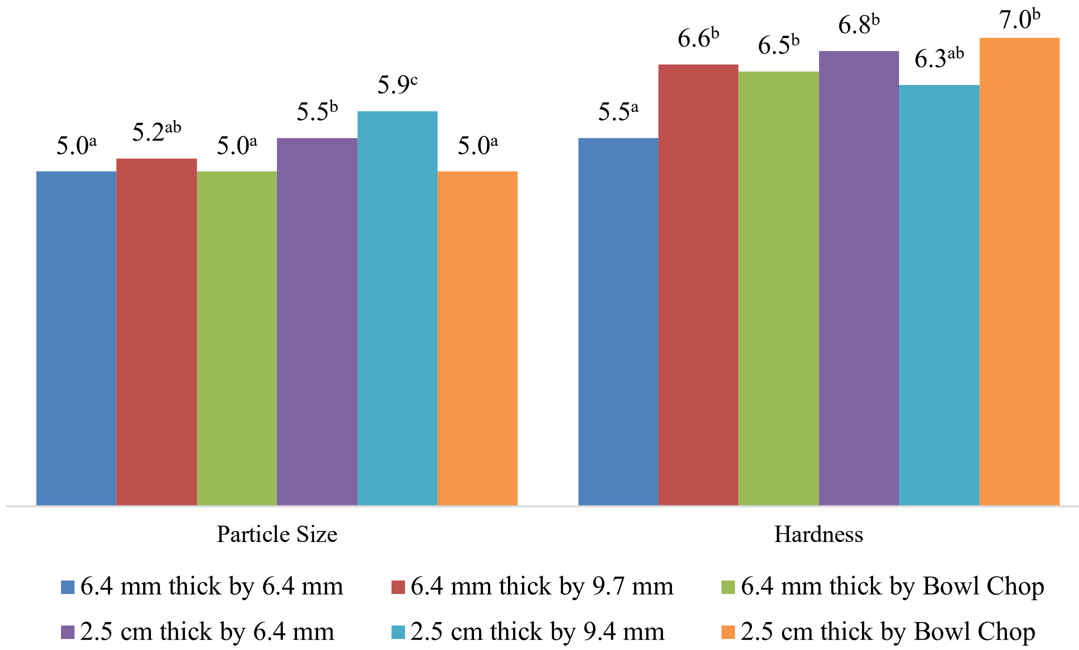


Figure 15. Patty thickness by final grind method interaction least squares mean for particle size (P = 0.002) and hardness texture attributes where 0 = none and 15 = extremely intense.

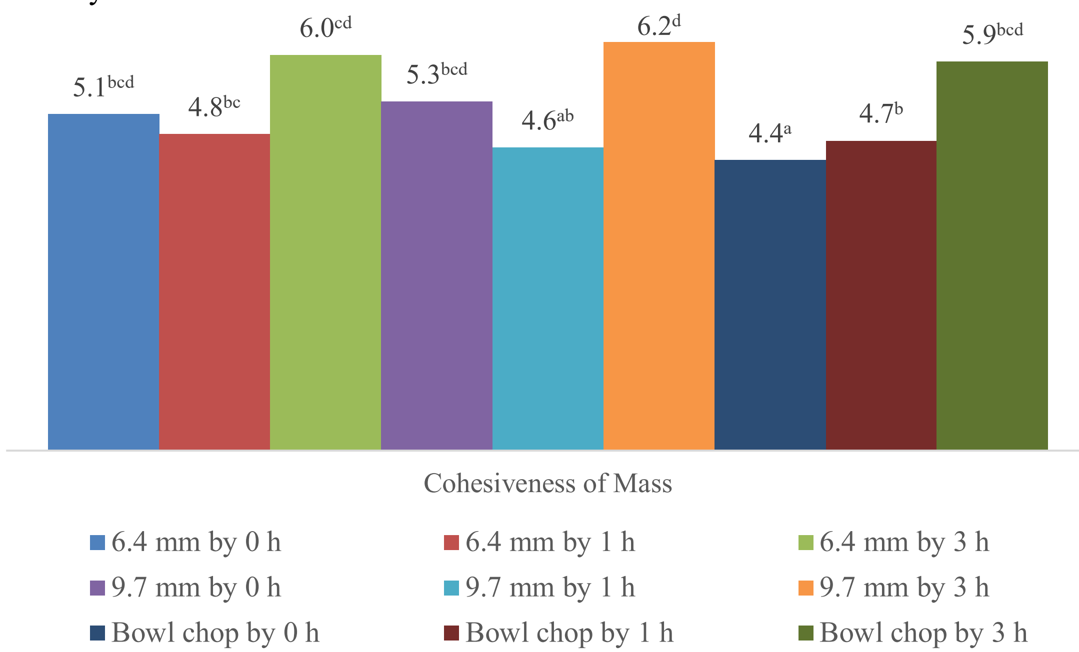


Figure 16. Final grind method by holding time interaction least squares mean for cohesiveness of mass (P = 0.03) texture attribute where 0 = none and 15 = extremely intense.

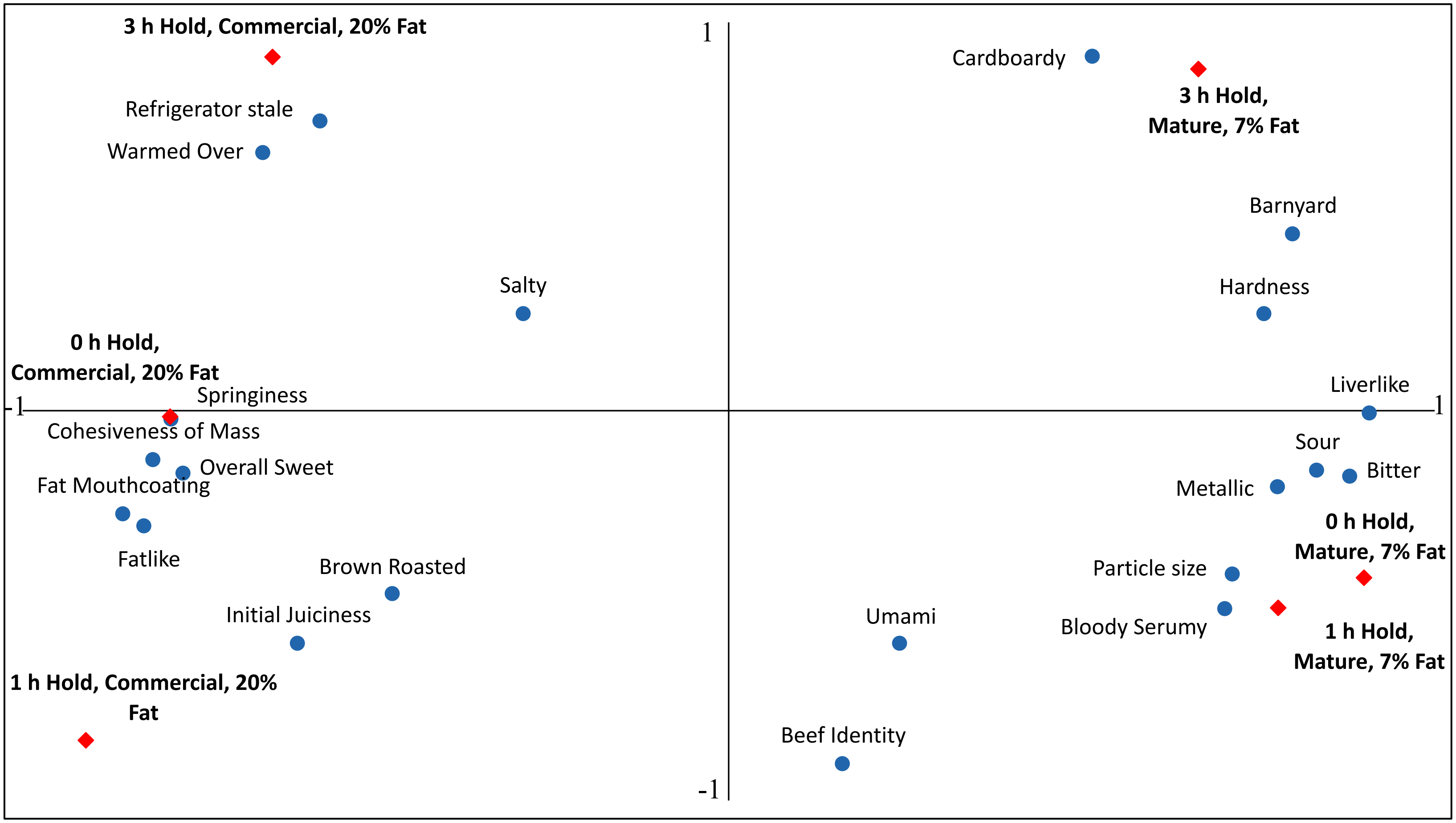


Figure 17. Principal Component Analysis of meat source and holding time treatments (♦)and descriptive flavor and texture attributes (•) (F1 accounts for 57.86% of the variation and F2 accounts for 17.43% of the variation).

Table 12. Cook yield and cook time least squares means for ground beef patties segmented by main effects of meat source, patty thickness, final grind method, cooking method, holding time, and their significant two-way interactions ($p < 0.05$).

Treatment	Cook Yield, %	Cook Time, min
Meat Source[d]	<0.0001	0.94
Commercial, 20% fat	67.8[a]	8.8
Mature, 7% fat	73.2[b]	8.8
Patty Thickness[d]	<0.0001	<0.0001
6.4 mm	72.5[b]	3.7[a]
2.54 cm	68.4[a]	13.8[b]
Final Grind Method[d]	0.38	0.05
6.4 mm grind	70.7	8.3
9.7 mm grind	70.7	8.8
Bowl-chop	70.1	9.2
Cooking Method[d]	0.79	0.003
Grill	70.8	11.4[b]
Clam-shell	70.1	6.2[a]
Holding Time[d]	0.83	0.56
0 h	71.0	8.2
1 h	70.3	8.6
3 h	70.2	9.5
Patty Thickness by Cooking Method[d]	-	<0.0001
6.4 mm by Grill	-	3.5[a]
6.4 mm by Clam-shell	-	3.9[a]
2.5 cm by Grill	-	19.2[c]
2.5 cm by Clam-shell	-	8.5[b]
RMSE[e]	3.03	2.80

[abc] Mean values within a column and interaction followed by the same letter are not significantly different ($P < 0.05$).
[d]P-value from Analysis of Variance table.
[e]RMSE = Root Meat Square Error.

Table 13. Simple correlation coefficients[a] between chemical measures and trained descriptive sensory panel flavor attributes.

	Lipid (%)	Moisture (%)	Fatty Acids									
			14:0	14:1	16:0	16:1	18:0	18:1	18:1 (n-11)	18:3	20:0	20:4
Bloody/Serumy	-0.26	0.26	-0.17	-0.21	-0.13	-0.22	0.17	-0.26	-0.27	0.09	0.14	0.15
Fat-like	0.65	-0.65	0.53	0.59	0.41	0.58	-0.53	0.64	0.58	-0.37	-0.38	-0.35
Metallic	-0.40	0.40	-0.29	-0.34	-0.22	-0.33	0.29	-0.38	-0.30	0.14	0.21	0.23
Liver-like	-0.59	0.59	-0.52	-0.57	-0.39	-0.56	0.52	-0.58	-0.49	0.27	0.40	0.25
Overall Sweet	0.21	-0.21	0.19	0.20	0.13	0.18	-0.19	0.20	0.11	-0.09	-0.12	-0.11
Sour	-0.35	0.35	-0.31	-0.34	-0.18	-0.33	0.31	-0.32	-0.24	0.20	0.17	0.22
Bitter	-0.23	0.22	-0.19	-0.22	-0.10	-0.23	0.19	-0.21	-0.19	0.07	0.13	0.11
Barnyard	-0.30	0.30	-0.29	-0.29	-0.22	-0.27	0.29	-0.29	-0.22	0.26	0.16	0.19
Burnt	0.13	-0.14	0.09	0.09	0.17	0.08	-0.11	0.15	0.16	-0.17	-0.09	-0.07
Refrigerator Stale	0.11	-0.10	0.04	0.09	-0.04	0.14	-0.04	0.12	0.27	-0.01	-0.04	-0.09
Warmed Over	0.17	-0.17	0.11	0.15	0.03	0.18	-0.10	0.18	0.27	-0.05	-0.08	-0.12
Cardboardy	-0.14	0.14	-0.10	-0.10	-0.11	-0.08	0.10	-0.14	-0.08	0.09	0.06	0.09
Hardness	-0.25	0.24	-0.21	-0.23	-0.11	-0.24	0.20	-0.23	-0.19	0.07	0.14	0.13
Springiness	0.14	-0.14	0.04	0.07	0.03	0.06	-0.04	0.13	0.11	-0.01	-0.01	-0.14
Initial Juiciness	0.40	-0.40	0.32	0.35	0.28	0.34	-0.33	0.40	0.33	-0.22	-0.25	-0.19
Cohesiveness of Mass	0.25	-0.25	0.21	0.23	0.11	0.22	-0.20	0.23	0.21	-0.22	-0.07	-0.24
Particle Size	-0.26	0.26	-0.24	-0.26	-0.18	-0.27	0.24	-0.26	-0.19	0.06	0.21	0.06
Fat Mouth-coating	0.68	-0.68	0.56	0.62	0.46	0.61	-0.57	0.68	0.61	-0.37	-0.42	-0.34

[a] Simple correlation coefficients > 0.13 are significant (*P* < 0.05).

Table 14. Overall list of volatile aromatic compounds in 3 h held samples.

Variable	Compound	Mean	Standard Deviation
C1	1-Octanol	10474	32602
C2	1-Octen-3-ol	114936	313402
C3	1-Pentanol	11064	20905
C4	1-Tetradecanol	10082	80658
C5	2-Octenal	308331	459117
C6	2-Decenal	44798	85148
C7	2-Propanone	39895	118472
C8	2,3-Dimethylbenzalldehyde	385	1744
C9	2,3-Octanedione	49234	93488
C10	2,4-Decadienal	4010	11140
C11	3-Dodecen-1-al	22627	51707
C12	Acetic acid	34620	209967
C13	Benzaldehyde	364738	430122
C14	Benzeneacetaldehyde	4126	7323
C15	Decanal	44383	79794
C16	2-Pentylfuran	70462	140493
C17	Hentriacontane	1678	4130
C18	Hexanal	673669	1288722
C19	Nonanal	920336	1501970
C20	Nonenal	90447	141921
C21	Tetradecanal	5518	10458
C22	1-Hexanol	3001	9318
C23	2-Heptanone	2800	7448
C24	2-Nonenal	11005	29552
C25	3-Methylbutanal	257	949
C26	Decane	4928	14082
C27	D-Limonene	4934	14380
C28	Dodecane	22417	73165
C29	Heptanal	146231	287599
C30	Nonadecane	2385	6430
C31	Octanoic Acid	1277	6814
C32	Pentanal	7116	19637
C33	Butylated hydroxytoluene	8825	29421
C34	3-Methylthiopropanal	247	932
C35	2-Ethyl-5-methylpyrazine	3726	25385
C36	2,5-Dimethylpyrazine	21767	91843
C37	3-ethyl-2,5-dimethylpyrazine	2971	10023
C38	1-Nonen-3-ol	4901	26498
C39	2-Heptenal	3089	13966
C40	Acetaldehyde	5225	6461
C41	2,3-Dihydrobenzofuran	528	2178
C42	Dodecanal	10760	33528
C43	2-Acetylpyrrole	4317	10612

Table 14 Continued. Overall list of volatile aromatic compounds in 3 h held samples.

Variable	Compound	Mean	Standard Deviation
C44	Octyl Formate	5295	26380
C45	Heptanol	9588	20969
C46	Nonacosane	1178	6733
C47	Propanal	425	1778
C48	2-Nonadecene	252	717
C49	1-Dodecanol	813	5101
C50	3-Hydroxy-2-butanone	2540	7145
C51	2-Decanone	8206	40681
C52	2,4-Nonadienal	2268	8879
C53	6,7-Dodecanedione	6412	30771
C54	3-Ethylbenzaldehyde	6589	10302
C55	Benzenemethanol	94	394
C56	Cyclooctanol	3135	13126
C57	Decanoic acid, ethyl ester	3150	11054
C58	Hexanoic acid	2617	8581
C59	Tridecane	9477	27460
C60	Undecenal	15775	54582
C61	Ethenyl hexanoate	23711	148131
C62	Pentadecane	1147	5093
C63	1-Decanol	739	4398
C64	Heptacosane	224	1034
C65	2-Octen-1-ol	2053	9790
C66	6,10-Dimethyl-2-undecanone	495	1618
C67	Cyclooctane	10512	34707
C68	Heptane	327	1383
C69	Octacosane	645	3275
C70	Styrene	9570	28769
C71	2-Cyclohexen-1-ol	10647	40877
C72	Heptanoic acid	1144	5282
C73	2-Ethyl-3,5-dimethylpyrazine	1251	4302
C74	Tetradecane	2711	10377
C75	Tricosane	867	3412
C76	2,8-Dimethylundecane	3257	16307
C77	Octadecanal	1175	5968
C78	Octanoic acid, ethyl ester	1641	7809
C79	2-(Hexyloxy)ethanol	4604	29817
C80	Tridecanal	3285	13487
C81	Heneicosane	762	2983
C82	Octadecane	1243	4223
C83	Trimethylpyrazine	1183	5113
C84	Butyrolactone	8621	71095
C85	2-Docecen-1-al	3083	11236
C86	2-Dodecenal	1766	7834

Figure 18. Partial least squares regression biplot for trained descriptive attributes (°), treatment (♦) and volatile aromatic compounds (•). Correlations on X and Y with Y accounting for 90.1% of the variation in X and X accounting for 88.1% of the variation in Y.

4. FLAVOR IN GROUND BEEF USING A HOME USE TEST

4.1. Materials and Methods

Trained sensory panelist training, testing and consumer evaluation procedures were approved by the Texas A&M Institutional Review Board (IRB2016-0420M).

4.1.1. Sample Selection

Beef round sirloin tip (knuckle), peeled (IMPS 167A), outside round flats (IMPS 171B), chuck, shoulder clods (IMPS 114), 80/20 coarse ground beef (IMPS 136), and 50/50 beef trim were all purchased from Ruffino Meats in Bryan, TX. A supplemental supply of beef trim and knuckles was purchased from Sam Kane Beef Processors in Corpus Christi, TX. Knuckles, bottom round flats, and clods were trimmed of all visible fat and connective tissue on the external surface. Each primal was then cubed into chunks and coarse ground (12.7 mm plate) using a grinder (Meat Grinder Model 1056, Biro Manufacturing Company, Marblehead, OH) and mixed in a mixer for 1 minute to ensure a homogenous mixture.

Three random samples from each coarse ground batch (knuckles, bottom round flats, clod hearts, and 50/50 trim) were taken to determine starting fat percentage of each source. Samples were homogenized in a food processor. Three replicates of each sample were used to determine the fat and moisture (Smart System[5] Moisture/Solids Analyzer and SMART Trac Fat Analysis System, CEM Corporation, Matthews, NC). After three readings for each source were taken, fat and moisture percentages were averaged and utilized when calculating for 10 and 20% final fat content for the four meat sources. A

Pearson square was utilized to calculate how much lean source and how much trim were needed for fat percentages for each batch.

The regular 80/20 treatments arrived in coarse ground chubs and were utilized as received. The regular 90/10 treatments were formulated by utilizing knuckles as the lean source and regular 80/20 as the fat source. Chuck 80/20 and 90/10 treatments were formulated by utilizing beef shoulder clods as the lean source and 50/50 trim as the fat source. Round 80/20 and 90/10 treatments were formulated by utilizing bottom round flats as the lean source and 50/50 trim as the fat source. Sirloin 80/20 and 90/10 treatments were formulated by utilizing knuckles as the lean source and 50/50 trim as the fat source. Once the eight initial treatments were formulated, three representative samples were taken for fat and moisture analysis as previously described. Final fat contents were verified to be ± 2% of the projected fat percentage.

Once all eight sources were validated by the fat analyzer, each batch was split into two groups. One group was run through the grinder plate (6.4 mm), and the other group was bowl-chopped (Model K64 Vacuum Cutter, Seydelmann, Stuttgart, Germany) for six revolutions at high speed (6,000 RPM) as determined based on preliminary testing. This resulted in 16 final treatments: regular 80/20, 6.4 mm grind; regular 80/20 bowl-chopped; regular 90/10, 6.4 mm grind; regular 90/10 bowl-chopped; chuck 80/20, 6.4 mm grind; chuck 80/20 bowl-chopped; chuck 90/10, 6.4 mm grind; chuck 90/10 bowl-chopped; round 80/20, 6.4 mm grind; round 80/20 bowl-chopped; round 90/10, 6.4 mm grind; round 90/10 bowl-chopped; sirloin 80/20, 6.4 mm grind; sirloin 80/20 bowl-chopped; sirloin 90/10, 6.4 mm grind; and sirloin 90/10 bowl-chopped.

Patties for each treatment were formed with a patty maker (Supermodel 54 Food Portioning Machine, Hollymatic Corporation, Countryside, IL) with a 2.54 cm plate. Patties were randomly assigned to trained panel testing or home use consumer evaluation. Once patties were labeled, they were placed in a single layer and crust frozen in a -40°C freezer for 20 m, and then vacuum packaged. Two patties were packaged together with a piece of patty paper between the patties. Chubs for each treatment were weighed to 454 g and placed in vacuum package bags. Patties and chubs for home use consumer evaluation were placed in vacuum package bags (B2470, Cryovac Sealed Air Corporation, Duncan, SC) with an oxygen transmission rate of 3 to 6 cc at 4°C (m^2, 24 h at 4°C, 0% RH) and a water vapor transmission rate of 0.5 to 0.6 g at 38°C (100% RH, 0.6 m^2, 24 h) and individually sealed. Patties designated for trained panel were placed into bags (B6620, Cryovac Sealed Air Corporation, Duncan, SC) with an oxygen transmission rate of 3 to 6 cc at 4°C (1 cm^3[STP]/ [m^2, 24 h, atm] @ 0% RH) and a water vapor transmission rate of 0.4 to 0.5 g at 37.7°C (100% RH, g/[100 in^2 – 24 h]) and five patties were sealed for each "sample" to be served to the trained panel. Three bags of five patties were collected from each treatment across three replicates, which were created by new orders of raw materials for three consecutive weeks.

Immediately after packaging, samples were taken to a -40°C freezer until frozen solid and then moved to a -23°C freezer where they were sorted by test and city and placed into labeled boxes until time of testing. These procedures were repeated for three weeks, with new shipments of meat arriving each week in order to produce three representative replicates. All testing was conducted within 6 months of processing.

4.1.2. Expert Trained Descriptive Beef Flavor Analysis

Patties were evaluated by an expert trained beef flavor descriptive attribute panel that helped develop and validate the beef lexicon (Adhikari et al., 2011). This panel was retrained for 16 d using the beef lexicon leading up to testing. Beef flavor attributes were measured using a 16-point scale (0 = none and 15 = extremely intense). Patties were thawed in a cooler (4°C) for approximately 24 h prior to testing. Raw temperatures and time put on the grill were recorded, along with end temperature, time off the grill, and final cook weights. Samples were cooked on a commercial flat top grill (Star Max 536TGF Countertop Electric Griddle with Snap Action Thermostatic Controls, Star International Holdings Inc. Company, St. Louis, MO) to an internal temperature of 71°C. Internal temperatures were monitored using thermocouple probes (Model SCPSS-040U-6, Type T thermocouple, Omega Engineering, Stamford, CT) by probing into the geometric center of the patty periodically throughout cooking and were displayed using a thermometer (Omega HH501BT Type T, Omega Engineering, Stanford, CT). After patties finished cooking and the final weight was recorded, patties were wrapped in foil and placed in a holding oven (Model 750-TH-II, Alto-Shaam, Menomonee Falls, WI) for up to 20 min, until served.

Panelists were provided with a warm-up sample to calibrate each sensory day. The warm-up was individually evaluated by each panelist and then discussed. Panelists came to consensus for all attributes prior to testing. Eight random samples over the course of a two-hour session were evaluated each sensory day. Each sample was served on a clear, plastic plate (clear 15.9 cm plastic plates premium quality, Members Mark, Sam’s Club, Bentonville, AR) marked with a random three-digit code. Samples consisted of half of a patty each, and panelists were given a new clear plastic fork (Dixie FH107, Georgia-Pacific, Atlanta, GA) and clear plastic knife (Dixie KH017, Georgia-Pacific, Atlanta, GA) to evaluate each sample.

Each panelist was given palate cleansers of their choice including double-distilled-deionized water, sparkling water (H-E-B Sparkling Pure Water Beverage 12 oz Cans, H-E-B Grocery Company, San Antonio, TX), and salt-less saltines (Premium Unsalted Tops Saltine Crackers, Nabisco, East Hanover, NJ). Each panelist was given a tablet (iPad Air 1, Apple Inc., Cupertino, CA) to record their individual data using an electronic spreadsheet (Microsoft Excel, One Drive, Microsoft Corporation, Redmond WA), and samples were evaluated independently. The trained panel for each sample evaluated flavor and texture attributes as defined in Table 1. The ground beef flavor attributes, definitions, and reference standards (Adhikari et al., 2011) as well as the ground beef texture attributes are included in Table 1. Data is also presented in Beavers (2016).

4.1.3. Home-Use Consumer Evaluation (HUT)

The home-use consumers were selected from the initial 80 consumers that participated in the central location test. This was conducted across four cities (Portland, OR; Manhattan, KS; Griffin, GA; State College, PA) in order to represent different geographical areas (East Coast, West Coast, South, and Middle) of the United States. Consumers (n = 320) were recruited for the study, 314 were given product and 206 consumers actively participated by returning the ballots. For each consumer, four treatments were randomly selected from the aforementioned treatments and the consumers received four packages of two patties and the four 454 g chubs from the same treatment. Each consumer received a total of eight samples. Consumers were asked to answer a questionnaire as they prepared each product that included cooking method, ingredients added, degree of doneness, cuisine classification, and preparation time. Consumers also were provided a ballot and asked to rate the cooked product for appearance, overall, flavor and texture liking using 9-point hedonic scales as in the original project (Appendix A; Table 4; AMSA, 2015; Meilgaard et al. 2007). Consumers were provided color scales for determination of degree of doneness using the Kansas Agricultural Experiment Station Ground Beef Patty Cooked Color Guide (Marksberry et al.; 1993) descriptions of cooking methods, and a self-addressed stamped envelope to return their ballot and questionnaire. After receipt of the questionnaire and ballot, consumers were mailed a $20 incentive for their participation.

4.1.4. Statistical Analyses

Consumer demographics were analyzed by determining frequencies in SAS (v9.4, SAS Institute, Cary, NC). Home use test sensory attributes were analyzed using the general linear model's procedure in SAS with a predetermined alpha of 5%. For trained panel results, data were averaged across panelists, order was defined as a random variable, and replicate was included in the model as a fixed effect. A full model was calculated where main effects of grind type, meat source, fat level and their two-way interactions were included. A final model used main effects of grind type, meat source, fat level and significant ($P < 0.05$) two-way interactions. Consumer sensory data were analyzed similarly. Least squares means were calculated. Post-hoc mean separation was done using Fisher's least significant difference ($P < 0.05$). Principal component analysis (PCA) and partial least squares regression (PLS) was conducted using XLSTAT (v2013, Addinsoft, New York, NY). Data were presented in bi-plots. Data from HUT from the chub form was excluded in comparisons of the CLT to the HUT. Word clouds were created using JMP Pro (14.0.0, SAS Institute, Cary, NC).

4.2. Results and Discussion

4.2.1. Expert Trained Descriptive Beef Flavor Analysis

The expert trained descriptive attribute panel was preformed simultaneously with Beavers (2016) and data are reported similarly. The sensory panelists were trained to identify the attributes as indicated in Table 1; however, animal hair, apricot, asparagus, barnyard, beet, chemical, chocolate/cocoa, cumin, dairy, fishy, floral, green hay-like, leather, nutty, painty, rancid, smoky wood, soapy, sour aromatics, and spoiled-putrid were not present. Main effects for flavor and basic taste attributes without interactions are presented in Table 17. Meat source impacted ($P < 0.05$) fat-like, liver, bitter, sour, sour milk/sour dairy, and cardboardy flavor and basic taste descriptive attributes. Regular and chuck meat sources were rated higher ($P = 0.02$) for fat-like flavor attributes than the patties made from the round source. The round source had the highest incidences of liver-like ($P = 0.04$), sour ($P < 0.0001$), and sour milk ($P = 0.005$) flavor and basic tastes descriptive attributes. Bitter basic taste was rated lower (P = 0.01) in regular patties than in patties made from the round and sirloin. Cardboardy flavor attribute was rated higher ($P = 0.04$) for sirloin meat source than the regular and chuck sources. Regular ground beef patties also were harder ($P = 0.007$) than chuck patties, and springier ($P = 0.009$) than all other meat sources (Table 18). Meisinger et al. (2006) found the V. *lateralis* (sirloin) had the most intense off-flavor. Although sirloin meat had off-flavors in the present study, the round produced the most negative flavors. Gredell (2018) found that ground beef patties formulated from the chuck trimmings were more desirable in flavor attributes as compared to ground beef formulations containing brisket or sirloin cap.

Fat level had a significant effect on flavor attributes (Table 17). Ground beef patties containing 10% lipid were higher in bitter ($P = 0.002$), cardboardy ($P = 0.0002$), liver-like ($P < 0.0001$), sour ($P < 0.0001$), and sour milk/sour dairy ($P = 0.01$) descriptive attributes compared to 20% fat patties. Similarly, Berry (1994) found that in 4% fat patties, more acid or sour flavors and basic tastes were present than in patties with 20% fat. Ground beef patties containing 20% lipid were higher in buttery ($P < 0.0001$), fat-like ($P < 0.0001$), heated oil ($P < 0.0001$), smoky charcoal ($P = 0.01$), sweet ($P = 0.005$), overall sweet ($P = 0.002$) flavor and basic taste descriptive attributes and were juicier ($P = 0.0001$; Table 18) compared to the 10% fat patties. Similarly, Trout et al. (1992) reported lower fat (5 and 10%) patties to have less juiciness and moisture release when compared to the 20 and 30% fat patties; however, they also showed greater patty firmness, cohesiveness, and crumbliness in the 10% fat patties. Cohesiveness of mass, hardness and springiness texture attributes were not affected by the fat percentage in this study. Higher fat-levels in ground beef has been shown to increase tenderness of ground beef (Berry, 1984), but this was not seen in the present study, as hardness was not affected. These results indicate that higher fat percentages have a higher prevalence of sweet and overall sweet flavors and lean source also may contribute. Similarly, Legako et al. (2016) reported that as fat increased in beef differing in quality grades so did the presence of overall sweet, which agrees with the conclusion from this study.

Grind treatment did not affect as many flavor and texture attributes as the source and fat treatments. Medicinal (Table 17) and umami (Table 20) flavor and basic taste descriptive attributes were the only flavor and basic tastes affected by grind treatments. Medicinal was higher (P = 0.04) for the bowl-chopped patties when compared to the patties from the 6.4 mm grind. Umami (P = 0.0005) basic taste was higher for ground beef patties ground to 6.4 mm than bowl-chopped patties. Grind method affected several texture attributes reported in Table 18. Bowl-chopped patties had smaller particle size (P = 0.0004), were harder (P < 0.0001) and springier (P < 0.0001) than the 6.4 mm-ground beef patties. These results were similar to Randall and Larmond (1977) who reported ground patties were more tender and less rubbery when compared to the flake cut patties. Although the patties were flaked instead of using the bowl-chopper, these are similar methods that do not compact the meat particles. Contrary to the results in this study, Lin and Keeton (1994) reported that flaked patties were juicer, less hard, dense and cohesive than patties that were coarse ground. In the current study, the grinding method did not affect cohesiveness of mass or juiciness and the bowl-chopped patties were harder than the ground patties.

Burnt and green flavor attributes displayed a interactions between the main effects reported in Table 19. Slight differences in burnt flavor descriptive attribute across meat source by grind and meat source by fat interactions were reported. Ground beef patties formulated from the round and ground using a 6.4 mm final grind size had more (P = 0.03) burnt flavor than regular bowl-chopped patties. There were no differences between the other sources and grinding methods. The regular, round, and sirloin 6.4 mm grind patties were higher (*P* < 0.05) in burnt intensity than the chuck patties ground to 6.4 mm. All of the sources of the bowl-chop method had similar amounts of burnt flavor attribute. Green also had a source by grind interaction where the round, bowl-chop patties had higher (P =0.02) amounts of green than the round, 6.4 mm patties. All the sources that were ground to 6.4 mm were similar in green intensities and the regular, sirloin, and chuck bowl-chopped also had similar values. Blackmon et al. (2015), also detected very low, but significant, difference in green hay-like flavors across meat source. This indicates that certain meat sources may have a higher prevalence of green flavor but depending on fat percentage the detection could be masked. Burnt flavor attribute also presented a source by fat interaction. All of the sources were similar in burnt flavor intensity across fat percentages except for patties from the sirloin meat source. The sirloin, 20% fat was significantly higher (*P* = 0.03) in burnt flavor when compared to the sirloin, 10% fat patties. Of the 10% fat treatment patties regular, and sirloin patties were similar in burnt flavor, but round patties had higher amounts of burnt flavor. Of the 20% fat treatments, patties from the sources were similar in burnt flavor intensity.

Beef identity, brown, roasted, bloody/serumy, umami, salty, and particle size descriptive attributes displayed a meat source by fat interaction presented in Table 20. Patties made from the round and chuck subprimals had similar (*P* <0.0001) beef identity for both the 10% and 20% fat patties. The sirloin meat source patties increased in beef identify as the fat level increased and the opposite occurred for the regular meat source patties. Troutt et al. (1992) reported that low-fat patties were not always lower in beef identity flavor and high-fat patties were not higher in beef identity flavor. Patties from the regular meat source may have had beef identity as the fat level increased as higher concentrations of fat could influence the formation of some lipid-derived volatiles (Mottram, 1998). Blackmon et al. (2015) also reported an interference with the development of lipid- and Maillard- derived volatiles as fat percentages increased in ground beef patties made from different lean sources.

Ground sirloin beef patties with 20% fat were highest in brown ($P = 0.02$) and roasted ($P < 0.0001$) and ground sirloin patties with 10% fat were lowest in brown and roasted. Patties from the other meat sources were similar in brown and roasted flavor compared across fat levels to sirloin ground beef patties with 10% lipid. These patties were in beef identity, brown, and roasted flavors.

Bloody/serumy flavor attribute was similar ($P = 0.01$) in regular, round, and chuck meat sources patties regardless of fat levels, except for the sirloin patties where 20% fat patties were lower in bloody/serumy than when compared to the 10% fat patties. The round, 10% fat patties had lower levels of bloody/serumy than patties from the other sources at 10% fat. Meisinger et al. (2006) reported no difference between the round and chuck patties in bloody intensity.

Regular and chuck ground beef patties from both fat percentages were similar ($P = 0.03$) in umami flavor. For the sirloin and round patties, umami increased as the fat percentage increased. Of the 10% fat sources, the chuck was the highest in umami and the other sources were similar. The 20% fat patties all had similar values for umami except for the regular 20% fat patties had the lowest in umami basic taste. Salty basic taste differed slightly between the treatments, but there was a significant interaction. The round and chuck patties from both fat levels were the same (P = 0.006) for salty flavor. The regular 10% fat patties were higher in salty basic taste than the 20% fat patties from the same source. The opposite reaction was observed for the sirloin patties, as the 10% fat patties were lower in salty basic taste than the 20% fat patties. Although it wouldn't be expected that meat source and lipid level would affect particle size, round and regular ground beef patties with 10% lipid had smaller particle size (P = 0.02) compared to round and regular ground beef patties at 20% lipid.

4.2.2. Consumer Demographics

Consumer demographics (n = 218) are reported in Table 22. Slightly more females (60.0%) participated in the study compared to males (40.0%). The majority of participants (97.6%) fell in the 21 to 65 y age range with a slightly heavier representation of the 26 to 35 y age range (28.7%). The majority of consumers represented Caucasian (non-Hispanic) ethnicity (78.1%), followed by Asian/Pacific Islanders (7.4%) and African-American (6.5%). Household incomes were fairly evenly distributed with 28.4% falling in the \$50,000 - \$74, 999 group and 25.1% falling in the \$25,001 - \$49,999 group, and roughly 14% - 16.3% for all other income brackets. The majority of individuals came from two-person households (42.6%), followed by three-person (22.7%), and one-person (14.4%) households. Most consumers surveyed were full-time employed (69.0%).

Consumers were heavy consumers of chicken, beef (steaks) and ground beef, pork, fish and eggs and tended to eat these protein sources at home and away from home. Most consumers reported consuming beef (steaks) 1 to 2 times per week (77.1%), followed by 3 to 4 times per week (14.3%). For ground beef consumption, the majority of consumers reported eating 1 to 2 times per week (69.2%) followed by 3 to 4 times per week (25.1%).

For ground beef, consumers preferred using pan-fry method (83.2%), followed by grilling outside (75.7%). Most consumers preferred to have their ground beef cooked to medium well (31.2%), closely followed by a medium degree of doneness (27.4%). The majority of consumers purchased beef traditionally at the retail store, and about 28% of consumers preferred grass fed or organic ground beef. The majority of consumers preferred to buy ground beef with fat percentages between 7 to 15%, with the most consumers buying 15% fat (28.7%).

Over 80% of consumers reported enjoying American, Chinese, Barbeque, Mexican/Spanish, and Italian cuisines. Lebanese, Indian, French, and Greek were among the lowest cuisines typically consumed. These results indicate that consumers in this study purchased ground beef and were an acceptable population to test the effects of ground beef fat level, meat source and grind size.

4.2.3. Consumer Preparation

Consumer preparation methods of the patties and chubs are presented in Table 23. The majority of consumers thawed the meat the day before (68.8%), while some consumers (about 13%) thawed the meat using the microwave. The thawing methods between patties and chubs was consistent. A much larger number of consumers broke apart the chubs into smaller pieces (41.4%) compared to the patties (15.1%). A higher percentage of consumers cooked ground beef in sauce with the chubs (16.1%) versus the patties (8.7%). The cooking differences between chubs and patties stood out in the outdoor grill and pan fry/sauté cooking methods. More consumers used an outdoor grill when given patties (25.4%) versus chubs (10.6%) and more consumers pan fried/sautéed the meat when given chubs (60.8%) versus patties (45.0%). Most consumers cooked their ground beef chubs (61.3%) and patties (45.6%) to well done. More consumers used the chubs and patties as a main course, but more consumers combined the ground beef chub with other ingredients compared to than the patties. The most common additive to the meat at the table was ketchup for patties (32.1%) and other for chubs (29.5%).

The HUT design allows consumers to choose how they prepare and eat the products (Boutrolle et al., 2007). Matuszewska et al. (1997) compared scores of margarine samples from three different tasting methods: consumer spreading on bread, prepared spread bread slice or margarine with no bread. The study showed that individual preparation led to better discrimination (Matuszewska et al., 1997). However, King et al. (2004) showed discrimination decreased with eating under natural eating conditions. Pizza was better discriminated when tested alone than when tested in combination with salad and beverages (King et al., 2004).

4.2.4. Consumer Perception

Consumer liking attributes for the home use test (HUT) of this study are presented in Table 23. Meat source affected raw appearance, overall, flavor and texture liking. Raw appearance liking was higher ($P = 0.04$) for the regular ground beef treatments and lowest for the round and sirloin ground beef. For overall, flavor, and texture liking, the consumers rated chuck ground beef the highest ($P < 0.05$) and regular and round ground beef the lowest. However, Wilfong et al. (2016) found no difference in consumer palatability between 80/20 ground chuck, 80/20 Certified Angus Beef Ground Chuck and 80/20 ground beef.

Fat level affected the raw appearance, cooked appearance and texture liking; however, did not affect overall or flavor liking. Consumers preferred ($P < 0.05$) the 10% lipid ground beef over the 20% lipid level ground beef for raw and cooked appearance and texture liking. This finding contradicts Berry and Leddy (1984), Cross et al. (1980), Garzon et al. (2003), and Kregel et al. (1986) who reported higher fat content ground beef had increased tenderness when compare to lower-fat formulations. Trout et al. (1992) reported lower fat (5 and 10%) formulations had a darker red color, lower cooking losses, and denser cooked physical structure than the higher fat (15, 20, 25, and 30%) formulation patties. In the current study, the higher liking for raw and cooked appearance for the 10% fat patties may have been influenced by these aforementioned factors. Patties with 6.4 mm grind size were rated higher ($P < 0.05$) than the bowl-chop method for overall, flavor and texture liking. Form did not affect the consumer liking attributes disagreeing with Law et al. (1965) who reported that bulk ground beef was rated higher in consumer liking attributes than formed patties.

A grind by fat interaction was present for overall liking ($P = 0.01$). Consumers preferred the 6.4 mm grind size with 10% lipid over the 6.4 mm grind size with 20% lipid. Both fat levels of bowl-chop patties were rated similarly. The meat source by fat interaction was significant for texture liking ($P = 0.01$). Regular 20% lipid, ground, round 10% lipid, and sirloin 20% lipid beef patties were lowest in texture liking compared to chuck and sirloin ground beef patties with 10% lipid. Raw appearance, cooked appearance, overall and overall flavor liking for the meat source by fat interaction were not significant ($P < 0.05$). Texture liking also had a grind by form interaction ($P < 0.05$). Both the 6.4 mm treatments for patties and chubs were liked more than ($P < 0.05$) the bowl-chop patties and chubs.

These results show that consumers preferred the chuck and sirloin ground beef with 10% fat level and ground to 6.4 mm. Although little flavor differences were attributed to grinding method, consumers preferred the 6.4 mm grind size ground beef over the bowl-chop ground beef. Form did not affect consumer attributes. As the consumers used different preparation methods and could have been masked differences.

Word clouds were used to show qualitative descriptors for the positive and negative open-ended questions from each meat source (Figure 19 - Figure 22). Across sources, consumers used similar wordings to describe what they liked and disliked. The most common words associated with liking were flavor, good, taste, juicy, and texture. The most common words for disliking were fatty, dry, chewy, gristly, greasy, texture, flavor, tough, and bland. There were a few differences between the different word clouds for meat source. More people commented on the appearance of the regular meat source as compared to ground beef from the other sources. For positive liking, flavor, good, taste, and texture appeared the across meat sources. One negative attribute mentioned across all meat sources was fatty, but dry was also was mentioned for the round and sirloin ground beef. While dry was also used for chuck and regular ground beef, consumers used it less. Greasy was present in all the negative word clouds but varied in size between them. The regular, round, and sirloin ground beef identified chewy as an identifier indicating that consumers perceived the regular, round and sirloin ground beef as chewier than ground beef from the chuck source. Consumers used fewer negative words for chuck ground beef.

4.2.5. Descriptive Attributes versus Consumer Liking Attributes

In order to understand how the descriptive attributes impacted the HUT consumer liking attributes and treatments, a PLS biplot was used (Figure 23). Patty treatments were used in this analysis as the descriptive attribute evaluation were in the patty form. Sirloin, 10% fat, bowl-chopped patties clustered with consumer liking attributes along with cohesiveness of mass and bloody/serumy descriptive attributes. Chuck, 10% fat, bowl-chop patties were also clustered in the same quadrant with the consumer liking attributes and green hay-like. The sirloin, 20% fat and chuck, 20% fat patties from both grind methods; sirloin, 10% fat, 6.4 mm; and round, 20% fat, bowl-chop patties were closely associated with refrigerator stale, barnyard, burnt, overall sweet, and warmed-over descriptive attributes. The regular, 20% fat patties from both grind methods were clustered with cooked milk, heated oil and fat-like descriptive attributes. Round, 10% fat patties from both grind sizes were related to sour, liver-like, bitter, sour milk/sour dairy, roasted, and cardboardy descriptive attributes. Regular 10% fat, 6.4 mm; round, 20% fat, 6.4 mm; and regular ,10% fat, bowl-chop patties were clustered with brown, musty/earthy/humus and hardness descriptive attributes. Sirloin, 10% fat, bowl-chop patties were most closely associated with HUT consumer liking.

4.2.6. Central Location Test versus Home Use Test

A comparison of CLT to HUT liking scores is reported in Table 25. Central location test data was collected by Beavers (2018). In the home use test data, only the patty form was used in this analysis, as only the patty form was used in the CLT. Overall, consumers gave higher ($P < 0.0001$) liking scores to patties in the HUT compared to the CLT. Previous studies have shown that consumer panelists tend to give higher acceptability scores in HUT when compared to the CLT (Boutrolle et al., 2005; Boutrolle et al., 2007; Daillant-Spinnler and Issanchou, 1995; Hellemann et al., 1993; King et al., 2007; King et al., 2004; Kozlowska et al., 2003; Laird, 2015; Murphy et al., 1958). Boutrolle et al. (2007) suggested that HUT consumers are allowed to choose when they consume the products which could be during their real consumption time and this might improve overall satisfaction. Consumers also have prolonged contact time with the product that could potentially increase satisfaction (Boutrolle et al., 2007). Another hypothesis could be that in CLT, the conditions are standardized, and the sensation of a formal experiment could have placed the consumers in an analytical mindset to be more critical of the samples (Boutrolle et al., 2007).

A sensory method by grind method interaction was present for all of the consumer liking attributes. In the CLT, consumers liked the appearance of the 6.4 mm grind better ($P < 0.0001$) than the bowl-chopped patties; however, in the HUT, consumers liked the appearance of the bowl-chopped patties better than the 6.4 mm grind size. For overall liking, overall flavor and overall texture liking, the CLT consumers liked the 6.4 mm patties better, but there was no difference for the HUT in consumer liking between the 6.4 and bowl-chop patties.

Overall flavor and overall texture liking displayed a sensory method by meat source interaction. In the CLT, consumers liked the flavor of the chuck patties and did not differentiate between patties from the other sources. In the HUT, the consumers liked the chuck and sirloin meat sources, followed by regular and then round patties. However, Pound et al. (2000) found that the formal condition of a CLT might lead the subjects to be more critical and demanding towards the tested products, but in this study HUT consumers were more critical in overall flavor. Overall texture liking was similar comparisons for HUT and CLT patties as the chuck and sirloin patties were rated higher in texture liking than the patties made from regular and round. In the HUT, consumers rated the sirloin patties higher than chuck patties. Overall, the HUT consumers liked the flavor and texture of patties more than the CLT consumers.

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4.4. Figures and Tables

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

Attributes	Definition	Reference
Apricot	Fruity aromatics that can be described as specifically apricot.	Sun sweet dried apricot = 7.5 (F)
Asparagus	The slightly brown, slightly earthy green aromatics associated with cooked green asparagus	Asparagus water =6.5 (F); 7.5 (A)
Animal hair	The aromatics perceived when raw wool is saturate with water.	Caproic acid = 12.0
Barnyard	Combination of pungent, slightly sour, hay-like aromatics, associated with farm animals and the inside of a horn.	White pepper in water = 4.0 (F); 4.5 (A) Tincture of civet = 6.0 (A)
Beef identity	Amount of beef flavor identity in the sample.	Swanson's beef broth = 5.0 80% lean ground beef = 7.0 Beef brisket = 11.0
Beet	A dark damp-musty-earthy note associated.	Food Club sliced beets juice with 1-part juice with canned red beets to 2 parts water = 4.0 (F)
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 = 5.5 Beef brisket = 6.0
Brown/roasted	A round, full aromatic generally associated with beef suet that has been broiled.	Beef suet = 8.0 80% lean ground beef = 10.0
Buttery	Sweet, dairy-like aromatic associated with natural butter	Land O'Lakes unsalted butter = 7.0
Burnt	The sharp/acrid flavor note associate with over-roasted beef muscle, something over-baked or excessively browned in oil.	Alf's red wheat Puffs = 5.0
Chemical	The aromatics associated with garden hose, hot Teflon pan, plastic packaging and petroleum-based product such as charcoal	Zip-Loc sandwich bag =13.0 Clorox in water = 6.5

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

Attributes	Definition	Reference
Chocolate/ Cocoa	The aromatics associated with cocoa beans and powdered cocoa and chocolate bars. Brown, sweet, dusty, often bitter aromatics.	Hershey's cocoa powder in water = 3.0 Hershey's chocolate kiss = 8.5
Cooked milk	A combination of sweet, brown flavor notes and aromatics associated with heated milk.	Mini Babybel original Swiss cheese = 2.5 Dillon's whole milk = 4.5
Cumin	The aromatics commonly associated with cumin and characterized as dry, pungent, woody a slightly floral	McCormick ground cumin = 7.0 (F); 10.0 (A)
Dairy	The aromatics associated with products made from cow's milk, such as cream, milk, sour cream or butter milk.	Dillon's reduced fat milk (2%) = 8.0
Fat-like	The aromatics associated with cooked animal fat.	Hillshire farms Lit'l beef smokies = 7.0 Beef suet = 12.0
Floral	Sweet light, slightly perfume impression associated with flowers	Welch's white grape juice in water = 5.0 Geraniol = 7.5 (A)
Green	Sharp, slightly pungent aromatics associated with green/plant/ vegetable matters such as parsley, spinach, pea pod, fresh cut grass, etc.	Hexanal in propylene glycol (5,000 ppm) = 6.5 (A) Fresh parsley water = 9.0
Green-hay like	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley and tea leaves.	Dry parsley in medium snifter = 5.0 (A) Dry parsley in ~30-mL cup = 6.0
Heated Oil	The aromatics associated with oil heated to a high temperature.	Wesson Oil, microwaved 3 min = 7.0 Lay's Potato Chips = 4.0 (A)
Leather	Musty, old leather (like old book bindings).	2,3,4-Trimethoxybenzaldehyde= 3.0(A)
Liver-like	The aromatics associated with cooked organ meat/liver.	Beef liver = 7.5 Oscar Mayer Braunschweiger liver sausage = 10.0

Table 15 Continued. Definition and reference standards for meat descriptive flavor aromatics and basic taste where 0 = none; 15 = extremely intense adapted from Adhikari et al. (2011).

Attributes	Definition	Reference
Medicinal	A clean sterile aromatic characteristic of antiseptic like products such as Band-Aids, alcohol and iodine	Band-Aid = 6.0 (A)
Metallic	The impression of slightly oxidized metal, such as iron, copper and silver spoons.	0.10% potassium chloride solution = 1.5 USDA choice strip steak = 4.0 Dole canned pineapple juice = 6.0
Musty/earthy/ Humus	Musty, sweet, decaying vegetation.	Sliced button mushrooms = 3.0 (F & A) 1000 ppm of 2,6-Dimethcycyclohexanol in propylene glycol = 9.0 (A)
Overall sweet	A combination of sweet taste and sweet aromatics. The aromatics associated with the impression of sweet.	Post-shredded wheat spoon size=1.5 (F) Hillshire farms Lit'l beef smokies = 3.0
Petroleum-like	A specific chemical aromatic associated with crude oil and it's refined products that have heavy oil characteristics	Vaseline petroleum jelly = 3.0 (A)
Rancid	The aromatics commonly associated with oxidized fat and oils. These aromatics may include cardboard, painty, varnish and fishy	Microwaved Wesson vegetable oil (3 min) = 7.0 Microwaved Wesson vegetable oil (5 min) = 9.0
Refrigerator stale	Aromatics associated with products left in refrigerator for an extended period of time and absorbing a combination of odors (lack of freshness/flat)	80% lean ground beef, stored overnight and served at room temperature = 4.5 (F); 5.5 (A)
Salty	The fundamental taste factor of which sodium chloride is typical.	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5

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

Attributes	Definition	Reference
Smoky Charcoal	An aromatic associated with meat juices and fat drippings on hot coats which can be acrid, sour, burned, etc.	Wright's Natural Hickory seasonings in water = 9.0 (A)
Smoky wood	Dry, dusty aromatic reminiscent of burning wood	Wright's Natural Hickory seasoning in water = 7.5 (A)
Soapy	An aromatic commonly found in unscented hand soap	Ivory bar soap in water = 6.5 (A)
Sour aromatics	The aromatics associated with sour substances.	Dillon's buttermilk = 5.0
Sour milk/ Sour dairy	Sour, fermented aromatics associated with dairy products such as buttermilk and sour cream.	Laughing cow light Swiss cheese= 7.0 Dillon's buttermilk = 9.0
Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Spoiled-putrid	The presence of inappropriate aromatics and flavors that is commonly associated with the products. It is a foul taste and/or smell that indicates the product is starting to decay and putrefy.	Dimethyl disulfide in propylene glycol 10,000 ppm) = 12.0 (aroma)
Sweet	The fundamental taste factor associated with sucrose.	2.0% sucrose solution = 2.0
Umami	Flat, salty, somewhat brothy. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% accent flavor enhancer solution = 7.5
Warmed-over	Perception of a product that has been previously cooked and reheated.	80% lean ground beef (reheated) = 6.0

Table 16. Definition and reference standards for meat descriptive texture attributes and their intensities where 0 = none, 15 = extremely intense adapted from Meilgaard et al. (2016).

Attributes	Definition	Reference
Cohesiveness of Mass	The degree to which chewed sample holds (at 10 – 15 chews) together in a mass.	Licorice = 0.0 Carrots = 2.0 Mushrooms = 4.0 Frankfurter = 7.0 American Process Cheese = 9.0 Soft Brownie = 13.0; Pillsbury Biscuit dough = 15.0
Hardness	The force to attain a given deformation, such as: force to compress with the molars; force to compress between tongue and palate; force to bite through with incisors.	Cream Cheese = 1.0 Egg White = 2.5 Yellow American Cheese = 4.5 Olives = 6.0 Hebrew National Frankfurter = 7.0 Planters Peanut = 9.5 Life Savers = 14.5
Initial Juiciness	The amount of perceived juice that is released from the product during the initial 2 – 3 chews.	Carrot = 8.5 Mushroom = 10.0 Cucumber = 12.0 Apple = 13.5 Watermelon = 15.0
Particle Size	The degree to how large or small the particle is.	Small pearly tapioca = 4.0 Boba tea tapioca = 8.0
Springiness	The degree to which sample returns to original shape or the rate with which sample returns to original shape.	Cream Cheese = 0.0 Frankfurter = 5.0 Marshmallow = 9.5 Gelatin dessert = 15.0

Table 17. Flavor and basic tastes descriptive attributes least squares means for ground beef patties segmented by main effects of meat source, fat percentage, and final grind size/method where 0 = none and 15 = extremely intense as presented in Beavers (2016).

Attribute	Fat-like	Metallic	Liver-like	Bitter	Sour	Sweet	Overall Sweet	Buttery	Smoky Charcoal
Source[c]	0.02	0.67	0.04	0.01	<0.0001	0.39	0.04	0.28	0.69
Regular	3.7[b]	2.5	0.2[a]	2.1[a]	2.4[a]	1.8	1.4[ab]	1	0.8
Round	3.3[a]	2.4	0.6[b]	2.4[b]	2.8[b]	1.8	1.2[a]	0.9	0.7
Sirloin	3.4[ab]	2.3	0.4[ab]	2.3[b]	2.4[a]	1.8	1.3[ab]	0.8	0.6
Chuck	3.6[b]	2.4	0.4[ab]	2.2[ab]	2.5[a]	1.9	1.5[b]	1	0.6
Fat Percentage[c]	<0.0001	<0.0001	<0.0001	0.002	<0.0001	0.005	0.002	<0.0001	0.01
10	3.1[a]	2.5[b]	0.6[b]	2.3[b]	2.7[b]	1.8[a]	1.2[a]	0.6[a]	0.5[a]
20	3.9[b]	2.2[a]	0.2[a]	2.2[a]	2.3[a]	1.9[b]	1.5[b]	1.2[b]	0.8[b]
Final Grind Method[c]	0.60	0.56	0.81	0.91	0.98	0.41	0.73	0.71	0.93
6.4 mm grind	3.5	2.4	0.4	2.3	2.5	1.8	1.4	0.9	0.7
Bowl-chop	3.5	2.4	0.4	2.2	2.5	1.8	1.3	0.9	0.7
RMSE[d]	0.52	0.43	0.50	0.27	0.28	0.26	0.32	0.58	0.64

[ab] Mean values within a column and interaction followed by the same letter are not significantly different ($P < 0.05$)
[c] P-value from Analysis of Variance table.
[d] RMSE = Root Mean Square Error

Table 17 Continued. Flavor and basic tastes descriptive attributes least squares means for ground beef patties segmented by main effects of meat source, fat percentage, and final grind size/method where 0 = none and 15 = extremely intense as presented in Beavers (2016).

Attribute	Refrigerator Stale	Sour Milk /Sour Dairy	Card-boardy	Warmed Over	Cooked Milk	Heated Oil	Medicinal	Musty/ Earthy	Petroleum-Like
Source[c]	0.41	0.005	0.04	0.16	0.35	0.71	0.16	0.19	0.15
Regular	0.1	0.2[a]	2.2[a]	0.5	0.3	0.8	0.1	0.5	0.6
Round	0.2	0.5[b]	2.3[ab]	0.4	0.2	0.8	0.1	0.8	0.3
Sirloin	0.2	0.1[a]	2.6[b]	0.7	0.3	0.8	0.1	0.9	0.4
Chuck	0.1	0.3[a]	2.3[a]	0.5	0.2	0.9	0.0	0.7	0.4
Fat Percentage[c]	0.64	0.01	0.0002	0.93	0.13	<0.0001	0.42	0.08	0.09
10	0.2	0.3[b]	2.5[b]	0.5	0.2	0.4[a]	0.1	0.8	0.3
20	0.2	0.2[a]	2.2[a]	0.5	0.2	1.2[b]	0.1	0.6	0.5
Final Grind Method[c]	0.10	0.61	0.43	0.07	0.58	0.75	0.04	0.15	0.64
6.4 mm grind	0.1	0.3	2.3	0.4	0.2	0.8	0.1[a]	0.6	0.4
Bowl-chop	0.2	0.2	2.4	0.6	0.2	0.8	0.2[b]	0.8	0.4
RMSE[d]	0.30	0.37	0.57	0.59	0.24	0.53	0.24	0.65	0.48

[ab] Mean values within a column and interaction followed by the same letter are not significantly different ($P < 0.05$)
[c] P-value from Analysis of Variance table.
[d] RMSE = Root Mean Square Error

Table 18. Texture descriptive attributes least squares means for ground beef patties segmented by main effects of meat source, fat percentage, and final grind size/method where 0 = none and 15 = extremely intense as presented in Beavers (2016).

Attribute	Cohesiveness of Mass	Hardness	Juiciness	Springiness
Source[c]	0.32	0.007	0.16	0.009
Regular	7.5	5.7[b]	10.7	5.6[b]
Round	7.3	5.6[b]	10.7	5.3[a]
Sirloin	7.4	5.5[ab]	10.5	5.2[a]
Chuck	7.4	5.3[a]	10.8	5.3[a]
Fat Percentage[c]	0.11	0.49	0.0001	0.09
10	7.4	5.6	10.5[a]	5.3
20	7.3	5.5	10.8[b]	5.4
Final Grind Method[c]	0.37	<0.0001	0.07	<0.0001
6.4 mm grind	7.4	5.3[a]	10.7	5.2[a]
Bowl-chop	7.4	5.7[b]	10.6	5.5[b]
RMSE[d]	0.36	0.52	0.56	0.49

[ab] Mean values within a column and interaction followed by the same letter are not significantly different (P < 0.05)
[c] P-value from Analysis of Variance table.
[d] RMSE = Root Mean Square Error

Table 19. Flavor descriptive attributes least squares means for ground beef patties segmented by interactions for burnt, green, and overall sweet where 0 = none and 15 = extremely intense as presented in Beavers (2016).

Treatment	Burnt	Green
Fat Percentage[c]	-	0.38
10	-	0.1
20	-	0.1
Source by Grind Interaction[e]	0.03	0.02
Regular, 6.4 mm	0.3[ab]	0.1[ab]
Regular, bowl-chop	0.3[a]	0.1[a]
Round, 6.4 mm	0.6[b]	0.1[a]
Round, bowl-chop	0.2[a]	0.2[b]
Sirloin, 6.4 mm	0.3[ab]	0.0[a]
Sirloin, bowl-chop	0.4[ab]	0.1[a]
Chuck, 6.4 mm	0.2[a]	0.1[ab]
Chuck, bowl-chop	0.4[ab]	0.0[a]
Source by Fat Interaction[e]	0.03	-
Regular, 10% fat	0.2[a]	-
Regular, 20% fat	0.4[abc]	-
Round, 10% fat	0.5[bc]	-
Round, 20% fat	0.3[abc]	-
Sirloin, 10% fat	0.2[a]	-
Sirloin, 20% fat	0.6[c]	-
Chuck, 10% fat	0.3[abc]	-
Chuck, 20% fat	0.3[abc]	-
RMSE[f]	0.49	0.20

[abcd] Mean values within a column and interaction followed by the same letter are not significantly different (*P* > 0.05).
[e] P-value from Analysis of Variance table.
[f] RMSE = Root Mean Square Error.

Table 20. Least squares means for beef identity, brown, roasted, bloody/serumy, umami, salty, and particle size flavor, basic taste, and texture descriptive attribute interactions where 0 = none and 15 = extremely intense as presented in Beavers (2016).

Treatment	Beef Identity	Brown	Roasted	Bloody/ Serumy	Umami	Salty	Particle Size
Final Grind Size/Method[e]	0.27	0.25	0.29	0.81	0.0005	0.18	0.0004
6.4mm grind	10.0	10.2	9.1	2.0	4.2[b]	2.2	3.7[b]
Bowl-chop	9.9	10.1	9.0	2.0	4.0[a]	2.2	3.5[a]
Source by Fat Interaction[e]	<0.0001	0.02	<0.0001	0.01	0.03	0.006	0.02
Regular, 10% fat	10.1[bc]	10.2[bc]	9.1[bc]	2.3[c]	3.9[a]	2.3[b]	3.6[ab]
Regular, 20% fat	9.6[a]	10.2[bc]	8.7[ab]	2.4[c]	3.8[a]	2.1[a]	4.0[c]
Round, 10% fat	9.9[ab]	10.2[bc]	9.2[cd]	1.7[a]	4.0[ab]	2.3[b]	3.4[a]
Round, 20% fat	10.0[bc]	10.1[bc]	9.1[cd]	1.7[a]	4.4[c]	2.2[b]	3.7[b]
Sirloin, 10% fat	9.5[a]	9.6[a]	8.5[a]	2.3[c]	3.7[a]	2.1[a]	3.6[ab]
Sirloin, 20% fat	10.3[c]	10.5[c]	9.5[d]	1.4[a]	4.3[c]	2.3[b]	3.5[ab]
Chuck, 10% fat	10.0[bc]	10.0[ab]	9.0[bc]	2.2[bc]	4.2[bc]	2.2[ab]	3.5[ab]
Chuck, 20% fat	10.2[bc]	10.1[bc]	9.1[cd]	1.8[ab]	4.5[c]	2.3[b]	3.5[ab]
RMSE[f]	0.57	0.66	0.57	0.71	0.48	0.20	0.32

[abcd]Mean values within a column and interaction followed by the same letter are not significantly different ($P > 0.05$).

Table 21. Demographic frequencies for home use beef consumers (n = 218) across four cities.

Question	Number of Respondents	Percentage of Respondents
Sex		
Male	86	40.0
Female	129	60.0
Age		
20 years or younger	3	1.4
21 – 25 years	24	11.1
26 – 35 years	62	28.7
36 – 45 years	39	18.1
46 – 55 years	49	22.7
56 – 65 years	37	17.1
66 years and older	2	1.0
Ethnicity		
African-American	14	6.5
Asian/Pacific Islanders	16	7.4
Caucasian (non-Hispanic)	168	78.1
Latino or Hispanic	9	4.2
Native American	2	1.0
Other	6	2.8
Household income		
Below $25,000	35	16.3
$25,001 - $49,999	54	25.1
$50,000 - $74,999	61	28.4
$75,000 - $99,999	35	16.3
$100,000 or more	30	14.0
Household size including yourself		
1	31	14.4
2	92	42.6
3	49	22.7
4	28	13.0
5	8	3.7
6 or more	8	3.7
Employment level		
Not employed	30	13.9
Part-time	37	17.1
Full-time	149	69.0

Table 21 Continued. Demographic frequencies for home use beef consumers (n = 218) across four cities.

Question	Number of Respondents		Percentage of Respondents	
Proteins consumed at home or at a restaurant (away from home)				
At Home	**Do not consume**	**Consume**	**Do not consume**	**Consume**
Chicken	6	209	2.8	97.2
Beef (steaks)	38	176	17.8	82.2
Ground Beef	10	175	5.4	94.6
Pork	23	162	12.4	87.6
Fish	31	154	16.8	83.2
Lamb	144	41	77.8	22.2
Egg	8	177	4.3	95.7
Soy Based Products	117	68	63.2	36.8
Away from Home /Restaurant	**Do not consume**	**Consume**	**Do not consume**	**Consume**
Chicken	10	204	15.4	84.6
Beef (steaks)	33	181	15.4	84.6
Ground Beef	18	167	9.7	90.3
Pork	41	144	22.2	77.8
Fish	21	164	11.3	88.7
Lamb	123	62	66.5	33.5
Eggs	21	164	11.3	88.7
Soy Based Products	123	62	66.5	33.5
Weekly consumption of protein				
Beef (steaks)				
0	12		5.7	
1 – 2	162		77.1	
3 – 4	30		14.3	
5 – 6	5		2.4	
7 or more	1		0.5	
Ground Beef				
0	3		1.4	
1 – 2	146		69.2	
3 – 4	53		25.1	
5 – 6	8		3.8	
7 or more	1		0.5	
Pork				
0	20		9.8	
1 – 2	167		81.5	
3 – 4	17		8.3	
5 – 6	1		0.5	
7 or more	0		0.0	
Lamb				
0	168		99.4	
1 – 2	1		0.6	
3 – 4	0		0.0	
5 – 6	0		0.0	
7 or more	0		0.0	

Table 21 Continued. Demographic frequencies for home use beef consumers (n = 218) across four cities.

Question	Number of Respondents	Percentage of Respondents
Chicken		
0	2	0.9
1 – 2	86	40.6
3 – 4	94	44.3
5 – 6	27	12.7
7 or more	3	1.4
Fish		
0	34	16.6
1 – 2	143	69.8
3 – 4	22	10.7
5 – 6	5	2.4
7 or more	1	0.5
Soy Based Products		
0	118	62.4
1 – 2	59	31.22
3 – 4	12	6.4
5 – 6	0	0.0
7 or more	0	0.0

What cooking method do you prefer to use when cooking ground beef?

	Do not use	**Use**	**Do not use**	**Use**
Pan-frying or skillet on the Stove		36	178	16.883.2
Grilling outside	52	162	24.3	75.7
Oven baking	140	74	65.4	34.6
Electric appliance (George Forman Grill or other Electric grill)	176	38	82.2	17.8
Stir fry	144	85	62.8	37.1
Oven broiling	179	35	83.6	16.4
Microwave	199	15	93.0	7.0

Degree of doneness preference for ground beef

Rare	2	0.9
Medium Rare	42	17.9
Medium	64	27.4
Medium Well	73	31.2
Well	37	15.8
Very Well	16	6.8

Table 21 Continued. Demographic frequencies for home use beef consumers (n = 218) across four cities.

Question	Number of Respondents		Percentage of Respondents	
When purchasing ground beef, what do you typically tend to buy at the retail store?				
	Do not	**Purchase**	**Do not**	**Purchase**
Grass Fed	174	39	81.7	18.3
Dry Aged	211	2	99.1	0.9
Organic	190	23	89.2	10.8
Traditional beef at the retail store	43	170	20.2	79.8
What percentage of fat do you normally buy when purchasing ground beef?				
	Do not	**Purchase**	**Do not**	**Purchase**
4%	190	22	89.6	10.4
7%	164	48	77.4	22.6
10%	156	56	73.6	26.4
15%	149	63	70.3	28.7
20%	175	37	82.6	17.4
27%	209	3	98.6	1.4
What type of ground beef do you typically buy at the retail store?				
	Do not	**Purchase**	**Do not**	**Purchase**
Ground Chuck	150	63	70.4	29.6
Ground Round	194	19	91.1	8.9
Ground Sirloin	180	33	84.5	15.5
Ground Beef	64	149	30.1	69.9
What flavor or types of cuisines do you like?				
	Do not eat	**Eat**	**Do not eat**	**Eat**
American	11	204	5.2	94.9
Chinese	41	174	19.1	80.9
French	127	88	59.1	40.9
Barbeque	17	198	7.9	92.1
Greek	117	98	54.4	45.6
Thai	98	117	45.6	54.4
Mexican/Spanish	29	186	13.5	86.5
Japanese	96	119	44.7	55.3
Lebanese	167	48	77.7	22.3
Indian	127	88	59.1	40.9
Italian	35	180	16.28	83.74

Table 22. Percentage of in-home consumer responses to preparation information for ground beef patties and chubs.

	Total	Chub	Patty
How did you thaw the meat?			
Placed in refrigerator day before	68.9	68.9	68.8
Placed in refrigerator same day	9.1	9.0	9.2
In microwave	12.0	11.2	12.9
At room temperature	9.8	9.9	9.7
Under cold water	3.1	3.4	2.7
Under hot water	3.0	3.2	2.8
Cooked frozen	2.2	1.9	2.4
Which of these, if any, did you do to the meat before cooking?			
Break apart into small pieces	28.2	41.4	15.1
Form into balls	5.8	7.9	3.7
Form into patties	33.4	32.2	34.5
None of these	26.1	14.4	37.7
Other	9.0	6.8	11.3
What was added to the beef, pork or chicken, if anything, as it was prepared or cooked?			
Salt	65.7	64.6	66.8
Pepper	61.0	59.2	62.7
Spices/herbs, such as garlic, oregano	42.0	48.3	41.8
Tenderizer such as Adolph's	1.6	2.1	1.2
Marinade	5.0	4.0	6.0
Flour or crumbs to top and/or bottom	3.7	5.1	2.3
Sauces, such as soy, BBQ, etc.	23.6	16.1	8.7
Other	23.6	26.3	21.0
How did you cook the meat?			
Outdoor grill	18.1	10.6	25.4
Broil	2.0	1.7	2.3
Indoor grill	6.8	5.1	8.5
Oven roast uncovered	7.3	7.4	7.3
Pan broil	7.1	7.1	7.1
Pan fry/sauté	52.9	60.8	45.0
Stir fry	1.4	1.6	1.2
Braise	0.1	0.0	0.3
Simmer and stew	4.0	5.8	2.2
Deep fry	0.3	0.0	0.5
Other	3.3	4.3	2.3
What was the degree of doneness for the meat when you ate it?			
Very rare	0.1	0.0	0.1
Rare	1.5	0.7	2.3
Medium rare	9.3	7.4	11.2
Medium	27.8	21.9	33.7
Well done	53.5	61.3	45.6
Very well	9.4	9.6	9.2

Table 22 Continued. Percentage of in-home consumer responses to preparation information for ground beef patties and chubs.

	Total	Chub	Patty
Was this meat the main course of the plate, was it combined with other ingredients as the main course or was it a side dish?			
Main course on plate	64.1	54.3	73.8
Combined with other ingredients	31.8	42.3	22.4
Side dish	4.1	4.4	3.8
Which of these did you add to the meal at the table before you ate?			
Nothing: ate it plain	26.7	27.0	26.3
Nothing: it was cooked in sauce	10.0	15.0	5.1
Salt	13.1	12.0	14.2
Pepper	10.8	9.9	11.7
Other dry ingredients	4.4	5.5	3.3
Ketchup	23.9	15.6	32.1
Other sauces (soy or BBQ sauce, A-1, etc.)	19.6	16.6	23.6
Other	29.3	29.5	29.0

Table 23. Home use consumer liking attributes for ground beef patties where 1 = extremely dislike and 9 = extremely like.

Effect	Raw Appearance Liking	Cooked Appearance Liking	Overall Liking	Flavor Liking	Texture Liking
Meat Source[c]	0.04	0.05	0.03	0.007	0.01
Regular	6.2[b]	6.7	6.2[a]	6.4[a]	5.9[a]
Round	5.8[a]	6.5	6.2[a]	6.4[a]	5.9[a]
Sirloin	5.9[a]	6.8	6.4[ab]	6.6[ab]	6.1[ab]
Chuck	6.0[ab]	6.8	6.5[b]	6.8[b]	6.3[b]
Fat Level, %[c]	<0.0001	0.0008	0.09	0.73	0.03
10	6.2[b]	6.8[b]	6.4	6.6	6.2[b]
20	5.8[a]	6.6[a]	6.3	6.5	6.0[a]
Grind[c]	0.12	0.27	<0.0001	0.03	<0.0001
6.4 mm	5.9	6.7	6.5[b]	6.6[b]	6.3[b]
Bowl	6.0	6.6	6.2[a]	6.5[a]	5.8[a]
Form[c]	0.52	0.66	0.88	0.33	0.98
Patty	6.0	6.7	6.4	6.5	6.1
Chub	5.9	6.7	6.4	5.6	6.1
Grind by Fat Interaction[c]			0.01		
6.4 mm, 10% fat			6.8[b]		
6.4 mm, 20% fat			6.5[a]		
Bowl-chop, 10% fat			6.4[ab]		
Bowl-chop, 20% fat			6.5[ab]		
Meat Source by Fat Interaction[c]					0.01
Regular, 10% fat					6.2[ab]
Regular, 20% fat					5.6[a]
Round, 10% fat					5.8[a]
Round, 20% fat					6.0[ab]
Sirloin, 10% fat					6.4[b]
Sirloin, 20% fat					5.9[a]
Chuck, 10% fat					6.3[b]
Chuck, 20% fat					6.2[ab]
Grind by Form Interaction[c]					0.02
6.4 mm, Patty					6.2[b]
6.4 mm, Chub					6.4[b]
Bowl-chop, Patty					5.9[a]
Bowl-chop, Chub					5.7[a]
Root Mean Square Error	1.85	1.56	1.71	1.69	1.94

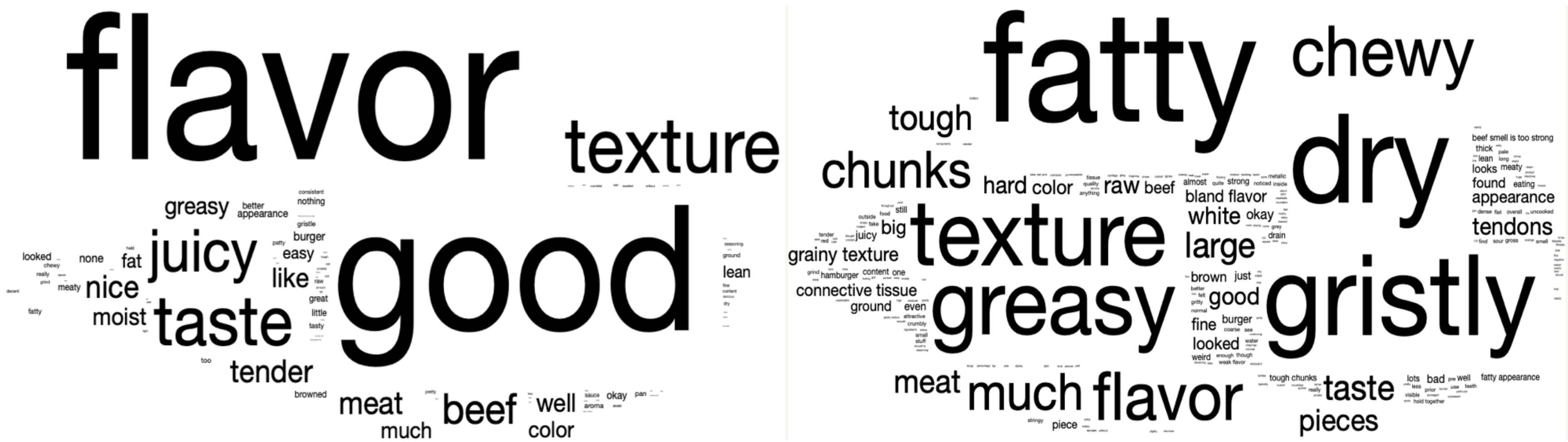
[ab]Mean values within a column and interaction followed by the same letter are not significantly different ($P < 0.05$).
[c] P-value from Analysis of Variance table.

(a) (b)

Figure 19. Home use consumer qualitative liking (a) and dislike (b) descriptors for chuck meat source word clouds.

(a) (b)

Figure 20. Home use consumer qualitative liking (a) and dislike (b) descriptors for regular meat source word clouds.



(a) (b)

Figure 21. Home use consumer qualitative liking (a) and dislike (b) descriptors for round meat source word clouds.

(a) (b)

Figure 22.Home use consumer qualitative liking (a) and dislike (b) descriptors for sirloin meat source word clouds.

Figure 23. Partial least squares regression biplot for home use consumer liking attributes (•), treatments (•), and descriptive flavor and texture attributes (•) where X is accounting for 31.1% of Y and Y accounting for 50.0% of X.

Table 24. Central location test (CLT) versus home use test (HUT) consumer liking attributes least squares means for ground beef patties where 1 = extremely dislike and 9 = extremely like.

	Cooked Appearance	Overall Liking	Overall Flavor	Overall Texture
Sensory[f]	<0.0001	<0.0001	<0.0001	<0.0001
CLT	5.7[a]	5.7[a]	5.8[a]	5.6[a]
HUT	7.1[b]	6.8[b]	6.9[b]	6.3[b]
Sensory by Grind[f]	<0.0001	<0.0001	<0.0001	<0.0001
CLT by 6.4 mm	5.9[b]	5.9[b]	6.1[b]	5.9[b]
HUT by 6.4 mm	7.0[c]	6.7[c]	6.9[c]	6.2[c]
CLT by Bowl-chop	5.5[a]	5.4[a]	5.6[a]	5.2[a]
HUT by Bowl-chop	7.2[d]	6.8[c]	6.9[c]	6.4[c]
Sensory by Source[f]			<0.0001	0.0002
CLT by Regular			5.7[a]	5.4[a]
HUT by Regular			6.7[d]	6.2[cd]
CLT by Round			5.8[a]	5.5[a]
HUT by Round			6.4[c]	6.0[c]
CLT by Sirloin			5.8[a]	5.6[b]
HUT by Sirloin			7.3[e]	6.7[e]
CLT by Chuck			6.0[b]	5.7[b]
HUT by Chuck			7.2[e]	6.3[d]
RMSE[g]	1.66	1.72	1.68	1.88

[abcde] Mean values within a column and interaction followed by the same letter are not significantly different ($P < 0.05$).
[f] P-value from Analysis of Variance table.
[g]RMSE = Root Meat Square Error.

5. RELATIONSHIPS BETWEEN LOIN COLOR, CUT THICKNESS, COOKING METHOD, WATER-HOLDING CAPACITY AND TENDERNESS FOR PORK COOKED TO 62.8°C

5.1. Materials and Methods

5.1.1. Sample Selection

Boneless and bone-in pork loins (IMPS 413 and 410, respectively) were purchased commercially on three different selection trips from Smithfield Foods in Sioux Falls, SD. The loins were selected to represent the National Pork Board subjective lean color scores of 2 and 4 (National Pork Board, 2011). The Smithfield Foods plant was selected as pigs from varying genetics are harvested and processed. It was determined by Smithfield personnel that selection at this plant would be most representative of pigs harvested in the US pork industry. Color score was determined by trained color evaluators (n = 2) using National Pork Board color cards based on color in the M. *Longissimus dorsi* at the blade end of the loin. pH was also determined. Vacuum-packaged loins were commercially transported to Texas A&M University in College Station, TX and aged 14 to 19 d. Loins were weighed in the original vacuum-package, removed from the package, dried slightly with a paper towel, reweighed, and percentage purge was calculated. Package purge was not obtained for bone-in loins.

For the bone-in loins, the tenderloin (IMPS 415) was removed first, denuded, and randomly assigned to treatments. The sirloin and blade end were removed to leave no more than eight ribs present. The bone-in ribeye chops (IMPS 1410B) were cut using a band saw (400, Marel, Norwich, England) to 1.3, 1.9 or 2.5 cm thick. Twelve chops were cut from each loin, assuring that a portion of the rib bone was present in each chop and randomly assigned to cooking treatment.

The blade end of the boneless loins was removed first and set aside until there were three blade ends available. Once three blade ends were available, blade chops (IMPS 1413.4) were cut to 1.3, 1.9 or 2.5 cm, and randomly assigned to cooking treatments. Three blade ends within color score were used to obtain 12 chops or 1 chop per treatment. After the blade and sirloin ends were removed, the boneless center-cut chops (IMPS 1413.1) were cu tot 1.3, 1.9 or 2.5 cm, and randomly assigned to cooking treatments. Twelve boneless chops were cut from each loin.

From the boneless loins defined above, boneless loin roasts (0.9 and 1.8 kg roasts) were cut from loins with color score 4. Whole boneless center-cut loin roasts were cut into 2.7 kg roasts from loins with color score 2. Each whole boneless center-cut loin was randomly assigned to treatment.

5.1.2. Water-holding capacity, pH, and color

Drip loss (%), a measure of water-holding capacity, was determined according to a modified method of Kauffman (1986). From raw chops and roasts, two 10 g sample cubes were removed from the posterior end of each chop or roast. Each 10 g sample was weighed and suspended by a paper clip and placed in a plastic bag (B01062, Nasco, Fort Atkinson, WI) sealed to assure that no evaporative water loss occurred. After storage for 24 hours at 4°C, the samples were reweighed and drip loss (%) was calculated based on beginning sample weight ((raw weight – drip weight) / raw weight * 100). Drip loss was used as an indication of water-holding capacity. Percent purge was obtained from the boneless loins by weighing the entire package, weighing the loin, and then weighing the package. Purge was not collected from the bone-in loins because the bone-in loins were not individually packaged.

Initial loins, chops and roasts were evaluated for raw objective color using a Minolta Chromameter (Spectro-photocolorimeter Minolta CR-400; Konica Minolta Sensing, Inc., Osaka, Japan) calibrated daily using a white tile (Y = 94.3, x = 0.3130, y = 0.3199). Cooked color was also evaluated on the chops and roasts. Three L*, a*, and b* color space values were recorded from each loin, chop or roast. The initial loin color values were obtained in the plant on the surface of the boneless loin and the M. *Longissimus dorsi* at the blade end of the bone-in loin. For the raw samples, the chop or roast was allowed to bloom for 20 minutes and color measurements were taken in triplicates on different sites on the chop surface or the loin surface of the roasts. For the cooked samples, the chop/roasts were cut in half and color measurements were taken from the inside of the chop/roast to observe the internal color when cooked to 62.8°C.

Duplicate pH measurements for the initial loin, chop, and roast were taken with a pH meter (HI98162, Hanna Instruments, Woonsocket, RI). The pH probe was calibrated daily using pH 4 and 7 standard solutions. The initial loin pH values were taken at the anterior and posterior ends of the boneless and bone-in loins. The chop/roast pH values were taken in duplicate from each chop or roast.

5.1.3. Cooking Methods

Four different cooking treatments were used for the bone-in chops, boneless chops, and blade chops within Chop thickness. Each chop was either cooked by an outside gas grill, oven-baked, pan-sautéed, or pan-fried and each roast including the tenderloins were cooked by the outside gas grill and the oven baking methods. The outside gas grill (Performance 4-Burner Liquid Propane Gas Grill with 1-side Burner, Char-Broil LLC. Columbus, GA) was preheated to ensure a grill temperature of 176.7°C. The chops and roasts were cooked with the lid closed and the lid was only opened to flip samples or to put new ones on the grill. The grill maintained a temperature of 176.7°C throughout the cooking process.

The chops and roasts were baked in a gas oven (GE Profile Freestanding Self Cleaning Gas Range, General Electric, Rapid City, SD) at 176.7°C on a stainless-steel pan (26639 Petite Roast Pan with Rack, Chicago Metallic, Chicago, IL). Pans were arranged so that air circulation was not blocked in the oven.

Chops were pan-sautéed and pan-fried in an enamel covered cast iron flat pan (EC11S43 Enameled Cast Iron Skillet, 11-inch, Lodge, South Pittsburg, TN) on a gas stove top (GE Profile Freestanding Self Cleaning Gas Range, General Electric, Rapid City, SD). For stove top cooking applications, a copper plate (10” Large Copper Heat Diffuser/defroster plate, Bella Copper, Ventura, CA) was inserted between the pan and the heat source to assure even distribution of heat across the pan surface. The pan surface temperature was 176.7°C prior to cooking for pan-sauté and pan fry. For pan-sauté and pan fry, 2 tablespoons of canola oil were added to the pre-heated pan. For the pan-sauté, pork chops were dusted with flour, weighed before and after flouring to account for the amount of pickup, and placed in the pre-heated pan and oil. This resulted in 24 treatments for each cut including the bone-in ribeye, boneless loin chops, and blade chops.

Beginning raw weight, pickup weight (if applicable), cooked weight, cook yield, total cook time, and final internal cook temperature were recorded. Surface temperature of each cooking method was monitored by an infrared reader (IRT-2, Thermoworks, Salt Lake City, UT). Internal temperature was monitored for each chop by inserting an iron-constantan thermocouple (Omega Engineering, Stanford, CT) into the geometric center of the chop or roast. For each cooking method, chops and roasts were cooked to 31.4°C flipped and completed cooking until the final internal temperature of 62.8°C was reached.

5.1.4. Warner-Bratzler Shear Force (WBSF)

After cooking, chops were covered with plastic wrap (Food Service Film Roll, Members Mark, Bentonville, AR) to minimize evaporative losses and cooled overnight at 4°C. Chops were removed from the cooler and brought to room temperature before coring. Four to six, 1.3 cm cores were removed parallel to the muscle fiber orientation. Cores were sheared using a United Testing machine (United SSTM-500, Huntington Beach, CA) at a cross-head speed of 200 mm/min using a 500 g load cell, and a 1.02 cm thick V-shape blade with a 60° angle and a half-round peak.

5.1.5. Statistical Analyses

Data was analyzed by Chop type using Analysis of Variance and an alpha ≤ 0.05 with SAS (v9.4, SAS Institute, Inc., Cary, NC). Selection trip was included in the model as a random effect and animal within NPB color standard was a fixed effect. The main effects of cut, color, chop thickness or roast weight, cooking method and their interactions were identified as main effects. Least squares means were calculated and if differences in effects were reported in the Analysis of Variance. Post-hoc mean separation was done using Fisher's least significant difference ($P < 0.05$).

5.2. Results and Discussion

5.2.1. Raw Analysis

The initial values from the blade-end of whole pork loins for color, pH and purge are reported in Table 26. As expected, 2-color score loins for both the bone-in and boneless loins were lower in objective color than ($P < 0.0001$) the color scores for 4-color score loins. The NPB color standards (National Pork Board, 2011) suggested that loins with a color score of 2 should have a Minolta L* color space value of approximately 55 and loins with a 4-color score should have Minolta L* color space values of approximately 43. The Minolta L* color space values were slightly elevated from those reported by National Pork Board (2011) but were proportionally different. Minolta instruments may provide slightly different values.

The a* values for the bone-in loins were much higher than ($P < 0.0001$) the boneless loins with the bone-in color-2 loin having the highest a*. The bone-in color-2 loins were also the highest ($P < 0.0001$) for the b* values, followed by the bone-in color-

4 loins, the boneless color-2, and finally, the boneless color-4. The pH values were significantly higher (*P* < 0.0001) for each loin type color-4 when compared to the color twos of each loin type. Purge was only collected from the boneless loins where the color-4 loins had significantly less (*P* < 0.0001) purge than the color-2 loins. These results indicated that loins within color score differed as expected and as previously reported for fresh loins differing in color scores. Moeller et al. (2010b), reported that an ultimate pH near 5.4 reduced consumers' satisfaction, however, increasing pH incrementally from 5.4 to 6.4 improved juiciness, tenderness and flavor. The higher pH values have been shown to predict more tender and juicy pork (Moeller et al., 2010a). Moeller et al. (2010b) concluded that ultimate pH had a significant effect on consumer perceptions and satisfaction. Consumer satisfaction decreased for products that were near 5.4, but incremental improvements in juiciness, tenderness, and flavor attributes were observed as pH increased up to 6.4 (Moeller et al., 2010b). The rate of pH decline and ultimate pH are critical factors in pork quality and will affect water-holding capacity and color (Pearce et al., 2011).

Objective color, pH, and drip loss were examined for raw pork blade chops (Table 27), boneless pork loin chops (Table 28), and raw pork bone-in pork loin chops (Table 29) by main effects. The L* and b* color space values differed (*P* < 0.0001) in blade, boneless loin and bone-in loin chops from the 2- and 4- color score loin treatments. Chops from color score 2 loins were lighter and had more yellow color compared to chops from color score 4 loins. Blade chops from color score 4 loins had a higher pH (*P* < 0.0001) and lower (*P* = 0.01) drip loss values than blade chops from color score 2 loins. However, for bone-in and boneless loin chops, pH, while higher in loin chops from color score 4 loins, the pH difference was not as large as reported for blade chops. Additionally, drip loss did not differ in loin chops from color score 2 and 4 loins. Huff-Lonergan et al. (2001) showed that pork with a low pH had higher drip loss and lighter color, whereas pork with a higher pH was darker in color and had lower drip loss. The different cooking methods and thickness tended to not affect raw measurement values. As chops were cut from the same loins and randomly assigned to treatments, chops would expectantly have similar objective color, pH and drip loss prior to cooking. However, raw bone-in pork loin chops assigned for baking had higher drip loss than chops assigned to pan fry and pan-sauté cook methods.

Raw measurements for the pork roasts and tenderloins are presented in Table 30. Whole boneless roasts were from color score 2 loins by design. Raw L*, a*, pH, and drip loss were not affected by the cooking treatments. As whole loin roasts were from different loins, this indicated that selection resulted in color score 2 loins that were similar in color scores, pH and drip loss. However, raw b* color space values were higher ($P = 0.02$) for roasts assigned to the baking method than roasts assigned to the grill method. There is no explanation for this difference.

The 0.9 and 1.8 kg roasts were cut from color score 4 boneless loins. Cooking methods did not affect the raw measurements indicating that loins were similar in raw color, pH and drip loss when assigned to treatment. However, heavier loins were slightly redder ($P = 0.0006$) and more yellow ($P = 0.002$), had slightly lower pH ($P = 0.02$) and slightly higher drip loss ($P = 0.04$) than lighter weight roasts. Tenderloins assigned to bake, or grill cooking treatments did not differ in raw color, pH or drip loss.

5.2.2. Cooked Analysis

Cook yield and cook time did not differ ($P > 0.05$) for blade chops from color score 2 and 4 loins (Table 31), but cooking method affected ($P < 0.05$) cook yield and cook time of blade chops. Cook yield was lowest ($P < 0.0001$) for blade chops cooked on the grill. Baked and pan-fried blade chops had similar cook yield and pan-sautéed blade chops had the highest cook yield. Cook time was highest for baked blade chops. Thicker chops had lower cook yields ($P < 0.0001$) and longer cook times ($P < 0.0001$). As expected, the thinnest blade chop took the least amount of time and had the greatest yield. The cooking method by thickness interaction was present for both cook yield ($P < 0.002$) and cook time ($P < 0.001$). All of the cooking methods followed the same trend with the thinnest blade chop having the highest yield and shortest cook time and the thickest chop having the least yield and longest cook time. The baking and grilling methods have similar values for the 1.3 and 1.9 cm thick chops. As the cook time increased for all cooking methods, the yield tended to decrease. Wählby et al. (2000) found that cooking losses for pork chops was strongly dependent on-air temperature and not as much on cooking time when pork chops were cooked to the same internal temperature. Chops cooked using the pan-sauté method had the highest cook yield and lower cook times. There was also a loin color by thickness interaction ($P = 0.03$) for cook time in blade chops. As the thickness increased for blade chops from loins across color scores, cook time also increased. However, blade chops from color score 2 loins that were 1.3 cm and 1.9 cm thick had lower cook times than blade chops from color score 4 loins. For blade chops that were 2.5 cm thick, blade chops from color score 2 loins had longer cook time than blade chops from color score 4 loins.

The cooked blade chop measurements for tenderness (Warner-Bratzler shear force; WBSF) and cooked color are reported in Table 32. Blade chops from loin color score 2 were tougher ($P < 0.0001$) and less red ($P < 0.01$) than blade chops from loin color score 4. For blade chops, cook method did not affect WBSF, but grilled blade chops had lower ($P < 0.005$) L* (were darker) and higher ($P < 0.0001$) b* (more yellow) color space values for internal cook color. Thicker blade chops had similar tenderness ($P = 0.55$) but were redder ($P < 0.0001$) and less yellow ($P < 0.0001$) than thin blade chops cooked to the same internal temperature.

For boneless loin chops, cook yield and cook time were evaluated to determine the differences between loin color scores, cooking methods, and chop thicknesses (Table 33). Boneless loin chops from 4 color score loins had higher ($P < 0.003$) cook yield than boneless loin chops from 2 color score loins; however, cook time did not differ. Boneless grilled loin chops had lower ($P < 0.0001$) cook yield than boneless pan-sautéed loin chops. As reported for blade chops, baked boneless loin chops had the longest cook time. Boneless pan-fried pork chops had the shortest cook times. As boneless pork loin chop thickness increased, cook yield increased ($P < 0.0001$) and cook time increased ($P < 0.0001$). However, there was a cook method by chop thickness interaction for cook time ($P < 0.0004$). In general, as boneless loin chop thickness increased, cook time increased incrementally. Cook times were longest for baked boneless loin chops and cook times were similar for boneless loin chops that were pan-fried, grilled and pan-sautéed across thickness levels. Baking is an indirect heating method. The hot air in the oven transfers to the surface of the meat and then the heat is slowly transferred to the center of the meat through water, fat, and proteins, but mostly water (Baghe-Khandan and Okos, 1981). Kirk (1984) noted that the most important factors when baking in an oven are the rate of evaporation, surface temperature of the food and thickness will impact the times and yields. This may explain by cook times were higher for boneless loin chops that were baked.

The cooked tenderness and color measurements for boneless loin chops are shown in Table 34. Loin color affected tenderness and L*, a*, and b* color space values of cooked boneless loin chops. Chops from color score 4 loins were more tender (P = 0.01), lighter (P < 0.01), redder (P < 0.0001), and more yellow (P < 0.009) than boneless loin chops from color score 2 loins. Cooking method affected in tenderness, L* and a* color space values in boneless loin chops. Boneless loin chops that were pan-fried and grilled were tougher (P = 0.01) than baked boneless loin chops but pan-sautéed boneless chops were similar in tenderness to the other cooking methods. Outside grilling is a unique type of cooking that combines convection and conduction heating to cook (Yancey et al., 2011). Heat is applied indirectly through hot air and directly through contact with the hot grills. The higher temperatures cause myofibrillar protein denaturation and structural changes to the muscle by pushing water from the meat causing a lower yield and tenderness (Davey and Gilbert, 1974). Baked boneless loin chops were lighter (P < 0.0001), with more red color (P < 0.0001) than grilled boneless loin chops for interior cooked chop color. The thinnest (1.3 cm) boneless loin chops were tougher (P < 0.02), with less red color (P < 0.0001), and more yellow (P < 0.0001) color internally than boneless pork loin chops that were 1.9 or 2.5 cm thick. Similarly, Simmins et al. (1985) reported 1.3 cm grilled pork chops had higher WBSF values and that grilled pork chops that were 1.9 and 2.5 cm did not differ in WBSF values. In another study, Weir et al. (1963) reported the thin (1.9 cm thick) chops were more tender than the thicker (3.8 cm thick) chops. The 1.3 cm chops had the lowest ($P < 0.0001$) a* value and the highest ($P = 0.0001$) b* value than the other two thicknesses.

Cook yield and cook time for the cooked bone-in chops are reported in Table 35. Cook yield and cook time were not affected ($P > 0.05$) by raw loin color score but bone-in loin chops differed ($P < 0.05$) in cook yield and cook time by cooking method and chop thickness. Cook yield was highest ($P < 0.0001$) for pan-sautéed bone-in loin chops and lowest for grilled bone-in loin chops. Baked and pan-fried bone-in loin chops had intermediate cook yields. Pan-sauté had the highest cook yield ($P < 0.05$) for the three chop types. This could be because the flour coated and protected the muscle fibers from losing water. Cook time was shortest ($P < 0.0001$) for pan-fried bone-in loin chops with pan-sautéed bone-in loin chops having slightly higher cook time. Grilled bone-in loin chops were intermediate in cook time and baked bone-in loin chops had the longest cook time. Thicker bone-in loin chops had lower cook yields ($P < 0.0001$) and the longest cook times ($P < 0.0001$). For the interaction of cook method by bone-in loin chop thickness, thicker chops had longer ($P < 0.0001$) cook times across cook methods and as chop thickness increased, cook time increased. However, baked bone-in loin chops had longer cook times and pan-fried and pan-sautéed bone-in loin chops had the shorter cook times across thickness levels.

Least squares means for tenderness and cooked objective color score values of bone-in loin chops are reported in Table 36. Loin color score impacted tenderness, a* and b* values but did not affect ($P > 0.05$) L* values. Bone-in loin chops from color score 4 loins were tougher ($P < 0.0001$), had higher ($P = 0.01$) a* color space values and lower ($P = 0.03$) b* color space values when compared to bone-in loin chops from color score 4 loins. Cooking method affected tenderness and objective color values. Pan-fried bone-in loin chops were toughest ($P < 0.0001$). Berry and Leddy (1984) suggested that frying caused a thick crust formation that could result in lower tenderness scores. Grilled bone-in loin chops had the lowest L* ($P = 0.04$) and a* ($P = 0.0002$) color space values. Baked bone-in loin chops had the lowest ($P < 0.0001$) b* color space values and grilled bone-in loin chops had the highest b* color space values. Thickness impacted a* and b* color space values. As bone-in loin chop thickness increased, a* color space values also increased ($P < 0.0001$). The thinnest bone-in pork chop had the highest ($P = 0.0002$) b* color space values.

Cook yield, cook time, WBSF values, and objective color values are reported in Table 37 for loin and tenderloin roasts. Baked whole boneless roasts from color score 2 loins had higher cook yield ($P < 0.0001$), longer cook times ($P < 0.0001$) and did not differ ($P > 0.05$) in color or tenderness from grilled whole boneless roasts. For smaller boneless loin roasts that were cut from raw loin color score 4 loins, baked roasts had higher cook yields ($P < 0.0001$), longer cook times, were tougher ($P = 0.009$), and had a redder internal cook color ($P < 0.0001$) than boneless loin roasts that were grilled. Heavier boneless loin roasts had lower cook yield ($P = 0.001$), longer cook times ($P = 0.001$), were tougher ($P = 0.001$) and were similar in internal color ($P > 0.05$) to lighter weight boneless loin roasts. Baked tenderloin roasts had higher cook yield ($P < 0.0001$), longer cook times ($P < 0.0001$) and were redder in internal color ($P = 0.0004$) than grilled tenderloin roasts.

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5.4. Figures and Tables

Table 25. Least squares means for initial Minolta CIE L*, a*, and b*, and pH on the loin blade end at the time of selection for bone-in and boneless pork loins, and purge (%) at fabrication for boneless pork loins.

Loin type	Color Score	CIE Color Space Values L*	a*	b*	pH	Purge (%)
P-value[e]		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Bone-in	2	52.8[c]	9.3[c]	6.1[d]	5.7[b]	-
Bone-in	4	45.9[a]	8.6[b]	3.8[c]	5.9[c]	-
Boneless	2	56.6[d]	3.7[a]	2.8[b]	5.5[a]	2.1[b]
Boneless	4	50.4[b]	3.8[a]	1.7[a]	5.7[b]	1.1[a]
RMSE[f]		2.01	1.18	0.89	0.14	0.76

[abcd] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[e] P-value from Analysis of Variance table.
[f] RMSE = Root Mean Square Error.

Table 26. Least squares means for raw Minolta CIE L*, a*, and b*color space values, pH, and drip loss values for raw blade pork chop treatments.

	CIE Color Space Values				Drip
Treatments	L*	a*	b*	pH	Loss (%)
Loin Color Score[c]	<0.0001	0.30	<0.0001	<0.0001	0.01
2	61.7[b]	4.9	5.7[b]	5.3[a]	1.4[b]
4	53.0[a]	5.5	3.9[a]	5.9[b]	0.9[a]
Cook Method[c]	0.56	0.43	0.61	0.71	0.69
Bake	57.0	5.3	4.9	5.7	1.1
Pan Fry	57.4	5.1	4.7	5.7	1.2
Grill	57.3	5.3	4.9	5.7	1.1
Pan-sauté	57.7	5.0	4.8	5.7	1.2
Chop Thickness[c]	0.18	0.36	0.78	0.29	0.62
1.3	57.1	5.3	4.8	5.7	1.1
1.9	57.7	5.1	4.9	5.7	1.2
2.5	57.2	5.1	4.8	5.7	1.1
RMSE[d]	3.50	1.73	1.31	0.16	0.66

[ab] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[c] P-value from Analysis of Variance table.
[d] RMSE = Root Mean Square Error.

Table 27. Least squares means for raw Minolta CIE L*, a*, and b*, pH, and drip loss values for raw boneless pork loin chops by main effect treatments.

Treatments	CIE Color Space Values L*	a*	b*	pH	Drip Loss (%)
Loin Color Score[c]	<0.0001	0.06	<0.0001	<0.0001	0.20
2	60.1[b]	4.4	5.0[b]	5.5[a]	1.6
4	52.7[a]	5.2	4.0[a]	5.8[b]	1.2
Cook Method[c]	0.99	0.17	0.52	0.86	0.22
Bake	56.4	4.7	4.4	5.7	1.5
Pan Fry	56.4	4.8	4.5	5.7	1.3
Grill	56.4	4.9	4.6	5.7	1.4
Pan-sauté	56.4	4.8	4.5	5.7	1.4
Chop Thickness[c]	0.93	0.46	0.80	0.70	0.30
1.3	56.5	4.9	4.5	5.7	1.3
1.9	56.4	4.8	4.5	5.7	1.4
2.5	56.4	4.8	4.5	5.7	1.5
RMSE[d]	2.44	0.90	1.06	0.14	0.86

[ab] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[c] P-value from Analysis of Variance table.
[d] RMSE = Root Mean Square Error.

Table 28. Least squares means for raw Minolta CIE L*, a*, and b*, pH, and drip loss values for raw bone-in loin chop by main effect treatments.

	CIE Color Space Values				Drip
Treatments	L*	a*	b*	pH	Loss (%)
Loin Color Score[c]	<0.0001	<0.0001	<0.0001	0.001	0.99
2	57.5[b]	5.57[b]	4.8[b]	5.6[a]	1.4
4	56.4[a]	3.87[a]	3.5[a]	5.7[b]	0.8
Cook Method[c]	0.68	0.96	0.78	0.99	0.04
Bake	57.1	4.7	4.1	5.7	1.3[b]
Pan Fry	56.7	4.7	4.1	5.7	1.0[a]
Grill	56.9	4.8	4.2	5.7	1.1[ab]
Pan-sauté	57.1	4.7	3.1	5.7	0.9[a]
Chop Thickness[c]	0.93	0.002	0.30	0.09	0.78
1.3	57.0	5.0[b]	4.2	5.7	1.0
1.9	57.0	4.6[a]	4.2	5.7	1.1
2.5	57.0	4.6[a]	4.0	5.7	1.1
RMSE[d]	2.45	1.07	1.05	0.14	0.89

[ab] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[c] P-value from Analysis of Variance table.
[d] RMSE = Root Mean Square Error.

Table 29. Least squares means for raw Minolta CIE L*, a*, and b*, pH, and drip loss values for raw boneless pork roasts and tenderloin roasts.

Treatments	CIE Color Space Values L*	a*	b*	pH	Drip Loss (%)
Whole Boneless Roasts Color Score 2					
Cook Method[c]	0.19	0.49	0.02	0.83	0.48
Bake	58.7	5.8	6.4[b]	5.6	5.6
Grill	57.4	5.5	5.6[a]	5.6	5.6
RMSE[d]	2.98	1.21	1.18	0.12	1.04
Chop Boneless Roasts Loin Color Score 4					
Cook Method[c]	0.37	0.05	0.59	0.31	0.75
Bake	46.4	5.0	2.2	6.0	0.87
Grill	45.8	5.4	2.3	6.0	0.82
Raw Chop Weight[e]	0.46	0.0006	0.002	0.02	0.04
0.9 kg	45.8	4.8[a]	1.9[a]	6.1[b]	0.51[a]
1.8 kg	45.4	5.6[b]	2.6[b]	6.0[a]	1.18[b]
RMSE[d]	3.42	1.00	1.03	0.18	0.76
Tenderloin					
Cook Method[c]	0.99	0.91	0.11	0.94	0.99
Bake	48.4	7.8	3.3	5.9	0.75
Grill	48.4	7.9	3.9	5.9	0.75
RMSE[d]	2.72	1.51	1.18	0.20	0.34

[ab] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[c] P-value from Analysis of Variance table.
[d] RMSE = Root Mean Square Error.

Table 30. Least squares means for cook yield and cook time for the cooked blade chop main effects and significant ($P < 0.05$) interactions.

Treatments	Cook Yield (%)	Cook Time (min.)
<u>Loin Color Score</u>[e]	0.95	0.49
2	89.8	12.8
4	90.2	13.8
<u>Cook Method</u>[e]	<0.0001	<0.0001
Bake	89.9^{b}	24.1^{b}
Pan Fry	90.5^{b}	9.2^{a}
Grill	85.4^{a}	10.0^{a}
Pan-sauté	94.3^{c}	9.9^{a}
<u>Chop Thickness</u>[e]	<0.0001	<0.0001
1.3 cm	91.9^{c}	7.8^{a}
1.9 cm	90.2^{b}	13.2^{b}
2.5 cm	87.9^{a}	18.9^{c}
<u>Cook Method by Chop Thickness</u>[e]	0.002	0.0003
Bake by 1.3 cm	90.4^{de}	16.3^{d}
Bake by 1.9 cm	90.2^{de}	24.4^{e}
Bake by 2.5 cm	89.0^{cd}	31.6^{f}
Pan Fry by 1.3 cm	93.0^{f}	4.5^{a}
Pan Fry by 1.9 cm	90.4^{de}	9.0^{b}
Pan Fry by 2.5 cm	88.0^{bc}	14.2^{cd}
Grill by 1.3 cm	86.6^{b}	5.6^{a}
Grill by 1.9 cm	85.6^{b}	10.0^{b}
Grill by 2.5 cm	83.8^{a}	14.4^{cd}
Pan-saute by 1.3 cm	97.4^{g}	4.7^{a}
Pan-saute by 1.9 cm	94.5^{f}	9.5^{b}
Pan-saute by 2.5 cm	90.9^{e}	15.5^{cd}
<u>Loin Color Score by Chop Thickness</u>[e]		0.03
2 by 1.3 cm		6.9^{a}
2 by 1.9 cm		12.3^{b}
2 by 2.5 cm		19.2^{e}
4 by 1.3 cm		8.6^{a}
4 by 1.9 cm		14.1^{c}
4 by 2.5 cm		18.7^{d}
RMSE[f]	3.87	4.49

[abcd] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[e] P-value from Analysis of Variance table.
[f] RMSE = Root Mean Square Error

Table 31. Least squares means for Warner-Bratzler Shear Force, cooked Minolta CIE L*, a*, and b* color space values for the cooked blade chops.

Treatments	Warner-Bratzler Shear Force Values (kg)	CIE Color Space Values L*	a*	b*
Loin Color Score[d]	<0.0001	0.38	0.01	0.51
2	1.9[b]	78.1	4.2[a]	11.2
4	1.6[a]	76.9	6.0[b]	11.1
Cook Method[d]	0.06	0.005	0.69	<0.0001
Bake	1.6	77.5[b]	5.2	10.7[a]
Pan Fry	1.8	77.6[b]	5.1	11.1[b]
Grill	1.8	76.4[a]	4.9	11.7[c]
Pan-sauté	1.7	78.3[b]	5.2	11.0[ab]
Chop Thickness[d]	0.55	0.42	<0.0001	<0.0001
1.3 cm	1.8	77.4	4.4[a]	11.6[b]
1.9 cm	1.7	77.8	5.2[b]	10.9[a]
2.5 cm	1.7	77.2	5.8[c]	10.9[a]
RMSE[e]	3.87	4.49	2.18	1.50

[abc] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[d] P-value from Analysis of Variance table.
[e] RMSE = Root Mean Square Error.

Table 32. Least squares means for cook yield and cook time for cooked boneless loin chops.

Treatments	Cook Yield (%)	Cook Time (min.)
Loin Color Score[e]	0.003	0.05
2	87.3[a]	16.4
4	90.4[b]	15.0
Cook Method[e]	<0.0001	<0.0001
Bake	88.6[b]	26.6[d]
Pan Fry	89.4[b]	10.8[a]
Grill	84.6[a]	12.9[b]
Pan-sauté	92.9[c]	12.5[c]
Chop Thickness[e]	<0.0001	<0.0001
1.3 cm	90.9[c]	8.8[a]
1.9 cm	88.5[b]	16.4[b]
2.5 cm	87.2[a]	21.9[c]
Cook Method by Chop Thickness		0.0004
Bake by 1.3 cm		17.9[e]
Bake by 1.9 cm		26.7[f]
Bake by 2.5 cm		35.2[g]
Pan Fry by 1.3 cm		5.2[a]
Pan Fry by 1.9 cm		11.5[b]
Pan Fry by 2.5 cm		15.8[d]
Grill by 1.3 cm		6.4[a]
Grill by 1.9 cm		14.2[cd]
Grill by 2.5 cm		18.2[e]
Pan-saute by 1.3 cm		5.7[a]
Pan-saute by 1.9 cm		13.2[bc]
Pan-saute by 2.5 cm		18.4[e]
RMSE[f]	4.27	4.58

[abcd] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[e] P-value from Analysis of Variance table.
[f] RMSE = Root Mean Square Error.

Table 33. Least squares means for Warner-Bratzler Shear Force, cooked Minolta CIE L*, a*, and b* color space values for the cooked boneless loin chops.

Treatments	Warner-Bratzler Shear Force Values (kg)	CIE Color Space Values L*	a*	b*
Loin Color Score[e]	0.01	0.01	<0.0001	0.009
2	2.4[b]	78.7[b]	4.1[a]	10.7[a]
4	2.2[a]	76.7[a]	5.8[b]	11.1[b]
Cook Method[e]	0.01	<0.0001	<0.0001	0.11
Bake	2.2[a]	78.6[c]	5.0[b]	10.6
Pan Fry	2.4[b]	77.4[ab]	5.2[b]	10.9
Grill	2.3[b]	77.0[a]	4.4[a]	11.1
Pan-sauté	2.3[ab]	77.8[b]	5.2[b]	10.9
Chop Thickness[e]	0.02	0.89	<0.0001	0.0001
1.3 cm	2.4[b]	77.6	4.3[a]	11.3[b]
1.9 cm	2.2[a]	77.8	5.1[b]	10.8[a]
2.5 cm	2.2[a]	77.7	5.3[b]	10.6[a]
RMSE[f]	0.48	2.71	1.31	1.54

[abcd] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[e] P-value from Analysis of Variance table.
[f] RMSE = Root Mean Square Error.

Table 34. Least squares means for cook yield and cook time for the cooked bone-in loin chops.

Treatments	Cook Yield (%)	Cook Time (min)
Loin Color Score[e]	0.89	0.53
2	92.0	12.3
4	92.4	12.1
Cook Method[e]	<0.0001	<0.0001
Bake	91.3[b]	22.6[d]
Pan Fry	92.8[c]	7.5[a]
Grill	87.9[a]	10.3[c]
Pan-sauté	96.8[d]	8.6[b]
Chop Thickness[e]	<0.0001	<0.0001
1.3 cm	93.2[b]	8.0[a]
1.9 cm	92.6[b]	11.6[b]
2.5 cm	90.8[a]	17.1[c]
Cook Method by Chop Thickness		<0.0001
Bake by 1.3 cm		16.1[e]
Bake by 1.9 cm		21.4[f]
Bake by 2.5 cm		30.2[g]
Pan Fry by 1.3 cm		4.3[a]
Pan Fry by 1.9 cm		7.0[b]
Pan Fry by 2.5 cm		11.2[c]
Grill by 1.3 cm		6.7[b]
Grill by 1.9 cm		10.5[c]
Grill by 2.5 cm		13.7[d]
Pan-saute by 1.3 cm		4.8[a]
Pan-saute by 1.9 cm		7.8[b]
Pan-saute by 2.5 cm		13.2[d]
RMSE[f]	3.57	4.15

[abcd] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[e] P-value from Analysis of Variance table.
[f] RMSE = Root Mean Square Error.

Table 35. Least squares means for Warner-Bratzler Shear Force, cooked Minolta CIE L*, a*, and b* color space values for the cooked bone-in loin chops.

Treatments	Warner-Bratzler shear force values (kg)	CIE Color Space Values L*	a*	b*
Loin Color Score[e]	<0.0001	0.89	0.01	0.03
2	2.2[a]	77.0	4.9[b]	11.1[a]
4	2.3[b]	77.1	4.2[a]	11.6[b]
Cook Method[e]	<0.0001	0.04	0.0002	<0.0001
Bake	2.1[a]	77.2[b]	4.6[b]	10.6[a]
Pan Fry	2.4[c]	77.3[b]	4.8[b]	11.6[bc]
Grill	2.3[b]	76.4[a]	4.1[a]	11.8[c]
Pan-sauté	2.2[ab]	77.4[b]	4.6[b]	11.3[b]
Chop Thickness[e]	0.06	0.12	<0.0001	0.0002
1.3 cm	2.3	76.7	4.0[a]	11.7[b]
1.9 cm	2.3	77.2	4.6[b]	11.3[a]
2.5 cm	2.2	77.3	5.1[c]	11.0[a]
RMSE[f]	0.38	3.25	1.36	1.40

[abcd] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[e] P-value from Analysis of Variance table.
[f] RMSE = Root Mean Square Error.

Table 36. Least squares means for cook yield, cook time, Warner-Bratzler Shear Force, cooked Minolta CIE L*, a*, and b* color space values for cooked loin and tenderloin roasts.

Treatments	Cook Yield (%)	Cook Time (min)	Warner-Bratzler Shear Force Values (kg)	CIE Color Space Values L*	a*	b*
Whole Boneless Roasts, Raw Loin Color 2						
Cook Method[c]	<0.0001	<0.0001	0.62	0.85	0.28	0.34
Bake	84.7[b]	97.9[b]	2.5	77.3	4.4	9.9
Grill	74.7[a]	66.3[a]	2.4	77.4	4.0	10.4
RMSE[d]	3.99	11.62	0.35	3.40	1.19	1.84
Boneless Roasts, Raw Loin Color 4						
Cook Method[c]	<0.0001	<0.0001	0.009	0.41	<0.0001	0.23
Bake	85.1[b]	76.0[b]	2.3[a]	74.3	6.6[b]	8.9
Grill	72.6[a]	50.6[a]	2.6[b]	74.9	4.4[a]	9.4
Raw Weight[c]	0.001	0.001	0.001	0.21	0.81	0.17
0.9 kg	80.5[b]	58.8[a]	2.3[a]	75.1	5.6	8.8
1.8 kg	77.1[a]	67.8[b]	2.6[b]	74.2	5.4	9.4
RMSE[d]	5.02	13.3	0.49	3.01	1.89	1.70
Tenderloin						
Cook Method[c]	<0.0001	<0.0001	0.14	0.76	0.0004	0.31
Bake	89.6[b]	41.2[b]	1.9	68.7	11.5[b]	11.1
Grill	81.3[a]	28.5[a]	2.1	69.0	9.3[a]	11.6
RMSE[d]	2.79	6.86	0.40	3.05	1.76	1.63

[ab] Mean values within a row followed by the same letter are not significantly different ($P > 0.05$).
[c] P-value from Analysis of Variance table.
[d] RMSE = Root Mean Square Error.

6. CONCLUSIONS

6.1. The Flavor and Texture Attributes of Ground Beef Descriptive Analysis

Hamburger production and consumption in America is a huge industry and all processing measures impact the flavor and texture of ground beef patties. From this study, the positive and negative flavor and texture attributes of different ground beef patty processing were found.

Although the commercial 20% ground beef patties had the most positive flavors, the mature, 20% fat patties were close behind the commercial meat source. The lower fat was detrimental to the mature source and exacerbated the negative attributes. Mature meat is a sizable source of ground beef for the industry and must be utilized somehow. Increasing the fat in the mature patties, eliminated most of the off-flavors and made it comparable with the gold standard as being the commercial meat source. Patty thickness impacted flavor attributes with thicker patties having more positive flavor and texture attributes than thinner patties. However, thick patties from mature beef that was 7% lipid had higher levels of negative flavor attributes.

Grind size impacted patty flavor and texture attributes but not to as great of an extent as patty thickness and meat source. Ground beef patties that were either bowl-chopped or ground to a final grind size of 6.4 mm had more positive flavor and texture attributes than ground beef patties ground to 9.7 mm final grind size. Cooking impacted flavor and texture attributes. Patties cooked on the clam-shell style grill had more oxidized flavors, which were magnified when 6.4 thick patties were cooked, than patties cooked on a flat grill. Hand-formed patties had more positive flavor and texture attributes than machine-formed patties, especially when patties were 2.54 cm thick.

Holding patties in a steam table for up to 3 hours mainly increased oxidative flavors but had minimal effects on positive flavor and texture attributes across all treatments. In a high-fat patty, limiting the amount of holding time is key. In the lower fat patties, up to one hour holding time was not detrimental to the patty. Selecting specific ground beef patty manufacturing and cooking methods can be used to improve the flavor traits of patties and should be used to maximize consumer acceptance.

6.2. Flavor in ground beef using a home use test to determine flavor in ground beef

With ground beef accounting for such a large percentage of beef consumption, understanding how flavor and texture affect overall consumer liking is becoming more crucial. This study confirmed that source, fat level, and final grind method contributed in flavor development and consumer perception.

Consumers preferred the 6.4 mm grind over the bowl-chopped patties across all consumer attributes except appearance. Some premium ground beef concepts use bowl-chopped ground beef. Bowl-chopping results in harder, and springier ground beef with less defined particle size. When not associated with marketing, consumers did not prefer bowl-chopped ground beef compared to normal grind-type ground beef.

The central location consumers generally preferred 6.4 mm ground beef patties that contain 20% fat patties that are derived from chuck lean sources (Beavers, 2018). Central location consumers preferred the texture of 20% fat patties over 10% fat patties, and 20% fat patties also scored higher across many positive trained panel attributes compared to the 10% fat patties. This was apparent when the ground beef was prepared for consumers but not when consumers prepared the product at home. Interestingly, when consumers prepared either patties or chubbed ground beef at home, they preferred 10% lipid ground chuck or sirloin beef in patties or chubs ground to a 6.4 mm grind size.

Today's restaurant industry is offering more choices for a hamburger and have created a premium hamburger through these choices. In an effort to create a better hamburger, hamburger chains have used different sources, fat contents and grind methods to create a premium hamburger. In this home-use study, when consumers prepared the meat themselves, they preferred patties or chubs that were 10% fat, chuck or sirloin meat source, and traditionally ground to 6.4 mm plate size.

6.3. Relationships between loin color, cut thickness, cooking method, water-holding capacity and tenderness for pork cooked to 62.8°C

With the reduction in degree of doneness for pork, understanding how cooking method, chop thickness, and raw loin quality affect final cooked pork color, tenderness, cook yield and cook time is critical. Cooking method and chop thickness dramatically affected cook yield and the time to reach 63.2°C internal degree of doneness. A common theme throughout for pork chops was as thickness increased, cook time increased and cook yield decreased. Baking pork chops or roasts had the longest cooking times and tended to have the lowest cook yields. Pan-sautéing and pan frying had in shorter cook times that resulted in higher cook yields and acceptable tenderness values. The blade and boneless chops from loin color score 4 were more tender than comparable chops from loin color score 2, but the opposite was reported for bone-in loin chops. Chop thickness had a minor effect on cook measurements, tenderness and color for blade and bone-in chops, but chop thickness for boneless chops impacted these parameters to a greater extent. Thin boneless loin chops were tougher than thicker boneless loin chops. Although pork that was baked had the longest cook time, baked bone-in and boneless chops were tender. Grilled pork chops and roasts had the lowest cook yield. Overall, this study showed that raw loin color impacted the raw color, pH and drip loss of pork. In addition, when blade, bone-in or boneless pork chops and roasts from these loins, cooking method and chop thickness impacted cook yield, cook time, cooked color, and tenderness.

APPENDIX A

SECTION 3: TRAINED DESCRIPTIVE ANALYSIS TRAINING GUIDELINES

Day 1

- Introduce Universal Scale for flavor intensity
  - Soda flavor in Saltine Crackers = 2.0
  - Apple flavor in Motts Apple Sauce = 5.0
  - Orange flavor in Minute Maid Orange Juice = 7.0
  - Grape flavor in Welch's Grape Juice = 10.0
  - Cinnamon flavor in Big Red Chewing Gum = 12.0
- Introduce basic tastes, and beef flavor identity flavor attributes
- Sample evaluation for the introduced attributes
  - High Beef Flavor/Aroma ID- Ground Hamburger patty cooked on grill to 165F
  - Low Beef Flavor/Aroma ID-Standard Strip Steak Cooked on grill to 70C

Day 2

- Review previously introduced attributes
- Introduce brown/roasted and bloody/serumy flavor attributes
- Sample evaluation for the introduced attributes
  - 923 - Select Tenderloin steak grilled to 65C-high bloody/serum, metallic notes
  - 147 - Select Flat Iron steak grilled to 137F-unknown, panelists determine levels

Day 3

- Review previously introduced attributes
- Introduce metallic flavor attribute
- Sample evaluation for the introduced attributes
  - Tenderloin- 137°F
  - Flat Iron- 137°F
  - Strip Steak- 125°F
  - Strip Steak- 165°F
  - Ground Beef crumbles- Browned

Day 4

- Review previously introduced attributes
- Introduce liver-like and fat-like flavor attributes
- Sample evaluation for the introduced attributes
  - 70% lean GB patties
  - 80% lean GB patties
  - 98% lean GB patties

Day 5

- Review previously introduced attributes

- Introduce overall sweet flavor attribute
- Sample evaluation for the introduced attributes
    - ¼ inch ground chuck patty
    - 1 inch ground chuck patty
    - ½ inch ground chuck with accent

Day 6

- Review previously introduced attributes
- Introduce burnt and green-haylike flavor attributes
- Sample evaluation for the introduced attributes
    - ¼ inch ground chuck patty
    - 1 inch ground chuck patty
    - ½ inch ground chuck with 10g dried parsley

Day 7

- Review previously introduced attributes
- Introduce sour aromatic flavor attribute
- Sample evaluation for the introduced attributes
    - Grass fed steak 137°F Grill
    - Strip steak 137°F Grill
    - 1 inch 80/20 GB Grill
    - ½ inch Grass fed GB
    - 1 inch 80/20 GB George Foreman
    - 1 inch 96/4 Grill
    - Choice steak 137°F
    - ¼ inch 80/20 George Foreman
    - ¼ inch 80/20 GB Grill
    - ¼ inch 96/4 George Foreman

Day 8

- Review previously introduced attributes
- Introduce cardboardy, musty-earthy/humus, leather, animal hair, and barnyard flavor attributes

Day 9

- Review previously introduced attributes
- Introduce green, asparagus apricot, beet, floral, and cumin flavor attributes

Day 10

- Review previously introduced attributes
- Introduce sour milk/sour dairy, dairy, cooked milk, buttery, and chocolate/cocoa flavor attributes

Day 11

- Review previously introduced attributes
- Introduce chemical, medicinal, warmed-over, refrigerator stale, rancid, heated oil and spoiled putrid flavor attributes

Day 12

- Review previously introduced attributes

- Introduce soapy, petroleum-like, smoky wood, and smoky charcoal flavor attributes

Day 13

- Review previously introduced attributes
- Sample evaluation for the introduced attributes
    - 1 inch 80/20
    - 1 inch 93/7
    - ¼ inch 93/7
    - ¼ inch 80/20

Day 14

- Review previously introduced attributes
- Sample evaluation for the introduced attributes
    - 1 inch 80/20
    - 1 inch 93/7
    - ¼ inch 93/7
    - ¼ inch 80/20
    - ½ inch 80/20

Day 15

- Review previously introduced attributes
- Introduce hardness texture attribute
- Sample evaluation for the introduced attributes
    - 80/20 1 inch GEORGE FOREMAN
    - 80/20 ¼ inch Gril
    - 80/20 1 inch Grill
    - 80/20 ¼ inch GEORGE FOREMAN

Day 16

- Review previously introduced attributes
- Introduce springiness texture attribute
- Sample evaluation for the introduced attributes

    - ¼ inch George Foreman
    - ¼ inch Grill
    - 1 inch George Foreman
    - ¼ inch George Foreman
    - 1 inch George Foreman
    - ¼ inch Grill

Day 17

- Review previously introduced attributes
- Introduce cohesiveness of mass texture attribute
- Sample evaluation for the introduced attributes
    - 1 inch George Foreman
    - Mature ¼ inch George Foreman
    - 1 inch George Foreman
    - Mature ¼ inch Grill

Day 18

- Review previously introduced attributes
- Introduce particle size texture attribute
- Sample evaluation for the introduced attributes
    - 1 in, 3/8 in grind, George Foreman
      ¼ inch, ¼ in grind, George Foreman
    - 1 inch, ¼ in grind, George Foreman
    - ¼ inch, bowl-chopped, George Foreman

Day 20

- Review previously introduced attributes
- Introduce initial juiciness texture attribute
- Sample evaluation for the introduced attributes

Day 21

- Review previously introduced attributes
- Introduce fat mouthcoating texture attribute
- Sample evaluation for the introduced attributes
    - 73% fat, 1 in thick, grill
    - 93% fat, ¼ in thick, grill
    - 80% fat, 1 in thick, grill
    - 93% fat, 1 in thick, grill

Day 22

- Review previously introduced attributes
- Sample Evaluation
    - ¼ in grind 1 inch Grill
    - 3/8 in grind 1 inch Grill
    - bowl-chop 1 inch Grill
    - ¼ in grind 1 inch George Foreman
    - 3/8 in grind 1 inch George Foreman
    - bowl-chop 1 inch George Foreman
    - ¼ in grind ¼ inch Grill
    - 3/8 in grind ¼ inch Grill
    - bowl-chop ¼ inch Grill
    - ¼ in grind ¼ inch George Foreman
    - 3/8 in grind ¼ inch George Foreman
    - bowl-chop ¼ inch George Foreman

APPENDIX B

SECTION 4: TRAINED DESCRIPTIVE ANALYSIS TRAINING GUIDELINES

Day 1

- Introduce Universal Scale for flavor intensity
  - Soda flavor in Saltine Crackers = 2.0
  - Apple flavor in Motts Apple Sauce = 5.0
  - Orange flavor in Minute Maid Orange Juice = 7.0
  - Grape flavor in Welch's Grape Juice = 10.0
  - Cinnamon flavor in Big Red Chewing Gum = 12.0
- Introduce basic tastes, beef flavor identity, brown/roasted, bloody/serumy flavor attributes
- Sample evaluation for the introduced attributes
  - Select strip steak – 65°C
  - Ground sirloin 9010 – 70°C
  - Beef brisket – 70°C
  - Ground round – 70°C

Day 2

- Review previously introduced attributes
- Introduce metallic and fat-like flavor attribute
- Sample evaluation for the introduced attributes
  - Beef brisket – 70C
  - Select beef ribeye – 70*C
  - Select strip steak – 70°C
  - 73/27 ground beef 2.54 cm thick patty
  - Select strip steak – 70°C

Day 3

- Review previously introduced attributes
- Introduce umami and overall sweet basic taste and flavor attributes
- Sample evaluation for the introduced attributes
  - 80/20 ground chuck, 2.54 cm thick patty – 70°C
  - 80/20 ground round patty with 0.5g accent seasoning, 2.54 cm thick patty – 70°C
  - 90/10 ground sirloin, 2.54 cm thick patty – 70°C
  - 73/27 ground beef, 2.54 cm thick patty – 70°C

Day 4

- Review previously introduced attributes
- Introduce chocolate/cocoa, burnt, green-haylike, and musty-earthy/humus flavor attributes
- Sample evaluation for the introduced attributes
  - 80/20 ground chuck, 2.54 cm thick patty – 70°C
  - 90/10 ground sirloin, 2.54 cm thick patty – 70°C
  - 80/20 ground chuck with 10 g dried parsley – 70°C

- 73/27 ground beef, 2.54 cm thick patty – 70°C

Day 5

- Review previously introduced attributes
- Introduce cardbardy, leather, animal hair, and barnyard flavor attributes
- Sample evaluation for the introduced attributes
    - 73/27 ground beef, 2.54 cm thick patty – 70°C
    - 90/10 ground sirloin, 2.54 cm thick patty – 70°C
    - 80/20 ground chuck, 2.54 cm thick patty – 70°C
    - 80/20 ground chuck with 5 g white pepper– 70°C
    - 93/7 ground beef, 2.54 cm thick patty – 70°C

Day 6

- Review previously introduced attributes
- Introduce green, asparagus apricot, beet, floral, and cumin flavor attributes
- Sample evaluation for the introduced attributes
    - 90/10 ground sirloin, 2.54 cm thick patty – 70°C
    - 80/20 ground chuck, 2.54 cm thick patty – 70°C
    - 73/27 ground beef, 2.54 cm thick patty – 70°C
    - 85/15 ground round, 2.54 cm thick patty – 70°C
    - 93/7 ground beef, 2.54 cm thick patty – 70°C

Day 7

- Review previously introduced attributes
- Introduce sour milk/sour dairy, dairy, cooked milk and buttery flavor attributes
- Sample evaluation for the introduced attributes
    - 85/15 ground round, 2.54 cm thick patty – 70°C
    - 90/10 ground sirloin, 2.54 cm thick patty – 70°C
    - 80/20 ground beef, 2.54 cm thick patty – 70°C
    - 93/7 ground beef , 2.54 cm thick patty – 70°C
    - 80/20 ground chuck, 2.54 cm thick patty – 70°C

Day 8

- Review previously introduced attributes
- Introduce soapy, petroleum-like, smoky wood, smoky charcoal, astringent, and nutty flavor attributes
- Sample evaluation for the introduced attributes
    - 80/20 ground chuck, 2.54 cm thick patty – 70°C
    - 93/7 ground beef, 2.54 cm thick patty – 70°C
    - 85/15 ground round, 2.54 cm thick patty – 70°C
    - 80/20 ground chuck, 2.54 cm thick patty – 70°C
    - 90/10 ground sirloin, 2.54 cm thick patty – 70°C
    - 73/27 ground beef, 2.54 cm thick patty – 70°C

Day 9

- Review previously introduced attributes
- Introduce warmed over, refrigerator stale, springiness, hardness, cohesiveness of mass, particle size and initial juiciness flavor and texture attributes
- Sample evaluation for the introduced attributes

- 93/7 ground beef, 2.54 cm thick patty – 70°C
- 90/10 ground sirloin, 2.54 cm thick patty – 70°C
- 73/27 ground beef, 2.54 cm thick patty – 70°C
- 85/15 ground round, 2.54 cm thick patty – 70°C

Day 10

- Review previously introduced attributes
- Introduce chemical, medicinal, rancid, heated oil, and spoiled putrid, flavor attributes
- Sample evaluation for the introduced attributes
    - 80/20 ground beef, 2.54 cm thick patty – 70°C
    - 73/27 ground beef, 2.54 cm thick patty – 70°C
    - 85/15 ground round, 2.54 cm thick patty – 70°C

Day 11

- Review previously introduced attributes
- Sample Evaluation
    - 73/27 ground beef, 2.54 cm thick patty – 70°C
    - 85/15 ground round, 2.54 cm thick patty – 70°C
    - 90/10 ground sirloin, 2.54 cm thick patty – 70°C
    - 73/27 ground beef, 2.54 cm thick patty – 70°C
    - 80/20 ground chuck, 2.54 cm thick patty – 70°C
    - 93/7 ground beef, 2.54 cm thick patty – 70°C

Day 12

- Review previously introduced attributes
- Sample Evaluation
    - 80/20 ground sirloin, bowl-chopped , 2.54 cm thick patty – 70°C
    - 90/10 ground round, 6.4 mm grind, 2.54 cm thick patty – 70°C
    - 90/10 regular, bowl-chopped, 2.54 cm thick patty – 70°C
    - 90/10 ground chuck , 6.4 mm grind.54 cm thick patty – 70°C
    - 90/10 regular, bowl-chopped, 2.54 cm thick patty – 70°C
    - 90/10 ground chuck, bowl-chopped, 2.54 cm thick patty – 70°C
    - 90/10 ground round, 6.4 mm grind, 2.54 cm thick patty – 70°C
    - 80/20 ground chuck, bowl-chopped, 2.54 cm thick patty – 70°C

Day 13

- Review previously introduced attributes
- Sample Evaluation
    - 80/20 regular, bowl-chopped, 2.54 cm thick patty – 70°C
    - 90/10 ground round, 6.4 mm grind, 2.54 cm thick patty – 70°C
    - 80/20 regular, bowl-chopped, 2.54 cm thick patty – 70°C
    - 90/10 ground chuck, bowl-chopped, 2.54 cm thick patty – 70°C
    - 80/20 ground sirloin, bowl-chopped , 2.54 cm thick patty – 70°C
    - 80/20 ground round, bowl-chopped, 2.54 cm thick patty – 70°C
    - 80/20 regular, 6.4 mm, 2.54 cm thick patty – 70°C
    - 80/20 ground chuck, bowl-chopped, 2.54 cm thick patty – 70°C

Day 14

- Review previously introduced attributes

- Sample Evaluation
    - 80/20 regular, 6.4 mm grind, 2.54 cm thick patty – 70°C
    - 90/10 ground chuck, bowl-chopped, 2.54 cm thick patty – 70°C
    - 80/20 regular, bowl-chopped, 2.54 cm thick patty – 70°C
    - 80/20 regular, bowl-chopped, 2.54 cm thick patty – 70°C
    - 80/20 ground round, bowl-chopped, 2.54 cm thick patty – 70°C
    - 90/10 ground round, 6.4 mm grind, 2.54 cm thick patty – 70°C
    - 90/10 ground round, 6.4 mm grind, 2.54 cm thick patty – 70°C

Day 15

- Review previously introduced attributes
- Sample Evaluation
    - 80/20 ground chuck, 2.54 cm thick patty – 70°C
    - 85/15 ground round, 2.54 cm thick patty – 70°C
    - 93/7 ground beef, 2.54 cm thick patty – 70°C
    - 80/20 ground chuck, 2.54 cm thick patty – 70°C
    - 90/10 ground sirloin, 2.54 cm thick patty – 70°C

Day 16

- Review previously introduced attributes
- Sample Evaluation
    - 80/20 ground chuck, 2.54 cm thick patty – 70°C
    - 80/20 ground beef, 2.54 cm thick patty – 70°C
    - 80/20 ground round, bowl-chopped, 2.54 cm thick patty – 70°C
    - 73/27 ground beef, 2.54 cm thick patty – 70°C
    - 80/20 ground chuck, 2.54 cm thick patty – 70°C
    - 80/20 ground round, bowl-chopped, 2.54 cm thick patty – 70°C

APPENDIX C

GROUND BEEF PATTY COOKED COLOR GUIDE*

*Reprinted from Marksberry, C. L., D. H. Kroph, M. C. Hunt, M. A. Hague, and K. E. Warren. 1993. Ground Beef Patty Cooked Color Guide. Kansas Agri. Exp. Station. Manhattan, KS.

APPENDIX D

INSTRUCTIONS FOR HOME USE TEST PARTICIPANTS

Respondent Number_________ Date meat was consumed _______
Sample Number ____________ Order ______________________

Instructions for Study Participants

Thank you for taking part in this important study. Your participation and opinions are valuable. Please read this page carefully and keep it handy in case you would like to refer to it throughout the study. This package should contain 6 ballots, stamped return envelope, and a degree of doneness chart.

A. **How to Handle the Meat**
   1. **Storage:** Meat is perishable! Proper refrigerator and freezer storage is essential to maintain its quality and safety. Immediately place the beef in the freezer when you receive it. When you receive the meat it will already be vacuum packaged and frozen.
   2. **Thawing:** The best way to thaw meat is in the refrigerator, never at room temperature. A microwave oven also can be used for defrosting.

B. **How to Prepare the Meat**
   1. Please cook the samples in the order that is on the ballots and samples. The order number is located at the top of the ballot sheet and also the number on the colored dot on your sample.
   2. Please cook the meat as you normally would – as if you had purchased that meat in your local food store.

C. **How to Fill Out the Ballots**
   1. Each ballot is the same color as the color dot placed on the meat and the number on the meat will correspond with the number on the ballot. Please make sure you are filling out the correct ballot for each piece of meat. The front page of the ballot is about the preparation of the sample and the back page has questions that you will answer while you are eating the sample.

D. **Return**
   1. Make sure you return 6 ballots in the stamped, self-addressed envelope and your return address. After we receive your 6 completed ballots, we will immediately send you a $20 gift card in return for your efforts.

Thank you so much for your participation.

IRB NUMBER: IRB2016-0420M
IRB APPROVAL DATE: 10/06/2016
IRB EXPIRATION DATE: 07/15/2021

APPENDIX E

HOME USE TEST BALLOT

Respondent Number_________ Date meat was consumed _______
Sample Number ____________ Order ______________________

1. How did you thaw the meat? (Please select as many as apply)
   - ☐ Placed in refrigerator day before
   - ☐ Placed in refrigerator same day
   - ☐ In microwave
   - ☐ At room temperature
   - ☐ Under cold water
   - ☐ Under hot water
   - ☐ Cooked frozen

2. How much do you like or dislike the appearance of the sample before cooking?

   ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

   Dislike Extremely — Neither Like or Dislike — Like Extremely

3. Which of these, if any, did you do to the meat before cooking?
   - ☐ Break apart into small pieces
   - ☐ Form into balls
   - ☐ Form into patties
   - ☐ None of these
   - ☐ Other (Explain) ____________________

4. What was added to the ground beef, if anything, as it was prepared or cooked? (Please select as many as apply)
   - ☐ Salt
   - ☐ Pepper
   - ☐ Spices/herbs, such as garlic, oregano, etc.
   - ☐ Tenderizer such as Adolph's
   - ☐ Marinade
   - ☐ Flour, crumbs or other coating to top and/or bottom
   - ☐ Sauces, such as soy, BBQ, etc.
   - ☐ Other (Explain) _____________________

5. How did you cook the meat?
   - ☐ Outdoor grill
   - ☐ Broil
   - ☐ Indoor grill
   - ☐ Oven roast uncovered
   - ☐ Panbroil
   - ☐ Pan/fry/sauté
   - ☐ Stir fry
   - ☐ Braise
   - ☐ Simmer and stew
   - ☐ Deep fry
   - ☐ Other (Explain) ________________

6. Circle what degree of "doneness" was the beef when you consumed it? (Refer to the degree of doneness chart provided in the packet)

   Very Rare   Rare   Medium Rare   Medium   Well Done   Very Well

7. Circle is this meat was the main course on the plate, was it combined with other ingredients as the main course or was it a side dish?

   Main course on plate   Combined with other ingredients   Side dish

8. Which of these did you add to the meat at the table before you ate? (Please select as many as apply)
   - ☐ Nothing: ate it plain
   - ☐ Nothing: it was cooked in sauce
   - ☐ Salt
   - ☐ Pepper
   - ☐ Other dry seasonings
   - ☐ Ketchup
   - ☐ Other sauces such as soy sauce, BBQ sauce, A-1, etc
   - ☐ Other (Explain) _______________________

IRB NUMBER: IRB2016-0420M
IRB APPROVAL DATE: 10/06/2016
IRB EXPIRATION DATE: 07/15/2021

Respondent Number_________ Date meat was consumed _______
Sample Number ____________ Order ______________________

9. How much do you like or dislike the COOKED APPEARANCE of this meat?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely	Neither Like or Dislike	Like Extremely

10. How much do you like or dislike this meat OVERALL of this meat?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely	Neither Like or Dislike	Like Extremely

11. How much do you like or dislike of the OVERALL FLAVOR of this meat?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely	Neither Like or Dislike	Like Extremely

12. How much do you like or dislike of the OVERALL TEXTURE of this meat?

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Dislike Extremely	Neither Like or Dislike	Like Extremely

13. Please write any words that describe what you LIKE about this meat.
____
____

14. Please write any words that describe what you DISLIKE about this meat.
____
____