THESIS

INFLUENCE OF POST-MORTEM AGING TIME AND METHOD ON FLAVOR AND TENDERNESS OF BEEF, AND COMPARISON OF RETAIL CUTTING YIELDS, TIMES, AND VALUE IN THIRTEEN BEEF SUBPRIMALS FROM BEEF AND HOLSTEIN CATTLE

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ABSTRACT

INFLUENCE OF POST-MORTEM AGING TIME AND METHOD ON FLAVOR AND TENDERNESS OF BEEF AND COMPARISON OF RETAIL CUTTING YIELDS, TIMES, AND VALUE IN THIRTEEN BEEF SUBPRIMALS FROM BEEF AND HOLSTEIN CATTLE

The objective of this study was to identify flavor and tenderness differences in beef aged for different lengths of time and using different methods. Strip loin sections from commodity, USDA Choice beef carcasses (n = 38) were randomly assigned to 1 of 8 aging treatments: 1) 3 d wet-aged; 2) 14 d wet-aged; 3) 28 d wet-aged; 4) 35 d wet-aged; 5) 49 d wet-aged; 6) 63 d wet-aged, 7) 21 d dry-aged; and 8) 14 d wet-aged followed by 21 d dry-aged (combination). Trained sensory panelists rated the cooked product for flavor and textural attributes, and samples were evaluated for Warner-Bratzler and slice shear force, fatty acid composition, amino acid composition, and volatile flavor compounds. Wet-aging of beef up to 35 d caused no changes ($P > 0.05$) in flavor notes. However, beef wet-aged for 49 d or longer was rated lowest ($P < 0.01$) for the attribute of beef flavor ID and greatest ($P \leq 0.02$) for metallic, sour, oxidized, nutty, musty/earthy, and liver-like. No differences ($P > 0.05$) were identified between wet-aging, dry-aging, or the combination of both for any flavor attributes. Fatty acid profiles did not differ ($P > 0.05$) by aging length of time or method. Concentrations of amino acids and volatile flavor compounds increased ($P < 0.01$) during the wet-aging period, but minimal differences in these compounds were noted between wet- and dry-aged beef. Additionally, beef that was wet-aged for 3 d was toughest ($P < 0.01$). Nonetheless, tenderness improvement only occurred up to 28 d of wet-aging, where no subsequent differences ($P > 0.05$) were noted. Results suggested that wet-aging to extreme lengths of time may have a dramatic effect on flavor profile of beef,

without necessarily improving tenderness. Additionally, eating quality characteristics do not necessarily differ between wet- and dry-aged beef.

Holsteins comprise approximately 20% of the U.S. fed beef slaughter, and the carcass characteristics of Holsteins tend to differ (on average) from those of traditional beef breeds. Retail cutting yields, cutting times, and resulting value were evaluated in thirteen subprimal cuts from carcasses of fed Holstein (n = 398) and beef-breed (n = 404) origin. Generally, subprimals from carcasses of beef-breeds were heavier ($P < 0.05$) than those derived from Holsteins. Greater ($P < 0.01$) saleable yields of retail cuts were noted for ribeye rolls, short loins, and inside rounds (individual muscle) from carcasses of Holsteins, and bottom round flats from carcasses of beef-breeds. Saleable yields of all other subprimal cuts did not differ ($P > 0.05$) between cattle types. Only the amount of time taken to cut center-cut top sirloin butts derived from beef-breeds were faster ($P < 0.01$) than those for cuts from carcasses of Holsteins; in all other instances, times for cutting subprimals derived from Holstein carcasses were either faster ($P < 0.05$) or not different ($P \geq 0.05$). Retail prices among cuts from differing breed types were minimal, but true differences ($P < 0.05$) in cutting yields for ribeye rolls and short loins from carcasses of Holsteins may generate greater values to a steak cutter or retailer. Such advantages could be attributed to smaller, more manageable, and leaner cuts produced from carcasses of Holsteins. Therefore, further research regarding retail cutting differences between cattle types may provide insight for operations seeking maximum retail yields and profit.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

REVIEW OF LITERATURE

POSTMORTEM AGING AND EATING QUALITY ATTRIBUTES

Beef Consumption and Eating Quality

Beef seems to satisfy consumer demand for a nutritional product that delivers a positive eating experience. As consumers earn greater income, they are more likely to increase their consumption of higher-quality proteins, and particularly meat. The importance of eating satisfaction is recognized as indicated by consumer willingness to pay (Feuz et al., 2004) . While often associated with taste, other contributing factors to the eating quality of meat include animal welfare, price, and country of origin (Thorslund et al., 2016). Production time, limited resources, and high-cost inputs make high-quality beef one of the most expensive proteins commonly available in the market. Competing proteins, such as poultry and pork, are significantly cheaper, easier to prepare, convenient, and more universally dependable. Thus, extensive research has been conducted to maintain the integrity and consistent deliverability of beef quality, addressing eating satisfaction traits evaluated by consumers: tenderness, flavor, and juiciness. Aaslyng and Meinert (2017) proposed that future meat consumers will focus purchasing decisions heavily on meat flavor, and distinct and potentially customized flavors will have demand in the market. While tenderness was once considered a major challenge in the beef industry, flavor has recently been identified as more important to markets closely related to the consumer (Igo et al., 2014). Therefore, attempts to deliver characterized flavors in the interest of repeat consumer purchases are warranted in the beef supply chain. Post-mortem aging of beef has been extensively studied and serves as just one of many factors contributing to eating quality and consumer satisfaction

(Spanier et al., 1997; Jeremiah and Gibson, 2003; Sitz et al., 2006; Laster et al., 2008; Smith et al., 2008; O'Quinn et al., 2016).

Post-Mortem Aging

The ability to store beef before its consumption is central to the U.S. beef distribution chain. Convenience and economic factors associated with stored meat have led merchandisers to realize enhanced eating quality profiles for aged product. Postmortem aging improves consistency of beef quality, and specifically tenderness (Tatum et al., 1999). Flavor attributes also have been affected by the length and method by which meat is aged (Spanier et al., 1997; Jeremiah and Gibson, 2003; Sitz et al., 2006). Two methods of aging, wet or dry, are practiced in industry. Invention of vacuum packaging by Grinstead (1952) made wet-aging the most popular and commonly used aging method used today due to significant improvements in food safety, product appearance, and convenience. Alternatively, dry-aging requires an open-air, controlled environment and is much more management intensive, contributing to its presence mostly in niche markets. Consequently, "aged beef" has positive implications for consumers. It often garners a premium on high-end restaurant menus around the world.

Extensive research has been conducted evaluating the effects of aging on flavor and sensory characteristics. However, the impact of aging on beef flavor have not always been consistent in the literature, particularly in the comparisons of wet- vs. dry-aging. Previous work by Spanier et al. (1992) showed that, while vacuum packaging retards off-flavor development, it does not completely stop the process, and loss of desirable flavor characteristics still occurred. Flavor generally remains unchanged early postmortem, and up to 35 d postmortem in some studies (Minks and Stringer, 1972; Jeremiah and Gibson, 2003; Bruce et al., 2005; Laster et al., 2008; Lepper-Blilie et al., 2016). However, prolonged aging is reported to produce flavor notes

typically characterized as undesirable off-flavors, such as livery (Campo et al., 1999; Jeremiah and Gibson, 2003; Yancey et al., 2006). Development of these off-flavors compromises desirable beef flavor attributes, and leads to an inverse relationship between extended aging length and flavor integrity (Van Ba et al., 2012; Lepper-Blilie et al., 2016; O'Quinn et al., 2016). Dry-aged beef is marketed under claims of "buttery and rich," "superb in taste and texture," "superior in taste and tenderness," "mellow and intense," and "earthy and nutty" (Savell, 2008). Still, discrepancies exist in the characterization of dry-aged beef flavor. Some studies showed higher intensities for beef flavor and browned/roasted flavor for dry-aged beef (Warren and Kastner, 1992; Campbell et al., 2001; O'Quinn et al., 2016), while others did not discern flavor differences between wet- and dry-aging (Parrish et al., 1991; Jeremiah and Gibson, 2003; Sitz et al., 2006; Laster et al., 2008; Smith et al., 2008). In a review of the scientific literature addressing dry-aging of beef, Savell (2008) noted variable parameters for air flow, temperature, days of aging, and relative humidity. This suggested that flavor differences between wet- and dry-aged beef, or lack thereof, may be highly related to environmental conditions. Additionally, the amount of marbling in dry-aged cuts may affect the extent to which the process influences sensory attributes. Typically, dry-aging is performed on cuts of higher quality, upper two-thirds USDA Choice or better. Lepper-Blilie et al. (2012) concluded dry-aging of beef with less than a Sm^{50} level of marbling results in inconsistent flavor enhancement and should not be considered. Therefore, further research is needed to better understand the contribution of a variety aging parameters to the flavor profile of beef.

Tenderness has long been a significant challenge in the beef industry, and consumers place a great deal of influence on tenderness to determine acceptability and overall eating satisfaction of beef (Huffman et al., 1996). Significant research has been conducted in attempt to

maximize tenderness of the beef supply, and postmortem aging has been identified as a major contributor to combatting tenderness inadequacies (Minks and Stringer, 1972; Warren and Kastner, 1992; Jeremiah and Gibson, 2003; Gruber et al., 2006). Postmortem aging time has the greatest effect on tenderness, due to protein degradation, and generally, longer wet-aged beef is more tender. The greatest tenderness improvements have been noted early in the aging period, within 7 d postmortem (Minks and Stringer, 1972; Bruce et al., 2005). In an effort to understand how even low quality beef can be upgraded for consumer acceptability, Gruber et al. (2006) explained that over 95% of the aging response for *M. Longissimus dorsi* was completed by 15 d for upper two-thirds USDA Choice and 26 d for USDA Select. This suggests the role of postmortem aging in equilibrating the tenderness profile of meat from different quality grades. Aging method, wet or dry, has been shown to have minimal to no effect on tenderness (Warren and Kastner, 1992; Sitz et al., 2006; Laster et al., 2008; Lepper-Blilie et al., 2016).

Despite compositional changes in meat during the aging period, juiciness generally has been minimally affected by length of aging time or method. Dry-aging contributes to greater cooler shrink than wet-aged product (Parrish et al., 1991; Laster et al., 2008; Smith et al., 2008). This, along with the formation of external crust which must be trimmed prior to consumption, makes dry-aging costly to operations who are not able to assume these inefficiencies. Dikeman et al. (2013) showed that dry-aged steaks had lower moisture content than those wet-aged. This suggested dehydration in the dry-aging process may contribute to decreased juiciness. However, several studies have found aging time to have no influence on juiciness (Minks and Stringer, 1972; Parrish et al., 1991; Sitz et al., 2006; Laster et al., 2008; Smith et al., 2008).

The remainder of this section of the review will evaluate palatability attributes affected by post-mortem aging in attempt to better understand how post-mortem aging can be used to manipulate the sensory profile of beef, particularly with respect to flavor.

Flavor & Flavor Development

Flavor is a perceived sense, attributed to aroma and the basic tastes (salty, sweet, sour, bitter, and umami) experienced during consumption of food. Raw meat has a mild aroma and blood-like flavor (Idolo Imafidon and Spanier, 1994; Stetzer et al., 2008). However, when meat is heated, precursor compounds give rise to a matrix of odors and flavors sensed by the taste buds and olfactory bulb (Brewer, 2007). Two primary reactions in the cooking process contribute to this occurrence: 1) the Maillard reaction between water-soluble components, and 2) the thermal degradation of lipids (Idolo Imafidon and Spanier, 1994; Mottram, 1998). Although not a focus of this review, additional flavor precursors in meat include: peptides, nucleotides, salts, acids, minerals, and thiamin (Idolo Imafidon and Spanier, 1994; Dashdorj et al., 2015). Over 1,000 volatile flavor compounds are generated by these processes, but only some of these play pertinent roles in the ultimate flavor of meat (Idolo Imafidon and Spanier, 1994). Aldehydes and ketones are primarily generated from thermal lipid oxidation, and heterocyclic compounds are main products of the Maillard reaction (Farmer et al., 1999). Furthermore, volatile organic compounds generated from bacterial populations during meat spoilage have been identified in work by Casaburi et al. (2015), further complicating the number of mechanisms which give rise to flavor (Table 1.1). Given a myriad of precursor compounds contribute to the composition of meat and flavor, one specific compound cannot be singly attributed to a flavor profile, making for a complex understanding of the process behind flavor development. Furthermore, cooking method, cooking temperature, breed type, and diet contribute to this complexity (Idolo Imafidon

and Spanier, 1994; G Koutsidis et al., 2008).Mottram (1998) simplified the matter, suggesting the lipid portion of meat provides species-specific differences in flavor, and the lean portion (or water soluble constituents) provides a characteristic meaty flavor and aroma. Both portions have been shown to interact with each other and their synergistic action is essential to aroma development (Mottram and Edwards, 1983). Consideration of the multitude of compounds associated with flavor development is important to understanding how practices, such as post-mortem aging, might affect a flavor profile.

Lipids

Lipid fraction of meat consists of triglycerides and phospholipids, both of which liberate free fatty acids during proteolysis and lipolysis (Toldra´, 1998). Phospholipids supply lipid for aroma development, while triglycerides play a more limited role (Mottram and Edwards, 1983). Lean tissue of meat, and intramuscular fat, contains phospholipids as a structural component, so subcutaneous fat is not necessary to impart flavor changes during cooking (Mottram, 1998). Unsaturated fatty acids derived from this phospholipid portion are especially prone to autooxidation and, as a result, significantly contribute to meat flavor differences among species (Mottram, 1998). For example, short, branched chain unsaturated fatty acids found in sheep meat have been shown to contribute to pungent and undesirable flavors in cooked mutton (Wong et al., 1975). Differences in digestive systems contribute to different fatty acid profiles among ruminants and non-ruminants. Pork and poultry meat is comprised of a greater amount of polyunsaturated fatty acids than beef or lamb (Calkins and Hodgen, 2007). Oleic acid (C18:1) is the most abundant fatty acid in beef, and it is associated with characteristic cooked beef fat aroma and flavor (Melton et al., 1982). Additional factors affecting fatty acid profiles of meat include animal diet, breed type, and genetics (Melton et al., 1982; Gorraiz et al., 2002), and

cooking method (Legako et al., 2015).When meat is cooked, lipid acts as a solvent to disperse volatile flavor compounds (Moody, 1983).

The instability of fatty acids, and particularly those unsaturated ones, readily lend them to degradation by oxidation. Lipid oxidation can be best described in three phases: initiation, propagation, and termination (Frankel, 1980). Initiation is the removal of hydrogen from an organic substrate, creating a free radical, when activated by light, heat, or metal. In the propagation step, a free radical reacts with oxygen to form a peroxy radical, which further reacts with organic substrate to generate hydroperoxides and free radicals. Termination proceeds when two peroxy radicals combine to form non-radical products. Exposure of fatty acids to heat provides sufficient environment for oxidation to proceed. Consequently, an understanding of meat composition, and fatty acids in this case, can provide insight to flavors generated during cooking.

Thermal degradation of lipids generates aldehydes, alcohols, ketones, hydrocarbons, esters, and carboxylic acids, all contributors to meat flavor (Mottram, 1998). However, aldehydes are suggested to be most responsible for species-to-species differences (Mottram, 1998). Hexanal, 2(Z)-octenal, 2(E)- nonenal, 1-octen-3-ol, and 1-octen-3-one have been identified as the most pronounced volatile flavor compounds in the autoxidation of linoleic acid (C18:2), another unsaturated fatty acid commonly associated with beef (Ullrich and Grosch, 1987). Hexanal has been identified as a major volatile product of lipid oxidation from unsaturated fatty acids and shown as an indicator of oxidative stability, paralleling thiobarbituric acid (TBA) values in ground pork (Shahidi et al., 1987b). Further, livery and off-flavor notes have been linked to lipid oxidation products pentanal, hexanal, hexanol, 1-octen-3-ol, and nonanal (Hodgen et al., 2006; Yancey et al., 2006; Calkins and Hodgen, 2007).

The effect of postmortem aging on volatile flavor compounds elicited from fatty acid oxidation is not well understood, and minimal work evaluating fatty acid profiles of wet- and dry-aged meat has been reported. Those compounds associated with lipid oxidation, such as nonanal, 2,3-octanedione, pentanal, 3-hydroxy-2-butanone, 2-pentyl furan, 1-octen-3-ol, butanoic acid, pentanal and hexanoic acid, have been shown to increase with aging (Stetzer et al., 2008). Generally, hydrocarbons are products of lipid oxidation, which may lead to rancid off-flavors during long-term storage (Mottram, 1998). However, unsaturated hydrocarbons have the highest odor thresholds compared of all hydrocarbons (Champagne and Nawar, 1969), and it has been suggested that these compounds minimally contribute to meat flavor (Shahidi et al., 1987a). Ismail et al. (2008) showed that lipid oxidation by TBARS analysis increased over a 3 week aging period. But, lipid oxidation also has been reported to be much slower in vacuum packaged meat (King et al., 1995). Beef vacuum aged for 47 d has been shown to have similar TBARS concentrations to beef aged for 1 d (Yang et al., 2002). O'Quinn et al. (2016) found no differences in fatty acid profiles for beef wet-aged 14 d and 46 d, suggesting lack of lipid oxidation during aging. Discrepancies may be related to the weakness of malondialdehyde as the sole indicator of lipid oxidation (Meagher and Fitzgerald, 2000).

Water-Soluble Compounds

In an extensive review on meat flavor, Dashdorj et al. (2015) identified a multitude of compounds impacting flavor and diagrammed actions of water-soluble precursors (Table 1.2). Although numerous reactions and compounds affect meat flavor, amino acids and sugars will be the primary focus of this review. As a result of the Maillard reaction, total quantities of amino compounds and sugars decrease when meat is heated (Macy et al., 1964), and these water soluble precursor compounds contribute significantly to the aroma of cooked beef (Wasserman and

Gray, 1965). Certain precursor compounds have been shown as limiting factors for flavor development, suggesting variability in meat composition can affect flavor (Farmer et al., 1999). Initial steps of the Maillard reaction produce Amadori compounds, but it is subsequent processes, particularly those where amino acids are degraded by carbonyl compounds known as Strecker degradation, that provide the compounds contributing to aroma in cooked meat (Mottram, 1998). The steps and products of the Maillard reaction, including Amadori rearrangement and Strecker degradation, have been previously reviewed by Van Boekel (2006), and a depiction of the process taken from this review is shown in Figure 1.3.

Many volatile compounds are important in the formation of meat flavor. Sulfur-compounds generated from the reaction of cysteine and ribose are especially important for characteristic meat aroma (Mottram, 1998). These reactions have been attributed to the formation of pyrazines, responsible for aromas such as meaty and roasty (Tai and Ho, 1997). Sulfur-containing volatiles have low odor thresholds, so even minute amounts can have significant implications on flavor (Wasserman, 1979). Thiols and disulfides have been identified as contributors to the meaty aroma in meat and are thought to be the result of thermal degradation of sulfur containing amino acids (Mottram, 1998). Content of 2-methyl-3-furanthiol (MFT) has been reported highest in beef compared to other species (Kerscher and Grosch, 1998), and oxidation of MFT to disulphide gives an ‘aged beef’ aroma (Rowe, 2002).

Postmortem aging has an influence on water soluble components of meat. Enzymatic activity, and specifically the action of aminopeptidases, in postmortem muscle is responsible for degradation of amino acids through glycolytic or oxidative pathways (Aristoy and Toldrá, 1998).This degradation has been shown to affect flavor, as amino acids released from these peptidases are major contributors to flavor, including rancid, sour, and salty (Toldrá and Flores,

2000). G. Koutsidis et al. (2008) showed amino acids to increase during aging but only after 7 d, and sulfur-containing amino acids, cysteine and ribose, were relevant to flavor development in meat aged past 21 d (G. Koutsidis et al., 2008). Thus, reducing sugar and free amino acid composition of meat contributes to flavor differences in aged meat.

Bacterial Metabolism

Fresh meat provides sufficient environment for growth of microorganisms which may contribute to meat spoilage. These microorganisms are able to utilize meat precursors, such as sugars and amino acids, as food sources, which may alter the composition of meat and eleicited flavors and flavor compounds. An exhaustive review of these processes in meat spoilage has been completed by Casaburi et al. (2015). Factors affecting growth of these microbial spoilage organisms, and the volatile compounds they produce, include storage time and method. While hundreds of studies have evaluated the volatile compounds produced by bacteria during storage, few have analyzed flavors imparted to fresh meat and made the connection to bacteria. Exogenous enzymes from microbial origin have been shown to contribute to altered falvor in dry-fermented sausages (Toldra´, 1998). Aging time and loss of beef quality have been related to increases in 2,3,3-trimethylpentane, 2,2,5-trimethylhexane, 3-octene, 3-methyl-2-heptene, 2-octene, and 2-propanone, as well as increases in *Enterobacteriaceae* and APC counts (Insausti et al., 2008). Joffraud et al. (2001) identified how some bacterial strains in cold smoked salmon were directly realted to volatile compounds and aroma development.

Tenderness

Tenderness can be described as the amount of pressure exerted on a piece of meat for mastication. Postmortem changes in the conversion of muscle to meat have a profound influence on meat tenderization. After exsanguination, anaerobic metabolism contributes to significant

changes in the intracellular matrix of the muscle cell, and meat toughening occurs during the first 24 h postmortem as a result of rigor-induced sarcomere shortening (Koohmaraie, 1996). Weakening of structural muscle cell components follows, as a result of protein degradation and oxidation (Huff Lonergan et al., 2010). Ouali et al. (2006) described the process of meat tenderization by 3 systems: 1) cathepsins; 2) calpains; and 3) proteasomes.

Cathepsins are organelle bound enzymes and must be released from lysosomes to impede a degradative effect on myofibrils (Ouali et al., 1987; Koohmaraie et al., 1988). Thirteen lysosomal peptide hydrolases have been identified, but only 7 are found in muscle: cathepsin A, B, C, D, H, L, and lysosomal carboxypeptidase (Goll et al., 1983). The pH of meat (approximately 5.6) is most suitable for optimal activity of cathepsins D, B, and L (Chéret et al., 2007). The role of cathepsins in postmortem aging of meat has been somewhat discredited. Dransfield et al. (1992) found no change in lysosomal proteinases between electrically stimulated and non-stimulated beef during the first 24 h postmortem, when most changes in tenderness are found to occur. Hopkins and Thompson (2002) also reported cathepsins play little to no role in the tenderization early in aging. However, lysosomal integrity weakens with advanced aging (Zeece et al., 1992). Calkins and Seideman (1988) demonstrated associations between aging response, tenderness, and cathepsins B and H. Cystatins act as inhibitors in the cathepsin system (Zeece et al., 1992). Yet, cystatin activity has been shown to have minimal influence on cathepsins during aging (Shackelford et al., 1991), further downplaying the enzymatic activity of cathepsins and underpinning their limited role on tenderness in the aging period.

Paramount and claimed most influential to protein degradation is the system of calpains. These calcium-dependent, cysteine proteases exist in two forms delineated by calcium

concentrations required for enzymatic activity: 1) μ-calpain (requires micromolar concentrations of calcium), and 2) m-calpain (requires millimolar concentrations of calcium). The calpain molecule is comprised of a 28kDa and 80kDa subunits which contain amino acid sequences and serve as the binding sites for calcium (Goll et al., 2003; Huff Lonergan et al., 2010). μ-Calpain serves as the primary enzyme responsible for protein degradation and tenderization (Geesink et al., 2006) and is reported to contribute to 65-80% of postmortem tenderization within 72 h postmortem (Taylor et al., 1995). Costameres, and constituent proteins desmin and vinculin, as well as titin and nebulin, provide excellent substrate for the calpain system; therefore, myofibril activity is most compromised in the I-band and thin filament/Z-disk interaction, with less of a direct effect at the actual Z-disk (Taylor et al., 1995). Endogenous cellular calcium causes calpains to undergo autolysis, and Koohmaraie (1992) described only μ-calpain to lose activity in postmortem storage while m-calpain remains stable. Kauffman et al. (1964) found tenderness advantages in higher pH meat. Lower temperature increases rate of autolysis in calpains, while lower pH has an inverse relationship (Koohmaraie, 1992). Much like cystatin inhibits cathepsin, calpastatins are the inhibitors of calpain. Additionally, caspases have been shown to play a role in the calpain system, where they contribute to degradation of calpastatins and are responsible for apoptosis (Kemp et al., 2009).

After action of calpains subsides due to complete autolysis, enzymatic activity by proteasomes may intervene and remain high after death, affecting tenderness (Lamare et al., 2002). Proteasomes have been shown to have activity after 7 days or more of postmortem aging, with no effect on myofibril degradation (Thomas et al., 2004). The action of these proteasomes was suggested by Robert et al. (1999) to be synergistic with the calpain system, where large proteins, or slightly denatured myofibrils degraded by calpains, act as substrates to be

hydrolyzed into smaller peptides by proteasomes. Oxidized proteins are reported to be degraded by 20S and 26S proteasomes, which do not require ATP to function (Davies, 2001).

Juiciness

Juiciness is a contributing factor to the textural properties of meat, including tenderness, and can be described as the amount of moisture exuded from a piece of meat upon mastication. Muscle is primarily comprised of water (approximately 75%), and water may be located in 3 spaces of muscle ultrastructure: 1) within the myofibril; 2) the intracellular space between myofibrils; or 3) extracellularly between muscle bundles (Huff-Lonergan and Lonergan, 2005). Proteins, such as desmin, which tie the myofibril to the cell membrane may be degraded rapidly postmortem, resulting in increased cell shrinkage and persistence of water within the intracellular space, reducing drip loss (Huff-Lonergan and Lonergan, 2005). Because activation of proteolytic enzymes is directly related to environmental conditions, pH contributes greatly water-holding capacity (WHC). During the aging period, pH has been shown to increase in vacuum packaged meat up to 16 days (Boakye and Mittal, 1993). Thus, proteolytic enzymes may indirectly responsible for increased WHC of aged meat, as degradation of structural components allows intracellular water to "leak" into the extracellular space.

IMPACT OF FED HOLSTEIN CATTLE ON THE RETAIL MEAT INDUSTRY

Calf-Fed Holstein Steers

Holstein cows represent 86% of the 9.3 million U.S. dairy cow population (USDA, 2012; USDA, 2014a), and fed Holstein steers and heifers constitute a significant portion of the U.S. fed beef supply. Estimates from the National Beef Quality Audit in 2016 suggested that fed Holstein cattle comprise 20.4 percent of the U.S. fed beef slaughter, up from 5.5 percent since 2011

(National Cattlemen's Beef Association, 2016). An understanding of the beef and dairy cowherds provides insight to differences in these two production systems, as 49% of the dairy cowherd, and only 8% of the beef cowherd, are located on operations of 1,000 head or more (USDA, 2012). This, combined with the extensive use of artificial insemination, suggests sameness across the dairy genetic pool. Consequently, the U.S. dairy cattle population, and fed Holstein steers and heifers, are a consistent supply, contributing to significant marketing opportunities, whether that be of meat or milk.

Production management strategies for fed Holstein cattle greatly impact the resulting product. Traditionally, weaned Holstein calves were backgrounded on a forage-based diet, like the native beef steer, before being placed in a feedlot. However, once fed a high-concentrate diet, these calves assume significant compensatory growth, especially due to the innate large frame size of the breed. For common in-weights of approximately 340 kilograms, out weights of an average of 599 and 572 kilograms were achieved for Holstein and beef steers, respectively, demonstrating the weight differential when managing the two cattle types (Rust and Abney, 2005). Many times, additional days on feed and genetics allow Holsteins to exceed live weights of 1500 pounds. Packers and retailers alike face challenges processing and marketing beef from excessively large animals, such as the conventionally-fed Holstein. Tall framed animals are prone to bruising during transport and subsequent product loss on the harvest floor. Extremely long carcasses may be contaminated and require trimming during harvest. Extra-large subprimals are difficult to conform to a standard sized box, and targeted portion sizes of steaks and roasts may be difficult to obtain due to oblong and large muscle sizes (particularly *M. Longissimus dorsi*), resulting in cuts of decreased thickness. These challenges make the Holstein less

desirable to the feeding industry, who may be penalized by packers or faced with challenges marketing conventionally-raised, finished Holsteins in the first place.

Management of Holsteins with respect to feeding strategy and a market end-weight goal has been shown to maximize economic return (Chester-Jones and DiCostanzo, 1996). The calf-fed model generates a more desirable animal and marketable product to meet industry specifications. Once weaned, calves (approximately 300 pounds) are immediately placed in the feedlot, fed a primarily concentrate-based diet, and finished at approximately 1250 pounds (Rust and Abney, 2005). Holstein steers require more days on feed (approximately 300) and assume a greater feed-to-gain rate than beef cattle to achieve a marbling amount equivalent to USDA Choice (Perry et al., 1991). While lighter weight Holstein calves require more days on feed, their cost of gain is improved to that of heavier weight counterparts and even comparable to beef steers (Rust and Abney, 2005). Holstein calves may need to be managed differently from beef calves to maximize efficiency and produce an acceptable end-product, and the calf-fed model overcomes significant challenges associated with feeding Holstein cattle.

With predominant emphasis on milking ability, Holsteins exhibit carcass characteristics that differ from those of native beef animals, especially when red meat yield is considered. Selection for body volume, frame size, and milking capacity has shifted development of the Holstein frame and body type away from an emphasis on muscle accretion. Dairy carcasses are naturally lighter muscled than beef counterparts and contain a greater proportion of bone (Branaman et al., 1962; McKenna et al., 2002). Consequently, Holsteins generate a carcass with a lower muscle-to-bone ratio relative to native beef cattle (Lawrence et al., 2010). This, combined with greater gut fill, results in 2-4% lower dressing percentage in Holsteins compared to beef breeds (Rust and Abney, 2005). Even though consumers have been shown to not

differentiate steaks from beef and Holstein animals (Thonney et al., 1991), the muscling of a dairy type carcass can be characterized by a triangular shaped ribeye muscle (*M. Longissimus dorsi*), less desirable to a retail and foodservice scene accustomed to a symmetrical shape. Furthermore, increased days on feed may be attributed to an increased incidence of liver abscesses, and subsequent condemnation, in Holsteins (Reinhardt and Hubbert, 2015). Many of these disadvantages make packers only willing to purchase Holsteins at a significant discount to the beef market, all of which may not entirely be warranted given the value of cutability attributes in the marketing system (Cross and Savell, 1994). In many countries, Holstein calves not destined to make herd replacements, including many bull calves, are killed at birth, which most definitely indicates inefficiencies in the production system and need for recognition of value in beef from Holstein cattle.

Management practices of the "correct" Holstein can provide advantages to beef breeds and a quality product. Dairy carcasses are significantly leaner, with less subcutaneous fat compared to carcasses of beef-type cattle; yet, they also contain a greater amount of kidney, pelvic, and heart fat, the result of fat partition differences among cattle types (McKenna et al., 2002). Smaller ribeye sizes, coupled with feeding time, allow Holsteins to deposit a greater percentage of intramuscular fat, generating a greater quality grade (McKenna et al., 2002), and thus, enhancing palatability characteristics (Smith et al., 1984; Garmyn et al., 2011; Emerson et al., 2013). Comparisons of Holstein steaks to beef-breed may suggest advantages in tenderness and flavor for Holstein (Thonney et al., 1991; Abney, 2004). Moreover, increased hot carcass weights over the last 10 years (National Cattlemen's Beef Association, 2016) have presented packers with challenges of large subprimals, and retailers with large, thin-cut steaks. In this case, the small ribeye size from a calf-fed Holstein works to the steak cutter's advantage. Furthermore,

use of beta-agonists has been shown to increase subprimal yield and saleable yield in Holsteins, particularly in the round, and suggests Holstein steers may be more sensitive to beta-agonist use than beef breeds (Boler et al., 2009; Howard et al., 2014). Advantages of feeding beta-agonists to Holsteins are primarily realized in the conversion of carcass-to-subprimal as opposed to subprimal-to-retail conversion (Haneklaus et al., 2011). Challenges in product produced from Holstein carcasses are primarily derived from feeding management. Therefore, minimization of these challenges through the correctly managed Holstein may allow producers to capitalize on value from the advantages of Holstein beef.

Retail Cutting

Since the National Consumer Retail Beef Study in the 1980's indicated the importance of lean beef to the consumer, retailers responded by minimizing trim levels of products (Cross et al., 1986; Cross and Savell, 1994). The historical premise of selling meat on a weight basis led to need for butchers to maximize yield in every way possible. Therefore, an understanding of raw materials and how to maximize their yield and ultimate value through cutting is pertinent. Unlike large packers who can process tallow, beef fat is of little to no value to small processors, and bone shares a similar relationship. Leaner incoming subprimals give cutters a greater opportunity to maximize yield and generate more closely trimmed cuts desirable to the consumer.

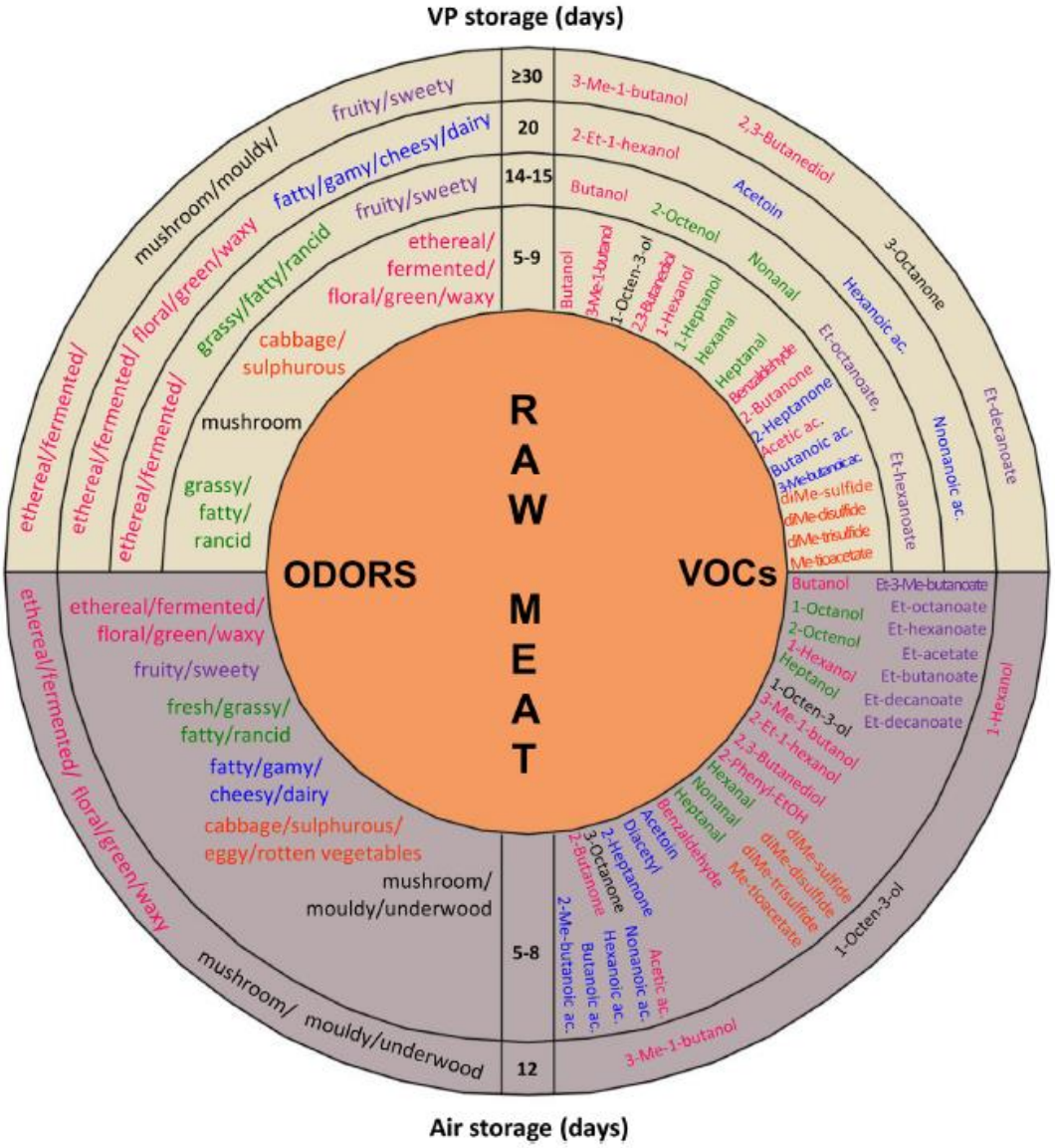

Figure 1.1. Meat spoilage aroma wheel from Casaburi et al. (2015).

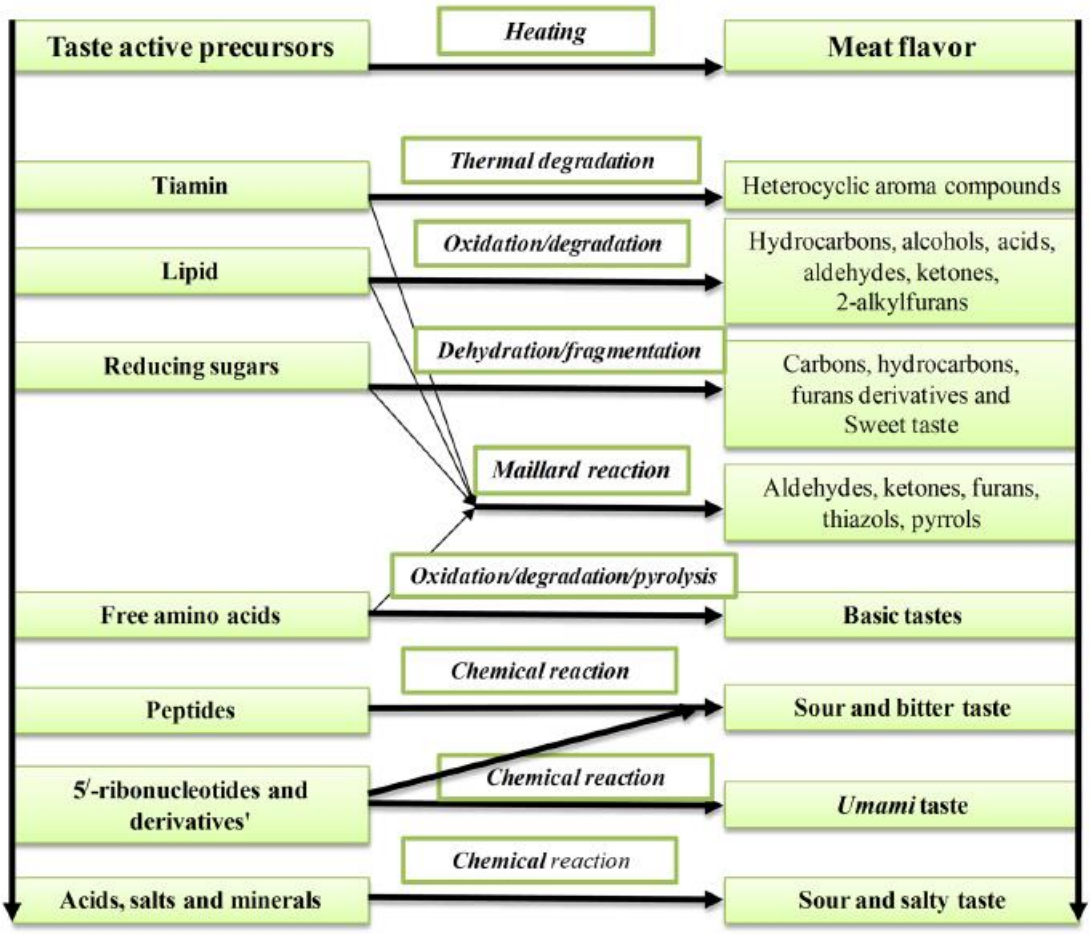

Figure 1.2. Water-soluble precursors and their mode of action to produce specific flavors (Dashdorj et al., 2015).

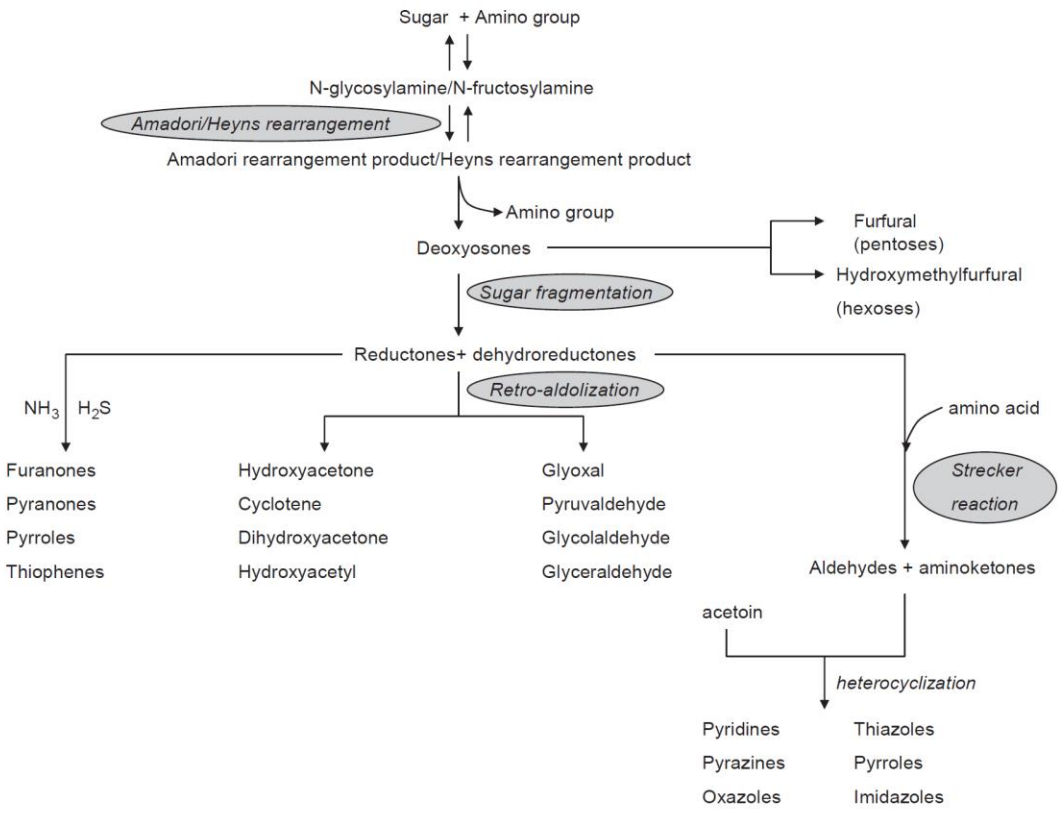

Figure 1.3. The general progression of the Maillard reaction and its products (Van Boekel, 2006).

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CHAPTER II

INFLUENCE OF POST-MORTEM AGING TIME AND METHOD ON FLAVOR AND TENDERNESS OF BEEF

SUMMARY

Sensory and compositional changes were evaluated in beef aged to different lengths of postmortem aging time (3 d to 63 d) and using different methods (wet- and dry-aging). Beef wet-aged longer than 35 d was associated with appreciable increases in off-flavor notes, such as sour and oxidized. Additionally, volatile flavor compounds and amino acids increased during the aging period and were likely responsible for flavor changes. Fatty acid analysis indicated lipid oxidation was negligible in aged beef. Tenderness (slice shear force, Warner-Bratzler shear force, and sensory evaluation) improved in wet-aging up to 28 d, with no subsequent response to aging. Aging method did not greatly influence the composition or sensory profile of beef. Therefore, extreme aging lengths may deteriorate the flavor profile of beef without improving tenderness. Further work should identify mechanisms behind the compositional changes in aged beef contributing to altered flavor profiles, such as microbial growth.

INTRODUCTION

Postmortem aging of beef is widely accepted to enhance eating quality characteristics. It is well-established that aging improves tenderness. However, there persists disagreement in the literature about the consequences of aging on beef flavor (Warren and Kastner, 1992; Idolo Imafidon and Spanier, 1994; Campbell et al., 2001; Sitz et al., 2006; Laster et al., 2008; Smith et al., 2008). Postmortem aging may be completed by utilizing: 1) wet-aging, where meat is stored

in a vacuum package, or 2) dry-aging, where beef is held in a controlled environment, with high humidity and adequate air flow. Beef is most commonly vacuum packaged for efficient distribution. However, dry-aging has found a popular presence in niche markets, even though yield loss makes the process quite expensive. Dry-aged beef is marketed under claims of "buttery and rich," "superb in taste and texture," "superior in taste and tenderness," "mellow and intense," and "earthy and nutty" (Savell, 2008). Consumers who prefer enhanced flavor profiles imparted by a particular aging method are willing to pay more for this eating experience (Sitz et al., 2006). Still, an acceptable level of tenderness impacts perception of other eating satisfaction attributes, including flavor (Feuz et al., 2004). Gruber et al. (2006) suggested that management of post-mortem aging time may result in similar tenderness from muscles of different quality grades. Therefore, when used appropriately, aging may allow establishments to improve raw materials and develop a product to capitalize on consumer preferences.

Aging has been shown to impact flavor characteristics through altered flavor compound profile analysis (King et al., 1995). Precursors to flavor compounds include fatty acids, reducing sugars, and free amino acids (Mottram, 1998). Furthermore, differences in fatty acid profiles in wet- and dry-aged beef have been previously related to intensity of individual flavor attributes (Gredell et al., 2018). Therefore, evaluation of aged beef composition may give insight to changes in eating quality characteristics influenced by different aging parameters. The aim of this study was to specifically identify the effect of aging time and method on flavor, flavor compound development, and tenderness.

MATERIALS AND METHODS

Institutional Animal Care and Use Committee approval was not required for this study as samples were obtained from a federally inspected harvest facility.

Sample Collection, Treatment Designation, and Fabrication

Pairs of boneless strip loins (Institutional Meat Purchase Specifications #180; NAMP, 2010) were collected from "A" maturity, commodity, USDA Choice beef carcasses (n = 38) of cattle harvested on the same day. Hot carcass weight (kg), fat thickness (cm), ribeye area (cm^2; longissimus muscle), and marbling score ($Small^{00}$ – $Small^{99}$) were recorded by trained individuals from Colorado State University (USDA, 1997; Table 2.1). Comparison of visual marbling within the longissimus between the 12th and 13th ribs was made using official USDA marbling photographs (National Cattlemen's Beef Association, Centennial, CO, USA). After collection, strip loins were transported under refrigeration (2°C) to the Colorado State University Meat Laboratory. On the same day as collection, each strip loin was fabricated into four- 9 cm sections, such that 8 sections per carcass were produced. Sections within each carcass were randomly assigned to 1 of 8 post-collection aging time and method treatments: 1) 3 d wet-age; 2) 14 d wet-age; 3) 28 d wet-age; 4) 35 d wet-age; 5) 49 d wet-age; 6) 63 d wet-age; 7) 21 d dry-age; and 8) 14 d wet-age followed by a 21 d dry-age (combination). Sections assigned to a wet-aging treatment were vacuum packaged and stored at 2°C for their respective aging period. Sections assigned to a to a dry-aging treatment (21 d dry-age and combination) were inoculated with Bactoferm 600 Mould (*Penicillium nalgiovense*; The SausageMaker Inc., Buffalo, NY, USA) to reflect commercial dry-aging practices. This was accomplished by emptying 25-g of dehydrated inoculum into 0.2 L of deionized water, holding at room temperature for approximately 12 h, and diluting into 10 L of deionized water. Sections were fully submersed in solution, immediately removed, and placed in a dry-aging cabinet open to air, with subcutaneous fat side up. Inoculation of sections assigned to combination aging was performed after wet-aging. No visible mold growth was observed for the duration of the dry-aging process. Yet,

viability of culture was confirmed by mold growth on tryptic-soy agar plates (Accumedia-Neogen, Lansing, MI, USA). Environmental conditions may be to blame for lack of mold growth. The dry-aging cabinet (Model CFD-2RR; Avantco Refrigeration, USA) was set to the minimum cooling setting (Carel Industries, Padova, Italy) and maintained at 3.1°C (Multitrip Green – Multi Use Temperature Data Logger; Temprecord International Ltd., Auckland, New Zealand) with 70-90% relative humidity (Model WH 1436K; Shenzhen Willhi Electronics Co., Ltd., Shenzhen, Guangdong, China) and continuous air flow (Model HT-90; Honeywell International Inc., El Paso, TX, USA). Sections were randomly relocated within the dry-aging cabinet at 14 d. Further, to capture yield loss, initial (before inoculation) and final weights were recorded for sections exposed to the dry-aging treatment (21 d dry-age and combination). Upon completion of their respective treatment, all sections were vacuum packaged (if not already) and placed in -20°C frozen storage.

To obtain steaks for analysis, frozen sections were faced on both sides to remove a thin slice (approximately 0.32 cm) and trimmed of external crust (if needed). Two- 2.54 cm thick steaks were cut from each end of each section and identified for sensory analysis and shear force, while the remaining middle steak was identified for chemical analysis. All steaks were trimmed of fat, connective tissue, and secondary muscles, such that only *M. longissimus lumborum* remained. Identified steaks were vacuum packaged and stored at -20°C until analysis.

Cooking Procedures

Frozen steaks identified for sensory and shear force analysis were tempered for 24 to 65 h at 2°C to attain a raw internal temperature of 0 to 4°C at time of cooking. Steaks were cooked at 204°C, 0% relative humidity, and default fan speed in a combi-oven (Model SCC WE 61 E; Rational, Landberg am Lech, Germany) on a grill grate (Model SCC WE 61 E; Rational,

Landberg am Lech, Germany) until a peak internal temperature of 71°C was measured, using a calibrated, type K thermocouple thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation, Middlefield, CT, USA) placed in the geometric center of each steak, and recorded. Steak temperature was monitored in the cooking process using an oven core temperature probe (Model SCC WE 61 E; Rational, Landberg am Lech, Germany) placed in the geometric center of the steak. To appropriately account for potential differences in cooking rates, steaks from wet-aging treatments were cooked separate from those including a dry-aging treatment.

Trained Sensory Analysis

Trained sensory analysis was conducted at Colorado State University. Flavor attributes associated with aged beef were evaluated using the lexicon developed by Adhikari et al. (2011). Panelists were trained to identify and quantify the following attributes: beef flavor ID; browned; roasted; metallic; fat-like; sour; oxidized; nutty; musty/earthy; liver-like; overall tenderness; initial juiciness; and sustained juiciness. A 15-point scale was used to objectively quantify the presence or absence of each flavor note (0 = none/not present, 2 = barely detectable, 4 = identifiable but not very intense, 6 = slightly intense, 8 = moderately intense, 10 = intense, 12 = very intense, 15 = extremely intense). Flavor attribute descriptors and training anchors are presented in Table 2.2.

Steaks were cooked, and temperatures were measured, according to aforementioned procedures. Immediately after cooking, each steak was vacuum packaged and held (no longer than 40 minutes) in a combi-oven (Model SCC WE 61 E; Rational, Landberg am Lech, Germany) set at 57°C, 100% humidity, and default fan speed until designated panel time. Samples were transferred to a circulating water bath (Fisher Scientific Isotemp Heated

Immersion Circulators: Model 6200 H24; Thermo Fisher Scientific, Waltham, MA, USA) set at 55°C until served.

Each steak was randomly assigned to 1 of 19 independent panel sessions, such that 16 steaks (2 from each treatment) were randomly fed during each panel. A minimum of 5 panelists evaluated samples per session. No panelist served on more than 2 panels per day, with a minimum of 1 hour between sessions. Panelists were seated in individual cubicles in a dark room under red incandescent lighting. Distilled water and unsalted saltine crackers were supplied as palette cleansers. Immediately before serving, cooked steaks were trimmed of remaining external fat and connective tissue and cut into 1 cm^3 pieces. Each panelist received 2 to 3 pieces for sensory attribute evaluation. Panelist responses were recorded on an electronic ballot generated by an online survey software (Qualtrics, Provo, UT, USA). Intensity ratings for each attribute were averaged among panelists for each sample.

Shear Force Measurements

Frozen steaks identified for shear force were randomly assigned to 1 of 3 shear force days. Warner-Bratzler shear force (WBSF) and slice shear force (SSF) measurements were obtained from every steak using procedures described by Lorenzen et al. (2010). Steaks were grouped by similar weight, size, and shape, and cooked according to the previous procedures. Pre-cook and post-cook temperatures and weights were recorded on each steak. Within 5 minutes of recording peak internal temperature, the lateral end of the steak was squared, and a 1 by 5 cm slice was removed parallel to muscle fibers. This slice was sheared perpendicular to muscle fibers, using a slice shear force machine (Tallgrass Solutions, Inc., Manhattan, KS, USA) equipped with a flat, blunt-end blade (crosshead speed: 500 mm/min, load capacity: 50 kg), resulting in a single peak SSF measurement for each steak. Remaining steak portion equilibrated

to room temperature (22°C) or below and 4 to 6 cores (1.2 cm diameter) were removed parallel to muscle fibers. Each core was sheared perpendicular to muscle fibers using a Warner-Bratzler shear force machine (Tallgrass Solutions, Inc., Manhattan, KS, USA) fitted with a Warner-Bratzler shear head (crosshead speed: 225 mm/min, load cell capacity: 50 kg). Peak shear force of each core was recorded and resulting values were averaged to obtain a single WBSF measurement for each steak.

Homogenization and Composite Designation for Chemical Analysis

Frozen steaks designated for chemical analysis were placed in ice water for approximately 1 min and thawed enough to be hand cut into small pieces. Steak pieces were frozen by liquid nitrogen, transferred to a blender (NutriBullet LEAN, Pacoima, CA, USA), ground into a fine powder, and stored in an individual bag at -20°C. Blender cups, blades, and other utensils were rinsed and dried between samples, and liquid nitrogen or a -20°C freezer chilled these items for use in the process. After individual homogenization, each sample was randomly assigned to 1 of 8 composites per treatment, such that 3 to 5 samples comprised a composite. Equal proportions of homogenized sample were weighed to generate a 100 g composite. These composite samples were vacuum packaged and stored at -20°C until further analysis.

Volatile Flavor Compound Analysis

An Agilent 7890B series gas chromatograph (Agilent Technologies, Santa Clara, CA, USA) in combination with a 5977A mass selection detector (Agilent Technologies, Santa Clara, CA, USA) was used to collect volatile flavor compounds from all raw composited samples. Once homogenized, 5.0 g of raw sample were weighed into a 20 mL glass GC vial (Art # 093640-036-00, Gerstel, Linthicum, MD, USA) and 10 µL of an internal standard solution (1,2

dichlorobenzene, 2.5µg/µl) was added to the vial. Each vial was capped with a 1.3 mm polytetrafluoroethylene septa and metal screw cap (Art # 093640-040-00, Gerstel, Linthicum, MD, USA). Prepped vials were loaded by a Gerstel automated sampler (MPS, Gerstel Inc., Linthicum, MD, USA) for a 5 min incubation period at 30˚C in a Gerstel agitator (500 rotations/min). Incubation was followed by a 20 min extraction period of which volatile compounds were collected from the headspace of the vial while by solid phase microextraction (SPME), utilizing an 85-µm film thickness carboxen polydimethylsiloxane fiber (Stableflex 24 Ga, Supelco, Bellefonte, PA, USA). After extraction, volatile compounds were injected into a VF-5ms capillary column (30m × 0.25mm × 1.00 µm; Agilent J&W GC Columns, Netherlands) and separated. Ions were detected within the range of 33-500 m/z by the mass spectrometer with an electron impact mode at 70eV. Validation of volatile compound identities was completed using comparison to external authentic standards.

Fatty Acids and Free Amino Acids

Fatty acid and free amino acid composition was determined from all raw composited samples. All water-soluble compounds underwent an initial extraction and purification similar to Koutsidis et al. (2008). Lipid constituents were extracted using a modified Folch method (Folch et al., 1957). Extracted lipid were fractionated using a Sep-Pak silica gel cartridge (Waters Corporation, Milford, MA, USA). Fatty acids in polar lipid (phospholipid) were saponified and derivatized to fatty acid methyl esters (FAME) using sodium methoxide in methanol (Li and Watkins, 2001), whereas saponification and derivatization for those in neutral lipid was performed using methanolic potassium hydroxide (Maxwell and Marmer, 1983). Fatty acid methyl esters were analyzed on an Agilent Technologies (Santa Clara, CA, USA) 7890B series gas chromatograph (GC) equipped with an HP-88 capillary column (100m x 0.25mm i.d.;

Agilent Technologies, Santa Clara, CA, USA) and a flame-ionization detector (FID). Identification and quantification of FAMES was carried out by an internal standard calibration, comparing with FAME authentic standard (Nu-Check Prep, Inc, Standard group 610). Free amino acids were determined by using an EZ-Fast amino acid derivatization kit (Phenomenex, Torrance, CA, USA). Derivatized amino acids were quantified by GC-MS (Agilent 7890B-5977A).

Statistical Analysis

Analysis was performed for a randomized complete block design, using mixed modeling procedures (PROC GLIMMIX) of SAS (Version 9.4; SAS Institute Inc., Cary, NC). Carcass was included in the model as a random effect to account for blocking structure, and treatment was included in the model as a fixed effect. For sensory analysis, panel session was evaluated as a random effect and feed order as a fixed effect. Final cooking temperature was initially included for sensory analysis as a covariate but removed in the final model because it was not significant ($P > 0.05$). However, final cooking temperature was included in the model for WBSF and SSF analysis. The same carcass was not represented in the same composited sample across all treatments, so blocking effect was lost in analysis of chemical components. Still, chemical analysis was evaluated as a completely randomized design. For volatile flavor compounds, samples which failed to reach the minimum threshold detection level were recorded as zeros. Treatment comparisons were tested for significance using Tukey adjusted pairwise comparisons and significance at $\alpha < 0.05$. Denominator degrees of freedom were calculated using Kenward-Roger approximation. Correlation analysis (PROC CORR) was used to determine Pearson correlation coefficients between sensory ratings and chemical constituents, including flavor precursors and volatile flavor compounds. Sensory ratings for those carcasses represented within

a composite were averaged, such that a mean rating for each attribute was represented within a single composite.

RESULTS AND DISCUSSION

Proximate Analysis

Carcass data (Table 2.1) showed no difference ($P = 0.94$) in intramuscular fat between sides of the same carcass used in assignment of treatments to strip loin sections, as expected. Previous research showed that Small marbling scores produce fat percentages in the range of 4.7 to 5.5% (Campion et al., 1975), which were similar to our findings (Table 2.3). However, while marbling did not play a role in total crude fat content differences, combination aging (14 d wet-age, followed by 21 d dry-age, for a total of 35 d) produced the greatest percentage of fat (6.24%), which was greater ($P = 0.03$) than 35 d wet-aging. Additionally, 21 d dry-aging and combination aging exhibited 25.7% and 24.2% shrink, respectively, in the dry-aging cabinet (data not reported). Although comparison was not made to wet-aging, previous research showed greater cooler shrink in dry-aged product (Parrish et al., 1991; Laster et al., 2008; Smith et al., 2008). Moisture content has been reported lower in raw dry-aged steaks than wet-aged steaks (Dikeman et al., 2013). Table 2.5 shows dry-aging treatments (21 d dry-age and combination) resulted in less ($P < 0.01$) cook loss compared to wet-aged steaks. This was consistent with findings of Laster et al. (2008) and suggests dehydration in the dry-aging process may concentrate components in meat and affect composition.

Trained Sensory Analysis

Aging length affected flavor profile, particularly in long wet-aged beef (Table 2.4). Wet-aging up to 35 d showed no change ($P > 0.05$) in the mean intensity rating for any flavor notes. Other studies have shown that aging to similar lengths of time or less also produce no changes in

flavor (Minks and Stringer, 1972; Jeremiah and Gibson, 2003; Bruce et al., 2005; Laster et al., 2008; Lepper-Blilie et al., 2012). However, beef wet-aged for 49 d or longer was rated lowest ($P < 0.01$) for beef flavor ID and greatest ($P \leq 0.02$) for metallic, sour, oxidized, nutty, musty/earthy, and liver-like. No difference ($P > 0.05$) was noted between beef wet-aged 49 d or 63 d for any flavor notes. Aged flavor has been shown to increase when beef is aged longer than 35 d (Lepper-Blilie et al., 2012). Further, Jeremiah and Gibson (2003) and Yancey et al. (2006) showed livery notes to intensify with prolonged wet-aging. Campo et al. (1999) also found livery notes to increase markedly at 21 d of vacuum aging and showed a relationship between increased aging time and acid flavor. With development of minor flavor notes at advanced aging lengths, flavors typically associated with beef, such as beef flavor ID, browned, and roasted, became compromised. Although we refrain from claiming certain attributes as desirable and undesirable due the objectivity approach with trained sensory ratings, lengthy aging times have been described as a deterrent to desirable flavors commonly found in meat (Van Ba et al., 2012; O'Quinn et al., 2016). Yet, most of our ratings represented low levels of detection on a 15-point scale. These minor but detectable differences also have been reported on a 9-point scale (Campo et al., 1999). Training references and verbal anchors used for the present study did not guide panelists to detect differences within a fraction of a rating, nor were ratings reported to this degree. Therefore, while some attributes may be significantly different, they may be negligible. In understanding truly appreciable differences, long wet-aged beef may be characterized by especially sour and oxidized flavors.

Aging method (wet versus dry) had minimal influence on flavor and tenderness of beef (Table 2.4). Dry-aging has previously been found to impart more intense ratings for beef flavor and browned/roasted (Warren and Kastner, 1992; Campbell et al., 2001; O'Quinn et al.,

2016).Lepper-Blilie et al. (2012) showed aged flavor to be greater in dry-aged loins than in wet-aged counterparts. In the present study, greater numerical mean ratings for beef flavor ID, browned, and roasted were noted for beef dry-aged for 21 d compared as an intermediate to beef wet-aged for 14 d and 28 d. However, no statistical differences ($P > 0.05$) were found to occur as a consequence of using the differing aging methods. Multiple previous studies also showed no differences in flavor attributes when comparing wet- and dry-aging (Parrish et al., 1991; Jeremiah and Gibson, 2003; Sitz et al., 2006; Laster et al., 2008; Smith et al., 2008). These discrepancies may be explained by variable dry-aging environments and trimming of dry-aged beef, given the significant external crust formed in the process. Furthermore, effect of marbling has been suggested to consistently impact flavor of dry-aged beef, and low levels of marbling (less than Sm^{50}) have also been shown to limit discernible flavor differences (Lepper-Blilie et al., 2012).

Similar to our findings in comparing solely wet aging versus dry-aging, a combination of the two aging methods (total aging of 35 d) produced no statistical flavor differences ($P > 0.05$) when compared to 35 d wet-aging. Campbell et al. (2001) reported similar findings, where vacuum aging for 7 or 14 d prior to dry-aging had no effect on flavor. It was expected crude fat differences (Table 2.3) found between combination aging and 35 d wet-aging would result in an effect on fat-like flavor. Yet, trained panelists did not detect differences ($P > 0.05$) for these attributes. Warren and Kastner (1992) also found no difference in fat flavor intensity between wet- and dry-aged strip steaks.

As expected, sensory tenderness generally improved as aging length increased (Table 2.4). Trained panelists rated beef wet-aged for 3 d the lowest ($P < 0.01$), on average, for overall tenderness. Yet, tenderness improvement was only seen to a point in the aging progression, and

wet-aging 28 d or longer generated no difference ($P > 0.05$). Previous studies showed that aging improves sensory ratings for tenderness (Warren and Kastner, 1992; Campo et al., 1999). In the present study, tenderness ratings for beef dry-aged 21 d were lower ($P < 0.01$) than beef wet-aged 28 d but not different ($P > 0.05$) from beef wet-aged 14 d. Beef aged with a combination of methods (total age of 35 d) was not different ($P > 0.05$) from 35 d wet-aged beef for overall tenderness. Furthermore, ratings for initial juiciness and sustained juiciness were not different ($P = 0.25$ and $P = 0.18$, respectively) regardless of aging length or aging method. The lack of differences in tenderness and juiciness between wet- and dry-aging was supported by previous research reports (Warren and Kastner, 1992; Sitz et al., 2006; Laster et al., 2008; Lepper-Blilie et al., 2012). Therefore, the effect of aging on tenderness may be more related to aging length and less associated with aging method.

Shear Force

Both slice shear force (SSF) and Warner-Bratzler shear force (WBSF) were affected by wet-aging time (Table 2.5). Beef wet-aged for 3 d exhibited the greatest ($P < 0.01$) SSF and WBSF values. Wet-aging for 28 d or longer resulted in no differences ($P > 0.05$) for SSF or WBSF values. These findings supported those of trained sensory panelists, as instrumental tenderness improved only to a point within the wet-aging process. Gruber et al. (2006) reported WBSF values for wet-aged Select strip steaks were improved up to 28 d postmortem, with 96% of the aging response for tenderness to occur by 26 d of aging. They also showed no improvement in WBSF values for wet-aged premium Choice strip steaks past 21 d. Therefore, excessive aging time is not necessary to achieve maximal tenderness and, as noted in sensory analysis, may come at a sacrifice to flavor integrity.

Aging method (wet versus dry) had minimal impact on SSF and WBSF values (Table 2.5). SSF values for beef dry-aged 21 d were lower ($P < 0.01$) than beef wet-aged 14 d but not different ($P > 0.05$) from beef wet-aged 28 d. Additionally, mean WBSF values did not differ ($P > 0.05$) between wet- and dry-aged beef. Combination aging showed a similar result, and least squares means for SSF and WBSF values did not differ ($P > 0.05$) from 35 d wet-aging. Parrish et al. (1991) also showed no difference in objective tenderness measurements between aging methods, and Campbell et al. (2001) found steaks dry-aged for 21 d to have lower WBSF values than control steaks with no age. Consequently, it is likely aging method does not play a role in tenderness improvement, and these findings further show the more pertinent role of aging length in tenderness improvement.

Fatty Acid Analysis

Polar and neutral fractions of fatty acids showed minimal, if any, differences due to aging length and method (Appendix A.1 and A.2). Only C14:1 in the polar fraction generated a significant treatment effect, where combination aging produced greater ($P = 0.02$) concentrations, on average, than 35 d wet-aging. Work by Gredell et al. (2018) conflicts with this finding, as levels of C14:1 *cis*-9 were greater in fresh beef than dry-aged beef. The reason for this discrepancy is unknown, but the magnitude of difference reported in our study was quite small and may not have been biologically meaningful. Anaerobic conditions of vacuum packaging and intact meat have been shown to prevent lipid oxidation (King et al., 1995; Spanier et al., 1997), so the results of our study were not surprising. Limited research has been conducted on fatty acid profiles of wet- and dry-aged beef. O'Quinn et al. (2016) and Gredell et al. (2018) found different fatty acid profiles for wet- and dry-aging, suggesting differences in oxidative stability between the two methods. However, differences in processing (such as trimming of

crust on dry-aged samples) and muscle form (whole versus ground) may be credited to these discrepancies within our study. Our findings indicated the relationship of fatty acids with flavor development as explained by aging treatment is negligible at best.

Free Amino Acids

Progressive aging length, from 3 d to 63 d, resulted in increased ($P < 0.001$) mean total concentration of free amino acids (Table 2.6). Additionally, all individual amino acids, except valine and beta-alanine, increased ($P \leq 0.033$) from wet-aging 3 d to 63 d. Previous studies found comparable results regarding increased amino acid content during postmortem aging (Ginger et al., 1954; Nishimura et al., 1988; Moya et al., 2001; G. Koutsidis et al., 2008). Amino acid content is affected by cooking (Ginger et al., 1954; Nishimura et al., 1988); thus, evaluation of raw sample in our study represents levels of amino acids in beef that has not experienced Maillard reactions. Endogenous proteinases are likely responsible for this observation, but microbial growth and exogenous enzymatic activity has also been proposed as an option of amino acid production (Toldra´, 1998). One primary metabolic function of lactic acid bacteria is the conversion of peptides to amino acids (Christensen et al., 1999).

No previous studies were found to have evaluated amino acid differences in wet- and dry-aged beef. Our study showed aging method to have minimal effect on amino acid content (Table 2.6). Generally, beef dry-aged for 21 d had amino acid concentrations intermediate to those of beef wet-aged for 14 and 28 d. Combination aging produced greater ($P < 0.001$) concentrations of leucine, asparagine, phenylalanine, and alpha-aminoadipic acid and less ($P < 0.001$) cysteine when compared to beef solely wet-aged for 35 d, even though total concentrations were not different ($P > 0.05$) between the two treatments. Thus, aging length is likely more responsible for elicitation of amino acids than aging method.

Volatile Organic Compounds

Mean concentrations of volatile organic compounds are presented in Table 2.7. Aging treatment influenced ($P < 0.05$) concentrations of more than 30 compounds. Only positive relationships were shown between increased aging length and volatile compound production, and 14 compounds increased ($P < 0.01$) in concentration from 3 d to 63 d of wet-aging. Previous work has shown aging time to affect those volatile compounds primarily derived from lipid oxidation (Stetzer et al., 2008). However, the lack of differences in fatty acid profiles in our study suggest lipid oxidation was limited. The Maillard reaction has also been identified as primary contributor to flavor compounds when meat is cooked (Mottram, 1998); however, all samples processed for volatile compound analysis were raw and extraction method of volatiles was performed at 30ºC. This leads us to believe other metabolic processes may contribute to production of volatile flavor compounds and consequently, flavor changes, during the progression of aging time. Aging method had less conclusive effects on volatile flavor compound production, affirmed by the lack of flavor differences noted by sensory panelists in wet- and dry-aged beef.

Wet-aging to extended lengths resulted in development of volatile flavor compounds (Table 2.7). Ethanol increased ($P < 0.01$) by 49 d, with its greatest ($P < 0.01$) production at 63 d. Ismail et al. (2008) also found drastic increases of ethanol during aging of irradiated meat, pointing towards microbial growth as a cause. Lactic acid producing bacteria have been shown to generate ethanol in an anaerobic environment, such as vacuum-packaged meat (Mayr et al., 2003), which may be related to the sour notes panelists associated with long wet-aged beef. Further, acetic acid increased ($P < 0.01$) from 3 d to 63 d. Levels of butanoic acid and butanoic acid, methyl ester increased ($P < 0.01$) from 3 to 63 d of wet-aging. Stetzer et al. (2008) found

similar results. Butanoic acid is commonly seen in studies evaluating spoilage (Casaburi et al., 2015), and increases have been associated with lactic acid producing bacteria during storage of vacuum-packaged beef (Jones, 2004). Aliphatic hydrocarbons pentane and octane, as well as aromatic hydrocarbon p-xylene, all reached their greatest ($P < 0.01$) concentration at 63 d wet-aging. Octane and xylene have been used as adherence mechanisms for lactic acid bacteria (Marín et al., 1997), suggesting an affinity for these compounds by growing microbial populations. Moreover, hydrocarbons minimally contribute to meat flavor (Shahidi et al., 1987a). Hexanal has been identified as a marker for lipid oxidation (Shahidi et al., 1987b), and increases due to extended storage have been noted in previous aging studies (Ismail et al., 2008). While hexanal increased numerically during wet-aging in our study, differences were not statistically significant, further reflecting the lack of change in fatty acids. Ketones also increased during wet-aging, and 2,3-pentanedione, 2-pentanone, and 2-propanone were all greatest ($P < 0.01$) at 63 d of wet-aging. Previous studies have shown 2-propanone to increase with aging time, adversely affecting meat quality attributes (Insausti et al., 2008; O'Quinn et al., 2016). Moreover, increases in 2-propanone have been linked to increases in *Enterobacteriaceae* and APC counts (Insausti et al., 2008). Gunter et al. (1994) demonstrated the pathway by which lactic acid is converted to 2,3-pentanedione, and Joffraud et al. (2001) found lactic acid bacteria to be a contributor of 2,3-pentanedione and related buttery flavor in smoked salmon. Cheddar cheese flavor has been identified with 2-pentanone (Aston and Dulley, 1982). Strecker aldehydes 2-methylbutanal, 3-methylbutanal, and phenylacetaldehyde also increased ($P < 0.01$) during wet-aging. Various groups of lactic acid bacteria have been shown to generate 3-methylbutanal in vacuum packaged meat (Hernández- Macedo et al., 2011), and Nychas et al. (2008) reported 2-methylbutanal as an end product of Gram-negative bacteria. Phenylacetaldehyde is an

intermediate in anaerobic metabolism of phenylalanine (Schneider et al., 1997). Although sulfur-containing compounds play a substantial role in flavor development, much like our study, aging time has no effect on these compounds (Ismail et al., 2008). Therefore, volatile flavor compound in wet-aged beef, as affected by aging length, may be products of microbial metabolism, specifically species of lactic acid producing bacteria.

Aging method generated less distinct differences in volatile compounds, much like our findings in analysis of flavor attributes (Table 2.7). Gredell et al. (2018) and O'Quinn et al. (2016) found differences in volatile compounds between wet- and dry-aging. Yet, both studies, unlike ours, also showed changes in fatty acid profiles due to aging method. King et al. (1995) showed vacuum-packaged beef to have greater concentrations of acids, and reduced concentrations esters and hydrocarbons, than dry-aged beef. However, these analyses were performed on cooked sample. In our study, only one volatile compound was definitively different between wet- and dry-aging treatments. Dry-aging increased ($P < 0.01$) concentrations of 2-heptanone. Concentrations of 2,3-butanedione were greater ($P < 0.01$) in combination aging and numerically greater (not statistically) in 21 d dry-aging. Production of 2-heptanone and 2,3-butanedione in dry-aged beef has been shown in previous studies (O'Quinn et al., 2016; Gredell et al., 2018). These compounds are fermentative products of lactic acid bacteria metabolism (Joffraud et al., 2001). Growth of lactic acid bacteria has been shown to markedly increase in dry-aged beef, particularly from 3 d to 25 d of age (Ryu et al., 2018), but as noted in evaluation of aging length, this growth may be less of an effect of aging method. Differences for other volatile compounds existed in comparisons of: 1) 21 d dry-aging as an intermediate between 14 d and 28 d wet-aging; and 2) combination aging (35 d total age) with 35 d wet-aging. However, inconsistencies in these 2 comparisons together do not allow for accurate speculation on the

definite effect of aging method. Regardless, it seems aging time was more directly related to changes in volatile flavor compounds, and aging method cannot be characterized by certain flavors or volatile flavor compounds.

Relationships between Amino Acids and Sensory Attributes

Pearson correlations showing relationships between amino acids and sensory attributes are shown in Table 2.8. Total amino acid content was negatively associated ($P < 0.05$) with beef flavor ID and roasted. Alternatively, very strong positive relationships ($P < 0.01$) were noted for total amino acid content and many minor flavor notes: sour, oxidized, nutty, musty/earthy, and liver-like ($r = 0.72$, $r = 0.52$, $r = 0.55$, $r = 0.71$, $r = 0.54$, $r = 0.68$, respectively). These relationships were likely the result of amino acids acting as a flavor precursor, since amino acid analysis was performed on raw samples. Thus, increases in amino acids during wet-aging were strongly related to changes in intensity ratings of multiple sensory attributes. Moreover, all individual amino acids, except valine, were positively correlated ($P < 0.01$) to overall tenderness. Enzymatic activity of calpains during postmortem aging degrades proteins, including those structural proteins which contribute to tenderness, and amino acid profiles have established that these same degradative enzymes also have an effect on flavor (Toldrá and Flores, 2000). Additional relationships of individual amino acids and sensory attributes were exhaustive and can be further evaluated in Table 2.8.

Relationships between Volatile Organic Compounds and Sensory Attributes

Volatile organic compounds contribute greatly to the aroma component of meat flavor (Mottram, 1998). Consequently, many of the flavor attributes in our study showed relationships to volatile compounds (Table 2.9). Ethanol showed some of the most negative associations ($P < 0.01$) with beef flavor ID, browned, and roasted. Likewise, some of the most positive

relationships ($P < 0.05$) were established for ethanol and metallic, sour, oxidized, nutty, musty/earthy, and liver-like. Positive relationships ($P < 0.01$) existed between 2-propanone and sour, oxidized, musty/earthy, and liver-like. These findings agreed with Gredell et al. (2018), who showed strong positive correlations of 2-propanone with bloody/metallic, earthy/mushroom, and sour/acidic. Moreover, 2- and 3- methylbutanal were positively correlated ($P < 0.01$) with sour, oxidized, nutty, musty/earthy, and liver-like flavors. This also was similar to the results reported by Gredell et al. (2018), where the same volatiles showed strong positive correlations with earthy/mushroom, nutty/roasted-nut, livery, and sour/acidic. O'Quinn et al. (2016) also found 2- and 3- methylbutanal to be positively correlated with nutty flavor. However, his work also found 3-methylbutanal negatively associated with livery flavor, and both 2- and 3-methylbutanal showed positive associations with browned/grilled flavor and buttery/beef fat flavor. Hydrocarbons octane, pentane, and p-xylene all showed strong positive correlations with sour, oxidized, and musty/earthy flavors, and strong negative associations with beef flavor ID. As would be expected, acetic acid was most highly associated with positive levels of sour flavor. Relationships of these volatile compounds to flavor attributes were not surprising given changes in both sensory attributes and flavor compounds noted during differing aging times.

Conclusions

Aging length had a profound impact on flavor and tenderness of beef strip loins, while dry-aging did not result in drastically different responses compared to wet-aging for the same traits. Wet-aging beef longer than 35 d resulted in development of minor flavor notes not typically associated with beef, especially sour and oxidized, at a compromise to major beef flavor notes, such as beef flavor ID. Fatty acid profiles indicated lipid oxidation in wet-aged beef is negligible at best. Aging affected amino acid profiles which, consequently, corresponded to

flavor changes. Flavor attributes also were associated with several volatile flavor compounds elicited during the wet-aging period. Beef wet-aged up to 28 d achieved maximum tenderness without sacrifice to flavor profile changes. Dry-aging did not impart a different flavor profile and, likewise, volatilome from wet-aging. Further, no additive effect of wet- and dry-aging influenced flavor or tenderness.

Results further substantiate that aging is an effective method to alter eating quality attributes of beef. Microbial growth and metabolism may influence changes in flavor of aged beef. Therefore, utilization of parameters with extreme aging length may significantly impact flavor, with no realization of improved tenderness. Given the results of our study, and evaluation by many others, dry-aging of beef with low levels of marbling (Small) cannot be expected to consistently alter the flavor or tenderness profile of beef. Wet-aging may provide for just as equal of an eating experience, without realization of yield loss associated with dry-aging. Still, further research evaluating a variety of wet- and dry-aging parameters, and those mechanisms which cause changes in flavor, may more correctly identify an ideal aging protocol, particularly to consumers. Results allow for determination of a baseline by which establishments can begin to maximize positive palatability traits associated with aged beef.

Table 2.1. Comparison of carcass characteristics. One of eight treatments was randomly assigned to one of eight strip loin sections, collected from sides of the same carcass.

Aging Method	Total Age (d)	Hot Carcass Weight (kg)	12th-Rib Fat (cm)	Ribeye Area[1] (cm^2)	Marbling Score[2]
Wet	3	451.66	1.26	99.93	432.63
	14	451.66	1.22	99.39	431.84
	28	451.66	1.21	99.83	432.63
	35	451.66	1.25	98.90	428.95
	49	451.66	1.30	98.47	429.21
	63	451.66	1.28	99.56	429.74
Dry	21	451.66	1.25	99.78	429.47
Combination[3]	35	451.66	1.18	99.93	430.79
SEM[4]		6.12	0.09	1.58	2.66
P – Value		1.00	0.99	1.00	0.94

[1]Longissimus muscle area between the 12th and 13th ribs.
[2]Marbling assessed at longissimus surface between the 12th and 13th ribs by comparison with official USDA marbling photographs (National Cattlemen's Beef Association, Centennial, CO, USA). Marbling score units: 400 = $Small^{00}$, 500 = $Modest^{00}$.
[3]Wet-age period of 14 d followed by dry-age period of 21 d.
[4]Standard error (largest) of the least squares means.

Table 2.2. Sensory attributes, descriptors, and anchors on a 15-point scale used for trained sensory analysis adapted from Adhikari et al. (2011).

Attribute	Description	Anchor
Beef Flavor ID	The flavor associated with cooked beef; basic meaty flavor of unseasoned beef broth.	Swanson's beef broth = 5.0 80% lean ground beef = 7.0 Beef brisket cooked to 71ºC = 11.0
Browned	The flavor associated with grilled beef; carmelized.	Beef suet (broiled) = 8.5
Roasted	The flavor associated with roasted beef.	80% lean ground chuck = 10.0
Metallic	The impression of slightly oxidized metal, such as iron, copper, and silver spoons.	0.10% potassium chloride solution = 1.5 Select strip steak = 4.0 Dole canned pineapple juice = 6.0
Fat-Like	The aromatics associated with cooked animal fat.	Hillshire Farms Lit'l beef smokies = 7.0 Beef suet = 12.0
Sour	The fundamental taste factor associated with citric acid.	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Oxidized	The aromatics commonly associated with oxidized fat and oils; cardboard, painty, varnish and fishy.	Microwaved Wesson vegetable oil (3 min at high) = 7.0 Microwaved Wesson vegetable oil (5 min at high) = 9.0
Nutty	A combination of slightly sweet, brown, woody, oily, musty, astringent, and bitter aromatics commonly associated with nuts, seeds, beans, and grains.	Mixture of Diamond sliced almonds and Diamond shelled walnuts = 7.5
Musty/Earthy	Musty, sweet, decaying vegetation.	Raw mushroom = 12.0
Liver-Like	Aromatics associated with cooked organ meat/liver.	Beef liver (broiled) = 7.5
Overall Tenderness	The amount of force required to masticate a piece of meat.	Beef shank cooked to 71ºC = 7.0 Select strip steak cooked to 71ºC = 9.0 Tenderloin steak cooked to 71ºC = 14.0
Initial Juiciness	The amount of perceived juice initially released from the product during mastication (within the first 5 chews).	Select strip steak cooked to 58ºC = 11.0 Select strip steak cooked to 82ºC = 9.0
Sustained Juiciness	The amount of perceived juice released from delayed mastication (after 5 chews).	Select strip steak cooked to 71ºC = 5.0 Upper 2/3 Choice strip steak cooked to 71ºC = 8.0

Table 2.3. Percentage crude fat[1] as determined by proximate analysis of raw beef strip loin steaks representing eight aging treatments.

Aging Method	Total Age (d)	Crude Fat[1], %
Wet	3	5.23[ab]
	14	5.24[ab]
	28	5.35[ab]
	35	4.90[b]
	49	5.57[ab]
	63	5.31[ab]
Dry	21	5.70[ab]
Combination[2]	35	6.24[a]
SEM[3]		0.25
P – Value		0.03

[abc] Least squares means in the same row lacking a common superscript differ ($P < 0.05$)
[1]Lipid extractions made using chloroform methanol mixture as described by Folch et al. (1957)
[2]Wet-age period of 14 d followed by dry-age period of 21 d
[3]Standard error (largest) of the least squares means

Table 2.4. Trained sensory ratings[1] for attributes of beef strip loin steaks representing eight aging treatments.

	Wet-age (d)						Dry-age (d)	Combination [2]	SEM[3]	*P* - Value
Attribute	3	14	28	35	49	63	21			
Beef Flavor ID	7.46^{a}	7.43^{a}	7.45^{a}	7.28^{a}	6.75^{b}	6.54^{b}	7.54^{a}	7.33^{a}	0.13	<0.01
Browned	4.64^{a}	4.46^{ab}	4.55^{a}	4.40^{ab}	4.19^{b}	4.16^{b}	4.63^{a}	4.63^{a}	0.13	<0.01
Roasted	5.03^{bc}	5.08^{bc}	5.19^{ab}	5.13^{bc}	4.82^{c}	4.86^{c}	5.45^{a}	5.25^{ab}	0.12	<0.01
Metallic	1.78^{ab}	1.74^{ab}	1.70^{b}	1.79^{ab}	1.92^{ab}	1.99^{a}	1.83^{ab}	1.80^{ab}	0.09	0.02
Fat-Like	1.56	1.67	1.62	1.63	1.54	1.51	1.57	1.56	0.07	0.31
Sour	1.45^{c}	1.38^{c}	1.59^{c}	1.69^{bc}	2.61^{a}	2.83^{a}	1.68^{bc}	2.01^{b}	0.11	<0.01
Oxidized	0.32^{c}	0.23^{c}	0.27^{c}	0.43^{bc}	0.61^{ab}	0.68^{a}	0.34^{c}	0.31^{c}	0.05	<0.01
Nutty	0.55^{b}	0.57^{b}	0.54^{b}	0.61^{b}	1.17^{a}	1.06^{a}	0.55^{b}	0.78^{b}	0.08	<0.01
Musty/Earthy	0.65^{c}	0.57^{c}	0.70^{c}	0.99^{bc}	2.08^{a}	2.37^{a}	0.69^{c}	1.25^{b}	0.13	<0.01
Liver-Like	0.26^{cd}	0.15^{d}	0.26^{cd}	0.28^{cd}	0.63^{ab}	0.64^{a}	0.34^{cd}	0.42^{bc}	0.06	<0.01
Overall Tenderness	8.00^{d}	8.76^{bc}	9.13^{ab}	9.22^{ab}	9.26^{a}	9.22^{ab}	8.61^{c}	8.86^{abc}	0.14	<0.01
Initial Juiciness	5.51	5.63	5.56	5.64	5.66	5.33	5.43	5.48	0.14	0.25
Sustained Juiciness	5.55	5.58	5.63	5.64	5.68	5.33	5.42	5.42	0.14	0.18

[a-e] Least square means in the same row lacking a common superscript differ ($P < 0.05$).
[1]Attributes were scored using a 15-point scale: 0 = very tough, very dry, and not present; 15 = very tender, very juicy, and very intense.
[2]Wet-age period of 14 d followed by dry-age period of 21 d.
[3]Standard error (largest) of the least squares means.

Table 2.5. Slice shear force (SSF) values, Warner-Bratzler shear force (WBSF) values, and cook loss of beef strip loin steaks representing eight aging treatments.

Aging Method	Total Age (d)	SSF (kg)	WBSF (kg)	Cook Loss (%)
Wet	3	14.63[a]	3.57[a]	25.00[a]
	14	13.14[ab]	3.28[ab]	24.26[a]
	28	12.06[bc]	2.75[cd]	24.44[a]
	35	11.50[c]	2.72[d]	22.33[a]
	49	11.49[c]	2.64[d]	22.31[a]
	63	10.96[c]	2.62[d]	23.47[a]
Dry	21	11.38[c]	3.08[bc]	18.61[b]
Combination[1]	35	11.36[c]	2.89[cd]	17.28[b]
SEM[2]		0.41	0.09	0.65
P – Value		<0.01	<0.01	<0.01

[a-d] Least squares means in the same column lacking a common superscript differ ($P < 0.05$).
[1]Wet-age period of 14 d followed by dry-age period of 21 d.
[2]Standard error (largest) of the least squares means.

Table 2.6. Concentrations (ng/g) of amino acids identified for raw beef strip loin steaks representing eight aging treatments.

	Wet-age (d)						Dry-age (d)	Combination [1]	SEM[2]	*P* - Value
Amino Acid (ng/g)	3	14	28	35	49	63	21			
Alanine	0.563^{c}	0.736^{bc}	0.683^{c}	0.676^{c}	0.892^{bc}	1.331^{a}	0.777^{bc}	1.052^{ab}	0.077	<0.001
beta-Alanine	0.154^{b}	0.156^{ab}	0.158^{a}	0.156^{ab}	0.156^{ab}	0.157^{ab}	0.157^{ab}	0.156^{ab}	0.001	0.033
alpha-Aminoadipic acid	0.001^{f}	0.004^{e}	0.007^{c}	0.007^{c}	0.011^{b}	0.014^{a}	0.005^{d}	0.010^{b}	0.001	<0.001
Asparagine	0.109^{c}	0.111^{c}	0.138^{c}	0.156^{c}	0.436^{ab}	0.518^{a}	0.187^{c}	0.350^{b}	0.024	<0.001
Aspartic acid	0.088^{e}	0.094^{de}	0.115^{cd}	0.133^{c}	0.174^{b}	0.218^{a}	0.109^{de}	0.137^{c}	0.005	<0.001
Cysteine	0.114^{e}	0.150^{d}	0.199^{c}	0.215^{c}	0.252^{b}	0.309^{a}	0.140^{d}	0.148^{d}	0.008	<0.001
Cystine	0.002^{d}	0.003^{cd}	0.005^{bcd}	0.005^{bcd}	0.009^{a}	0.007^{ab}	0.005^{bcd}	0.006^{abc}	0.001	<0.001
Glutamic acid	0.138^{f}	0.256^{e}	0.427^{cd}	0.489^{c}	0.641^{b}	0.776^{a}	0.353^{de}	0.468^{c}	0.025	<0.001
Glutamine	0.138^{f}	0.256^{e}	0.427^{c}	0.489^{c}	0.641^{b}	0.776^{a}	0.353^{d}	0.468^{c}	0.025	<0.001
Glycine	0.146^{d}	0.452^{c}	0.768^{ab}	0.799^{a}	0.629^{abc}	0.488^{bc}	0.638^{abc}	0.598^{abc}	0.068	<0.001
Histidine	0.246^{d}	0.336^{bcd}	0.388^{ab}	0.379^{abc}	0.350^{abc}	0.445^{a}	0.282^{cd}	0.321^{bcd}	0.022	<0.001
Hydroxyproline	0.007^{b}	0.011^{ab}	0.013^{a}	0.012^{ab}	0.012^{ab}	0.013^{a}	0.012^{a}	0.014^{a}	0.001	0.005
Isoleucine	0.098^{d}	0.162^{bc}	0.16^{bc}	0.163^{bc}	0.178^{bc}	0.32^{a}	0.128^{cd}	0.188^{b}	0.013	<0.001
Leucine	0.307^{d}	0.304^{d}	0.469^{cd}	0.521^{c}	0.953^{a}	0.632^{bc}	0.552^{c}	0.81^{ab}	0.048	<0.001
Lysine	0.159^{f}	0.225^{ef}	0.304^{d}	0.337^{cd}	0.424^{b}	0.517^{a}	0.264^{de}	0.391^{bc}	0.017	<0.001
Methionine	0.095^{d}	0.126^{cd}	0.166^{bcd}	0.208^{bc}	0.228^{ab}	0.296^{a}	0.14^{cd}	0.207^{bc}	0.019	<0.001
Ornithine	0.130^{e}	0.138^{d}	0.142^{cd}	0.143^{cd}	0.156^{b}	0.188^{a}	0.140^{cd}	0.146^{c}	0.002	<0.001
Phenylalanine	0.138^{e}	0.217^{d}	0.289^{c}	0.315^{c}	0.427^{b}	0.541^{a}	0.265^{cd}	0.398^{b}	0.015	<0.001
Proline	0.192^{d}	0.239^{bc}	0.244^{bc}	0.25^{b}	0.218^{cd}	0.297^{a}	0.212^{cd}	0.231^{bc}	0.007	<0.001
Serine	0.237^{d}	0.364^{cd}	0.565^{b}	0.569^{b}	0.550^{b}	0.800^{a}	0.489^{bc}	0.595^{b}	0.035	<0.001
Threonine	0.112^{c}	0.201^{c}	0.409^{b}	0.463^{ab}	0.490^{ab}	0.567^{a}	0.359^{b}	0.469^{ab}	0.032	<0.001
Tryptophan	0.005^{d}	0.012^{cd}	0.016^{cd}	0.031^{bc}	0.042^{b}	0.066^{a}	0.019^{cd}	0.029^{bc}	0.004	<0.001
Tyrosine	0.151^{g}	0.216^{f}	0.288^{de}	0.309^{cd}	0.365^{ab}	0.410^{a}	0.251^{ef}	0.342^{bc}	0.012	<0.001
Valine	0.182^{c}	0.203^{bc}	0.374^{abc}	0.408^{abc}	0.531^{a}	0.243^{abc}	0.382^{abc}	0.491^{ab}	0.068	0.002
Total Amino Acids	3.373^{f}	4.713^{e}	6.326^{d}	6.744^{cd}	8.123^{ab}	9.151^{a}	5.864^{d}	7.558^{bc}	0.253	<0.001

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

[1]Wet-age period of 14 d followed by dry-age period of 21 d.

[2]Standard error (largest) of the least squares means.

Table 2.7. Concentrations (ng/g) of volatile organic compounds identified for raw beef strip loin steaks representing eight aging treatments[1].

Volatile (ng/g)	Wet-age (d)						Dry-age (d)	Comb.[2]	SEM[3]	*P* - Value
	3	14	28	35	49	63	21			
Alcohols										
1-Hexanol	0.62	0.76	0.94	1.19	0.94	0.76	1.15	0.80	0.23	0.60
1-Octanol	1.29	1.36	1.54	1.82	1.47	0.93	1.48	0.92	0.26	0.22
1-Octen-3-ol	2.26	2.41	2.55	3.29	2.41	1.69	3.16	1.62	0.59	0.42
1-Pentanol	2.73^{b}	3.13^{b}	3.23^{b}	3.90^{b}	2.58^{b}	8.54^{a}	4.41^{ab}	1.90^{b}	0.96	<0.01
1-Penten-3-ol	0.05	0.06	0.06	0.09	0.08	0.10	0.13	0.07	0.02	0.07
2,3-Butanediol	0.04^{b}	0.20^{b}	0.28^{b}	1.08^{b}	2.25^{b}	8.58^{b}	0.18^{b}	29.13^{a}	3.60	<0.01
Ethanol	0.51^{c}	3.85^{c}	24.41^{c}	77.91^{c}	311.46^{b}	569.05^{a}	5.54^{c}	37.63c	34.73	<0.01
Carboxylic Acids										
Acetic acid	1.50^{d}	2.00^{cd}	2.46^{bcd}	3.29^{bcd}	4.46^{abc}	6.29^{a}	2.67^{bcd}	5.26^{ab}	0.63	<0.01
Butanoic acid	18.35^{c}	25.37^{bc}	28.83^{bc}	49.55^{abc}	39.19^{bc}	70.34^{ab}	67.68^{ab}	92.86^{a}	10.55	<0.01
Hexanoic acid	9.71	10.78	12.96	15.17	12.74	8.78	15.69	14.27	2.58	0.46
Nonanoic acid	50.76^{ab}	34.79^{ab}	49.84^{ab}	45.90^{ab}	38.69^{ab}	16.98^{b}	36.10^{ab}	53.50^{a}	7.74	0.03
Octanoic acid	0.09	0.06	0.09	0.10	0.09	0.02	0.05	0.12	0.03	0.26
Esters										
Butanoic acid, methyl ester	1.46^{c}	1.92^{bc}	1.90^{bc}	2.83^{abc}	2.25^{bc}	3.95^{a}	3.35^{ab}	3.20^{ab}	0.37	<0.01
Heptanoic acid, methyl ester	0.71^{a}	0.75^{a}	0.91^{a}	1.01^{a}	1.01^{a}	1.00^{a}	1.05^{a}	0.85^{a}	0.08	0.03
Hexanoic acid, methyl ester	22.97^{b}	22.95^{b}	24.69^{b}	28.34^{ab}	24.77^{b}	30.71^{ab}	38.87^{a}	28.47^{ab}	2.40	<0.01
Nonanoic acid, methyl ester	0.52	0.65	0.59	0.53	0.54	0.54	0.60	0.42	0.10	0.87
Octanoic acid, methyl ester	1.35^{b}	2.11^{ab}	2.86^{ab}	3.12^{a}	3.13^{a}	2.10^{ab}	2.26^{ab}	1.71^{ab}	0.35	<0.01
Propanoic acid, methyl ester	2.38^{b}	3.36^{ab}	2.95^{b}	3.65^{ab}	2.62^{b}	2.56^{b}	5.41^{a}	3.36^{ab}	0.52	<0.01
Furans										
2-Pentyl furan	0.14	0.16	0.22	0.23	0.16	0.07	0.22	0.10	0.05	0.31
Hydrocarbons										
1-Octene	0.65	0.65	0.77	1.09	0.74	2.34	1.52	1.24	0.39	0.04
Decane	1.34^{abc}	1.44^{abc}	1.29^{c}	1.58^{abc}	1.32^{bc}	1.65^{abc}	1.80^{ab}	1.81^{a}	0.11	<0.01
D-limonene	0.09^{b}	0.14^{ab}	0.20^{a}	0.23^{a}	0.10^{b}	0.10^{b}	0.14^{ab}	0.14^{ab}	0.02	<0.01
Octane	0.82^{b}	0.97^{b}	1.02^{b}	1.24^{b}	0.98^{b}	4.24^{a}	1.52^{b}	0.99^{b}	0.29	<0.01
Pentane	1.91^{b}	2.61^{b}	2.28^{b}	3.19^{b}	2.10^{b}	21.59^{a}	3.36^{b}	1.72^{b}	2.07	<0.01
p-Xylene	0.36^{b}	0.48^{b}	0.44^{b}	0.42^{b}	0.43^{b}	1.13^{a}	0.42^{b}	0.42^{b}	0.11	<0.01
Toluene	24.79^{ab}	20.01^{ab}	21.50^{ab}	30.57^{ab}	24.28^{ab}	4.39^{b}	41.34^{a}	27.30^{ab}	6.37	0.02
Ketones										
2,3-Butanedione	21.96^{abc}	18.40^{bc}	11.75^{bc}	17.43^{bc}	5.96^{c}	9.43^{c}	28.27^{ab}	37.83^{a}	4.17	<0.01
2,3-Pentanedione	0.50^{b}	0.50^{b}	0.50^{b}	0.50^{b}	0.50^{b}	0.52^{a}	0.50^{b}	0.50^{b}	<0.01	<0.01
2-Butanone	4.04	5.49	3.52	5.14	2.96	7.70	5.18	4.34	1.62	0.58
2-heptanone	0.53^{b}	0.55^{b}	0.61^{b}	0.65^{b}	0.64^{b}	0.66^{b}	1.08^{a}	1.04^{a}	0.07	<0.01
2-Pentanone	0.06^{c}	0.07^{c}	0.06^{c}	0.08^{c}	0.05^{c}	0.25^{ab}	0.14^{bc}	0.30^{a}	0.03	<0.01
2-Propanone	13.19^{b}	23.97^{b}	24.85^{b}	37.66^{ab}	18.46^{b}	77.86^{a}	34.70^{b}	37.92^{ab}	9.03	<0.01
3-Hydroxy-2-butanone	32.58^{abc}	36.19^{abc}	24.13^{abc}	34.91^{abc}	10.33^{c}	14.88^{bc}	53.93^{ab}	62.46^{a}	9.58	<0.01
Lactones										
Butyrolactone	0.06^{b}	0.06^{b}	0.07^{b}	0.13^{ab}	0.10^{b}	0.11^{b}	0.12^{ab}	0.18^{a}	0.03	0.02
n-Aldehydes										
Acetaldehyde	0.46^{ab}	0.65^{ab}	0.81^{ab}	0.98^{ab}	0.00^{b}	0.00^{b}	0.96^{ab}	1.76^{a}	0.32	<0.01
Heptanal	0.69	1.26	1.86	2.26	1.79	1.08	0.95	0.59	0.39	0.03
Hexanal	3.84^{b}	17.95^{ab}	32.54^{ab}	43.03^{a}	36.67^{a}	25.63^{ab}	13.7^{ab}	4.42^{b}	7.14	<0.01
Nonanal	0.23^{b}	0.41^{ab}	0.69^{ab}	0.92^{a}	0.63^{ab}	0.31^{ab}	0.39^{ab}	0.29^{b}	0.14	0.01
Octanal	1.74^{b}	2.90^{ab}	4.37^{ab}	5.11^{a}	4.25^{ab}	3.34^{ab}	1.87^{ab}	2.51^{ab}	0.73	0.01

Pentanal	0.02[b]	0.07[ab]	0.11[ab]	0.16[a]	0.13[ab]	0.14[ab]	0.04[ab]	0.01[b]	0.03	<0.01
Pyrazines										
2,5-dimethyl-Pyrazine	0.00	0.02	0.04	0.11	0.07	0.01	0.07	0.56	0.13	0.07
Methyl-Pyrazine	<0.01[b]	0.01[ab]	0.02[ab]	0.06[ab]	0.03[ab]	0.01[b]	0.04[ab]	0.32[a]	0.07	0.04
Strecker Aldehydes										
2-methylbutanal	0.03[b]	0.04[b]	0.09[b]	0.26[b]	0.77[ab]	1.70[a]	0.04[b]	0.67[ab]	0.24	<0.01
3-methylbutanal	0.05[b]	0.06[b]	0.67[b]	2.74[b]	7.27[b]	21.54[a]	0.13[b]	5.65[b]	2.78	<0.01
Benzaldehyde	0.76	0.91	1.11	1.10	1.12	0.92	0.71	0.96	0.18	0.66
Phenylacetaldehyde	0.51[b]	0.55[b]	0.68[b]	1.11[b]	3.82[a]	3.65[a]	0.54[b]	1.32[b]	0.46	<0.01
Sulfides										
Carbon disulfide	1027.16[b]	2875.02[ab]	3817.50[ab]	2919.12[ab]	2388.87[ab]	1365.46[ab]	3965.28[a]	3386.91[ab]	642.27	0.01
Dimethyl sulfide	1.78[ab]	2.44[ab]	2.12[ab]	2.96[a]	1.19[ab]	1.33[ab]	1.41[ab]	0.93[b]	0.43	0.02
Dimethyl-Disulfide	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	<0.01	0.24
Thiols										
Methanethiol	0.26	0.25	0.31	0.40	0.45	0.38	0.47	0.67	0.13	0.40

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

[1]Treatments: 1) 3 d wet-age; 2) 14 d wet-age; 3) 28 d wet-age; 4) 35 d wet-age; 5) 49 d wet-age; 6) 63 d wet-age; 7) 21 d dry-age; 8) 14 d wet-age followed by a 21 d dry-age (combination).

[2]Combination: Wet-age period of 14 d followed by dry-age period of 21 d.

[3]Standard error (largest) of the least squares means.

Table 2.8. Pearson correlation coefficients showing relationships between quantities of amino acids and beef sensory attributes for eight aging treatments[1].

Amino Acid	Beef Flavor ID	Browned	Roasted	Metallic	Fat-Like	Sour	Oxidized	Nutty	Musty/ Earthy	Liver-Like	Overall Tender-ness	Initial Juiciness	Sustained Juiciness
Alanine	-0.40**	-0.24	-0.15	0.29*	-0.04	0.54**	0.35**	0.35**	0.52**	0.42**	0.41**	-0.10	-0.19
alpha-aminoadipic acid	-0.49**	-0.30*	-0.21	0.29*	-0.10	0.70**	0.51**	0.59**	0.75**	0.56**	0.66**	-0.04	-0.06
Asparagine	-0.57**	-0.34**	-0.30*	0.39**	-0.11	0.79**	0.54**	0.61**	0.79**	0.63**	0.47**	-0.09	-0.12
Aspartic acid	-0.60**	-0.35**	-0.31*	0.31*	-0.18	0.78**	0.59**	0.63**	0.83**	0.59**	0.55**	-0.12	-0.11
Beta-alanine	-0.03	0.01	0.21	0.16	0.16	0.05	0.06	0.02	-0.01	0.11	0.41**	0.07	-0.01
Cysteine	-0.54**	-0.38**	-0.34**	0.28*	-0.10	0.69**	0.57**	0.57**	0.74**	0.49**	0.62**	-0.05	-0.02
Cystine	-0.53**	-0.34**	-0.24	0.16	-0.03	0.55**	0.51**	0.39**	0.55**	0.47**	0.44**	-0.15	-0.18
Glutamic acid	-0.57**	-0.33**	-0.28*	0.30*	-0.10	0.77**	0.60**	0.59**	0.77**	0.58**	0.66**	-0.09	-0.10
Glutamine	0.12	-0.06	0.07	-0.01	0.19	-0.05	-0.02	-0.11	-0.14	-0.05	0.45**	0.22	0.19
Glycine	-0.07	-0.10	0.04	-0.14	-0.04	0.06	0.12	-0.01	0.02	0.00	0.42**	0.07	0.05
Histidine	-0.27*	-0.20	-0.10	0.27*	0.12	0.35**	0.29*	0.27*	0.37**	0.26*	0.61**	0.00	-0.04
Hydroxyproline	-0.12	-0.14	0.00	0.16	0.08	0.29*	0.22	0.08	0.14	0.19	0.56**	0.15	0.11
Isoleucine	-0.43**	-0.26*	-0.21	0.19	-0.07	0.57**	0.43**	0.43**	0.61**	0.43**	0.50**	-0.09	-0.17
Leucine	-0.42**	-0.21	-0.17	0.27*	-0.09	0.61**	0.36**	0.47**	0.55**	0.50**	0.44**	-0.02	0.00
Lysine	-0.52**	-0.28*	-0.24	0.30*	-0.09	0.75**	0.55**	0.58**	0.75**	0.56**	0.65**	-0.09	-0.12
Methionine	-0.40**	-0.22	-0.17	0.37**	0.08	0.59**	0.33**	0.54**	0.68**	0.40**	0.61**	-0.05	-0.01
Ornithine	-0.58**	-0.37**	-0.35**	0.31*	-0.14	0.77**	0.65**	0.58**	0.78**	0.57**	0.51**	-0.10	-0.12
Phenylalanine	-0.55**	-0.31*	-0.26*	0.30*	-0.11	0.76**	0.54**	0.60**	0.78**	0.59**	0.62**	-0.11	-0.14
Proline	-0.31*	-0.18	-0.20	0.07	-0.05	0.34**	0.33**	0.26*	0.38**	0.22	0.50**	-0.05	-0.12
Serine	-0.40**	-0.18	-0.12	0.19	-0.11	0.59**	0.47**	0.44**	0.59**	0.47**	0.61**	-0.07	-0.10
Threonine	-0.40**	-0.17	-0.12	0.16	-0.15	0.60**	0.48**	0.47**	0.58**	0.48**	0.61**	-0.04	-0.05
Tryptophan	-0.46**	-0.28*	-0.17	0.37**	-0.03	0.67**	0.49**	0.58**	0.71**	0.53**	0.52**	-0.09	-0.09
Tyrosine	-0.49**	-0.29*	-0.21	0.27*	-0.06	0.70**	0.49**	0.55**	0.71**	0.53**	0.70**	-0.07	-0.10
Valine	-0.14	-0.02	-0.07	-0.04	-0.14	0.18	0.07	0.16	0.17	0.06	0.23	0.08	0.10
Total Amino Acids	-0.52**	-0.29*	-0.22	0.27*	-0.11	0.72**	0.52**	0.55**	0.71**	0.54**	0.68**	-0.06	-0.09

[1]Treatments: 1) 3 d wet-age; 2) 14 d wet-age; 3) 28 d wet-age; 4) 35 d wet-age; 5) 49 d wet-age; 6) 63 d wet-age; 7) 21 d dry-age; 8) 14 d wet-age followed by a 21 d dry-age (combination).

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

Table 2.9. Pearson correlation coefficients showing relationships between quantities of volatile compounds and beef flavor attributes of eight aging treatments[1].

Volatile Compound	Beef Flavor ID	Browned	Roasted	Metallic	Sour	Oxidized	Nutty	Musty/ Earthy	Liver-Like
Alcohols									
1-Hexanol	0.05	-0.03	0.04	-0.02	0.01	0.03	-0.02	-0.08	-0.07
1-Octanol	0.12	-0.04	0.00	-0.17	-0.15	-0.05	-0.09	-0.20	-0.21
1-Octen-3-ol	0.11	-0.06	0.02	-0.03	-0.12	-0.04	-0.11	-0.19	-0.19
1-Pentanol	-0.28*	-0.22	-0.17	0.07	0.35**	0.42**	0.15	0.27*	0.19
1-Penten-3-ol	0.05	-0.11	-0.02	0.18	0.16	0.17	0.11	0.09	0.11
2,3-Butanediol	-0.07	0.13	0.01	0.11	0.19	0.06	0.23	0.22	0.17
Ethanol	-0.66**	-0.45**	-0.46**	0.29*	0.77**	0.63**	0.56**	0.78**	0.57**
Carboxylic Acids									
Acetic acid	-0.36**	-0.19	-0.20	0.21	0.55**	0.37**	0.41**	0.53**	0.43**
Butanoic acid	-0.07	0.03	0.09	0.19	0.29*	0.15	0.20	0.24	0.25*
Hexanoic acid	0.12	0.04	0.13	0.01	-0.04	-0.08	-0.07	-0.12	-0.11
Nonanoic acid	0.19	0.31*	0.14	-0.34**	-0.26*	-0.38**	-0.20	-0.29*	-0.34**
Octanoic acid	0.08	0.18	0.07	-0.15	-0.10	-0.15	-0.10	-0.14	-0.14
Esters									
Butanoic acid, methyl ester	-0.14	-0.15	-0.06	0.18	0.29*	0.33**	0.23	0.32*	0.35**
Heptanoic acid, methyl ester	-0.15	-0.10	0.01	0.18	0.20	0.12	0.13	0.15	0.11
Hexanoic acid, methyl ester	-0.02	-0.12	0.10	0.12	0.08	0.14	0.02	0.02	0.08
Methyl propionate	0.31*	0.11	0.19	0.08	-0.21	-0.10	-0.14	-0.25*	-0.09
Nonanoic acid, methyl ester	0.01	-0.15	0.00	-0.24	-0.07	-0.13	-0.09	-0.11	-0.25*
Octanoic acid, methyl ester	-0.06	-0.11	0.04	0.12	0.11	0.03	0.10	0.06	0.04
Furans									
2-Pentyl furan	0.15	-0.02	0.04	-0.12	-0.15	-0.08	-0.14	-0.22	-0.23
Hydrocarbons									
1-Octene	-0.09	-0.08	0.06	-0.03	0.27*	0.43**	0.10	0.18	0.29*
Decane	0.10	0.06	0.23	0.12	0.09	0.06	0.04	0.08	0.20
D-limonene	0.29*	0.10	0.11	-0.17	-0.24	-0.20	-0.20	-0.25*	-0.21
Octane	-0.43**	-0.27*	-0.19	0.16	0.52**	0.48**	0.26*	0.48**	0.33**
Pentane	-0.41**	-0.19	-0.17	0.12	0.52**	0.55**	0.29*	0.48**	0.41**
p-Xylene	-0.37**	-0.19	-0.14	0.09	0.46**	0.43**	0.23	0.39**	0.29*
Toluene	0.40**	0.29*	0.39**	0.16	-0.24	-0.20	-0.16	-0.28*	-0.09
Ketones									
2,3-Butanedione	0.35**	0.23	0.28*	0.09	-0.26*	-0.23	-0.17	-0.27*	-0.10
2,3-Pentanedione	-0.33**	-0.27*	-0.20	0.06	0.37**	0.42**	0.17	0.31*	0.16
2-Butanone	-0.01	-0.07	0.05	0.03	-0.03	0.18	0.02	0.04	0.08
2-heptanone	0.15	0.13	0.33**	0.09	0.04	-0.12	-0.05	-0.06	0.09
2-Pentanone	-0.08	0.10	0.12	0.10	0.28*	0.22	0.22	0.24	0.31*
2-Propanone	-0.19	-0.09	-0.02	0.17	0.35**	0.41**	0.24	0.32**	0.36**
3-Hydroxy-2-butanone	0.33**	0.24	0.30*	0.09	-0.25*	-0.22	-0.14	-0.27*	-0.09
Lactones									
Butyrolactone	-0.01	0.09	0.09	0.18	0.17	0.07	0.13	0.15	0.18
n-Aldehydes									
Acetaldehyde	0.31*	0.29*	0.35**	0.09	-0.23	-0.26*	-0.19	-0.29*	-0.16
Heptanal	0.01	-0.12	-0.11	-0.10	-0.04	0.01	0.02	-0.02	-0.09
Hexanal	-0.13	-0.25*	-0.19	0.00	0.12	0.14	0.10	0.12	0.02
Nonanal	0.03	-0.04	-0.01	-0.13	-0.07	-0.06	-0.04	-0.07	-0.14

Octanal	-0.10	-0.11	-0.12	-0.06	0.06	0.09	0.09	0.08	-0.01
Pentanal	-0.20	-0.31*	-0.26*	-0.01	0.18	0.23	0.11	0.18	0.06
Pyrazines									
2,5-dimethyl-Pyrazine	0.08	0.22	0.15	0.16	0.06	-0.08	0.04	0.05	0.05
Methyl-Pyrazine	0.08	0.24	0.16	0.17	0.05	-0.08	0.05	0.05	0.05
Strecker Aldehydes									
2-methylbutanal	-0.36**	-0.25*	-0.31*	0.24	0.55**	0.46**	0.45**	0.55**	0.43**
3-methylbutanal	-0.39**	-0.31*	-0.35**	0.18	0.54**	0.47**	0.39**	0.55**	0.41**
Benzaldehyde	-0.01	0.00	-0.03	-0.11	0.06	0.04	0.06	0.02	0.04
Phenylacetaldehyde	-0.49**	-0.34**	-0.34**	0.35**	0.68**	0.48**	0.62**	0.70**	0.55**
Sulfides									
Carbon disulfide	0.20	0.15	0.26*	-0.02	-0.14	-0.23	-0.09	-0.24	-0.17
Dimethyl sulfide	0.20	-0.14	0.03	0.02	-0.27*	-0.06	-0.22	-0.24	-0.10
Dimethyl-Disulfide	0.09	0.23	0.02	-0.10	-0.12	-0.13	-0.03	-0.10	-0.12
Thiols									
Methanethiol	0.09	0.05	0.20	0.18	0.09	-0.07	0.14	0.16	-0.02

[1]Treatments: 1) 3 d wet-age; 2) 14 d wet-age; 3) 28 d wet-age; 4) 35 d wet-age; 5) 49 d wet-age; 6) 63 d wet-age; 7) 21 d dry-age; 8) 14 d wet-age followed by a 21 d dry-age (combination).

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

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

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CHAPTER III

COMPARISON OF RETAIL CUTTING YIELDS, TIMES, AND VALUE IN THIRTEEN BEEF SUBPRIMALS FROM BEEF AND HOLSTEIN CATTLE

SUMMARY

The effect of cattle type, specifically Holstein versus beef breeds, was evaluated for subprimal cutting yields, the time that it takes to fabricate cuts, and value among several different subprimals. Subprimals from carcasses of beef-breeds were generally heavier than those derived from Holstein carcasses. Saleable yields did not differ by breed type. However, cuts from carcasses of Holsteins having greater amounts of subcutaneous and intermuscular fat, including short loins and ribeye rolls, had improved retail yields compared to beef breeds. Additionally, cuts from carcasses of Holsteins were fabricated more quickly than those from carcasses of beef breeds, likely a result of less fat trimming and more manageable sizes. Resulting fabrication values favored and warranted priority selection of certain Holstein subprimals by steak cutters and retailers.

INTRODUCTION

Fed Holstein cattle constitute a major proportion of the U.S. beef supply, with estimates reported of approximately 20% (National Cattlemen's Beef Association, 2016). However, harvesting of Holsteins presents challenges to the packing industry, particularly those which have not been managed as calf-fed cattle. Compared to beef breeds of cattle, longer carcasses, increased liver condemnation rates, decreased dressing percentage, and inferiority in muscle:bone make Holsteins generally less desirable (McKenna et al., 2002; Rust and Abney,

2005). As a result, some packers only procure Holstein types of cattle when they are available at a significant discount; this cost differential is commonly referred to as the "dairy discount." Still, others in the industry have recognized that calf-fed Holsteins, correctly managed early in their life cycle, may generate an advantageous product relative to beef breeds. Increased marbling and decreased external fatness has been noted when comparing Holsteins to beef breeds (McKenna et al., 2002; Moore et al., 2012). Furthermore, Abney (2004) suggested that feeding cattle starting at an earlier age, such as the method by which calf-fed Holsteins are produced, may enhance eating quality traits. As carcass weights have increased steadily over the last 10 years (National Cattlemen's Beef Association, 2016), many retailers have expressed concern about muscle sizes that are too large to target a portion size with ideal thickness. Therefore, benefits from fabrication of Holstein carcasses may include smaller subprimals and muscle sizes, as well as faster cutting times from naturally leaner, more manageable cuts. Furthermore, extensive artificial insemination in the dairy industry indicates that Holstein cattle are derived from a very tight genetic pool, which may lend itself to a highly consistent product. Previous studies evaluating cutability differences among breed types have found conflicting results and may be outdated, especially given more efficient modern-day production practices (Branaman et al., 1962; Cole et al., 1964; Pearson, 1966; Dikeman et al., 1977; Garcia-de-Siles et al., 1977). Therefore, the objective of the present study was to identify differences in composition of subprimals between today's Holstein and beef-breeds carcasses by measures of retail cutting yields, time for retail fabrication, and subsequent value.

MATERIALS AND METHODS

Institutional Animal Care and Use Committee approval was not required for this study as samples were obtained from a federally inspected harvest facility.

Sample Collection

Vacuum packaged subprimals (Table 3.1) from commodity, USDA Choice carcasses of beef breeds (n = 404) and fed Holstein cattle (n = 398) were collected from commercial packing facilities, transported to a meat research laboratory, and stored at 2ºC for 12 to 16 d postmortem. Carcasses were fabricated into subprimals according to the Institutional Meat Purchasing Specifications (IMPS) (NAMP, 2010; USDA, 2014b). Subprimals included: Rib, Ribeye Roll, Lip-On (IMPS 112A); Chuck, Shoulder (Clod) (IMPS 114C); Chuck, Chuck Roll (IMPS 116A); Round, Sirloin Tip (Knuckle), Peeled (IMPS 167A); Round, Top (Inside) (IMPS 169); Round, Top (Inside) (individual muscle; IM) (IMPS 169E); Round, Outside Round (Flat) (IMPS 171B); Round, Eye of Round (IM) (IMPS 171C); Loin, Short Loin (IMPS 173); Loin, Strip Loin (IMPS 175); Loin, Top Sirloin Butt, Boneless (IMPS 184); Loin, Top Sirloin Butt, Center-Cut, Cap Off (IM), Boneless (IMPS 184B); and Loin, Tenderloin, Full, Side Muscle On, Defatted (IMPS 189A). Subprimals were selected to simulate high volume throughput in the retail industry.

Retail Cutting Tests

Experienced meat cutters from Colorado State University performed cutting tests, and the same cutters were used for all treatments of the each subprimal. Cutting test procedures were similar to those outlined by Haneklaus et al. (2011). Subprimals were weighed before and after unpackaging, and empty bags were drained and weighed to calculate purge loss. All resulting component weights from cutting were recorded electronically. Cutters were instructed to fabricate according to modern retailing schemes, guided by the Uniform Retail Meat Identity

Standards (URMIS; Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003) and The Meat Buyer's Guide (NAMP, 2010). Each cutter generated the same number and type of cuts from each subprimal. Cutters were instructed to maximize yield as much as possible, while still meeting cutting specifications. Rulers were provided to gauge thickness of steaks and roasts. Maximum fat thickness on all retail cuts was 0.32 cm according to current retail practices. From remaining portions not classified as steaks or roasts, Beef for Stew (URMIS 1727) was produced when possible and defined as pure lean approximately 2.54 cm^3. Lean not classified as Beef for Stew (URMIS 1727), including that which adhered to fat, was identified as trimmings. Trimmable fat, connective tissue, and bone was sorted as fat/refuse. Component classification was exclusively at the determination of the cutter. Cutting time was measured from first knife stroke (or saw contact in the case of Short Loins) to last knife stroke and recorded. Component classification was not included in this time. After each piece, technicians ensured recovery of 100 ± 2% (3% for Short Loins due to bone dust not recovered), and only data from subprimal cuts for which data adhered to these criteria were included the study.

Rib, Ribeye Roll, Lip-On

The posterior end of ribs, ribeye rolls, and lip-on ribeyes were faced to remove a thin slice (approximately 0.32 cm thick). Tails were cut to 2.54 cm from the outer tip of the *M. longissimus thoracis* at approximately a 45 degree angle to the cutting table. Exterior fat was trimmed to 4 mm. Subprimals were cut to maximize yield of 2.54 cm Ribeye Steaks (URMIS 1209) from end-to-end. Number of steaks generated were recorded.

Chuck, Shoulder (Clod)

Any remaining *M. latissimus dorsi* or *M. tensor fasciae antibrachii* was removed and classified as trim. Ventral end of the *M. triceps brachii-long head* was removed just enough to

square up the subprimal. Exterior fat was trimmed to 0.32 cm. One- 5.08 cm thick Shoulder Pot Roast (URMIS 1132) was removed from the ventral end of subprimal, followed by 3- 1.27 cm thick Shoulder Steaks (URMIS 1133). Remaining dorsal portion was cut to maximize yield of 1- or 2- 5.08 cm Shoulder Pot Roasts (URMIS 1132).

Chuck, Chuck Roll

Connective tissue and *M. subscapularis* were removed. Anterior corner was squared to the subprimal, removing excessive neck. Any remaining *M. rhomboideus* was also removed laterally to the subprimal. Starting at the posterior end, 2- 2.54 cm thick Chuck Eye Steaks (URMIS 1102), followed by 1- 5.08 cm thick Chuck Under Blade Pot Roast (URMIS 1151), and 3- 1.27 cm thick Chuck Under Blade Steaks (URMIS 1158) were removed. The remaining anterior portion was cut to maximize yield of 2- or 3- 5.08 cm thick Chuck Under Blade Pot Roasts (URMIS 1151).

Round, Sirloin Tip (Knuckle), Peeled

Patella end was cut to square up entire subprimal. Dorsal end was faced to remove a thin slice (approximately 0.32 cm thick). Three- 1.27 cm thick Round Tip Steaks Cap Off (URMIS 1535) were cut from the dorsal end. One- or 2- 5.08 cm thick Round Tip Roasts Cap Off (URMIS 1526) were cut from the remaining portion to maximize yield.

Round, Top (Inside)

External fat was trimmed to 0.32 cm. *M. sartorius* and *M. pectineus* were removed. Dorsal side was faced to remove a thin slice (approximately 0.32 cm thick). One- 5.08 cm thick Top Round Roast Cap Off (URMIS 1455) was removed from the dorsal end, followed by 3- 1.27 cm thick Top Round Steaks (URMIS 1553). Remaining portion was cut into 1- or 2- 5.08 cm thick Top Round Roasts (URMIS 1455) to maximize yield. *M. gracilis* was trimmed on all

steaks and roasts to not exceed more than 1.91 cm from *M. semimembranosus* or *M. adductor femoris* at any point.

Round, Top (Inside) (IM)

The dorsal side was faced to remove a thin slice (approximately 0.32 cm thick). One- 5.08 cm thick Top Round Roast (URMIS 1455) was removed from the dorsal end, followed by 3- 1.27 cm thick Top Round Steaks (URMIS 1553). Remaining portions were cut into 1- or 2- 5.08 cm thick Top Round Roasts (URMIS 1455) to maximize yield.

Round, Outside Round (Flat)

Heavy connective tissue ("silver skin") was removed, and external fat was trimmed to 0.32 cm. One- 10.16 cm thick Bottom Round Rump Roast (URMIS 1519) was cut from the ventral end, followed by 3- 1.27 cm thick Bottom Round Steaks (URMIS 1466). The remaining portions were cut into 2- or 3- 5.08 cm thick Bottom Round Roasts (URMIS 1464) to maximize yield.

Round, Eye of Round (IM)

External fat was trimmed to 0.32 cm. Dorsal and ventral ends of *M. semitendinosus* were squared, the remaining subprimal was portioned into 2- or 3- 10.16 cm long Eye Round Roasts (URMIS 1480) to maximize yield.

Loin, Short Loin

Posterior end was faced to remove a thin slice (approximately 0.64 cm thick). Subprimal was cut to maximize steak yield of 2.54 cm thick Porterhouse Steaks (URMIS 1330) and 2.54 cm thick T-Bone Steaks (URMIS 1369). Porterhouse Steaks were classified as those with *M. psoas major* diameter of at least 3.2 cm when measured parallel to the backbone (NAMP, 2010), and all those steaks which failed to meet this requirement were classified as T-Bone Steaks,

regardless of *M. psoas major* size. Number of steaks was recorded for both Porterhouse Steaks and T-Bone Steaks.

Loin, Strip Loin

Posterior ends (vein end) were faced to remove a thin slice (approximately 0.32 thick). Remaining subprimal was cut to maximize 2.54-cm thick Strip Steaks (URMIS 1404). After steaking, external fat was trimmed to 0.32 cm. Tail was cut to 2.54 cm from the outer tip of the *M. longissimus lumborum* at approximately a 45 degree angle to the ventral edge of each steak.

Loin, Top Sirloin Butt, Boneless

M. biceps femoris was isolated and cut to maximize 2.54 cm Top Sirloin Cap Steaks (URMIS 1421), beginning from the anterior end. *M. gluteus accessorius* and *M. gluteus profundus* were removed, such that only *M. gluteus medius* remained. External fat was trimmed to 0.32 cm. *M. gluteus medius* was faced on the anterior side to remove a thin slice (approximately 0.32 cm thick). The remaining portion was maximized for yield of 2.54 cm Top Sirloin Steaks Cap Off (URMIS 1426). Number of the different types of steaks was recorded.

Loin, Top Sirloin Butt, Center-Cut, Cap Off (IM), Boneless

M. gluteus accessorius and *M. gluteus profundus* were removed, such that only *M. gluteus medius* remained. External fat was trimmed to 0.32 cm. *M. gluteus medius* was faced on the anterior side to remove a thin slice (approximately 0.32 cm thick). The remaining portion was maximized for yield of 2.54 cm Top Sirloin Steaks Cap Off (URMIS 1426). Number of steaks were recorded.

Loin, Tenderloin, Full, Side Muscle On, Defatted

Fat on the dorsal side was trimmed to 0.32 cm. *M. quadratus lumborum* and *M. iliacus* were removed if present, such that only *M. psoas major* and *M. psoas minor* remained. Steak

yield was maximized for 3.81 cm thick Tenderloin Steaks (URMIS 1388) until the diameter (measured from ventral edge to dorsal edge) was less than 2.54 cm.

Statistical Analysis

Comparisons of the effects of cattle type for each subprimal were analyzed as a completely randomized design. Cutter was strategically excluded from the model as a covariate to allow for cutter-to-cutter variation representative of an industry setting. Least squares means were calculated using a one-way ANOVA model in the emmeans package (Lenth, 2018) of R statistical software (R Core Team, 2013), with significance at $\alpha < 0.05$. When evaluating treatment effect for saleable yield and cutting time of all subprimals combined, least squares means were averaged over all subprimals, and subprimal was included in the model as a fixed effect.

Retail Values

Cutting yields for each subprimal were assigned values on a retail cut basis using a 5-year (2013 to 2017) weighted average price as reported by the USDA Markets News Portal (https://marketnews.usda.gov/mnp/dataDownload; Table B.4). A subsample of trimmings from each subprimal was evaluated for fat content to appropriately value lean trim. Most trimmings were about 85% lean by weight (data not reported), and a common retail price for corresponding ground beef was used for all subprimals. Cutting yields for all saleable retail cuts were multiplied by appropriate retail prices to establish value. Valuations were totaled for all saleable cuts, and the difference between the subprimals derived from carcasses of beef breeds vs. carcasses of Holsteins were calculated. The positive difference was reported for either breed type (Table 3.4).

RESULTS AND DISCUSSION

Minimal differences were found in mean total saleable yields or cutting times for subprimals derived from carcasses of Holstein vs. beef breeds (Table 3.2 and 3.3, respectively). Previously reported retail cutting tests have found similar results among cattle types (Pearson, 1966; Dikeman et al., 1977). Greater ($P < 0.01$) saleable yields were generated for short loins, ribeye rolls, and inside rounds (IM) from Holstein carcasses, and bottom round flats from carcasses of beef breeds. Cutting times were faster ($P < 0.01$) for ribeye rolls, sirloin tips, short loins, and strip loins from Holstein carcasses, and center-cut top sirloin butts from beef breed carcasses. Additionally, when all cuts were considered, cutting times needed for carcasses of Holsteins were faster ($P < 0.01$) than those for beef breeds. As expected, total subprimal weight was heavier ($P \leq 0.03$) for all subprimals from carcasses of beef breeds, except for shoulder clods and center-cut top sirloin butts, which did not differ by breed type ($P > 0.05$; Tables 3.5 through 3.15).

Differences in the composition of Holstein beef may contribute to improved saleable yields and reduced time necessary to fabricate subprimals derived from carcasses of Holsteins. McKenna et al. (2002) and Warren et al. (2008) showed that Holstein cattle produce leaner carcasses than their counterpart beef breeds, suggesting that Holsteins produce subprimals with less trimmable fat (improving saleable yield) and that require less trimming (improving cutting time). Our study noted yield differences in cuts known as “middle-meats,” including the ribeye roll and short loin. These cuts may experience the greatest yield benefit from cattle type primarily due to additional subcutaneous and intermuscular fat accretion relative to other cuts. Minimal retail cutting yield differences between cattle types for many subprimals likely was due to ideal incoming specification and quality assurance of wholesale product. Holstein animals are

generally lighter muscled than beef breeds (McKenna et al., 2002), which may contribute to smaller and more manageable subprimals, and reducing the amount of time needed to fabricate retail cuts. However, it is difficult to draw true conclusions with respect to necessary cutting times among breed types in this study given that subprimals and cuts were represented just once in the study.

Cutting yield advantages with respect to retail values are presented in Table 3.4. Most values were similar, which was expected given a lack of differences in saleable yields between breed types. Subprimals comprised of retail cuts with the greatest value were affected most. Of those subprimals with true differences in saleable yield of retail cuts among breed types (ribeye roll, short loin, inside round (IM), and outside round flat), the short loin exhibited the greatest advantage ($0.51/pound). Due to variable costs of operation, the profit advantage for cutting time differences due to breed type could not be calculated, although it may be relevant for some large-scale operations.

The following discussion evaluates each subprimal and how certain components may contribute to cutting yield and time differences, resulting in a retail price advantage between cattle type.

Rib, Ribeye Roll, Lip-On

Despite a total subprimal weight difference, numbers of steaks did not differ ($P = 0.26$) by breed type (Table 3.5). Since steaks were cut to a common thickness, this suggested that subprimal length was similar, and individual steak weights were lower for cuts derived from carcasses of Holsteins. No difference ($P = 0.14$) existed between breed types in percentage of ribeye steaks yielded from subprimals. However, total saleable yield was greater ($P < 0.01$) for cuts derived from carcasses of Holsteins, and this might have been attributed to increased yields

of trimmings ($P < 0.01$) and reduced yields of fat/refuse ($P < 0.01$). Cutting times werefaster ($P < 0.01$) for rib cuts derived from carcasses of Holsteins, which may also have been a result of decreased fat.

Chuck, Chuck Roll

Percentage yields of chuck eye steaks, chuck steaks, and chuck roasts were greater ($P < 0.01$) for in chuck cuts derived from carcasses of Holsteins (Table 3.6). However, beef-breed chuck rolls compensated for this difference with greater yields of ($P < 0.01$) trimmings; thus, total saleable yield was not different ($P = 0.68$) between breed types. Retail prices of chuck steaks and roasts are not drastically different from trimmings, so price differential between cattle types was negligible.

Round, Sirloin Tip (Knuckle), Peeled

Tip roast yield was greater ($P < 0.01$) in knuckle cuts from carcasses of Holsteins, and steak and stew meat yields were greater ($P \leq 0.01$) in knuckle cuts from beef breeds (Table 3.7). However, this did not contribute ($P = 0.26$) to a saleable yield difference. Purge weights were greater ($P < 0.01$) in cuts from carcasses of beef breeds ; but, this difference was not explainable and negligible in importance. Cutting times were faster ($P < 0.01$) for knuckle cuts from carcasses of Holsteins due to smaller starting subprimal weights.

Round, Top (Inside) (IM)

Percentage yields of top round roasts from inside rounds (IM) were greater ($P = 0.04$) in cuts derived from carcasses of beef breeds, and trimmings yields were greater ($P < 0.01$) from top rounds of Holstein carcasses (Table 3.8). Furthermore, percentages of purge yields were greater ($P < 0.01$) for top rounds from carcasses of beef-breeds, with a difference of approximately 1.5%. Holstein carcass subprimals only had slightly more fat (not statistically

different), and subprimals from both breed types were aged for similar lengths. Thus, such a magnitude of difference in purge yields was unexplained.

Round, Outside Round (Flat)

Bottom round flats from carcasses of beef breeds generated less ($P < 0.01$) fat than those derived from Holsteins, contributing to a greater ($P < 0.01$) saleable yield (Table 3.9). This unexpected difference in fat yields between the two breed types may have been due to trimming specifications and quality control at different originating packing facilities. Purge differed ($P < 0.01$), with beef breeds yielding greater amounts.

Round, Eye of Round (IM)

Eye of rounds from carcasses of beef breeds yielded greater ($P = 0.01$) percent of roasts, and carcasses from Holsteins produced greater ($P < 0.01$) percent trimmings and fat/refuse (Table 3.10). Again, purge differences ($P < 0.01$) were negligible. Saleable yields did not differ ($P = 0.87$) between breed types. Cutting time trended to be faster ($P = 0.05$) for beef breeds, which may be attributed to less fat trimming.

Loin, Short Loin

Short loins from carcasses of beef breeds had greater ($P < 0.01$) yields for porterhouse steaks, stew meat, and trimmings, and short loins from Holstein carcasses had greater ($P < 0.01$) yields for T-bone steaks (Table 3.11). Moreover, fat was greater ($P < 0.01$) in short loins from beef breed carcasses (approximately 6%). Consequently, short loins from Holsteins yielded approximately 6% greater ($P < 0.01$) total saleable yield. This translates to a $0.51/pound advantage for cutting Holstein short loins, which may be relevant in large-scale production. These findings directly mirror cutting time differences, where Holstein short loins cut approximately 70 s faster ($P < 0.01$), likely the result of less steak trimming. Despite a lower

muscle-to-bone ratio in Holsteins, it appears fat has a greater influence on total saleable yield when cutting short loins. Number of total steaks did not differ ($P = 0.63$) between the breed types. However, a greater ($P < 0.01$) number of porterhouse steaks came from carcasses of beef breeds, and a greater ($P < 0.01$) number of T-bone steaks came from Holsteins. These findings are not surprising given the muscle disadvantages of the Holstein and the basis of classification for these steaks on tenderloin (*Psoas major*) size.

Loin, Strip Loin

Percent strip steaks was greater ($P < 0.01$) in strip loins from Holstein carcasses, and percent trimmings was greater ($P < 0.01$) for beef breed carcasses (Table 3.12). Fat trended to be greater ($P = 0.10$) for beef breeds, which may have contributed to slower ($P = 0.02$) cutting times.

Loin, Top Sirloin Butt, Center-Cut, Cap Off (IM), Boneless

Percent fat/refuse was lower ($P < 0.01$) for center-cut top sirloin butts from beef breeds, which may correlate with a faster ($P < 0.01$) cutting time (Table 3.13).

Loin, Tenderloin, Full, Side Muscle On, Defatted

Percent tenderloin steaks was greater ($P < 0.01$) for beef breed carcasses, and percent trimmings was greater ($P < 0.01$) for Holsteins (Table 3.14). This may the result of smaller tenderloins in Holsteins. However, these components did not produce an overall yield difference ($P = 0.89$) between breed types. Due to the high value of tenderloins steaks, the cutting yield advantage of tenderloin steaks from beef breeds resulted in a $0.37/pound advantage for the whole subprimal over Holsteins.

Chuck, Shoulder (Clod)

No difference ($P > 0.05$) existed for component yields, saleable yield, or cutting time in shoulder clods from carcasses of beef breeds or Holsteins (Table B.1).

Round, Top (Inside)

Although negligible and unexplained, purge was greater ($P < 0.01$) in top rounds from beef breeds (Table B.2). No other differences ($P > 0.05$) for component yield, saleable yield, or cutting time were noted.

Loin, Top Sirloin Butt, Boneless

No differences ($P > 0.05$) were found for any component yields, total saleable yield, steak count, or cutting time for top sirloin butts (Table B.3). Purge differences ($P < 0.01$) were negligible.

Conclusions

Subprimals which contain a great deal of external and intermuscular fat were most affected by breed type. Consequently, some subprimals from Holsteins, including short loins and ribeye rolls, yielded a higher percent of saleable of cuts. These yield advantages translated to a price advantage cutting, which may be relevant for certain operations. Moreover, less trimming time, added with smaller and more manageable cuts, may allow for faster cutting times in product from Holstein carcasses. Furthermore, retail cuts from Holstein carcasses may more frequently target an acceptable portion size. This may warrant retailers and steak cutters to purchase certain subprimals of beef from Holstein carcasses to maximize economic efficiencies. However, further research and selection parameters, which may include different production practices (short fed versus long fed) and live traits (light weight versus heavy weight), are needed

to truly unravel cutting differences in different breeds of cattle, such as Holsteins and beef breeds.

Table 3.1. Study design.

Subprimal	IMPS[1]	Beef-Breed Type *(n)*	Holstein *(n)*
Ribeye Roll, Lip-On	112A	30	30
Shoulder Clod	114C	30	32
Chuck Roll	116A	29	30
Sirloin Tip (Knuckle)	167A	30	29
Inside Round	169	36	36
Inside Round (IM)	169E	32	30
Outside Round Flat	171B	31	31
Eye of Round	171C	36	36
Short Loin	173	30	28
Strip Loin	175	31	30
Top Sirloin Butt	184	30	30
Top Sirloin Butt, Center-Cut	184B	30	30
Tenderloin	189A	34	32
Total		404	398

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).

Table 3.2. Comparison of saleable yields[1] between beef-breed type and Holstein subprimals expressed as a percentage of total subprimal weight[2].

Subprimal	IMPS[3]	Beef-Breed Type (%)	Holstein (%)	SEM[4]	*P* - Value
Ribeye Roll, Lip-On	112A	93.77	96.50	0.42	<0.01
Shoulder Clod	114C	94.71	94.62	0.40	0.87
Chuck Roll	116A	95.98	96.11	0.21	0.68
Sirloin Tip (Knuckle)	167A	93.97	94.52	0.34	0.26
Inside Round	169	83.10	83.35	0.60	0.77
Inside Round (IM)	169E	92.82	93.82	0.26	<0.01
Outside Round Flat	171B	91.32	88.51	0.53	<0.01
Eye of Round	171C	94.71	94.62	0.40	0.87
Short Loin	173	83.11	89.26	0.48	<0.01
Strip Loin	175	90.83	91.75	0.45	0.15
Top Sirloin Butt	184	78.62	80.59	0.74	0.06
Top Sirloin Butt, Center-Cut	184B	93.97	93.14	0.33	0.08
Tenderloin	189A	90.89	90.78	0.57	0.89
Total		92.26	92.50	0.14	0.23

[1]Saleable yield includes steaks, roasts, Beef for Stew (URMIS 1727), and trim and excludes fat/refuse and purge.
[2]Total subprimal weight represents the initial weight of the item without packaging.
[3]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[4]Standard error (largest) of the least squares means.

Table 3.3. Comparison of cutting times[1] (seconds) to fabricate beef-breed type and Holstein subprimals into retail cuts.

Subprimal	IMPS[2]	Beef-Breed Type (s)	Holstein (s)	SEM[3]	*P* - Value
Ribeye Roll	112A	204.6	168.0	7.8	<0.01
Shoulder Clod	114C	184.2	196.2	7.2	0.30
Chuck Roll	116A	210.0	216.6	6.6	0.47
Sirloin Tip (Knuckle)	167A	144.0	118.2	5.4	<0.01
Inside Round	169	274.8	263.4	10.8	0.32
Inside Round (IM)	169E	160.2	153.0	6.6	0.44
Outside Round Flat	171B	204.0	213.0	9.0	0.49
Eye of Round	171C	63.0	70.2	3.0	0.05
Short Loin	173	196.8	127.2	7.2	<0.01
Strip Loin	175	264.6	216.6	14.4	0.02
Top Sirloin Butt	184	279.6	294.0	10.8	0.33
Top Sirloin Butt, Center-Cut	184B	78.0	92.4	3.0	<0.01
Tenderloin	189A	211.2	207.0	18.0	0.86
Total		190.8	180.0	2.4	<0.01

[1]Measured from first knife stroke (or saw contact for Short Loins) to last knife stroke.
[2]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[3]Standard error (largest) of the least squares means.

Table 3.4. Comparison of retail price[1] advantages[2] from cutting yields of beef-breed type and Holstein subprimals.

Subprimal	IMPS[3]	Beef-Breed Advantage (USD/pound)	Holstein Advantage (USD/pound)
Ribeye Roll, Lip-On[4]	112A		0.14
Shoulder Clod	114C	0.02	
Chuck Roll	116A		0.03
Sirloin Tip (Knuckle)	167A	0.01	
Inside Round	169		0.02
Inside Round (IM)[4]	169E		0.04
Outside Round Flat[4]	171B	0.11	
Eye of Round	171C	0.03	
Short Loin[4]	173		0.51
Strip Loin	175		0.15
Top Sirloin Butt	184		0.09
Top Sirloin Butt, Center-Cut	184B	0.05	
Tenderloin	189A	0.37	

[1]Retail prices were determined from a 5-year weighted average as reported by USDA Market News Portal (https://marketnews.usda.gov/mnp/dataDownload).
[2]Calculated as the difference of sum of retail prices for all components, given cutting yield performance, between beef-breed type and Holstein subprimals. Only the positive result is shown.
[3]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[4]Significant difference in saleable yield ($P < 0.05$).

Table 3.5. Least squares means of retail yields, number of steaks, and cutting times for retail cuts from beef-breed type and Holstein ribeye rolls (IMPS[1] 112A).

Component	URMIS[2]	Beef-Breed (n=30)	Holstein (n=30)	SEM[3]	*P* - Value
Total Weight[4] (kg)		7.87	7.03	0.07	<0.01
Retail Yield (%)					
Ribeye Steaks	1209	86.86	87.65	0.37	0.14
Trimmings		6.92	8.85	0.51	<0.01
Fat/Refuse		5.31	2.09	0.41	<0.01
Purge		0.18	0.68	0.07	<0.01
Saleable Yield[5]		93.77	96.50	0.42	<0.01
Number of Steaks		14.57	14.83	0.17	0.26
Cutting Time[6] (s)		204.6	168.0	7.8	<0.01

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

Table 3.6. Least squares means of retail yields and cutting times for retail cuts from beef-breed type and Holstein chuck rolls (IMPS[1] 116A).

Component	URMIS[2]	Beef-Breed (n=29)	Holstein (n=30)	SEM[3]	*P* - Value
Total Weight[4] (kg)		12.69	9.62	0.24	<0.01
Retail Yield (%)					
Chuck Eye Steaks	1102	9.21	10.88	0.27	<0.01
Chuck Steaks	1158	12.03	13.70	0.41	<0.01
Chuck Roasts	1151	53.18	56.04	0.77	0.01
Beef for Stew	1727	4.45	4.12	0.47	0.62
Trimmings		17.12	11.37	0.69	<0.01
Fat/Refuse		2.74	3.01	0.20	0.33
Purge		0.47	0.19	0.06	<0.01
Saleable Yield[5]		95.98	96.11	0.21	0.68
Cutting Time[6] (s)		210.0	216.6	6.6	0.47

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

Table 3.7. Least squares means of retail yields and cutting times for retail cuts from beef-breed type and Holstein sirloin tips (knuckles) (IMPS[1] 167A).

Component	URMIS[2]	Beef-Breed (n=30)	Holstein (n=29)	SEM[3]	*P* - Value
Total Weight[4] (kg)		5.73	5.15	0.10	<0.01
Retail Yield (%)					
Tip Roasts	1526	53.68	61.97	1.07	<0.01
Tip Steaks	1535	26.33	21.95	0.75	<0.01
Beef for Stew	1727	6.12	3.75	0.65	0.01
Trimmings		7.85	6.86	0.62	0.26
Fat/Refuse		4.01	4.23	0.31	0.61
Purge		1.02	0.32	0.11	<0.01
Saleable Yield[5]		93.97	94.52	0.34	0.26
Cutting Time[6] (s)		144.0	118.2	5.4	<0.01

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

Table 3.8. Least squares means of retail yields and cutting times for retail cuts from beef-breed type and Holstein inside rounds (IM) (IMPS[1] 169E).

Component	URMIS[2]	Beef-Breed (n=32)	Holstein (n=30)	SEM[3]	*P* - Value
Total Weight[4] (kg)		6.73	6.27	0.15	0.03
Retail Yield					
Top Round Roasts	1454	58.66	55.60	1.03	0.04
Top Round Steaks	1553	26.39	27.17	0.77	0.47
Beef for Stew	1727	5.27	6.05	0.69	0.42
Trimmings		2.50	5.01	0.32	<0.01
Fat/Refuse		2.93	3.28	0.23	0.26
Purge		3.08	1.66	0.14	<0.01
Saleable Yield[5]		92.82	93.82	0.26	<0.01
Cutting Time[6] (s)		160.2	153.0	6.6	0.44

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

Table 3.9. Least squares means of retail yields and cutting times for retail cuts from beef-breed type and Holstein outside round flats (IMPS[1] 171B).

Component	URMIS[2]	Beef-Breed (n=31)	Holstein (n=31)	SEM[3]	*P* - Value
Total Weight[4] (kg)		7.20	6.36	0.17	<0.01
Retail Yield (%)					
Rump Roast	1519	24.06	23.93	0.89	0.91
Bottom Round Roasts	1464	42.89	39.69	1.16	0.06
Bottom Round Steaks	1466	13.64	13.38	0.58	0.75
Beef for Stew	1727	8.73	9.51	0.40	0.18
Trimmings		1.99	2.01	0.31	0.97
Fat / Refuse (%)		6.55	10.02	0.50	<0.01
Purge (%)		1.07	0.46	0.08	<0.01
Saleable Yield[5]		91.32	88.51	0.53	<0.01
Cutting Time[6] (s)		204.0	213.0	9.0	0.49

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

Table 3.10. Least squares means of retail yields and cutting times for retail cuts from beef-breed type and Holstein eye of rounds (IMPS[1] 171C).

Component	URMIS[2]	Beef-Breed (n=36)	Holstein (n=36)	SEM[3]	*P* - Value
Total Weight[4] (kg)		3.13	2.36	0.05	<0.01
Retail Yield (%)					
Eye Round Roasts	1480	82.74	80.11	0.73	0.01
Beef for Stew	1727	10.78	10.45	0.73	0.75
Trimmings		0.73	2.70	0.24	<0.01
Fat/Refuse		3.25	5.19	0.31	<0.01
Purge		1.34	0.51	0.13	<0.01
Saleable Yield[5]		94.71	94.62	0.40	0.87
Cutting Time[6] (s)		63.0	70.2	3.0	0.05

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

Table 3.11. Least squares means of retail yields, number of steaks, and cutting times for retail cuts from beef-breed type and Holstein short loins (IMPS[1] 173).

Component	URMIS[2]	Beef-Breed (n=30)	Holstein (n=28)	SEM[3]	*P* - Value
Total Weight[4] (kg)		11.44	9.03	0.19	<0.01
Retail Yield (%)					
Porterhouse Steaks	1330	49.90	43.16	1.02	<0.01
T-Bone Steaks	1369	29.84	44.91	1.06	<0.01
Beef for Stew	1727	1.99	0.64	0.23	<0.01
Trimmings		1.38	0.55	0.13	<0.01
Fat/Refuse		13.37	7.07	0.50	<0.01
Purge		0.23	0.32	0.08	0.38
Saleable Yield[5]		83.11	89.26	0.48	<0.01
Number of Cuts					
Porterhouse Steaks	1330	9.17	6.93	0.20	<0.01
T-Bone Steaks	1369	6.30	8.43	0.21	<0.01
Total		15.47	15.36	0.16	0.63
Cutting Time[6] (s)		196.8	127.2	7.2	<0.01

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first saw contact to last knife stroke.

Table 3.12. Least squares means of retail yields and cutting times for retail cuts from beef-breed type and Holstein strip loins (IMPS[1] 175).

Component	URMIS[2]	Beef-Breed (n=31)	Holstein (n=30)	SEM[3]	*P* - Value
Total Weight[4] (kg)		6.39	4.71	0.10	<0.01
Retail Yield (%)					
Strip Steaks	1404	83.89	86.40	0.57	<0.01
Trimmings		6.93	5.35	0.39	<0.01
Fat/Refuse		7.22	6.21	0.43	0.10
Purge		0.89	0.82	0.09	0.57
Saleable Yield[5]		90.83	91.75	0.45	0.15
Cutting Time[6] (s)		264.6	216.6	14.4	0.02

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

Table 3.13. Least squares means of retail yields, number of steaks, and cutting times for retail cuts from beef-breed type and Holstein top sirloin butts, center-cut (IMPS[1] 184B).

Component	URMIS[2]	Beef-Breed (n=30)	Holstein (n=30)	SEM[3]	*P* - Value
Total Weight[4] (kg)		3.51	3.50	0.06	0.90
Retail Yield (%)					
Top Sirloin Steaks	1426	85.75	85.15	0.61	0.49
Beef for Stew	1727	2.97	2.57	0.54	0.61
Trimmings		5.25	5.42	0.39	0.76
Fat/Refuse		2.98	4.67	0.31	<0.01
Purge (%)		1.64	0.93	0.15	<0.01
Saleable Yield[5]		93.97	93.14	0.33	0.08
Number of Cuts					
Top Sirloin Steaks		6.33	6.37	0.10	0.82
Cutting Time[6] (s)		78.0	92.4	3.0	<0.01

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

Table 3.14. Least squares means of retail yields and cutting times for retail cuts from beef-breed type and Holstein tenderloins (IMPS[1] 189A).

Component	URMIS[2]	Beef-Breed (n=34)	Holstein (n=32)	SEM[3]	*P* - Value
Total Weight[4] (kg)		3.28	3.11	0.05	0.02
Retail Yield (%)					
Tenderloin Steaks	1388	61.62	56.77	0.68	<0.01
Beef for Stew	1727	7.79	7.50	0.54	0.70
Trimmings		21.48	26.51	0.86	<0.01
Fat/Refuse		6.89	7.46	0.58	0.48
Purge		0.68	0.46	0.12	0.19
Saleable Yield[5]		90.89	90.78	0.57	0.89
Cutting Time[6](s)		211.2	207.0	18.0	0.86

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

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APPENDIX A

Table A.1. Percentages of polar fatty acid identified for raw beef strip loin steaks representing eight aging treatments.

Fatty Acid	Wet-age (d)						Dry-age (d)	Combination[1]	SEM[2]	*P* - Value
	3	14	28	35	49	63	21			
C10:0	0.04	0.03	0.05	0.05	0.05	0.04	0.04	0.05	0.01	0.37
C12:0	0.10	0.10	0.11	0.10	0.11	0.10	0.11	0.11	0.01	0.95
C12:1	0.03	0.04	0.04	0.05	0.04	0.04	0.04	0.04	<0.01	0.09
C14:0	0.42	0.42	0.41	0.41	0.42	0.42	0.36	0.40	0.02	0.14
C14:1	0.89[b]	1.00[ab]	0.96[ab]	0.90[b]	1.01[ab]	0.94[ab]	1.05[ab]	1.17[a]	0.06	0.02
C16:0	20.98	21.26	21.60	20.97	21.70	20.90	20.53	21.21	0.58	0.87
C16:1	1.42	1.35	1.34	1.31	1.32	1.34	1.32	1.32	0.04	0.47
C17:0	1.30	1.22	1.24	1.19	1.23	1.29	1.26	1.28	0.04	0.43
C17:1	1.10	1.06	1.00	1.04	1.02	1.13	1.06	1.04	0.03	0.23
C18:0	8.53	8.63	8.51	8.99	8.92	8.45	8.75	8.66	0.25	0.76
C18:1 t6-8	0.25	0.26	0.24	0.25	0.25	0.24	0.25	0.23	0.01	0.88
C18:1 t9	0.57	0.56	0.57	0.56	0.60	0.54	0.53	0.55	0.02	0.46
C18:1 t10	3.52	3.64	3.69	3.35	3.63	3.33	3.61	3.71	0.12	0.18
C18:1 t11	1.14	1.15	1.15	1.14	1.15	1.18	1.16	1.13	0.03	0.95
C18:1 c9	18.13	18.48	18.16	18.33	18.24	18.37	17.79	17.88	0.30	0.74
C18:1 c11	3.13	3.21	2.98	3.29	2.98	3.01	2.69	2.40	0.22	0.13
C18:2	23.62	22.06	22.83	22.76	21.54	23.22	24.03	22.33	1.05	0.74
C18:3	0.80	0.87	0.81	0.83	0.81	0.84	0.86	0.88	0.03	0.19
C20:0	0.12	0.13	0.12	0.12	0.12	0.12	0.12	0.11	<0.01	0.37
unknown	0.15	0.15	0.15	0.15	0.15	0.15	0.17	0.17	0.01	0.85
C18:2 c9 t11	0.41	0.45	0.41	0.43	0.43	0.42	0.43	0.45	0.02	0.32
C18:2 t10 c12	0.06	0.05	0.07	0.05	0.06	0.06	0.05	0.05	0.01	0.86
C20:1	0.29	0.32	0.29	0.30	0.31	0.30	0.30	0.32	0.01	0.37
C20:4	13.03	13.55	13.29	13.42	13.91	13.58	13.49	14.52	0.40	0.27

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

[1]Wet-age period of 14 d followed by dry-age period of 21 d.

[2]Standard error (largest) of the least squares means.

Table A.2. Percentages of neutral fatty acid identified for raw beef strip loin steaks representing eight aging treatments.

Fatty Acid	Wet-age (d)						Dry-age (d)	Combination [1]	SEM[2]	*P* - Value
	3	14	28	35	49	63	21			
C10:0	0.04	0.04	0.05	0.04	0.04	0.04	0.03	0.03	0.01	0.75
C12:0	0.09	0.09	0.08	0.08	0.09	0.09	0.09	0.09	0.01	0.93
C12:1	0.03	0.03	0.03	0.04	0.03	0.03	0.03	0.03	<0.01	0.37
C14:0	3.58	3.54	3.35	3.69	3.36	3.64	3.46	3.57	0.10	0.16
C14:1	0.78	0.77	0.77	0.75	0.77	0.79	0.76	0.86	0.04	0.61
C16:0	25.87	25.78	26.61	26.35	26.62	25.90	26.45	26.55	0.35	0.42
C16:1	3.97	3.96	3.83	3.79	3.79	3.76	3.74	3.50	0.11	0.14
C17:0	1.07	1.07	1.05	1.10	1.09	1.06	1.07	0.98	0.03	0.17
C17:1	0.94	0.94	0.92	0.95	0.94	0.91	0.94	0.83	0.03	0.05
C18:0	14.41	14.49	14.96	14.42	14.41	15.15	15.16	15.51	0.30	0.05
C18:1 t6-8	0.33	0.33	0.32	0.31	0.32	0.31	0.32	0.35	0.01	0.22
C18:1 t9	1.12	1.12	1.07	1.11	1.02	1.13	1.08	1.04	0.05	0.70
C18:1 t10	4.41	4.35	4.09	4.14	4.20	3.87	4.09	4.11	0.12	0.06
C18:1 t11	1.03	1.00	1.06	1.08	1.07	1.12	1.10	1.07	0.03	0.19
C18:1 c9	36.02	36.18	35.77	36.03	36.06	36.08	35.60	35.37	0.51	0.95
C18:1 c11	1.99	2.03	2.03	1.96	2.00	2.05	1.94	2.02	0.04	0.49
C18:2	3.13	3.12	2.84	2.98	2.99	2.89	2.92	2.80	0.15	0.76
C18:3	0.14	0.14	0.15	0.14	0.14	0.13	0.14	0.15	<0.01	0.63
C20:0	0.11	0.10	0.10	0.10	0.11	0.10	0.10	0.11	<0.01	0.66
unknown	0.14	0.12	0.13	0.12	0.13	0.14	0.15	0.13	0.01	0.81
C18:2 c9 t11	0.35	0.34	0.34	0.35	0.36	0.35	0.36	0.38	0.01	0.58
C18:2 t10 c12	0.04	0.05	0.04	0.03	0.03	0.03	0.04	0.04	0.01	0.25
C20:1	0.25	0.25	0.24	0.25	0.25	0.25	0.25	0.28	0.01	0.58
C20:4	0.18	0.18	0.17	0.18	0.18	0.18	0.18	0.19	0.01	0.58

[1]Wet-age period of 14 d followed by dry-age period of 21 d.
[2]Standard error (largest) of the least squares means.

Table A.3. Pearson correlation coefficients showing relationships between polar fatty acid concentrations and sensory attributes from eight aging treatments[1].

	Sensory Attribute												
Fatty Acid	Beef Flavor ID	Browned	Roasted	Metallic	Fat-Like	Sour	Oxidized	Nutty	Musty/ Earthy	Liver-Like	Overall Tenderness	Initial Juiciness	Sustained Juiciness
C10:0	-0.22	-0.24	-0.14	0.00	-0.07	0.05	0.06	0.10	0.07	0.02	0.04	-0.14	-0.31*
C12:0	-0.08	0.00	0.06	0.04	0.01	0.05	0.19	-0.04	0.00	0.26*	0.02	0.08	0.01
C12:1	-0.06	-0.24	-0.19	-0.18	-0.02	0.03	0.28*	0.09	0.09	0.12	-0.03	0.04	0.03
C14:0	-0.03	-0.01	-0.21	-0.31*	-0.05	-0.06	0.02	-0.05	0.01	0.01	-0.04	-0.01	-0.17
C14:1	-0.07	0.09	0.18	-0.04	0.00	0.16	-0.17	0.03	0.02	0.03	-0.04	-0.06	-0.26*
C16:0	0.08	-0.01	-0.03	-0.20	-0.15	-0.06	0.10	0.07	0.04	0.17	0.03	0.11	0.11
C16:1	0.07	0.03	-0.11	0.14	0.01	-0.18	-0.07	-0.11	-0.10	-0.15	0.04	-0.26*	-0.15
C17:0	-0.01	0.18	-0.08	-0.03	0.06	0.03	0.06	0.15	0.11	0.18	0.01	-0.16	-0.13
C17:1	-0.01	0.15	-0.08	-0.05	-0.05	0.08	0.15	0.14	0.13	0.11	-0.02	-0.04	0.04
C18:0	-0.04	0.05	0.06	0.10	0.00	0.05	0.02	0.01	-0.03	-0.03	0.05	0.00	-0.04
C18:1 t6-8	0.12	-0.02	0.13	-0.06	-0.16	0.03	-0.10	-0.08	-0.05	-0.03	-0.05	0.16	0.21
C18:1 t9	-0.13	-0.05	0.00	-0.01	-0.03	0.05	0.01	-0.06	-0.01	0.06	0.00	0.05	-0.07
C18:1 t10	0.14	0.19	0.24	-0.02	0.06	-0.03	-0.25*	-0.05	-0.07	0.04	0.01	0.16	0.15
C18:1 t11	-0.03	0.04	0.01	-0.08	-0.15	0.04	0.09	0.05	0.06	0.13	0.01	0.00	0.03
C18:1 c9	-0.13	-0.20	-0.21	-0.16	-0.10	0.04	0.24	0.04	0.05	0.12	-0.08	0.03	0.00
C18:1 c11	0.05	-0.08	-0.10	-0.06	-0.11	-0.09	0.05	-0.14	-0.09	-0.06	-0.07	0.11	0.17
C18:2	0.06	0.01	0.07	0.21	0.17	-0.03	-0.13	-0.09	-0.07	-0.14	0.05	-0.03	-0.01
C18:3	-0.10	-0.04	0.08	-0.11	-0.09	0.04	-0.08	-0.03	-0.01	0.00	0.06	-0.04	-0.11
C20:0	0.03	0.13	-0.09	-0.03	-0.01	-0.04	0.05	-0.02	-0.08	-0.03	-0.06	0.10	0.11
unknown	-0.06	0.04	0.28*	0.16	0.02	0.13	-0.28*	-0.05	0.00	-0.09	0.12	-0.04	-0.14
C18:2 c9 t11	-0.12	0.06	0.02	-0.09	0.02	0.08	-0.01	0.05	0.01	-0.03	-0.07	-0.07	-0.15
C18:2 t10 c12	0.18	0.17	0.04	-0.04	-0.11	-0.09	0.05	0.00	-0.02	0.14	-0.05	0.11	0.21
C20:1	-0.13	0.05	0.02	-0.09	0.03	0.07	-0.01	0.04	-0.01	-0.04	-0.06	-0.06	-0.13

C20:4	-0.19	0.04	-0.06	-0.15	-0.07	0.14	0.07	0.17	0.15	0.04	-0.10	-0.17	-0.17

[1]Treatments: 1) 3 d wet-age; 2) 14 d wet-age; 3) 28 d wet-age; 4) 35 d wet-age; 5) 49 d wet-age; 6) 63 d wet-age; 7) 21 d dry-age; 8) 14 d wet-age followed by a 21 d dry-age (combination).

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

Table A.4. Pearson correlation coefficients showing relationships between neutral fatty acid concentrations and sensory attributes from eight aging treatments[1].

	Sensory Attribute												
Fatty Acid	Beef Flavor ID	Browned	Roasted	Metallic	Fat-Like	Sour	Oxidized	Nutty	Musty/ Earthy	Liver-Like	Overall Tenderness	Initial Juiciness	Sustained Juiciness
C10:0	-0.08	-0.16	-0.19	0.03	-0.15	-0.06	-0.03	0.04	0.02	-0.15	0.08	0.00	0.04
C12:0	-0.28*	-0.16	-0.20	0.10	-0.18	0.16	0.11	0.14	0.23	0.14	-0.13	-0.08	0.12
C12:1	0.03	-0.18	-0.29*	-0.02	-0.08	-0.10	0.21	0.09	0.01	-0.09	-0.06	-0.17	-0.04
C14:0	-0.06	-0.08	-0.19	-0.09	-0.17	-0.10	0.03	-0.12	-0.03	-0.20	-0.10	-0.18	-0.19
C14:1	-0.06	0.09	-0.01	-0.11	-0.13	0.10	-0.02	0.11	0.07	0.00	-0.07	-0.26*	-0.32*
C16:0	-0.12	-0.20	0.06	-0.08	0.06	0.08	-0.10	-0.08	0.01	0.02	0.11	0.12	-0.04
C16:1	0.16	0.20	0.03	0.00	0.10	-0.16	0.01	-0.12	-0.09	-0.04	-0.01	0.16	0.31*
C17:0	-0.01	-0.08	-0.06	0.13	0.04	0.11	0.20	0.09	0.05	-0.09	0.03	0.05	0.09
C17:1	0.06	-0.03	0.01	0.09	0.20	0.02	0.12	0.01	0.01	-0.11	-0.06	-0.06	-0.02
C18:0	-0.08	-0.07	0.03	0.02	0.03	0.06	-0.02	0.13	0.10	0.05	0.04	-0.22	-0.26*
C18:1 t6-8	-0.04	0.10	0.09	-0.18	-0.21	-0.07	-0.20	-0.11	-0.06	-0.09	-0.07	-0.13	-0.15
C18:1 t9	-0.11	0.02	0.08	0.12	0.06	0.00	-0.20	-0.15	-0.08	-0.10	0.21	0.04	0.01
C18:1 t10	0.26*	0.28*	0.21	-0.01	0.06	-0.22	-0.17	-0.12	-0.20	0.00	-0.04	0.05	0.05
C18:1 t11	-0.25*	-0.10	-0.08	0.15	-0.11	0.25*	0.28*	0.28*	0.29*	0.16	0.07	-0.11	-0.08
C18:1 c9	0.11	0.08	-0.04	0.03	-0.09	0.00	0.13	0.04	-0.03	0.08	-0.09	0.08	0.15
C18:1 c11	-0.15	0.00	-0.05	-0.13	-0.10	0.04	-0.10	0.03	0.01	-0.15	0.03	-0.01	-0.04
C18:2	-0.01	0.02	-0.12	0.07	0.12	-0.07	-0.03	-0.02	0.02	-0.19	0.05	0.00	0.13
C18:3	-0.01	-0.03	-0.05	-0.18	-0.21	-0.15	-0.24	-0.09	-0.10	-0.26*	-0.07	-0.23	-0.21
C20:0	-0.21	0.06	0.02	0.15	0.00	0.15	0.07	0.13	0.10	0.03	-0.11	-0.03	-0.09
unknown	-0.10	0.11	0.08	0.01	0.00	0.13	0.06	0.17	0.18	0.10	-0.01	-0.15	-0.14
C18:2 c9 t11	-0.23	0.05	0.03	0.10	0.05	0.15	0.04	0.10	0.11	0.10	-0.09	-0.07	-0.16

C18:2 t10 c12	0.07	0.05	0.10	-0.28*	0.09	-0.11	-0.20	-0.10	-0.12	-0.17	0.02	-0.08	-0.20
C20:1	-0.23	0.05	0.03	0.10	0.05	0.15	0.04	0.10	0.11	0.10	-0.09	-0.07	-0.16
C20:4	-0.23	0.05	0.03	0.10	0.05	0.15	0.04	0.10	0.11	0.10	-0.09	-0.07	-0.16

[1]Treatments: 1) 3 d wet-age; 2) 14 d wet-age; 3) 28 d wet-age; 4) 35 d wet-age; 5) 49 d wet-age; 6) 63 d wet-age; 7) 21 d dry-age; 8) 14 d wet-age followed by a 21 d dry-age (combination).

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

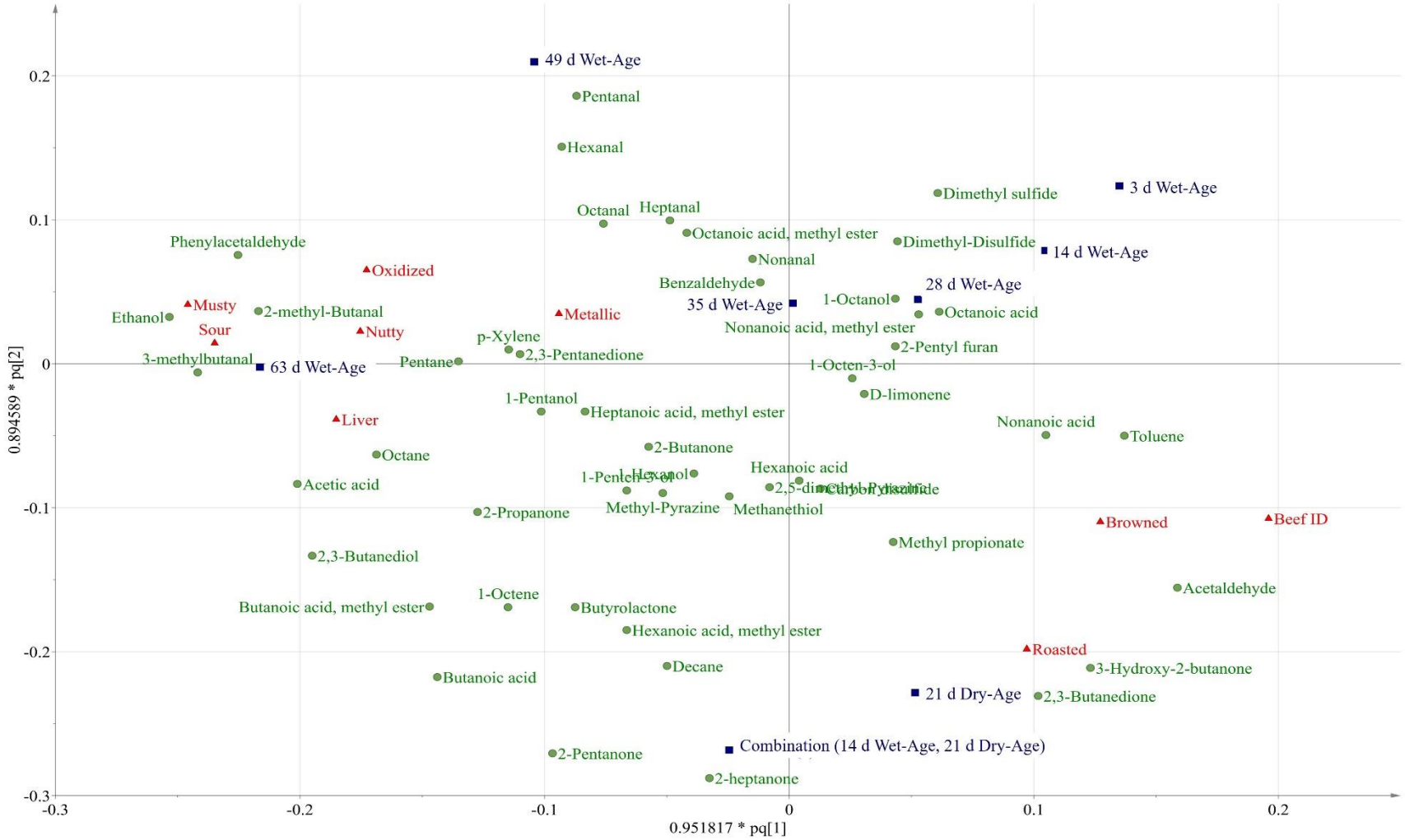

Figure A.1. Orthogonal partial lest squares discriminant analysis (OPLS-DA) loadings biplot for volatile organic compounds, sensory attributes, and aging treatments.

APPENDIX B

Table B.1. Least squares means of retail yields and cutting times for retail cuts from beef-breed type and Holstein shoulder clods (IMPS[1] 114C).

Component	URMIS[2]	Beef-Breed (n=30)	Holstein (n=32)	SEM[3]	*P* - Value
Total Weight[4] (kg)		6.04	5.88	0.13	0.36
Retail Yield (%)					
Shoulder Roasts	1132	39.69	39.48	0.92	0.87
Shoulder Steaks	1133	15.78	14.45	0.77	0.22
Beef for Stew	1727	6.90	6.29	0.72	0.54
Trimmings		32.34	34.41	1.08	0.18
Fat/Refuse		5.12	5.42	0.38	0.57
Purge		3.68	0.17	1.56	0.11
Saleable Yield[5]		94.71	94.62	0.40	0.87
Cutting Time[6] (s)		184.2	196.2	7.2	0.30

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

Table B.2. Least squares means of retail yields and cutting times for retail cuts from beef-breed type and Holstein inside rounds (IMPS1 169) and the related value of these retail cutting yields.

Component	URMIS[2]	Beef-Breed (n=36)	Holstein (n=36)	SEM[3]	*P* - Value
Total Weight[4] (kg)		11.89	10.42	0.23	<0.01
Retail Yield (%)					
Top Round Roasts	1454	41.21	42.09	0.63	0.33
Top Round Steaks	1553	21.50	21.34	0.49	0.82
Beef for Stew	1727	2.10	3.04	0.36	0.07
Trimmings		18.29	16.89	0.62	0.12
Fat/Refuse		14.75	14.88	0.59	0.88
Purge		1.09	0.68	0.09	<0.01
Saleable Yield[5]		83.10	83.35	0.60	0.77
Cutting Time[6] (s)		274.8	263.4	10.8	0.32

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

Table B.3. Least squares means of retail yields, number of steaks, and cutting times for retail cuts from beef-breed type and Holstein top sirloin butts (IMPS[1] 184).

Component	URMIS[2]	Beef-Breed (n=30)	Holstein (n=30)	SEM[3]	*P* - Value
Total Weight[4] (kg)		7.19	6.15	0.08	<0.01
Retail Yields (%)					
Top Sirloin Steaks	1426	54.13	54.63	0.70	0.62
Culotte Steaks	1421	15.59	15.28	0.38	0.57
Beef for Stew	1727	2.66	3.29	0.32	0.17
Trimmings		6.25	7.39	0.50	0.11
Fat/Refuse		19.78	18.34	0.75	0.18
Purge		0.65	0.19	0.09	<0.01
Saleable Yield[5]		78.62	80.59	0.74	0.06
Number of Cuts					
Top Sirloin Steaks		6.00	5.97	0.20	0.91
Culotte Steaks		5.17	5.37	0.13	0.29
Cutting Time[6] (s)		279.6	294.0	10.8	0.33

[1]Institutional Meat Purchase Specifications (NAMP, 2010; USDA, 2014b).
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).
[3]Standard error (largest) of the least squares means.
[4]Total subprimal weight represents the initial weight of the item without packaging.
[5]Saleable yield is expressed as a percentage of the total weight and only includes steaks, roasts, stew meat, and trimmings.
[6]Measured from first knife stroke to last knife stroke.

Table B.4. Retail prices from USDA Markets News Portal[1].

Retail Cut Name	URMIS[1]	USDA Retail Cut Name	Number of Stores with Ads	Price (USD/pound)
Bottom Round Roasts	1464	BOTTOM ROUND ROAST	1,810,910	3.91
Bottom Round Steaks	1466	BOTTOM ROUND STEAK	786,535	4.07
Chuck Eye Steaks	1102	CHUCK/SHLDR/ARM STEAK	2,753,600	4.22
Chuck Roasts	1151	CHUCK/SHLDR/ARM ROAST	3,885,785	4.08
Chuck Steaks	1158	CHUCK/SHLDR/ARM STEAK	2,753,600	4.22
Top Sirloin Cap Steaks	1421	RUMP STEAK	23,120	4.95
Eye Round Roasts	1480	EYE OF ROUND ROAST	1,085,825	4.10
Porterhouse Steaks	1330	PORTERHOUSE STEAK	930,360	7.98
Ribeye Steaks	1209	BNLS RIBEYE STEAK	1,764,020	9.09
Rump Roast	1519	RUMP ROAST	739,495	3.82
Shoulder Roasts	1132	CHUCK/SHLDR/ARM ROAST	3,885,785	4.08
Shoulder Steaks	1133	CHUCK/SHLDR/ARM STEAK	2,753,600	4.22
Tip Roasts	1526	SIRLOIN TIP ROAST	867,820	4.01
Tip Steaks	1527	SIRLOIN TIP STEAK	688,415	4.41
Beef for Stew	1727	STEW MEAT	1,853,615	4.55
Strip Steaks	1404	BNLS NEW YORK STRIP STEAK	2,583,125	8.14
T-Bone Steaks	1369	T-BONE STEAK	2,254,070	7.54
Tenderloin Steaks	1388	TENDERLOIN	733,815	11.24
Top Round Roasts	1454	TOP ROUND ROAST	775,695	4.00
Top Round Steaks	1553	TOP ROUND STEAK	713,560	4.31
Top Sirloin Steaks	1426	BNLS TOP SIRLOIN STEAK	1,725,460	5.75
Trimmings		GROUND BEEF 80-89%	2,837,470	3.73

[1]https://marketnews.usda.gov/mnp/dataDownload.
[2]Uniform Retail Meat Identity Standards (Industry-Wide Cooperative Meat Identifcation Standards Committee, 2003).