THESIS

# IMPACT OF UNCONVENTIONAL BEEF CARCASS RIB SEPARATION, OVEN TEMPERATURE, AND DEGREE OF DONENESS ON EATING QUALITY OF BEEF

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Fall 2016

Master's Committee

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ABSTRACT

IMPACT OF UNCONVENTIONAL BEEF CARCASS RIB SEPARATION, OVEN TEMPERATURE, AND DEGREE OF DONENESS ON EATING QUALITY OF BEEF

The beef industry is interested in separating the rib and chuck between the 4$^{th}$ and 5$^{th}$ rib bones to increase weight, yield and value for the wholesale “rib” primal. This study was conducted to assess the impacts of separating the wholesale primal rib between the 4$^{th}$ and 5$^{th}$ rib bones versus the 5$^{th}$ and 6$^{th}$ rib bones. Carcasses (N = 30) of the same US Quality Grade were selected and both wholesale primal ribs were removed; each primal rib from within each carcass was assigned to a rib-length classification by alternating sides and fabricated them into either a primal wholesale rib containing 8-bone ribs by separating it from the chuck between the 4$^{th}$ and 5$^{th}$ rib bones, or containing the a traditional 7-bone ribs by separating it from the chuck between the 5$^{th}$ and 6$^{th}$ rib bones; each rib was then further reduced to a 112A Ribeye Roll. All comparisons between the 8-bone ribs and 7-bone ribs Ribeye Rolls were made within animal. Individual identification was maintained for each rib, and traditional carcass data measurements were collected from each sampled carcass. Concurrent to the fabrication procedures, weights for each cut were collected and comprehensive, sequential yield data were obtained as each was fabricated into retail cuts. Within 7 days of collection, sampled Ribeye Rolls were transported to a steak portioning facility and were cut into equally portioned ribeye steaks. All meaningful dimensional measurements were obtained by imaging the steakes. Steaks were individually identified, packaged, frozen and stored for subsequent shear force evaluation. Warner-Bratzler Shear Force values were obtained for the primary muscles of every steak obtained from

subprimaals that were 8-bone ribs in length by removing 1-6 cores (12.7 mm in diameter) per muscle and shearing them once via an Instron device fitted with a Warner-Bratzler head perpendicular to muscle fiber orientation. A mean WBSF value for each muscle was obtained by averaging the individual shear force values for each core. Thawed steaks were cooked to a peak internal temperature of 71°C and internal cooked temperature of steaks was monitored using a thermocouple. Effects of separation procedures were assessed using analysis of variance with a repeated measure. Effects of the interaction of treatment by steak location were evaluated for individual steak measurements obtained from images. The alternative fabrication style increased the length of wholesale ribs by 5.1 cm per side, which resulted in an average of 2.8 more steaks per carcass. There were no meaningful trends by steak location on the WBSF values and eating quality was not affected by fabrication style. Changing the fabrication style to generate longer wholesale rib cuts, that yield a greater number of ribeye steaks, would not detrimentally impact eating quality, but would add significant weight and value to the wholesale rib. These data should help to facilitate a modification of standardized cutting specifications for beef ribs by the industry and USDA-AMS to allow for a change in fabrication procedure.

It is believed that flavor of beef is what keeps consumers returning to the retail meat case to make purchases irrespective of price. Based on that, a second experiment aimed to evaluate the combination of oven temperature and degree of doneness as major contributors to steak tenderness and flavor development. A total of 20 combinations of cooking temperature and degree of doneness were evaluated in a factorial arrangment. Steaks were used as the experimental unit, and treatments were applied to individual steaks. Treatments were assigned to n = 30 replicates over steaks obtained from 90 carcasses. Strip loins were collected in a commercial beef slaughter facility and, on day 21 postmortem, paired strip steaks were sliced

producing a total of 24 steaks per carcass. Steaks were cooked at a randomly assigned oven temperature until it reached a internal peak temperature also randomly. The external and internal appearance of steaks were evaluated with a portable spectrophotometer and degree of doneness scores were assigned upon completion of cooking. Both Warner-Bratzler shear force (WBSF), slice shear force (SSF), and trained sensory panel analysis were conducted. Means for WBSF increased as degree of doneness increased. Steaks cooked to rare and medium rare degree of doneness produced lower SSF values than steaks cooked to well done degree of doneness. As rate of cooking increased, the visually-assessed internal color of cooked steaks appeared to be more pinkish-grey, rather than pink. Similarly, as degree of doneness increased, internal color of steaks shifted from a reddish-pink color to a light brown. Steaks cooked at a low cooking rate produced the darkest brown external color. As oven temperature (OVENTEMP) increased from 177°C to 343°C, external color of cooked steaks darkened and, as degree of doneness increased, external color of steaks also appeared darker. Generally, steaks cooked to a lower degree of doneness and lower rate of cooking had greater ratings for tenderness at the trained panel. At each OVENTEMP tested, steaks cooked to rare degree of doneness were among the most tender compared to all others; however, as cooking rate increased, overall tenderness decreased. As the degree of doneness increased, so did percent of moisture lost due to cooking. Steaks cooked at 177°C OVENTEMP to rare degree of doneness were among the most tender of all treatments and had one of the lowest cooking loss percentages. Furthermore, at those temperatures, juiciness ratings were greatest; juiciness scores were lowest when steaks were cooked at high cooking rate to a very well done degree of doneness. With the exception of steaks cooked at 66°C, juiciness ratings generally decreased as cooking rate increased. Steaks cooked at oven temperature of 177°C and well done degree of doneness had more intense beef flavor. Brown/grilled flavor

intensities generally increased as both rate of cooking and degree of doneness increased. However, influence of degree of doneness on brown/grilled intensity appeared to be more distinct at lower cooking rate. Some of the greatest burnt flavor intensities were observed in steaks cooked at 343°C to medium degree of doneness and above, indicating that at these degrees of doneness, cooking rate may be inadequate and result in formation of burnt off-flavor notes. Unlike brown/grilled and burnt flavor intensities, trained panel ratings for buttery and bloody intensity tended to decrease as both cooking rate and degree of doneness increased. Internal temperature seemed to have the greatest effect on ratings for buttery intensity when steaks were cooked at high cooking rates; buttery intensity ratings steadily decreased as degree of doneness increased. Results suggested that oven temperature and degree of doneness influence trained panel sensory ratings, shear force measurements, and percent cook loss. Sensory panel ratings showed that eating characteristics are influenced by more than just degree of doneness; oven temperature affect the temperature at which steaks reach a given final internal temperature, which, in turn, influences eating characteristics.

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# INTRODUCTION

Beef overall eating desirability is attributed to factors as tenderness, juiciness and flavor. One of the most important quality challenges for the industry is beef tenderness. Results of the most recent Beef Tenderness Survey showed that over 94% of beef from the rib and loin in foodservice and at the retail level were classified as tender or very tender (Guelker, 2013).

Beef carcass fabrication methods are based on historical reasons and/or traditional practices, and they are not always conducive to product eating quality or carcass value. Specifically, for the beef primal rib/chuck separation which currently is made between the 5$^{th}$ and 6$^{th}$ rib bones of the carcass, potential for maintaining eating quality while also improving cutout value could exist by separating the rib/chuck between the 4$^{th}$ and 5$^{th}$ rib bones.

Muscle characteristics vary within the carcass; so separating individual carcass muscles from which retail cuts can be made may improve product consistency and overall consumer satisfaction with finished, prepared beef products.

The beef industry is interested in further investigating and pursuing an option to separate the rib and chuck between the 4$^{th}$ and 5$^{th}$ rib bones of the carcass; necessarily, standardized beef purchasing specifications would need to be revised by the industry and by USDA-AMS for labeling and marketing purposes, which would ultimately result in adding additional weight and value to the “rib” primal without sacrificing desirable eating characteristics associated with ribs manufactured using more traditional carcass separation techniques. Therefore, the first chapter aims to further investigate the impact of separating wholesale beef ribs between the 4th and 5th rib bones of the carcass versus separating ribs at the 5$^{th}$ and 6$^{th}$ rib bones on beef tenderness, product composition (visible lean and fat), and cutting yields.

Likewise, with demand for beef challenged in the U.S, one of the greatest concerns is the relative price of beef compared to competing proteins. Most believe that the outstanding flavor of beef is what keeps consumers returning to the meat case to make purchases irrespective of price.

Since the industry is expecting consumers to pay more for beef than for competing proteins, the outstanding flavor of beef must be maintained and/or improved, allowing for beef consumers to be continually satisfied with the value propositions for the product. Flavor and tenderness are attributes that affect consumer acceptance of beef and that are reflected in their beef purchase decisions.

Very recent research conducted with Beef Checkoff funds demonstrated that differences in steak thickness, cooking method, cooking temperature, and cooking rate influence overall eating satisfaction and flavor of beef steaks (Shubert, 2015). Perhaps the most intriguing discovery of that research was improved tenderness and flavor observed in steaks that were cooked more slowly (Shubert, 2015). Therefore, the second experiment outlined here was aimed at expanding upon the research idea that rate of cooking and degree of doneness are major contributors to steak tenderness and flavor development. Ultimately, findings of this research will contribute to developing the most ideal cooking procedures to maximize steak eating experience.

CHAPTER 1

# REVIEW OF LITERATURE

## ***The U.S Beef Industry***

A new industry is rapidly emerging in the United States, especially food retailers, meat processors, and farmers and ranchers combining into fewer and larger businesses (Barkema et al., 2001).

According to Hosch (2012), several factors are responsible for driving industry growth over last 30 years: changes in food process technology has pointed to a greater variety of meat products available; increasingly-concentrated food retailing industry competition with restaurants and other foodservice establishments has increased the extent to which products are value-added or ready-to-eat and fully-prepared; adoption of coordinated supply chains through the use of sophisticated information, process, and distribution technologies, as well as inventory management allowing for more efficient and flexible deliveries; expansion of foodservice and fast-food chains, due to more eating-out, has increased demand for chicken and beef; demographic shifts in the consuming population in terms of age and marital status (more couples without kids and single consumers); increases in disposable income, because of two salaries within the family; expansion of exports; price stability; and industry consolidation (Hosch, 2012).

The beef industry has progressed in terms of vertical integration, advances in information technology, distribution systems, automatic slaughter lines, animal tracking systems, meat grading systems, packaging technology, and boxed-meat cutting technologies that are now used by meat processors. However, consumer awareness and confidence levels have shifted regarding food safety and healthy-food issues, causing all businesses involved in the food supply chain to re-evaluate their marketing, quality assurance and operating strategies. As a result, stringent public-sector focus has arisen on current industry policies and procedures (Ferreira, 2003).

The beef packing segment has gradually begun integrating feeding operations in which packers become more capable of controlling preharvest product quality, quantity, and procurement costs (Bastian et al. 2000).

Demand for meat products also have been influenced by convenience, variety, prices and services that food retail firms offer to consumers. Employing more than 80 percent of all workers in the food industry, and carrying more than 18,000 food items per store, the food retailing industry has been struggling with changing consumers' purchase behavior; they seem to prefer eating-at-home the same food that they would obtain in fine restaurants (ERS/USDA).

Meat pricing is mostly established by the market where supply and demand dictate daily prices. Grading systems concerning quality and yield have been developed to distinguish among differing market values for differing classifications of animals and carcasses. Processing costs explain less than ten percent of total costs for the industry. Since prices are pretty well established by the market, reduction in processing costs in this industry becomes a very important strategic decision.

***Beef Carcass Fabrication***

Since 1970, average live weights for beef cattle in the U.S. have increased roughly 136 kilograms, equating to an added 3.4 kilograms per animal per year (USDA-AMS, 1970, 2011). This significant increase in productivity of the United States beef industry is likely a result of intensified management strategies, crossbreeding and genetic evaluation of cattle, and a growing demand for United States beef (Mintert et al., 2009).

In the early 1800's, cutting methods varied greatly due to city location along the East coast (Figure 1). This variation in fabrication was a result of buying habits and cut preferences from consumers, as well as butcher tradition (Hosch, 2012).

Most modifications in carcass fabrication occurred post-halving of the carcass. The split of the hind and forequarter between the 12$^{th}$ and 13$^{th}$ rib was considered a reasonable and consistent cut in the beef carcass because it essentially 'quartered' carcass weight equivalently between the posterior and anterior portions of the carcass. The rib that remained on the forequarter was perceived to hold shape of the loin during fabrication of strip steaks (Tomhave, 1925), as well as to provide a way to hang the loin on the meat tree – a series of hooks on a trolley designed to hold subprimal cuts.

After the carcass had been split into fore- and hind-quarters, butchers were free to manipulate the carcass the way they wanted. Romans et al. (1974) described three popular styles of round fabrication: Eastern, Chicago, and Diamond; the difference being due to a modification of the angle, or combination of angles, at which the round-sirloin break occurred.

According to Hosch (2012), with the decision to engage in World War II, lifestyles and industries changed. In December of 1942, President Roosevelt's Office of Price Administration issued The Emergency Price Control Act (National Provisioner, 1942). Through this enactment, a maximum price for beef and veal carcasses, wholesale cuts and processed products was established to prevent early marketing of cattle, and to encourage farmers to keep their feedlots full and produce cattle with varying degrees of finish. Ceiling prices were set based on primal cut under consideration and grade of cattle.

In 1945, ceiling prices for beef were lifted, and in 1947, the Office of Price Administration was abolished (National Archives, 1995). Beef fabrication, though, did not resume to methods that were used before the Act. Major packing plants continued to separate the chuck and rib between the $5^{th}$ and $6^{th}$ rib junction and the sirloin/round between the fifth sacral vertebrae. Alternative fabrication methods were not researched until the early 1990's behind initiatives of the National Cattlemen's Beef Association (Seggern et al., 2005).

***Alternative Forequarter Fabrication***

Changes in consumer demand brought by convenience and perceived health concerns likely motivated recent structural alterations within the mat industry (Bastian et al. 2000).

The National Consumer Retail Beef Study (Savell et al. 1987) revealed that tenderness or meat texture is the single most important factor affecting consumer acceptance of beef products. Due to the effect of tenderness on consumer acceptability and the lack of tenderness in the beef chuck and round, alternative fabrication styles in both the fore and hindquarter emerged (Morgan et al., 1991).

Tenderness mapping via shear force results allowed muscle profiling work and an investigation of tenderness gradients across a muscle (Zuckerman et al., 2002).

The beef forequarter accounts for 52% of total carcass side weight, but marketability of cuts from the beef forequarter, primarily within the chuck primal, was futile due to high variability in the cut-out yield and muscle palatability characteristics (Johnson et al., 1988).

As a result of tradition and ease of fabrication, the beef chuck and rib today are separated at the $5^{th}$ and $6^{th}$ rib junction. Considering an ability to remove the thoracic limb before chuck/rib separation occurs, there is no logical explanation as to why this primal break remains (Reuter et al., 2002).

Because of a large growing price difference between middle meats and end meats, it is important to analyze critically the point of separation, during carcass fabrication, between the wholesale rib and wholesale chuck. The same muscles are present in the ribeye roll and the chuck eye roll. A separation point between two wholesale cuts of meat should be made at some point where there is a marked real value difference (Hosch, 2012).

Reuter et al. (2002) suggested moving the chuck-rib break to the $6^{th}$ and $7^{th}$ rib junction because of consistency in tenderness from ribs 7 through 12. This alteration would result in four fewer 2.5 cm steaks sold in the rib, but would guarantee a consistently tender ribeye roll.

Moving the chuck-rib break forward to the $4^{th}$ and $5^{th}$ rib junction should also be considered. There were no differences ($P<0.05$) in WBSF values among rib locations 4 through 6 and the 6th rib location currently is successfully marketed as ribeye steaks (Reuter et al., 2002).

According to Hosch (2012), efficiency in cattle production will continue to increase in the United States as long as a demand for high quality beef exists. So, the ability to develop alternative fabrication methods for heavy weight beef carcasses is essential. Today, the industry is faced with a challenge from consumers that demand cuts which are convenient to prepare and consistent in quality. Through utilization of single-muscle fabrication in both the chuck and round, the industry can provide a higher concentration of ‘steakable’ items to consumers that are uniform in tenderness. The beef industry needs to continue efforts in product development and promotion that address health and convenience concerns (Reuter et al., 2002).

***Beef Tenderness***

Tenderness is described as the amount of pressure needed to bite through a piece of meat. Of all eating quality traits, most research has been conducted on tenderness, and it is known to be the most important beef sensory trait when determining consumer acceptability (Miller et al., 2001).

Beef eating quality is dependent on a variety of inherent characteristics: tenderness, juiciness, and flavor. Tenderness is the most important economic and quality factor (NCBA 2001, 2010). Tenderness is influenced by various factors including postmortem proteolysis, intramuscular fat/marbling, connective tissue, and the contractile state of the muscle (Belew et al., 2003).

Beef muscles vary in amounts of collagenous and elastic tissue contained, as well as in amounts of fat contained and the size of muscle bundles (Lepetit, 2008). A portion of muscle profiling work relies on the importance of muscle fiber-type composition, and variation that exists between muscles (Palka, 2003).

This lack of demand is due to perceived differences in tenderness and apparent fiber-type composition distinctions (Belew et al., 2003). According to the 2010/2011 National Beef Tenderness Survey, cuts from the round continued to be the least tender, suggesting a need for improved aging and consumer education on preparation practices (NCBA, 2011).

Lorenzen et al. (2003), provided results showing that 51% of consumers think that tenderness is the most important beef sensory trait they looked for in a steak, followed by 39% and 10% for flavor and juiciness, respectively. Similar consumer responses for rank of importance of eating quality attributes have been reported in other studies as well (O'Quinn et al., 2012; Hunt et al., 2014). Variation in meat tenderness between different animals and muscles can be attributed to three biochemical properties of post-mortem muscle: collagen content and solubility, sarcomere length, and degree of postmortem proteolysis (Koohmaraie et al., 2002).

Due to the significant role that tenderness plays in beef marketing, vast improvements in genetic selection and management of cattle have been achieved by producers. Lusk et al. (2001) indicated that consumers are willing to pay a premium for tender steaks.

Miller et al. (2001) conducted a nation-wide consumer study to assess monetary value that consumers placed on tenderness. Results showed that 78% percent of consumers would pay a premium for beef that was guaranteed tender. Results also showed that consumers were able to distinguish steaks of different levels of tenderness, similar to those found by the WBSF instrument. A similar study undertaken by Boleman et al. (1997), where three groups of beef strip steaks were presented to consumers for purchase, were segregated by WBSF tenderness values: tender (2.27 to 3.58 kg), intermediate (4.08 to 5.40 kg) and tough (5.90 to 7.21 kg). Results showed that, not only were consumers willing to pay more for tender steaks, but 94.6% of consumers purchased tender steaks in a simulated purchasing scenario compared to 3.6% of intermediate steaks and 1.8% of tough steaks.

Research conducted in order to explain relationships between, and effects of, intramuscular fat on tenderness, juiciness, and flavor of beef products is extensive in the literature. Studies have been able to describe a low to moderate positive relationship between marbling and beef eating satisfaction traits (Briskey and Brey, 1964; Jeremiah et al., 1970; Smith et al., 2008). Properties of samples that have a greater amount of intramuscular fat include reduced resistance needed to disrupt myofibrils; this creates a more tender meat product because less force is needed to chew, or break apart the product (Corbin et al., 2014).

Van Wezemael et al. (2014) suggested that steaks with greater lubrication due to increased marbling can maintain quality attributes more sufficiently when exposed to extreme cooking methods, or when cooked to a more severe degree of doneness.

Lifestyle changes have had a major impact on consumption of beef. Much of a clear decline in beef consumption has been due to a change in the intensity of consumer preferences for attributes such as ease of preparation, convenience, and health which compete to fulfill consumer needs with other protein sources (Hosch, 2012).

***Degree of Doneness***

Doneness is a measurement of how thoroughly cooked a cut of meat is based on the color, juiciness and internal temperature when cooked. Gradations of cooking are most often used in reference to beef, but are also applicable to lamb, pork, poultry, veal and seafood (Wharton, 2008).

According to USDA (1993), as a result of Escherichia coli O157:H7 outbreaks associated with inadequate cooking of beef patties, various regulatory agencies and trade associations have issued changes in regulations or made suggestions regarding the cooking of beef. In early 1993, FDA issued interim guidelines to their Model Food Codes suggesting that beef be cooked to 68.3°C as minimum internal temperature.

The ability to deliver a product that maximizes customer satisfaction, maintains customer loyalty and increases patronage is a very complex issue facing the food service industry (McKenna et al., 2004).

Degree of doneness is the most influential factor determining internal color of cooked steaks. Beef steaks maybe cooked from “very rare” (64.4°C) to “very well done” (82.2°C), and it has been noted that a slower rate of heating will produce a less well-done internal appearance than a faster heating system (Berry, 1992).

Previous research has shown that preparation techniques, cooking methods, and end point temperature affect beef eating quality (Savell et al., 1987, 1989; Berry and Leddy, 1990; Belk et al., 1993; Berry and Bigner, 1995). The way that consumers choose to prepare steaks of any kind at home greatly influences their chances of a great eating experience (Goodson et al., 2002).

Similarly, the way that a foodservice restaurant chooses to prepare their steaks also can greatly influence odds of a consumer having a great eating experience. Cox et al. (1997) reported that steaks, which consumers considered ordered and delivered to their required degree of doneness, were not different in tenderness, taste and overall satisfaction across the range of doneness endpoints.

Tenderness of beef tends to decrease as endpoint temperature increases, and research has shown that the degree of doneness to which beef is cooked varies among United States consumers; 64-82% of beef consumers were shown to cook their steaks to “medium” or “very well done” (Wheeler et al., 1999); very high degrees of doneness.

When cooking beef from “rare” to “very well done”, changes occur in internal color of cooked meat. Myoglobin is the primary pigment responsible for fresh meat color and, during cooking, myoglobin is denatured to varying degrees, thereby influencing appearance of meat color to humans (Garcia-Segovia et al., 2007).

Degree of doneness has a profound effect on consumer satisfaction in the home and when dining away from home. Without question, more work needs to be conducted on why and how degree of doneness results in particular customer satisfaction ratings (Boleman et al., 1997).

***Beef Juiciness***

With such a large portion of the retail beef supply classified as tender, importance of juiciness and flavor to the consumer eating experience is magnified. Numerous relatively-recent studies have evaluated the contribution and importance of flavor to beef eating satisfaction (Brooks et al., 2012; Miller and Kerth, 2012; O'Quinn et al., 2012).

Principle sources of beef juiciness reside in the amount of bound and free water, and in the amount of intramuscular lipids available. When heated and masticated, broth then promotes saliva production. Therefore, juiciness has been attributed to the flow of juices from the actual meat and the moisture produced by saliva in the mouth during mastication (Gullett et al., 1984; Winger and Hagyard, 1994).

Previous work has shown the factors that have the greatest effect on beef juiciness include: ultimate pH, fat content, enhancement level, cooking method, and degree of doneness (Montgomery and Leheska, 2008).

Endpoint temperature, or degree of doneness, plays an important role in consumer beef eating experience (Cox et al., 1997). With higher degrees of doneness, there is more opportunity for cooking loss to occur which results in reduced juiciness. Cooking loss depends on raw meat quality, endpoint temperature and cooking method (Aaslyng et al., 2003), as well as pH and water retention capacity.. During heating, water is lost as temperature increases. Denaturation of meat proteins causes structural changes to cell membranes of muscle fibers, along with shrinkage of muscle fibers and connective tissue (Honikel, 1998), which all escalate loss of free and bound water. Thus, efforts to improve beef steak juiciness can be diminished if not prepared correctly in the home or restaurant.

***Beef Flavor***

While it has been known for many years that tenderness plays a large role in acceptability of meat by a consumer, it has become increasingly apparent that flavor also needs to be addressed. In a large, multiple-city study, flavor was found to be the most important factor affecting consumers’ meat buying habits and preferences when tenderness was held constant (Sitz et. al, 2005).

Flavor is an important component of beef taste to consumers. In the late 1800s, documented efforts first appeared that formally improved beef flavor in a controlled manner (Chemioux, 1874). For more than 140 years, Americans have sought to document and improve flavor of beef with patented discoveries and research (Bardella et. al, 1937). In fact, little evidence existed at the time as to the chemical characteristics of meat flavor, but it was reported that it was likely a composite of salts, acids and a group of products resulting from heating. Furthermore, these studies suggested that flavors most likely involved disintegration products of proteins and lipids (Bardella et. al, 1937).

Therefore, as the majority of United States beef supply reaches tenderness acceptability, and more recent consumer studies have shown flavor to be more highly related to consumer acceptance of beef than tenderness (Killinger et al., 2004; O'Quinn et al., 2012; Corbin et al., 2014), flavor has become a relatively important research topic.

Because of the relationship between flavor and meat eating quality, it is important to gain a better understanding of factors that influence flavor in order to produce the most flavorful and consistent product possible (Calkins and Hodgen, 2007).

Basic tastes detected on the tongue include sweet, sour, salty, bitter and, most recently, umami. Chandrashekar et al. (2006) described taste sensing as, instead of overly complex, quite simple. On the tongue, each taste bud is comprised of 50 to 150 taste receptor cells (TRCs) distributed across different papillae. Each TRC projects microvillae on the apical surface of the taste bud to form a 'taste pore', and this is the site of the interaction with the food containing the taste. It seems clear from their report that distinct cell types on the tongue express unique receptors and are tuned to detect each of the five basic tastes. Each receptor cell functions as a dedicated sensor, wired to give the stereotypic response for each taste, indicating that any of the

TRCs can taste any of the five tastes to varying degrees. On the other hand, the influence of aroma on flavor perception is a result of olfactory stimulation from volatile compounds that work with receptors on the roof of the nasal cavity (Idolo Imafidon and Spanier, 1994). It is these volatiles, rather than taste, that allow consumers to identify meat originating from different species (Resconi et al., 2013). More than one thousand volatile compounds have been reported in literature as being extracted from cooked beef samples (Van Ba et al., 2012), further emphasizing complexity of beef flavor.

According to Nursten (1981), significance of the Maillard reaction for food includes production of color, flavor and off-flavor, a reduction in nutritional value, possible toxicity and, finally, antioxidant properties. The main reaction in products involves breakdown of proteins in beef when they are in the presence of a reducing sugar.

Raw meat has little-to-no flavor outside of bloody and metallic; thus, meat flavor originates from numerous reactions between heat of cooking and the many flavor precursors naturally found in meat. The Maillard and related reactions are extraordinarily complex and contribute a myriad of compounds that are involved in flavors generally described as roasted, browned, meaty, caramelized, etc. (Mottram, 1998).

The pH of food plays a role in development of Maillard reaction flavors. As pH increases, color and polymeric compounds increase and nitrogen-containing compounds like pyrazines are favored (Mottram & Madruga, 1994).

According to Miller et al. (2001), many compounds contributing to beef flavor are water-soluble. As pH increases in meat, proteins have increased water binding properties. During cooking, fewer water-soluble proteins are lost from high-pH meat since there is less cooking loss.

Lean meat from different species generally possess similar flavor precursors and give off similar volatile compounds when cooked to produce characteristic meat flavors common to all species (Mottram, 1998). However, the ability to differentiate meat from varying species is predominantly attributed to lipid degraded compounds that give off various "fatty" aromas (Van Ba et al., 2012).

By far, the most important extrinsic factor that impacts generation of volatile aroma compounds is cooking method. When referring to cooking method, the primary factor which should be considered is whether the method heats the beef under moist conditions or dry conditions (Kerth and Miller, 2015).

Cooking rate has an influence on flavor intensity. Steaks cooked in a hotter oven, at a greater rate of cooking, have lower flavor intensity values as reported by Cross et. al. (1976). It has also been noted that cooking rate and holding time may also influence potency of beef off flavors. Slower cooking time and longer holding times may allow for off odors to dissipate and lessen in intensity (Calkins and Hodgen, 2007).

Moist heat cookery causes beef to be cooked at low temperatures close to the boiling point of water (<212 ◦F or <100 ◦C). These low temperatures prevent the surface of beef from reaching sufficient temperatures to develop Maillard products and, secondarily, fail to promote the initial step in the Maillard reaction, which is a dehydration step or a loss of water from the beef surface (Kerth and Miller, 2015).

Dry heat cookery such as grilling, broiling or pan-frying typically uses temperatures of >177◦C and results in the surface turning brown to black in color (Lorenzen et al., 1999, 2003). Dry, high-temperature cooking of beef is results in generation of Maillard products, which is an extremely complex process that involves not only the temperature but also the length of time that the beef is held at that temperature. A part of the process is the degree of doneness or cooked internal temperature of the beef. As degree of doneness increases, correspondingly, internal temperature also increases, and the time that beef will be held on the cooking surface will be longer. Not only will there be a difference in flavor because of the difference in the physical characteristics of the internal portion of the beef, but the external surface will have a completely different flavor profile because of the differences in the length of cooking time, even when the cooking temperature is held the same (Lorenzen et al., 1999, 2003).

Transfer of water within the beef, and then through evaporation from its surface, is mostly affected by the ability of muscle to bind water and its water-holding capacity. While little water actually is chemically bound to proteins within the muscle, it is held in place by capillary forces and water surface tension (electrostatic charges, mainly), and the ability of the muscle to hold water is primarily determined by the pH of the muscle.

As pH of the beef increases, water-holding capacity also increases and heat transfer increases (Meynier et. al, 1995). Pale, soft and exudative beef does not hold water well, so the free water travels readily to the surface of the meat, where it cools the heating surface and keeps the surface temperature low. This results in generation of mostly lipid-degradation products and few Maillard reaction products (Kerth and Miller, 2015).

Consumer sensory evaluation became a research tool for meat scientists and was used in the scientific literature to determine effects of pre and postharvest treatments on beef palatability. Results from these studies impacted beef production and processing procedures. Most of these studies used hedonic scales to assess overall liking and flavor, juiciness and tenderness liking, with most emphasis being on the impact of treatments on beef tenderness and overall liking (Kerth and Miller, 2015).

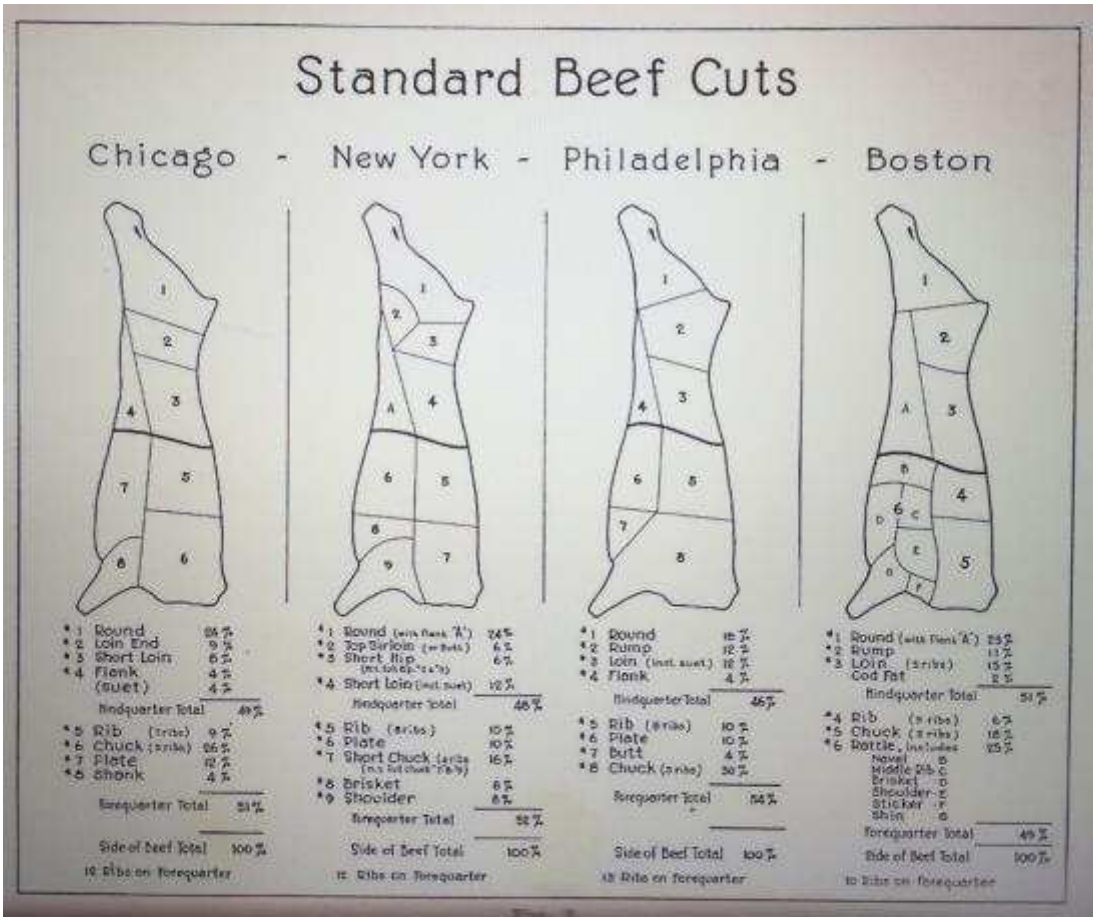


Figure 1. Cutting methods variation due to city location along the East coast (Hosch, 2012).

# CHAPTER 2

## CHARACTERIZING PRODUCTS FROM THE BEEF RIB RESULTING FROM AN ALTERNATIVE CARCASS BREAK

### INTRODUCTION

The manner in which beef carcasses are segregated into wholesale primal and subprimal cuts is based on historical precedence and/or tradition, and they are not always conducive to product eating quality or carcass value. Specifically, the rib/chuck separation currently is made between the 5$^{th}$ and 6$^{th}$ rib bones of the carcass; but potential for maintaining eating quality while improving cutout yield and value exists if the rib/chuck is segregated between the 4$^{th}$ and 5$^{th}$ rib bones. Reuter et al. (2002) stated that “Based on analyses of shear force and consideration of consumer purchase preference information, there seems to be no logical reason for separating the beef wholesale rib from the beef wholesale chuck between the 5$^{th}$ and 6$^{th}$ rib bones other than tradition.” Reuter et al. (2002) also suggested that separating the rib and chuck between the 4$^{th}$ and 5$^{th}$ rib bones was a viable option as it would have minimal effect on beef consumer satisfaction.

The beef industry was interested in further investigating and pursuing option to separate the rib and chuck between the 4$^{th}$ and 5$^{th}$ rib bones; this would necessitate adjustments in standardized trade specifications, particularly those maintained by USDA-AMS for use in commerce and marketing purposes. Such an adjustment would ultimately result in adding additional weight and value to the rib carcass wholesale primal without sacrificing desirable eating characteristics associated with current carcass segregation. Therefore, this study was conducted to further assess the impact of separating the beef rib between the 4$^{th}$ and 5$^{th}$ rib bones versus the 5th and 6th rib bones on beef tenderness, connective tissue content, product composition (visible lean and fat), and product yield.

## MATERIALS AND METHODS

### ***Sample Selection***

Thirty carcasses without major dressing defects present on the forequarter of the carcass, within the same US Quality Grade were selected at random in a commercial beef packing plant. Alternating sides of each carcass was fabricated into either an 8-bone rib, separated between the 4$^{th}$ and 5$^{th}$ rib bones (n = 30), or a traditional 7-bone rib, separated between the 5$^{th}$ and 6$^{th}$ rib bones (n = 30). All ribs were collected as NAMP 107-OP Ribs (whole, bone-in rib, cap-on). Existence of any partial rib (i.e., 6 ½, 7 ½ or 8 ½ ribs) resulted in the exclusion of carcasses and ribs from the sample. Individual identification was maintained for each rib, and traditional carcass data measurements were collected from each carcass from which the ribs originated. Following collection, all ribs (N = 30) were transported under refrigeration (2°C) to the Colorado State University Meat Laboratory, where they were stored until further fabrication the next day.

### ***Fabrication, Yield Data Collection, and Image Collection***

Within 24 h of arrival, 107 ribs were fabricated into a 109 Roast Ready (bone-in export) Rib, 109B Blade Meat (denuded), 112A Ribeye Roll, Lip-on (1x1, rib fingers on), 124 Back Ribs, lean trimmings, 50/50 trimmings, backstrap, and fat trim/refuse. Concurrent to the fabrication procedures, weights for each product were collected, and sequential yield data were obtained.

Throughout this process, individual product identification was maintained for 109B Blade Meat portions and 112A Ribeye Rolls. On the same day that fabrication and yield data were captured, digital images were captured from the 109B Blade Meat portions for the purpose of obtaining dimensional measurements, and all 112A Ribeye Rolls were vacuum sealed and stored (2°C) until portioning and image capture could be accomplished.

Within 7 days of product collection (within 6 days of vacuum packaging), 112A Ribeye Rolls were transported to a steak-portioning facility equipped with automated steak portioning equipment that used computer software capable of maximizing steak yields from each subprimal cut, where they were cut into equally-portioned ribeye steaks (340 g). At the time of portioning, steak weights, steak thicknesses, steak number/count, and trim weights were collected and recorded, and an image of each steak was obtained for the purpose of capturing dimensional measurements at a later time. All images were captured using a digital camera equipped with a fixed zoom lens attached to a tri-pod that allowed for the capture of images directly above each steak.

Fort the purposes of image capture, individual pieces (blade meat pieces and individual ribeye steaks) were placed on a clean, gridded background of known size. Individual images were downloaded and analyzed using image software capable of quantifying pixel size and number for images. All meaningful dimensional measurements were measured and recorded for each image, including total portion area, maximum length, maximum width, individual muscle area, individual muscle length, individual muscle width, fat depths, fat areas, tail length, tail area, total area of lean, and total area of fat.

Following image capture, steaks were individually identified, packaged, and aged at 2°C until 14 days postmortem. On day 14, steaks were individually frozen (-20°C) and stored until shear force evaluations were conducted. For ribeye steaks, means for each individual measurement were compared by treatment (8-bone rib or 7-bone rib) and steak location within the original ribeye subprimal.

***Warner-Bratzler Shear Force Analysis***

Warner-Bratzler Shear Force (WBSF) values were obtained for primary muscles (*Longissimus dorsi*, *Complexus*, and *Spinalis dorsi*) in every steak derived from all 30, 8-bone ribs (approximately 18 steaks per rib). Previously frozen steaks were randomly assigned to 1 of 5 cooking days, and thawed at 2°C for 36 to 48 h before cooking.

Thawed steaks were cooked to a peak internal temperature of 71°C using a convection oven (Model SCC WE 61 E; Rational, Landsberg am Lech, Germany) set at 204°C with 0% relative humidity. Internal temperature of steaks were monitored using a thermocouple during cooking, and steaks were removed from the oven in order to achieve the desired peak internal temperature. Following cooking, each steak was allowed to equilibrate to room temperature (22°C) and 1 to 6 cores (1.2 cm in diam.) were removed from each muscle within each steak parallel to muscle fiber orientation. Each core was sheared once, perpendicular to muscle fiber orientation, using a universal testing machine (Instron Corp., Canton, MA) fitted with a Warner-Bratzler shear head (crosshead speed: 200 mm/min, load cell capacity: 100 kg). Peak shear force of each core was recorded, and resulting values were averaged to obtain a single WBSF for each muscle within each steak.

***Survey Creation***

Selected images collected for purposes of dimensional measurement were utilized to create electronic surveys that were subsequently used in Best/Worst scaling comparisons and collect data regarding individual consumers, foodservice personnel, and/or purveyors perceptions of steak appearance and desirability by location within an 8-bone ribs ribeye roll. Steaks included in each survey comparison by consumers all were obtained from the same ribeye roll to negate influence on results of variance associated with color and marbling.

Consumers, foodservice personnel, and/or purveyors surveyed were directed to an internet survey link where they were presented with images in groups of 4 steaks, and they were asked to identify their most and least desirable steak among the 4 presented. Each consumer completing the survey were shown all steaks from an individual ribeye roll in all possible combinations allowing all steaks to be compared against all other steaks equally, and every steak had equal opportunity to be ranked as the most or least desirable when presented with 3 other steaks.

The survey resulted in a quantifiable, complete and accurate ranking of all steaks within a ribeye roll using Best/Worst scaling techniques. Dynamic routing software capabilities (Qualtrics) was used so that each individual surveyed could be asked specific questions about steaks that were ranked favorably or unfavorably in each survey. Surveys were created for distribution by the National Cattlemen's Beef Association (NCBA) marketing team.

Personnel of CSU were not responsible for identifying participants or distributing or executing surveys; however, CSU personnel assisted with data analysis and summarizing findings of surveys.

***Statistical Analyses***

This experiment was designed and analyzed as a repeated measure (8-bone rib vs. 7-bone rib). Least square means for all measurements were computed and compared using the GLM procedure of SAS; the experimental unit for this study was individual carcass. There were thirty (N = 30) experimental units total, thirty (n = 30) for each treatment. Least square means for each measurement were adjusted using the Tukey adjustment.

RESULTS AND DISCUSSION

***Description of Experimental Sample***

Carcass characteristics of cattle selected for this study are shown in Table 2.1. As expected, mean values for individual carcass traits did not differ (P > 0.05) by treatment.

As shown in Table 2.2, weights of products from rib fabrication differed (P < 0.05) among treatments, with the exception of rib fingers and 50/50 trim weights, which did not differ (P > 0.05) by whether the product was derived from 7-bone vs. 8-bone ribs. Specifically, the 8-bone 112A Ribeye Rolls were 0.56 Kg heavier (P < 0.05) than 7-bone 112A Ribeye Rolls, suggesting that there was potential for 1.12 Kg gain per carcass. Additionally, 8-bone 112A Ribeye Rolls produced 1.4 more steaks than the 7-bone 112A Ribeye Rolls, indicating that there was potential for 2.8 additional ribeye steaks per carcasses with a $4^{th}$ and $5^{th}$ rib bones chuck/rib separation (Table 2.3).

Tables 2.4, 2.5, and 2.6 display least squares means for 7-bone ribs vs. 8-bone ribs ribeye steaks for steak weight (g) and thickness (cm), maximum length (cm) and width (cm), and total area ($cm^2$) and tail length (cm). Values did not differ (P > 0.05) for thickness, maximum length, maximum width, or tail length by lengths' of rib subprimal. With the exception of steak 1 (P < 0.05), ribeye steak weights also did not differ (P > 0.05) by treatment. With the exception of steak 20 (P < 0.05), total area of ribeye steaks was not different (P > 0.05) between treatments.

Least squares means for total area ($cm^2$) of Longissimus dorsi (1-24) and Complexus (10-24) steaks are shown in Table 2.7. A treatment effect (P > 0.05) for LM area was not observed for the vast majority of steak locations, and complexus area did not differ by treatement at any steak location (P > 0.05). Tables 2.8, 2.9, and 2.10 show that Longissimus dorsi width, complexus length, and Spinalis dorsi width did not differ by treatment (P > 0.05). In general, the meaningful measurements for LM, Spinalis and Complexus did not differ by treatment ($P > 0.05$).

Effects of the 4th and 5th rib bones break on star fat area ($cm^2$) (steaks 10-25) are shown in Table 2.11. Excluding steaks 18 and 19 ($P < 0.05$), star fat area did not differ by length of the rib sabprimal ($P > 0.05$). Effects of the 4th and 5th rib bones break on length (cm) and width (cm) of intact backribs, Latissimus dorsi, Rhomboideus, Trapezius, and residual infraspinatus are found in Table 2.12.

***Warner-Bratzler Shear Force Analysis***

Shear force was measured in order to evaluate if there were differences in tenderness between steak locations for 7-bone ribs and 8-bone ribs. Table 2.13 shows effects of steak location on WBSF values. Rib fabrication method did not affect tenderness. No meaningful differences in tenderness existed amond steaks for LM, and WBSF values for the complexus and spinalis dorsi did not differ ($P > 0.05$) by steak location. Tenderness was not significantly affected by fabrication style and regardless of muscle size and proportion at any given ribeye roll location, the tenderness is similar for longissimus, complexus, and spinalis muscles in ribeye steaks. These findings are consistent with Reuter et al. (2002), finding that there was not a meaningful change in muscle tenderness at the point of the rib/chuck separation.

Results showed that tenderness of beef steaks was not affected by carcass separation style regardless of muscle size or proportion when removed from any point along the length of the ribeye roll, and that tenderness is similar for longissimus, complexus, and spinalis muscles in ribeye steaks.

### ***Conclusions and Industry Implications***

According to Reuter et al. (2002), consumers showed a visual preference for steaks from the posterior rib locations compared to the anterior rib locations, with the greatest numeric difference in average order of purchase occurring anatomically between the 4th and 5th rib bones locations. Consumers visually preferred steaks from 12th through 5th rib locations over steaks from 4th through 2nd rib bones locations. The lack of consumer willingness to purchase steaks from rib locations four through two is an important factor to be considered in deciding upon the point of separation between the wholesale rib and wholesale chuck.

Results of the present study suggest that additional steaks from the most anterior portion of the rib subprimal could be sold as ribeye steaks without any meaningful affect on tenderness, which could yield approximately four additional ribeye steaks per carcass. When multiplied by four steaks per carcass, the improved steak yield would result in one additional kilogram of ribeye steaks per carcass (although there would also be the same amount less in chuck roll yield).

A clearer understanding of the compositional, dimensional, and tenderness differences of steaks derived from beef ribs resulting from a chuck/rib separation between the 4th and 5th rib bones will facilitate the ability of the beef industry and USDA-AMS to make changes in standardized specifications for beef ribs, which could promote changes in fabrication procedures and improved carcass value.

**Table 2.1** Carcass data collected in-plant (n=30).

| Carcass Information | | | |
|---|---|---|---|
| | Rib Bones | | *P* Value |
| | 7 | 8 | |
| Ribeye Area | 14.80 | 14.87 | 0.8502 |
| Marbling | Sm 50 | Sm 55 | 0.2477 |

**Table 2.2.** Weight data comparing subprimals and trim pieces between 7-rib and 8-rib bones.

| Weight Data | | | | |
|---|---|---|---|---|
| Subprimal/TrimPiece Name | Weight, Kg | | Carcass Weight Difference, Kg | *P* Value[2] |
| | 7 | 8 | | |
| *Number of subprimals* | 30 | 30 | | |
| 107 OP Rib | 12.43 | 14.47 | 4.08 | <0.0001 |
| Roast Ready | 8.34 | 9.16 | 1.63 | 0.0058 |
| Blade Meat | 1.44 | 1.90 | 0.92 | <0.0001 |
| Back Strap | 0.11 | 0.14 | 0.05 | 0.0167 |
| Bones | 0.45 | 0.64 | 0.39 | <0.0001 |
| Fat / Trim Refuse | 2.05 | 2.47 | 0.83 | 0.0038 |
| 112A Ribeye Roll | 6.18 | 6.74 | 1.12 | 0.0171 |
| Back Ribs | 1.59 | 1.77 | 0.36 | 0.0123 |
| Rib Fingers | 0.13 | 0.13 | 0.00 | 0.9440 |
| 50/50 Trim | 0.44 | 0.51 | 0.15 | 0.0577 |
| Infraspinatus | 0.05 | 0.13 | 0.16 | 0.0022 |

[1]Estimated value based on lsmeans for weight-added to individual sides.

[2] $\alpha = 0.05$.

**Table 2.3.** Effect of 4th and 5th rib bones alternative rib-break on number of steaks retrievable from 112 Ribeye Rolls ($\alpha$ = 0.05).

| Steak Count & Steak Weight | | | | |
|---|---|---|---|---|
| | Rib Bones | | | |
| | 7 | 8 | Carcass Difference | *P* Value |
| *Number of subprimals* | 30 | 30 | | |
| Steak Count | 16.46 | 17.86 | 2.80 | 0.0427 |
| Total Weight, Kg | 5.98 | 6.44 | 0.92 | 0.0233 |
| Steak Yield | 85% | 86% | 1% | - |

**Table 2.4.** Effect of 4th and 5th rib bones alternative rib-break on least squares means for weight (g) and thickness (mm) of ribeye steaks ($\alpha$ = 0.05).

| | Weight Before Freeze, g | | | | | Thickness, mm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Steak | n= | | Rib Bones | | *P* Value | n= | | Rib Bones | | *P* Value |
| | 7 | 8 | 7 | 8 | | 7 | 8 | 7 | 8 | |
| 1 | 30 | 30 | 335.81 | 319.10 | 0.0272 | 30 | 30 | 26.06 | 25.30 | 0.5321 |
| 2 | 30 | 30 | 336.60 | 330.63 | 0.2055 | 30 | 30 | 24.10 | 23.36 | 0.3010 |
| 3 | 30 | 30 | 333.10 | 331.98 | 0.5378 | 30 | 30 | 23.06 | 22.93 | 0.8318 |
| 4 | 30 | 30 | 332.78 | 333.18 | 0.8199 | 30 | 30 | 22.30 | 22.76 | 0.3434 |
| 5 | 30 | 30 | 332.60 | 332.50 | 0.9553 | 30 | 30 | 22.20 | 22.53 | 0.5507 |
| 6 | 30 | 30 | 331.51 | 330.85 | 0.7088 | 30 | 30 | 21.66 | 22.16 | 0.4343 |
| 7 | 30 | 30 | 332.55 | 332.66 | 0.9473 | 30 | 30 | 21.33 | 21.80 | 0.4137 |
| 8 | 30 | 30 | 330.53 | 330.83 | 0.8766 | 30 | 30 | 21.13 | 21.16 | 0.9523 |
| 9 | 30 | 30 | 330.58 | 332.85 | 0.2020 | 30 | 30 | 21.20 | 21.86 | 0.2837 |
| 10 | 30 | 30 | 332.01 | 330.38 | 0.3845 | 30 | 30 | 21.20 | 21.56 | 0.5504 |
| 11 | 30 | 30 | 329.98 | 331.08 | 0.5153 | 30 | 30 | 21.76 | 21.63 | 0.8652 |
| 12 | 30 | 30 | 330.98 | 329.35 | 0.4380 | 30 | 30 | 21.26 | 21.46 | 0.7784 |
| 13 | 30 | 30 | 329.48 | 331.35 | 0.3789 | 30 | 30 | 21.93 | 21.96 | 0.9651 |
| 14 | 30 | 30 | 330.53 | 330.96 | 0.8592 | 30 | 30 | 22.00 | 22.46 | 0.5774 |
| 15 | 29 | 30 | 331.94 | 331.56 | 0.8917 | 29 | 30 | 22.17 | 22.50 | 0.7392 |
| 16 | 29 | 25 | 319.38 | 334.08 | 0.0673 | 29 | 25 | 20.84 | 23.44 | 0.0112 |
| 17 | 21 | 27 | 333.79 | 331.83 | 0.7957 | 21 | 27 | 22.61 | 22.85 | 0.8428 |
| 18 | 16 | 23 | 321.87 | 330.60 | 0.4137 | 16 | 23 | 20.81 | 22.47 | 0.1622 |
| 19 | 13 | 19 | 326.50 | 336.84 | 0.2341 | 13 | 19 | 22.46 | 23.15 | 0.6806 |
| 20 | 8 | 17 | 323.62 | 333.58 | 0.4570 | 8 | 17 | 20.75 | 23.00 | 0.2010 |
| 21 | 6 | 11 | 351.41 | 343.22 | 0.5275 | 6 | 11 | 24.83 | 24.00 | 0.8057 |
| 22 | 3 | 8 | 344.66 | 321.50 | 0.2303 | 3 | 8 | 21.00 | 23.50 | 0.4996 |
| 23 | 2 | 4 | 340.75 | 344.12 | 0.8487 | 2 | 4 | 23.00 | 21.50 | 0.7567 |
| 24 | - | 3 | - | 347.83 | - | - | 3 | - | 21.00 | - |
| 25 | - | 1 | - | 392.00 | - | - | 1 | - | 26.00 | - |

**Table 2.5.** Effect of 4th and 5th rib bones alternative rib-break on least squares means for maximum length (cm) and maximum width (cm) of ribeye steaks ($\alpha$ = 0.05).

| | Max Length, cm | | | | | Max Width, cm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Steak | n= | | Rib Bones | | *P* Value | n= | | Rib Bones | | *P* Value |
| | 7 | 8 | 7 | 8 | | 7 | 8 | 7 | 8 | |
| 1 | 30 | 30 | 21.59 | 21.79 | 0.6006 | 30 | 30 | 8.56 | 8.56 | 0.9706 |
| 2 | 30 | 30 | 22.20 | 22.40 | 0.5835 | 30 | 30 | 8.71 | 8.59 | 0.7013 |
| 3 | 30 | 30 | 22.50 | 22.56 | 0.9378 | 30 | 30 | 8.79 | 9.04 | 0.1905 |
| 4 | 30 | 30 | 22.94 | 22.56 | 0.3386 | 30 | 30 | 8.79 | 9.02 | 0.2634 |
| 5 | 30 | 30 | 22.94 | 22.94 | 0.9952 | 30 | 30 | 9.14 | 9.22 | 0.7498 |
| 6 | 30 | 30 | 23.01 | 22.83 | 0.6186 | 30 | 30 | 9.09 | 9.25 | 0.5031 |
| 7 | 30 | 30 | 23.01 | 22.89 | 0.7011 | 30 | 30 | 9.40 | 9.35 | 0.8817 |
| 8 | 30 | 30 | 22.89 | 22.43 | 0.2305 | 30 | 30 | 9.42 | 9.60 | 0.4574 |
| 9 | 30 | 30 | 22.71 | 22.58 | 0.7386 | 30 | 30 | 9.50 | 9.65 | 0.5270 |
| 10 | 30 | 30 | 22.61 | 22.28 | 0.3484 | 30 | 30 | 9.80 | 9.78 | 0.9455 |
| 11 | 30 | 30 | 22.20 | 22.30 | 0.7900 | 30 | 30 | 10.26 | 9.91 | 0.5121 |
| 12 | 30 | 30 | 22.35 | 22.35 | 0.9770 | 30 | 30 | 9.78 | 9.80 | 0.8567 |
| 13 | 30 | 30 | 22.12 | 22.17 | 0.9361 | 30 | 30 | 9.78 | 9.73 | 0.8032 |
| 14 | 30 | 30 | 22.17 | 21.56 | 0.2671 | 30 | 30 | 9.55 | 9.80 | 0.3164 |
| 15 | 29 | 30 | 22.15 | 22.15 | 0.9657 | 29 | 30 | 9.60 | 9.65 | 0.8270 |
| 16 | 29 | 25 | 22.35 | 22.05 | 0.4603 | 29 | 25 | 9.55 | 9.80 | 0.4189 |
| 17 | 21 | 27 | 22.73 | 22.17 | 0.2194 | 21 | 27 | 9.65 | 9.50 | 0.6116 |
| 18 | 16 | 23 | 22.63 | 22.28 | 0.5620 | 16 | 23 | 9.91 | 9.68 | 0.4179 |
| 19 | 13 | 19 | 22.30 | 22.53 | 0.6803 | 13 | 19 | 10.11 | 9.70 | 0.2181 |
| 20 | 8 | 17 | 23.14 | 22.28 | 0.2206 | 8 | 17 | 10.34 | 9.45 | 0.0805 |
| 21 | 6 | 11 | 23.22 | 23.09 | 0.8748 | 6 | 11 | 10.26 | 9.70 | 0.4342 |
| 22 | 3 | 8 | 23.62 | 21.95 | 0.2213 | 3 | 8 | 9.88 | 9.86 | 0.9558 |
| 23 | 2 | 4 | 22.45 | 22.17 | 0.8501 | 2 | 4 | 11.15 | 10.16 | 0.4795 |
| 24 | - | 3 | - | 23.32 | - | - | 3 | - | 10.29 | - |

**Table 2.6.** Effect of 4th and 5th rib bones alternative rib-break on least squares means for total area ($cm^2$) and tail length (cm) of ribeye steaks ($\alpha$ = 0.05).

| | Total Area, $cm^2$ | | | | | Tail Length, cm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Steak | n= | | Rib bones | | *P* Value | n= | | Rib bones | | *P* Value |
| | 7 | 8 | 7 | 8 | | 7 | 8 | 7 | 8 | |
| 1 | 30 | 30 | 193.55 | 193.55 | 0.9375 | 30 | 30 | 4.85 | 4.60 | 0.8872 |
| 2 | 30 | 30 | 193.55 | 193.55 | 0.9356 | 30 | 30 | 2.87 | 3.00 | 0.4805 |
| 3 | 30 | 30 | 193.55 | 193.55 | 0.7689 | 30 | 30 | 3.43 | 3.25 | 0.3338 |
| 4 | 30 | 30 | 193.55 | 193.55 | 0.4828 | 30 | 30 | 3.56 | 3.61 | 0.9945 |
| 5 | 30 | 30 | 193.55 | 193.55 | 0.4506 | 30 | 30 | 3.63 | 3.61 | 0.8641 |
| 6 | 30 | 30 | 193.55 | 193.55 | 0.5288 | 30 | 30 | 3.96 | 3.86 | 0.6546 |
| 7 | 30 | 30 | 193.55 | 193.55 | 0.3816 | 30 | 30 | 3.96 | 4.09 | 0.5237 |
| 8 | 30 | 30 | 193.55 | 193.55 | 0.6150 | 30 | 30 | 4.27 | 4.04 | 0.2618 |
| 9 | 30 | 30 | 193.55 | 193.55 | 0.4607 | 30 | 30 | 4.29 | 4.22 | 0.7075 |
| 10 | 30 | 30 | 193.55 | 193.55 | 0.3757 | 30 | 30 | 4.37 | 4.39 | 0.8908 |
| 11 | 30 | 30 | 193.55 | 193.55 | 0.5463 | 30 | 30 | 4.32 | 4.47 | 0.4882 |
| 12 | 30 | 30 | 193.55 | 193.55 | 0.8654 | 30 | 30 | 4.29 | 4.24 | 0.8153 |
| 13 | 30 | 30 | 193.55 | 193.55 | 0.2679 | 30 | 30 | 4.11 | 4.04 | 0.7667 |
| 14 | 30 | 30 | 193.55 | 193.55 | 0.9437 | 30 | 30 | 3.86 | 3.86 | 0.9579 |
| 15 | 29 | 30 | 187.10 | 193.55 | 0.4625 | 29 | 30 | 4.04 | 3.73 | 0.2423 |
| 16 | 29 | 25 | 187.10 | 161.29 | 0.5507 | 29 | 25 | 3.78 | 3.56 | 0.4272 |
| 17 | 21 | 27 | 135.48 | 174.19 | 0.0908 | 21 | 27 | 3.81 | 3.33 | 0.1066 |
| 18 | 16 | 23 | 103.23 | 148.39 | 0.2209 | 16 | 23 | 3.51 | 3.40 | 0.7571 |
| 19 | 13 | 19 | 83.87 | 122.58 | 0.4189 | 13 | 19 | 3.30 | 3.23 | 0.8363 |
| 20 | 8 | 17 | 51.61 | 109.68 | 0.0105 | 8 | 17 | 3.56 | 3.07 | 0.3846 |
| 21 | 6 | 11 | 38.71 | 70.97 | 0.2747 | 6 | 11 | 3.66 | 2.84 | 0.3161 |
| 22 | 3 | 8 | 19.35 | 51.61 | 0.3856 | 3 | 8 | 2.82 | 2.82 | 0.9955 |
| 23 | 2 | 4 | 12.90 | 25.81 | 0.4494 | 2 | 4 | 4.37 | 3.94 | 0.7910 |
| 24 | - | 3 | - | 19.35 | - | - | 3 | - | 4.72 | - |
| 25 | - | 1 | - | 6.45 | - | - | 1 | - | 4.47 | - |

**Table 2.7**. Effect of 4th and 5th rib bones alternative rib-break on longissimus dorsi and complexus area ($cm^2$)[1].

| | Longissimus dorsi Area, $cm^2$ | | | | | Complexus Area, $cm^2$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Steak | n= | | Ribe Bones | | *P* Value | n= | | Rib Bones | | *P* Value |
| | 7 | 8 | 7 | 8 | | 7 | 8 | 7 | 8 | |
| 1 | 30 | 30 | 96.13[a] | 96.45[a] | 0.9325 | - | - | - | - | - |
| 2 | 30 | 30 | 96.32[a] | 95.48[a] | 0.8117 | - | - | - | - | - |
| 3 | 30 | 30 | 94.64[a] | 93.81[a] | 0.8133 | - | - | - | - | - |
| 4 | 30 | 30 | 92.51[a] | 90.39[a] | 0.5336 | - | - | - | - | - |
| 5 | 30 | 30 | 91.35[a] | 89.35[a] | 0.6586 | - | - | - | - | - |
| 6 | 30 | 30 | 86.77[a] | 85.61[a] | 0.7755 | - | - | - | - | - |
| 7 | 30 | 30 | 83.74[a] | 82.13[a] | 0.6806 | - | - | - | - | - |
| 8 | 30 | 30 | 78.77[ab] | 78.26[a] | 0.8816 | - | - | - | - | - |
| 9 | 30 | 30 | 74.06[ab] | 72.77[ab] | 0.7519 | - | - | - | - | - |
| 10 | 30 | 30 | 70.64[ab] | 68.32[ab] | 0.5801 | 3 | 5 | 2.13[c] | 1.03[h] | 0.0134 |
| 11 | 30 | 30 | 65.22[ab] | 83.10[a] | 0.3566 | 10 | 11 | 2.06[c] | 1.93[h] | 0.4197 |
| 12 | 30 | 30 | 61.35[ab] | 60.84[ab] | 0.8895 | 20 | 17 | 3.48[c] | 3.10[h] | 0.5231 |
| 13 | 30 | 30 | 58.51[ab] | 55.93[ab] | 0.4657 | 23 | 25 | 4.19[c] | 4.45[h] | 0.718 |
| 14 | 30 | 30 | 54.26[b] | 52.97[ab] | 0.6344 | 26 | 30 | 6.13[c] | 6.39[gh] | 0.6232 |
| 15 | 29 | 30 | 52.26[b] | 50.12[ab] | 0.4675 | 27 | 29 | 8.52[bc] | 9.16[fg] | 0.6025 |
| 16 | 29 | 25 | 52.06[b] | 47.81[ab] | 0.1327 | 24 | 27 | 9.87[abc] | 11.35[ef] | 0.2278 |
| 17 | 21 | 27 | 51.30[b] | 45.48[b] | 0.0554 | 20 | 27 | 11.81[ab] | 14.39[de] | 0.0736 |
| 18 | 16 | 23 | 51.48[b] | 46.00[ab] | 0.1201 | 16 | 23 | 12.13[ab] | 15.68[cd] | 0.0406 |
| 19 | 13 | 19 | 50.97[b] | 47.03[ab] | 0.3237 | 13 | 19 | 14.71[ab] | 16.32[cd] | 0.3039 |
| 20 | 8 | 17 | 49.93[b] | 43.10[b] | 0.182 | 8 | 17 | 15.03[ab] | 18.06[bcd] | 0.1853 |
| 21 | 6 | 11 | 52.06[b] | 43.81[b] | 0.2055 | 6 | 11 | 16.97[a] | 19.16[bcd] | 0.2207 |
| 22 | 3 | 8 | 48.32[b] | 38.52[b] | 0.3854 | 3 | 8 | 16.13[ab] | 17.81[bcd] | 0.4187 |
| 23 | 2 | 4 | 55.80[ab] | 48.38[ab] | 0.4733 | 2 | 4 | 19.61[a] | 22.26[bc] | 0.4159 |
| 24 | - | 3 | - | 45.74[ab] | - | - | 3 | - | 26.71[ab] | - |
| 25 | - | 1 | - | 51.80[ab] | | - | 1 | - | 40.90[a] | |

[1] Area evaluated at steaks numbered beginning at the posterior end of the ribeye rolls (1-24 for longissimus and 10-24 for complexus.).

[a-h] LSMean values with different superscripts are different ($P < 0.05$).

**Table 2.8.** Effect of 4th and 5th rib bones alternative rib-break on least squares means for maximum length (cm) and maximum width (cm) of longissimus muscle of ribeye steaks ($\alpha = 0.05$).

| | *Longissimus dorsi* Length, cm | | | | | *Longissimus dorsi* Width, cm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Steak | n= | | Rib Bones | | *P Value* | n= | | Rib Bones | | *P Value* |
| | 7 | 8 | 7 | 8 | | 7 | 8 | 7 | 8 | |
| 1 | 30 | 30 | 16.71 | 16.46 | 0.4753 | 30 | 30 | 7.21 | 7.37 | 0.5921 |
| 2 | 30 | 30 | 16.76 | 16.84 | 0.8585 | 30 | 30 | 7.19 | 7.26 | 0.7140 |
| 3 | 30 | 30 | 16.59 | 16.69 | 0.7474 | 30 | 30 | 7.21 | 7.24 | 0.9259 |
| 4 | 30 | 30 | 16.69 | 16.46 | 0.5825 | 30 | 30 | 7.09 | 7.42 | 0.1272 |
| 5 | 30 | 30 | 16.36 | 16.59 | 0.5490 | 30 | 30 | 7.09 | 7.37 | 0.3237 |
| 6 | 30 | 30 | 16.05 | 16.15 | 0.7951 | 30 | 30 | 7.29 | 7.14 | 0.5659 |
| 7 | 30 | 30 | 15.70 | 15.52 | 0.6990 | 30 | 30 | 7.19 | 7.65 | 0.2007 |
| 8 | 30 | 30 | 14.66 | 14.83 | 0.7436 | 30 | 30 | 7.14 | 7.26 | 0.6481 |
| 9 | 30 | 30 | 14.50 | 14.48 | 0.9457 | 30 | 30 | 6.99 | 7.14 | 0.5944 |
| 10 | 30 | 30 | 13.84 | 13.56 | 0.5156 | 30 | 30 | 7.34 | 7.09 | 0.5701 |
| 11 | 30 | 30 | 12.95 | 12.85 | 0.8605 | 30 | 30 | 6.81 | 6.78 | 0.9161 |
| 12 | 30 | 30 | 12.50 | 12.45 | 0.9246 | 30 | 30 | 6.53 | 6.60 | 0.7169 |
| 13 | 30 | 30 | 11.86 | 11.84 | 0.9353 | 30 | 30 | 6.63 | 6.53 | 0.7037 |
| 14 | 30 | 30 | 11.40 | 11.05 | 0.3350 | 30 | 30 | 6.63 | 6.60 | 0.9344 |
| 15 | 29 | 30 | 10.80 | 10.44 | 0.3403 | 29 | 30 | 6.43 | 6.58 | 0.6470 |
| 16 | 29 | 25 | 10.95 | 10.29 | 0.0711 | 29 | 25 | 6.48 | 6.43 | 0.8302 |
| 17 | 21 | 27 | 10.90 | 10.13 | 0.0209 | 21 | 27 | 6.40 | 6.02 | 0.1875 |
| 18 | 16 | 23 | 10.62 | 10.08 | 0.2118 | 16 | 23 | 6.43 | 6.05 | 0.2919 |
| 19 | 13 | 19 | 10.59 | 10.34 | 0.5554 | 13 | 19 | 6.35 | 6.20 | 0.7180 |
| 20 | 8 | 17 | 10.59 | 9.83 | 0.1626 | 8 | 17 | 6.45 | 6.32 | 0.8359 |
| 21 | 6 | 11 | 11.02 | 9.96 | 0.0455 | 6 | 11 | 6.63 | 6.15 | 0.5375 |
| 22 | 3 | 8 | 10.52 | 8.86 | 0.2069 | 3 | 8 | 6.25 | 6.40 | 0.9039 |
| 23 | 2 | 4 | 10.80 | 9.80 | 0.3089 | 2 | 4 | 7.11 | 6.65 | 0.8113 |
| 24 | - | 3 | - | 10.69 | - | - | 3 | - | 5.92 | - |
| 25 | - | 1 | - | 11.07 | - | - | 1 | - | 6.99 | - |

**Table 2.9.** Effect of 4th and 5th rib alternative rib-break on least squares means for maximum length (cm) and maximum width (cm) of complexus muscle of ribeye steaks ($\alpha = 0.05$).

| | *Complexus* Length, cm | | | | | *Complexus* Width, cm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Steak | n= | | Rib Bones | | | n= | | Rib Bones | | |
| | 7 | 8 | 7 | 8 | *P* Value | 7 | 8 | 7 | 8 | *P* Value |
| 10 | 3 | 5 | 1.85 | 1.63 | 0.5922 | 3 | 5 | 2.36 | 1.30 | 0.0115 |
| 11 | 10 | 11 | 2.13 | 1.88 | 0.4947 | 10 | 11 | 1.83 | 1.68 | 0.3715 |
| 12 | 20 | 17 | 2.69 | 2.51 | 0.5466 | 20 | 17 | 1.96 | 2.11 | 0.5573 |
| 13 | 23 | 25 | 3.00 | 3.07 | 0.7776 | 23 | 25 | 2.03 | 2.29 | 0.3143 |
| 14 | 26 | 30 | 3.53 | 3.63 | 0.7653 | 26 | 30 | 2.49 | 2.74 | 0.4030 |
| 15 | 27 | 29 | 4.57 | 4.47 | 0.7949 | 27 | 29 | 2.97 | 3.20 | 0.4425 |
| 16 | 24 | 27 | 4.83 | 5.03 | 0.6178 | 24 | 27 | 3.20 | 3.45 | 0.2768 |
| 17 | 20 | 27 | 5.05 | 5.36 | 0.4656 | 20 | 27 | 3.63 | 3.63 | 0.9581 |
| 18 | 16 | 23 | 5.05 | 5.97 | 0.0648 | 16 | 23 | 3.68 | 4.11 | 0.2947 |
| 19 | 13 | 19 | 5.77 | 6.20 | 0.3800 | 13 | 19 | 3.86 | 4.34 | 0.2676 |
| 20 | 8 | 17 | 5.79 | 6.30 | 0.4541 | 8 | 17 | 3.78 | 4.52 | 0.1765 |
| 21 | 6 | 11 | 5.89 | 6.35 | 0.3734 | 6 | 11 | 4.52 | 4.55 | 0.9545 |
| 22 | 3 | 8 | 5.97 | 5.69 | 0.7752 | 3 | 8 | 3.86 | 4.57 | 0.3092 |
| 23 | 2 | 4 | 5.79 | 6.22 | 0.7303 | 2 | 4 | 4.70 | 5.03 | 0.7848 |
| 24 | - | 3 | - | 7.49 | - | - | 3 | - | 4.78 | - |
| 25 | - | 1 | - | 11.28 | - | - | 1 | - | 6.32 | - |

**Table 2.10**. Effect of $4^{th}$ and $5^{th}$ rib bones alternative rib-break on least squares means for maximum length (cm) and total area ($cm^2$) of spinalis muscle of ribeye steaks ($\alpha = 0.05$).

| | Spinalis Length, cm | | | | | Spinalis Area, $cm^2$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Steak | n= | | Rib Bones | | *P* Value | n= | | Rib Bones | | *P* Value |
| | 7 | 8 | 7 | 8 | | 7 | 8 | 7 | 8 | |
| 1 | 15 | 14 | 5.89 | 5.82 | 0.9269 | 15 | 14 | 7.74 | 6.32 | 0.3618 |
| 2 | 26 | 28 | 7.62 | 7.72 | 0.8174 | 26 | 28 | 11.42 | 10.32 | 0.4124 |
| 3 | 30 | 30 | 8.94 | 8.97 | 0.9594 | 30 | 30 | 15.23 | 14.77 | 0.7106 |
| 4 | 30 | 30 | 10.08 | 10.13 | 0.8954 | 30 | 30 | 18.00 | 18.52 | 0.6512 |
| 5 | 30 | 30 | 11.10 | 10.92 | 0.5579 | 30 | 30 | 22.39 | 22.06 | 0.7622 |
| 6 | 30 | 30 | 11.61 | 11.58 | 0.9684 | 30 | 30 | 26.39 | 26.00 | 0.7417 |
| 7 | 30 | 30 | 12.12 | 12.29 | 0.5389 | 30 | 30 | 29.42 | 28.39 | 0.3665 |
| 8 | 30 | 30 | 12.60 | 12.40 | 0.4893 | 30 | 30 | 31.35 | 30.84 | 0.6635 |
| 9 | 30 | 30 | 12.78 | 12.65 | 0.6934 | 30 | 30 | 32.90 | 33.10 | 0.8612 |
| 10 | 30 | 30 | 12.80 | 12.88 | 0.8194 | 30 | 30 | 35.48 | 34.58 | 0.434 |
| 11 | 30 | 30 | 12.75 | 12.93 | 0.6598 | 30 | 30 | 36.26 | 35.03 | 0.4289 |
| 12 | 30 | 30 | 12.90 | 13.16 | 0.5581 | 30 | 30 | 36.97 | 35.87 | 0.4848 |
| 13 | 30 | 30 | 12.57 | 12.78 | 0.6399 | 30 | 30 | 37.29 | 36.84 | 0.7621 |
| 14 | 30 | 30 | 11.96 | 12.12 | 0.7743 | 30 | 30 | 36.71 | 37.10 | 0.8069 |
| 15 | 29 | 30 | 11.20 | 11.43 | 0.6966 | 29 | 30 | 36.65 | 36.58 | 0.9629 |
| 16 | 29 | 25 | 11.20 | 10.74 | 0.5344 | 29 | 25 | 36.77 | 36.06 | 0.7019 |
| 17 | 21 | 27 | 10.77 | 10.11 | 0.4274 | 21 | 27 | 37.55 | 34.65 | 0.1733 |
| 18 | 16 | 23 | 10.59 | 9.19 | 0.0944 | 16 | 23 | 38.52 | 36.45 | 0.4865 |
| 19 | 13 | 19 | 9.91 | 8.92 | 0.3219 | 13 | 19 | 39.23 | 36.00 | 0.346 |
| 20 | 8 | 17 | 11.68 | 9.32 | 0.0166 | 8 | 17 | 42.77 | 36.52 | 0.0614 |
| 21 | 6 | 11 | 10.29 | 8.97 | 0.2767 | 6 | 11 | 36.00 | 36.71 | 0.7194 |
| 22 | 3 | 8 | 9.70 | 8.36 | 0.2887 | 3 | 8 | 34.90 | 33.68 | 0.8594 |
| 23 | 2 | 4 | 8.03 | 7.37 | 0.596 | 2 | 4 | 37.35 | 30.77 | 0.3138 |
| 24 | - | 3 | - | 7.01 | - | - | 3 | - | 20.71 | - |
| 25 | - | 1 | - | 8.36 | - | - | 1 | - | 4.87 | - |

**Table 2.11**. Effect of $4^{th}$ and $5^{th}$ rib bones alternative rib-break on least squares means for total area ($cm^2$) of star fat of ribeye steaks.

| Star Fat Area, $cm^2$ | | | | | |
|---|---|---|---|---|---|
| Steak | n= | | Rib Bones | | *P* Value |
| | 7 | 8 | 7 | 8 | |
| 10 | 29 | 30 | 8.84 | $8.64^{ab}$ | 0.8536 |
| 11 | 30 | 30 | 9.29 | $9.81^{a}$ | 0.5655 |
| 12 | 30 | 30 | 9.42 | $10.32^{a}$ | 0.3052 |
| 13 | 30 | 30 | 9.74 | $10.39^{a}$ | 0.4126 |
| 14 | 29 | 30 | 9.10 | $9.29^{ab}$ | 0.8074 |
| 15 | 28 | 30 | 8.58 | $8.64^{ab}$ | 0.952 |
| 16 | 25 | 18 | 7.81 | $7.55^{ab}$ | 0.8572 |
| 17 | 21 | 27 | 7.42 | $5.87^{ab}$ | 0.1657 |
| 18 | 16 | 23 | 7.16 | $4.32^{b}$ | 0.0257 |
| 19 | 13 | 19 | 6.84 | $3.48^{b}$ | 0.0067 |
| 20 | 8 | 17 | 4.65 | $3.10^{b}$ | 0.1219 |
| 21 | 6 | 11 | 3.61 | $3.48^{b}$ | 0.9156 |
| 22 | 3 | 7 | 3.68 | $2.45^{b}$ | 0.2495 |
| 23 | 1 | 3 | 3.81 | $2.39^{b}$ | 0.6686 |
| 24 | - | 2 | - | $5.10^{ab}$ | - |
| 25 | - | 1 | - | $7.42^{ab}$ | - |

$^{a,b}$ LSMean values with different superscripts are different ($P < 0.05$).

**Table 2.12.** Effect of 4th and 5th rib bones alternative rib-break on least squares means for total area ($in^2$) and maximum length (in) of backribs, latissimus, rhomboideus, trapezius, and infraspinatus fabricated from the 112 Ribeye Roll.

| | | Area, $cm^2$ | | | Length, cm | | |
|---|---|---|---|---|---|---|---|
| Cut | n = | Rib Bones | | *P* Value | Rib Bones | | *P* Value |
| | | 7 | 8 | | 7 | 8 | |
| Backribs | 60 | 618.39 | 676.84 | 0.0053 | 38.96 | 44.22 | <0.0001 |
| *Latissimus* | 60 | 218.32 | 241.03 | 0.1148 | 30.25 | 31.29 | 0.5696 |
| *Rhomboideus* | 60 | 179.87 | 271.16 | <0.0001 | 22.71 | 23.70 | 0.0615 |
| *Trapezius* | 60 | 346.77 | 425.10 | <0.0001 | 26.44 | 30.66 | <0.0001 |
| *Infraspinatus* | 21 | 63.16 | 69.10 | 0.7136 | 5.13 | 6.91 | 0.0349 |

**Table 2.13.** Effect of steak location on the Warner-Bratzler Shear Force values for *Longissimus dorsi*, *Spinalis*, and *Complexus* muscles of ribeye steaks (Steak 25 = most anterior side / Steak 1 = most posterior side).

| | Shear Force, kgf | | |
|---|---|---|---|
| Steak Number* | LD | S | C |
| 25 | $3.37^{ab}$ | 3.10 | 3.57 |
| 24 | $3.07^{ab}$ | 3.37 | 3.63 |
| 23 | $2.90^{ab}$ | 3.49 | 3.68 |
| 22 | $3.13^{ab}$ | 3.01 | 3.87 |
| 21 | $3.05^{ab}$ | 3.37 | 3.63 |
| 20 | $3.02^{ab}$ | 3.26 | 3.70 |
| 19 | $3.05^{ab}$ | 3.16 | 3.74 |
| 18 | $3.05^{ab}$ | 2.98 | 3.96 |
| 17 | $3.11^{ab}$ | 3.12 | 3.92 |
| 16 | $3.02^{ab}$ | 3.04 | 4.01 |
| 15 | $3.05^{ab}$ | 3.08 | 3.94 |
| 14 | $3.22^{ab}$ | 3.16 | 4.36 |
| 13 | $2.95^{ab}$ | 3.14 | 4.53 |
| 12 | $3.21^{ab}$ | 3.05 | 3.80 |
| 11 | $3.24^{ab}$ | 3.11 | 3.53 |
| 10 | $3.11^{ab}$ | 2.91 | - |
| 9 | $3.00^{ab}$ | 2.85 | - |
| 8 | $3.14^{ab}$ | 2.99 | - |
| 7 | $3.25^{ab}$ | 2.96 | - |
| 6 | $3.50^{a}$ | 3.05 | - |
| 5 | $3.34^{ab}$ | 3.17 | - |
| 4 | $3.31^{ab}$ | 3.28 | - |
| 3 | $3.25^{ab}$ | 3.19 | - |
| 2 | $3.06^{ab}$ | 3.11 | - |
| 1 | $2.66^{b}$ | 2.93 | - |
| P value | 0.0077 | 0.3226 | 0.1280 |

$^{a,b}$ LSMean values with different superscripts are different ($P < 0.05$).

# CHAPTER 3

# INFLUENCE OF RATE OF COOKING, COOKING TEMPERATURE, AND DEGREE OF DONENESS ON FACTORS CONTRIBUTING TO BEEF FLAVOR AND TENDERNESS

## INTRODUCTION

Even though beef demand has proven amazingly resilient in the past few years, one of the greatest concerns is the relative price of beef compared to competing proteins. Since it is expected that consumers will pay more for beef, the outstanding flavor of beef must be maintained and/or improved in order to keep the beef consumers continually satisfied. Importance of beef flavor in the marketplace is underscored by the fact that consumers' flavor preferences are reflected in beef purchase decisions (Sitz et al., 2005). During Phase I of the 2011 National Beef Quality Audit, it was pointed out that 4 out of 5 beef industry participants identified beef flavor as either the 1st or 2nd most important beef attribute (Igo et al., 2013).

Very recent research sponsored by Beef Checkoff funds demonstrated that differences in steak thickness, cooking method, cooking temperature, and cooking rate influence overall eating satisfaction of steaks and beef flavor (Shubert, 2015). Perhaps the most intriguing discovery of that research was related to the improvement in tenderness and flavor observed in steaks that were cooked more slowly (Shubert, 2015). Therefore, the present work aimed to study the effects of cooking temperature and degree of doneness as major contributors to steak tenderness and flavor development. Findings of this research should help with development of an optimized set of cooking procedures to improve the steak eating experience.

## MATERIALS AND METHODS

### *Experimental Design*

Combinations of oven temperature (OVENTEMP) and steak internal degree of doneness (INTEMP) were evaluated (Table 3.1). Individual steak was used as the experimental unit and assigned treatment was applied to the individual steak. Cooking rate was adjusted by controlling oven cooking temperature (66°C, 177°C, 246°C, and 343°C) and steak internal cooked degree of doneness (57°C, 63°C, 68°C, 74°C, 79°C, and 85°C) was monitored by controlling interior cooked temperature in the geometric center of each steak. For steaks cooked at an oven temperature of 66°C OVENTEMP, only two INTEMPs (57°C and 63°C) were evaluated, while all other cooking temperatures included all previously described degrees of doneness.

Striploins with similar marbling score were paired in groups of six, and each striploin was cut into four equal sections that generated three steaks 2.5cm thick. Each section was allocated to each treatment combination and each of the three steaks generated was assigned for trained sensory, shear-force, and flavor chemistry analysis. Each combination of OVENTEMP and INTEMP was replicated 30 times.

### *Product Collection and Fabrication plan*

Both strip loins were collected from 90 USDA Low Choice (Small$^{20}$ to Small$^{70}$) carcasses (N = 180) in a commercial beef slaughter facility. In an attempt to control variation in the sample, strip loins were collected in groups of 30 carcasses. Twenty-one days postmortem, 30 groups of six strip loins paired by marbling score and ribeye area were sliced producing a total of 24 2.5 cm thick steaks. From the 24 steaks, 7 of the 20 OVENTEMP × INTEMP combinations were randomly assigned to each set of striploins from a single carcass (Figure 3.1). One steak from each set of 3 was designated for either shear force, sensory panel, or flavor chemistry analysis. Remaining steaks assigned to a treatment were identified and saved as reserves.

***Cooking procedures***

Before cooking, frozen steaks were tempered at 2°C for 16-24 h. Steaks were grill marked in a crosshatch pattern (45° rotation from grill grates) on both sides, allowing one minute per hatch, on an open-hearth char broiler set at 315°C. Once steaks were grill marked, steaks were cooked in a Combi oven (Model SCC WE 61 E; Rational, Landsberg am Lech, Germany) at a dry-heat setting with 0% retained humidity in accordance with the prescribed cooking treatment for each steak with a fan speed of high to attain the desired peak internal temperature (Table 3.1). Internal temperature was measured with a thermocouple during the entire time that steaks were cooking. Cooking loss were quantified for each individual steak.

***External and Internal Steak Appearance***

Steaks designated for shear force assessment were cooked according to their respective treatments and subjected to Warner-Bratzler shear force (WBSF) and slice shear force (SSF) procedures. Immediately following cooking, but before shear force determinations, external and internal appearance of steaks was evaluated. A spectrophotometer (Hunter Associates Laboratory, Reston, VA) was used to collect CIE L* a* b* measurements on the exterior and interior of each steak. Three measurements of CIE L* a* b* were obtained from different locations within or on the outer surface of each steak to gather an average for each sample. Exterior measurements were obtained between char marks created by grill marking the steaks. Subjective measurements for degree of doneness and internal and external steak appearance also were recorded by 2 trained individuals. Visual degree of doneness was evaluated and recoded using a 5-point hedonic scale (1 = rare, 2 = medium rare, 3 = medium, 4 = medium well, and 5 =

well done) in reference to published photographic standards (AMSA, 1995). Internal steak appearance was recorded using an 8-point hedonic scale (1 = purple, 2 = red, 3 = reddish-pink, 4 = pink, 5 = pinkish-grey, 6 = light brown, 7 = medium brown, and 8 = dark brown). External steak appearance was evaluated in between char marks created by grill marking the steaks. Measurements were recorded using an 8-point hedonic scale (1 = light grey, 2 = grey, 3 = greyish-brown, 4 = light brown, 5 = brown, 6 = dark brown, 7 = brownish-black, 8 = black).

***Shear Force Analyses***

Both WBSF and SSF measurements were obtained from each steak designated for shear force evaluation using procedures described by Lorenzen et al. (2010). Within 5 min of recording peak internal temperature, a 1cm by 5 cm slice was removed from the steak parallel to muscle fiber orientation from the lateral end, and sheared perpendicular to muscle fiber orientation, using a universal testing machine (Instron Corp., Canton, MA) equipped with a flat, blunt-end blade (crosshead speed: 500 mm/min, load capacity: 100 kg), resulting in a single SSF measurement for each steak. The remaining portion of each steak was allowed to equilibrate to room temperature (22°C) and at least 4 cores (1.2 cm in diameter) were removed from each steak parallel to muscle fibers. Each core was sheared perpendicular to the muscle fibers using a universal testing machine (Instron Corp., Canton, MA) fitted with a Warner-Bratzler shear head (crosshead speed: 200 mm/min, load cell capacity: 100 kg). Peak shear force of each core was recorded and resulting values were averaged to obtain a single WBSF measurement for each steak.

***Trained Sensory Analyses***

Before cooking, frozen steaks were thawed at 0-4°C for 16-24 h. Due to limited oven capacity for the 20 oven treatments, all steaks used during the sensory panels were cooked in advance and reheated on the day of analysis. Sensory steaks were cooked following the same cooking protocols previously described.

Immediately after cooking, each steak was placed in a vacuum bag, chilled in an ice water bath for 5-15 min, vacuum packaged, and stored at 0-4°C for 16-48 h before sensory panel preparation and evaluatian. On the day of sensory analysis, steaks were reheated in a circulating water bath (Fisher Scientific™ Isotemp™ Heated Immersion Circulators: Model 6200 H24) set at 57.5°C for 30 min. Once removed from the water bath, steaks were trimmed of all external fat and connective tissue, sized into 1 cm cubes, and served to trained panelists. All panelists (n = 7-9) were trained to evaluate attributes of initial tenderness, sustained tenderness, overall tenderness, juiciness, beefy/brothy, browned/grilled, buttery/fat, burnt, bloody/metallic, livery, and oxidized flavors. Each panelist received 2-3 cubes and evaluated each sample for the aforementioned sensory characteristics using an unstructured line scale verbally anchored at both ends (0 = very tough, very dry, not present; 100 = very tender, very juicy, very intense). Samples representing 10 out of the 20 treatments were served on each panel.

***Statistical Analyses***

Least squares means of main and interactive effects on sensory attributes, color and shear force were compared using the MIXED model procedure of SAS with OVENTEMP and INTEMP being the main effects.

***ANTERIOR*** **Loin 1** ***POSTERIOR***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Wedge (Raw chemica l steak)* | *ST K 1* | *ST K 2* | *ST K 3* | *ST K 4* | *ST K 5* | *ST K 6* | *ST K 7* | *ST K 8* | *ST K 9* | *ST K 10* | *ST K 11* | *ST K 12* | *VEI N* |

***ANTERIOR*** **Loin 2** ***POSTERIOR***

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Wedge (Raw chemica l steak)* | *ST K 1* | *ST K 2* | *ST K 3* | *ST K 4* | *ST K 5* | *ST K 6* | *ST K 7* | *ST K 8* | *ST K 9* | *ST K 10* | *ST K 11* | *ST K 12* | *VEI N* |

Figure 3.1. Steak cutting guide within a carcass.

RESULTS AND DISCUSSION

***Shear Force Analyses***

Strip loin (top loin) steaks were selected for use as sample steaks in this study because they are the most typical cut served in restaurants and they also are available from retail outlets.

Results (Table 3.3) showed that both OVENTEMP and INTEMP influenced ($P < 0.01$) slice shear force (SSF) and Warner-Bratzler shear force (WBSF) values. As degree of doneness values increased ($P < 0.01$), WBSF also increased; a similar increase in SSF values was noted, although this trend was not as pronounced as for WBSF values. Steaks cooked to a medium rare degree of doneness had lower ($P < 0.01$) SSF values than steaks cooked to well done degree of doneness, and steaks cooked to medium and very well done were similar ($P > 0.05$) among treatments. Steaks cooked with lower cooking rate produced the lowest ($P < 0.01$) SSF and steaks cooked at a fast cooking rate produced the greatest ($P < 0.01$) SSF values among all tested. When cooked at high rate of cooking, steaks had greater ($P < 0.01$) WBSF values than when cooked at both 66°C or 177°C OVENTEMP, while steaks cooked at 343°C OVENTEMP produced WBSF values similar ($P < 0.05$) among treatments. Previous studies have shown that slower cooking rates and lower degrees of doneness result in reduced shear force values (King et al., 2003; Lorenzen et al., 2005).

### ***External and Internal Color***

Internal steak color is mostly affected by the degree of doneness. When steaks are cooked to a constant degree of doneness, cookery method and steak thickness also can influence internal steak color.

Instrumental CIE L*, a*, and b* measures for internal and external color are presented in Tables 3.4 and 3.5. Internal L* values were affected ($P < 0.05$) by a OVENTEMP × INTEMP interaction. At lower rate of cooking, steaks cooked to a medium rare degree of doneness had greater ($P < 0.05$) L* values than those cooked to rare degree of doneness, indicating a lighter color. Additionally, cooking at lower rate of cooking to rare and medium rare degree of doneness resulted in greater ($P < 0.05$) L* values than the same degree of doneness at each remaining cooking rates. Berry (1993) demonstrated that when steaks are submitted to a slower rate of heating, they are scored as having a lower degree of doneness rating. For all remaining cooking rates tested, L* values gradually increased as degree of doneness increased; however, many of these numerical differences were not statistically significant ($P > 0.05$). Internal a* values also declined ($P < 0.01$) as degree of doneness increased. Higher a* values are indicative of a redder color. Visual assessment ratings for internal color were influenced ($P < 0.01$) by both cooking rate and degree of doneness (Table 3.6). As cooking rate increased, visually-assessed internal color ratings for cooked steaks appeared to be more ($P < 0.01$) pinkish-grey, rather than pink. Similarly, as degree of doneness increased from rare to very well done, internal color of steaks shifted ($P < 0.01$) from a reddish-pink color closer to a light brown color. Degree of doneness (Table 3.8) paralleled trends for visually-assessed ratings of internal color.

External L* values were influenced ($P < 0.05$) by cooking rate; as cooking rate increased, L* values also increased ($P < 0.03$). External a* values were affected ($P < 0.05$) by both rate of cooking and degree of doneness. When the steaks were cooked at lower rate of cooking, the lowest a* values were observed ($P < 0.01$) of all cooking rates tested. Additionally, steaks cooked to well done and very well done had lower ($P < 0.05$) a* values than those cooked to rare degree of doneness, while all other degrees of doneness tested were similar ($P > 0.05$).

Visual assessment ratings for external color were affected ($P < 0.01$) by both rate of cooking and degree of doneness (Table 3.7). Steaks cooked at lower rate of cooking produced the darkest ($P < 0.01$) brown external color; thus, it appeared that slower cooking rates allowed for more time for surface browning. As cooking rate increased, external color of cooked steaks darkened ($P < 0.01$) and, additionally, as degree of doneness increased, external color of steaks appeared darker ($P < 0.01$).

***Taste Panel Analysis***

*Tenderness and Cook loss*

Least squares means for sensory panel attributes are provided in Table 3.9. A OVENTEMP × INTEMP interaction was observed for initial tenderness ($P < 0.01$), sustained tenderness ($P < 0.01$) and overall tenderness ($P < 0.01$). Generally, steaks cooked to a lower degree of doneness and with a lower cooking rate had greater ($P < 0.01$) ratings for trained panel tenderness. Considering each cooking rate tested, steaks cooked to a rare degree of doneness were among the most tender ($P < 0.01$) compared to all other degrees of doneness. However, as rate of cooking increased, overall tenderness declined ($P < 0.01$). This observation suggested that, even when the degree of doneness remains constant, cooking temperature can have a significant influence on tenderness.

Least squares means for percent cooking loss are provided in Table 3.10. Generally, as degree of doneness increased, so did percent moisture lost ($P < 0.01$). Steaks cooked at a high cooking rate to a rare degree of doneness were among the most tender of all treatments evaluated and had one of the lowest cooking loss percentages (P = < 0.01). Juiciness is heavily influenced by water loss which, in turn, influences lubrication during mastication. Increased water loss has been reported (Briskey and Kauffman, 1971) to cause an increase in perceived toughness when steaks are submitted to a sensory evaluation using trained taste panels.

*Juiciness*

An interaction between OVENTEMP and INTEMP was observed (P < 0.01) for trained panel juiciness ratings (Table 3.9), which are heavily influenced by water content. Hence, it was no surprise that juiciness ratings were greatest (P < 0.01) when steaks were cooked at a high rate of cooking to a rare degree of doneness and least (P < 0.01) when steaks were cooked at higher cooking rate to a well done and very well done. With the exception of steaks cooked at slower cooking rate, juiciness ratings decreased ($P < 0.01$) as OVENTEMP increased. Increasing cooking rate accelerated rates of evaporation and decreased juiciness ratings. When steaks were cooked at slower cooking rate, trained panelists rated steaks cooked to rare and medium rare less ($P < 0.01$) juicy than steaks cooked to the same degrees of doneness at a high rate of cooking. Therefore, at a low cooking rate, steaks cooked more slowly and were exposed for more time to heat, resulting in greater moisture loss and decreased juiciness ratings.

Cross et al. (1976) reported that perceived juiciness ratings can decrease when the cook loss is increased due to moisture loss during cooking. In this present study, conditions causing the greatest percent cook loss typically resulted in those steaks being rate the lowest for perceived juiciness scores.

*Flavor*

Results presented in Table 3.9 demostrate that trained panel flavor ratings for beefy/brothy, brown/grilled, buttery, burnt, and bloody were influenced ($P < 0.05$) by a OVENTEMP × INTEMP interaction. Steaks cooked at an oven temperature of 350°F and well done degree of doneness were reported as having more intense beef flavor ($P < 0.05$). No clear trends regarding differences in beefy/brothy ratings were noted. Eighteen out of 20 treatments produced similar ($P < 0.05$) ratings for beefy/brothy flavor intensity. In the current study, the treatments applied showed minimal impact on the development of beefy/brothy flavor.

Brown/grilled flavor intensities generally increased as both rate of cooking and degree of doneness increased; however, influence of degree of doneness on brown/grilled intensity appeared to be more distinct at lower rate of cooking. When cooked at slower rate of cooking, steaks cooked to medium rare degree of doneness had a more intense ($P < 0.01$) brown/grilled flavor than those cooked to rare degree of doneness. Furthermore, brown/grilled intensity gradually increased ($P < 0.01$) as degree of doneness increased when steaks were cooked at 177°C OVENTEMP. Yet, at 246°C OVENTEMP, an increase ($P < 0.01$) in brown/grilled intensity was only seen between INTEMP of 57°C and greater than or equal to 68°C. When steaks were cooked at 343°C OVENTEMP, no statistically important differences ($P > 0.05$) were observed, with the exception of steaks cooked to 68°C INTEMP, where brown/grilled intensity was perceived as a result of increased degree of doneness.

Similar to brown/grilled intensity, burnt intensity generally increased as both rate of cooking and degree of doneness increased. Some of the greatest ($P < 0.05$) burnt intensities were reported by panelists from steaks cooked at 343°C OVENTEMP to medium degree of doneness and above, indicating that at these degrees of doneness, the high cooking rate may be undesirable simply due to formation of burnt off-flavor notes. Cross et al. (1976) stated that rate of cooking influences steak flavor; steaks cooked in a hotter oven, at a more rapid rate of cooking, were rated by panelists as having reduced flavor intensity.

Unlike brown/grilled and burnt flavor intensities, trained panel ratings for buttery and bloody intensity tended to decrease as both cooking rate and degree of doneness increased. At slower rate of cooking, degree of doneness had no influence ($P > 0.05$) on intensity ratings for the buttery flavor note. So, internal temperature seemed to have the greatest effect on intensity ratings for the buttery note when steaks were cooked at higher cooking rate. At 343°C OVENTEMP, intensity ratings for the buttery note steadily decreased ($P < 0.05$) as degree of doneness increased. Furthermore, steaks cooked at 343°C OVENTEMP to very well done degree of doneness received the lowest ($P < 0.05$) intensity ratings for the buttery note of all treatments. When steaks were cooked at 246°C OVENTEMP, degree of doneness did not influence ($P > 0.05$) intensity ratings for the buttery note. At each cooking rate studied, intensity ratings for the bloody flavor note steadily decreased ($P < 0.01$) as degree of doneness increased. No differences ($P > 0.05$) were observed on ratings for the bloody flavor note when steaks were cooked to well done and very well done degrees of doneness, regardless of OVENTEMP. However, when steaks were cooked to rare degree of doneness, and an OVENTEMP of 66°C or 177°C, they were rated by panelists as having a more intense ($P < 0.05$) bloody flavor note than for those steaks cooked at 246°C and 343°C OVENTEMP. Among all of the steaks cooked to medium degree of doneness, those cooked at 343°C OVENTEMP received the lowest ratings ($P < 0.05$) for the bloody flavor note. In accordance with Kerth (2015), as intensity ratings by panelists for metallic and bloody notes increased, a corresponding increase in ratings for juiciness and tenderness was observed; and vice-versa.

Panel intensity ratings for livery off-flavor was affected ($P < 0.05$) by cooking rate, whereas panel intensity ratings for oxidized off-flavor was affected ($P < 0.05$) by main effects for both OVENTEMP and INTEMP; however, neither main effect resulted in meaningful, clear trends. Additionally, panel intensity ratings for these off-notes were generally low overall, and would not be expected to influence eating experience in the commercial main stream. Panel intensity ratings for the off-notes of livery and oxidized were analyzed to ensure that these off-flavors were not introduced during the water bath reheating process employed in this study. Oxidation can occur during storage and reheating of cooked meat, and the resulting off-notes are commonly referred to as “warmed over flavor”; however, vacuum packaging of steaks immediately after cooking and reheating in the absence of oxygen appeared to have the desired effect and prevented oxidation and development of warmed over flavor in steaks.

While consumer acceptability was not evaluated in the current study, other recent consumer studies found flavor to be the most important trait influencing consumer overall acceptability of beef (O’Quinn et al., 2012; Hunt et al., 2014; Legako et al., 2015).

***Conclusions and Industry Implications***

Recent consumer research and the most recent National Beef Quality Audit reported that beef flavor is a fundamental driver for beef demand. Additionally, recent research assessing steak cookery methods have identified that production procedures, specifically days on feed and breed type, impact beef flavor attributes considerably. Even further, muscle to muscle differences influence flavor of beef.

Results of the present study indicated that oven temperature and degree of doneness have a major impact on trained sensory panel ratings, shear force measurements, and percent cook loss. Generally, increased cooking rate and degree of doneness had a detrimental impact on sensory attributes, shear force and cook loss.

Panel sensory ratings also suggested that eating characteristics are influenced by more than just degree of doneness, but also by the rate at which steaks reach a given final internal temperature. Steaks cooked at oven temperature of 66°C produced tender steaks; however, the slow cooking rate also resulted in reduced ratings for juiciness and development of brown/grilled flavor notes. Additionally, the extended time required to cook steaks at 66°C would make this procedure an impractical cook method in a foodservice setting.

Beginning at 177°C, increasing oven temperature, while keeping degree of doneness constant, generally resulted in a decrease in tenderness, juiciness, and bloody flavor intensity, but an increase in brown/grilled flavor. Since consumer sensory panelists were not used in the current study, it is difficult to determine how tradeoffs in trained sensory ratings would exactly correlate to consumer ratings for acceptability. However, these data can be useful for the foodservice industry to assess sensory attributes that diverse cooking temperatures and degrees of doneness combinations promote in order to adequately select a cooking method that fits their needs.

**Table 3.1.** Cooking temperatures and internal temperatures variation.

| Oven Temperature, ºC | Internal Temperature, ºC |
|---|---|
| 66 | 57 |
| | 63 |
| 177 | 57 |
| | 63 |
| | 68 |
| | 74 |
| | 79 |
| | 85 |
| 246 | 57 |
| | 63 |
| | 68 |
| | 74 |
| | 79 |
| | 85 |
| 343 | 57 |
| | 63 |
| | 68 |
| | 74 |
| | 79 |
| | 85 |

**Table 3.2.** Flavor descriptors.

| Basic tastes | Meat-related flavors | Additional flavors |
|---|---|---|
| Sweet | Beef broth (beefy/brothy) | Earthy/mushroom |
| Sour | Browned/grilled meat | Nutlike/roasted nuts |
| Bitter | Beef fat/buttery | Livery |
| Salty | Bloody/Metallic | Fishy |
| Savory (Umami) | Grassy/hay like/Gamey | |

**Table 3.3.** Least squares means for slice shear force (kgf) and Warner-Bratzler shear force(Kgf) .

| Oven Temp, ºC | SSF, Kgf | WBSF, Kgf |
|---|---|---|
| 66 | 15.21$^{c}$ | 3.20$^{b}$ |
| 177 | 17.85$^{b}$ | 3.39$^{b}$ |
| 246 | 19.30$^{a}$ | 3.65$^{a}$ |
| 343 | 18.75$^{ab}$ | 3.55$^{ab}$ |
| *P* value | <.0001 | 0.0084 |
| Standard error | 0.7507 | 0.1396 |

| Int Temp, ºC | SSF, Kgf | Estimate |
|---|---|---|
| 57 | 16.60$^{b}$ | 2.66$^{e}$ |
| 63 | 16.93$^{b}$ | 2.99$^{d}$ |
| 68 | 17.90$^{ab}$ | 3.41$^{c}$ |
| 74 | 17.30$^{b}$ | 3.64$^{bc}$ |
| 79 | 19.32$^{a}$ | 3.81$^{b}$ |
| 85 | 18.60$^{ab}$ | 4.19$^{a}$ |
| *P* value | 0.0055 | <.0001 |
| Standard error | 0.6126 | 0.1085 |

$^{a,b,c,d,e}$ Values that do not share a common superscript in column differ ($P < 0.05$).
Higher standard error for the least square means.

**Table 3.4.** Least squares means for instrumental internal steak color**.**

| | | Internal Color | |
|---|---|---|---|
| Oven Temp, °C | Int Temp, °C | L* | b* |
| 66 | 57 | 50.18[b] | 20.51[b] |
| 66 | 63 | 54.22[a] | 19.55[bc] |
| 177 | 57 | 42.94[c] | 17.90[c] |
| 177 | 63 | 43.10[c] | 17.90[c] |
| 177 | 68 | 45.57[c] | 19.96[b] |
| 177 | 74 | 47.34[bc] | 19.67[bc] |
| 177 | 79 | 48.35[bc] | 19.05[bc] |
| 177 | 85 | 50.04[b] | 19.97[b] |
| 246 | 57 | 45.34[c] | 19.51[bc] |
| 246 | 63 | 44.15[c] | 19.33[bc] |
| 246 | 68 | 47.25[bc] | 20.71[ab] |
| 246 | 74 | 47.21[bc] | 20.09[b] |
| 246 | 79 | 48.10[bc] | 19.71[b] |
| 246 | 85 | 50.06[b] | 19.70[bc] |
| 343 | 57 | 43.62[c] | 20.64[ab] |
| 343 | 63 | 47.77[bc] | 22.30[a] |
| 343 | 68 | 49.10[bc] | 21.98[ab] |
| 343 | 74 | 50.26[b] | 22.25[a] |
| 343 | 79 | 44.13[c] | 20.41[b] |
| 343 | 85 | 50.06[b] | 19.37[bc] |
| *P* value | | 0.0376 | 0.0343 |
| Standard error | | 1.8059 | 0.8762 |

| Internal Color | |
|---|---|
| Int Temp, °C | a* |
| 57 | 19.87[a] |
| 63 | 18.01[b] |
| 68 | 17.65[b] |
| 74 | 15.45[c] |
| 79 | 14.60[c] |
| 85 | 11.28[d] |
| *P* value | <.0001 |
| Standard error | 0.6574 |

[a,b,c,d] Values that do not share a column superscript differ ($P < 0.05$).
Higher standard error for the least square means

**Table 3.5.** Least squares means for instrumental external steak color**.**

| External Color | | | |
|---|---|---|---|
| Oven Temp, ºC | L* | b* | a* |
| 66 | $23.21^{c}$ | $10.02^{d}$ | $12.30^{c}$ |
| 177 | $35.10^{b}$ | $19.50^{c}$ | $14.32^{a}$ |
| 246 | $36.84^{a}$ | $22.41^{b}$ | $13.65^{b}$ |
| 343 | $38.13^{a}$ | $25.00^{a}$ | $14.35^{a}$ |
| *P* value | <.0001 | <.0001 | 0.0001 |
| Standard error | 0.9519 | 0.6904 | 0.442 |

| External Color | |
|---|---|
| Int Temp, ºC | a* |
| 57 | $14.28^{a}$ |
| 63 | $13.88^{ab}$ |
| 68 | $13.81^{ab}$ |
| 74 | $13.76^{ab}$ |
| 79 | $13.40^{b}$ |
| 85 | $12.81^{b}$ |
| *P* value | 0.0352 |
| Standard error | 0.3466 |

[a,b,c,d] Values that do not share a column superscript differ ($P < 0.05$).
Higher standard error for the least square means

**Table 3.6.** Least squares means for visual internal color evaluation.

| Internal Color | |
|---|---|
| Oven Temp, ºC | Estimate |
| 66 | 4.86[a] |
| 177 | 4.86[a] |
| 246 | 4.53[b] |
| 343 | 4.13[c] |
| *P* value | <.0001 |
| Standard error | 0.1453 |

| Internal Color | |
|---|---|
| Int Temp, ºC | Estimate |
| 57 | 5.47[a] |
| 63 | 5.04[b] |
| 68 | 4.66[c] |
| 74 | 4.51[c] |
| 79 | 4.11[d] |
| 85 | 3.78[e] |
| *P* value | <.0001 |
| Standard error | 0.1267 |

[a,b,c,d,e] Values that do not share a common superscript in column differ ($P < 0.05$).
Higher standard error for the least square means

**Table 3.7.** Least squares means for visual external color evaluation.

| External Color | |
|---|---|
| Oven Temp ºC | Estimate |
| 66 | 6.22[a] |
| 177 | 4.84[b] |
| 246 | 4.69[c] |
| 343 | 4.33[d] |
| *P* value | <.0001 |
| Standard error | 0.1253 |

| External Color | |
|---|---|
| Int Temp, ºC | Estimate |
| 57 | 5.47[a] |
| 63 | 5.28[a] |
| 68 | 5.00[b] |
| 74 | 4.95[b] |
| 79 | 4.90[b] |
| 85 | 4.51[c] |
| *P* value | <.0001 |
| Standard error | 0.1092 |

[a,b,c,d] Values that do not share a common superscript in column differ ($P < 0.05$).
Higher standard error for the least square means

**Table 3.8.** Least squares means for visual degree of doneness.

| Degree of Doneness | |
|---|---|
| Oven Temp, ºC | Estimate |
| 66 | 2.36[a] |
| 177 | 2.24[ab] |
| 246 | 1.90[b] |
| 343 | 1.65[b] |
| *P* value | <.0001 |
| Standard error | 0.1825 |

| Degree of Doneness | |
|---|---|
| Int Temp, ºC | Estimate |
| 85 | 3.15[a] |
| 79 | 2.70[b] |
| 74 | 2.40[c] |
| 68 | 1.85[d] |
| 63 | 1.62[d] |
| 57 | 1.40[d] |
| *P* value | <.0001 |
| Standard error | 0.1465 |

[a,b,c,d] Values that do not share a common superscript in column differ ($P < 0.05$).

Higher standard error for the least square means

**Table 3.9.** Least squares means comparing consumer panel responses**.**

| | | Panel Responses | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Oven Temp** | **Int Temp** | **Initial Tenderness** | **Sustained Tenderness** | **Overall Tenderness** | **Juiciness** | **Beef/Brothy** | **Brown/Grilled** | **Buttery** | **Burnt** | **Bloody** |
| 66 | 57 | $71.08^{ab}$ | $69.03^{ab}$ | $71.08^{ab}$ | $59.76^{b}$ | $46.74^{c}$ | $39.00^{d}$ | $23.60^{ab}$ | $7.39^{cd}$ | $22.23^{b}$ |
| 66 | 63 | $72.32^{a}$ | $71.05^{a}$ | $72.32^{a}$ | $49.62^{de}$ | $51.90^{bc}$ | $47.48^{b}$ | $22.64^{ab}$ | $9.79^{c}$ | $18.52^{c}$ |
| 177 | 57 | $73.32^{a}$ | $71.67^{a}$ | $73.32^{a}$ | $65.06^{a}$ | $44.79^{c}$ | $36.03^{d}$ | $25.56^{a}$ | $5.64^{d}$ | $27.85^{a}$ |
| 177 | 63 | $68.80^{bc}$ | $67.32^{bc}$ | $68.80^{bc}$ | $59.50^{b}$ | $49.49^{c}$ | $43.25^{c}$ | $24.54^{ab}$ | $8.56^{cd}$ | $20.02^{bc}$ |
| 177 | 68 | $63.39^{de}$ | $61.26^{def}$ | $63.39^{de}$ | $55.03^{c}$ | $49.18^{c}$ | $39.74^{cd}$ | $22.16^{b}$ | $5.37^{d}$ | $17.66^{c}$ |
| 177 | 74 | $60.13^{f}$ | $58.03^{fg}$ | $60.13^{f}$ | $46.91^{ef}$ | $50.18^{c}$ | $45.14^{bc}$ | $18.62^{c}$ | $10.36^{bc}$ | $10.77^{de}$ |
| 177 | 79 | $59.73^{f}$ | $57.73^{g}$ | $59.73^{f}$ | $42.81^{g}$ | $53.32^{a}$ | $48.59^{ab}$ | $18.53^{c}$ | $11.00^{bc}$ | $9.29^{de}$ |
| 177 | 85 | $54.30^{h}$ | $52.31^{i}$ | $54.30^{h}$ | $41.44^{hi}$ | $52.70^{abc}$ | $48.56^{ab}$ | $21.09^{bc}$ | $10.50^{bc}$ | $6.54^{e}$ |
| 246 | 57 | $68.94^{b}$ | $67.17^{bc}$ | $68.94^{b}$ | $61.34^{b}$ | $49.18^{c}$ | $41.24^{cd}$ | $25.07^{ab}$ | $7.50^{cd}$ | $19.54^{bc}$ |
| 246 | 63 | $66.03^{cd}$ | $64.63^{cd}$ | $66.03^{cd}$ | $55.22^{c}$ | $49.77^{c}$ | $45.49^{bc}$ | $24.33^{ab}$ | $7.08^{cd}$ | $17.20^{c}$ |
| 246 | 68 | $61.27^{e}$ | $59.08^{efg}$ | $61.27^{e}$ | $52.20^{cd}$ | $48.70^{c}$ | $47.74^{b}$ | $23.19^{ab}$ | $10.00^{bc}$ | $11.28^{d}$ |
| 246 | 74 | $61.26^{e}$ | $59.80^{efg}$ | $61.26^{e}$ | $46.48^{ef}$ | $51.75^{c}$ | $48.77^{ab}$ | $21.84^{b}$ | $8.39^{cd}$ | $10.31^{de}$ |
| 246 | 79 | $58.06^{fg}$ | $56.54^{gh}$ | $58.06^{fg}$ | $46.42^{ef}$ | $49.60^{c}$ | $51.88^{ab}$ | $22.20^{b}$ | $12.16^{bc}$ | $8.22^{de}$ |
| 246 | 85 | $54.40^{h}$ | $52.75^{i}$ | $54.40^{h}$ | $42.29^{gh}$ | $50.72^{c}$ | $49.90^{ab}$ | $19.60^{bc}$ | $16.23^{ab}$ | $6.12^{e}$ |
| 343 | 57 | $65.91^{cd}$ | $64.36^{cd}$ | $65.91^{cd}$ | $59.74^{b}$ | $47.77^{c}$ | $45.25^{bc}$ | $23.65^{ab}$ | $7.87^{cd}$ | $20.06^{bc}$ |
| 343 | 63 | $63.55^{de}$ | $62.31^{de}$ | $63.55^{de}$ | $53.63^{c}$ | $51.52^{c}$ | $48.65^{ab}$ | $25.34^{a}$ | $11.60^{bc}$ | $11.49^{d}$ |
| 343 | 68 | $60.00^{f}$ | $56.90^{gh}$ | $60.00^{f}$ | $46.26^{ef}$ | $48.90^{c}$ | $52.55^{a}$ | $21.40^{bc}$ | $15.88^{ab}$ | $9.62^{de}$ |
| 343 | 74 | $55.57^{gh}$ | $53.44^{hi}$ | $55.57^{gh}$ | $44.07^{f}$ | $53.10^{ab}$ | $47.00^{bc}$ | $19.67^{bc}$ | $13.65^{b}$ | $7.25^{e}$ |
| 343 | 79 | $53.62^{h}$ | $51.32^{i}$ | $53.62^{h}$ | $38.78^{i}$ | $50.00^{c}$ | $49.20^{ab}$ | $16.83^{c}$ | $17.02^{ab}$ | $5.72^{e}$ |
| 343 | 85 | $55.84^{gh}$ | $54.25^{hi}$ | $55.84^{gh}$ | $35.40^{i}$ | $48.67^{c}$ | $50.03^{ab}$ | $15.54^{d}$ | $19.60^{a}$ | $5.46^{e}$ |
| *P* value | | 0.0083 | 0.0013 | 0.0020 | 0.0049 | 0.0411 | 0.0011 | 0.0355 | 0.0178 | 0.0101 |
| Standard error | | 1.8168 | 2.0052 | 1.9744 | 2.7231 | 3.2197 | 3.4532 | 2.8927 | 1.9370 | 2.5055 |

[1] Sensory panel scales (10 cm continuous line scale)

[a-d]Values that do not share a common superscript in column differ ($P < 0.05$).

Higher standard error for the least square means

**Table 3.10.** Least squares means for cook loss.

| Cookloss | | |
|---|---|---|
| Oven Temp, ºC | Int Temp, ºC | Estimate |
| 177 | 57 | 13.10[a] |
| 177 | 63 | 15.24[a] |
| 66 | 57 | 18.04[a] |
| 343 | 57 | 19.92[a] |
| 177 | 74 | 21.38[bc] |
| 246 | 57 | 22.20[bc] |
| 246 | 63 | 23.31[bc] |
| 343 | 63 | 24.09[c] |
| 177 | 68 | 24.42[c] |
| 343 | 68 | 24.63[c] |
| 246 | 68 | 24.95[c] |
| 66 | 63 | 26.55[cd] |
| 343 | 79 | 28.34[cd] |
| 177 | 79 | 28.81[cd] |
| 343 | 74 | 29.54[d] |
| 177 | 85 | 30.05[d] |
| 246 | 74 | 30.83[de] |
| 246 | 79 | 31.28[de] |
| 246 | 85 | 33.09[de] |
| 343 | 85 | 34.76[e] |
| *P* value | | 0.0008 |
| Standard error | | 1.8707 |

[a,b,c,d,e] Values that do not share a common superscript in column differ ($P < 0.05$).

Higher standard error for the least square means

**Table 3.11.** Least squares means for livery and oxidized flavors.

| | Panel Response | |
|---|---|---|
| Oven Temp, ºC | Livery | Oxidized |
| 66 | 1.76[a] | 1.85[a] |
| 177 | 0.80[b] | 0.85[b] |
| 246 | 0.78[b] | 1.46[a] |
| 343 | 0.98[b] | 1.60[a] |
| *P* value | 0.0385 | 0.0267 |
| Standard error | 0.4622 | 0.5934 |

| | Panel Response |
|---|---|
| Int Temp, ºC | Oxidized |
| 57 | 0.53[b] |
| 63 | 1.06[b] |
| 68 | 2.20[a] |
| 74 | 1.60[a] |
| 79 | 1.43[a] |
| 85 | 1.84[a] |
| *P* value | 0.0011 |
| Standard error | 0.5394 |

[1] Sensory panel scales (10 cm continuous line scale)

[a-d]Values that do not share a common superscript in column differ ($P < 0.05$).

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# Appendix A

# Consumer survey

What is the highest degree or level of school you have completed?

- Less than high school degree
- High school degree or equivalent
- Trade/technical/vocational training
- Some college but no degree
- Associate degree
- Bachelor degree
- Master degree
- Doctorate degree
- Other

What is your marital status?

- Single, Not married
- Married or domestic partnership
- Widowed

How many children(s) do you have?

- 0
- 1
- 2
- 3
- 4
- 5 or more

On average, how many meals per week do you eat beef?

- None
- 1 - 2
- 3 - 4
- 5 - 6
- 7 - 9
- 10 or more

Drag the following pictures into the box according to your preference.

**Items**

| Most Desirable |
|---|
| |

| Least Desirable |
|---|
| |

Drag the following pictures into the box according to your preference.

**Items**

| Most Desirable |
|---|
| |

| Least Desirable |
|---|
| |

Drag the following pictures into the box according to your preference.

**Items**

**Most Desirable**

**Least Desirable**

Drag the following pictures into the box according to your preference.

**Items**

**Most Desirable**

**Least Desirable**

Drag the following pictures into the box according to your preference.

**Items**

**Most Desirable**

**Least Desirable**

Drag the following pictures into the box according to your preference.

**Items**

**Most Desirable**

**Least Desirable**

Drag the following pictures into the box according to your preference.

**Items**

**Most Desirable**

**Least Desirable**

Drag the following pictures into the box according to your preference.

**Items**

**Most Desirable**

**Least Desirable**

Drag the following pictures into the box according to your preference.

**Items**

**Most Desirable**

**Least Desirable**

# Appendix B

## Shear force day data sheet for internal and external color measurements

NCBA Beef Flavor Project
Talita Mancilha
Cook Date____________

Sample #_____________

| External MiniScan Values | Internal MiniScan Values | Degree of Doneness |
|---|---|---|
| L* M______ | L* M______ | Rare |
| A* M______ | A* M______ | Medium Rare |
| B* M______ | B* M______ | Medium |
| | | Medium Well |
| | | Well Done |

Internal Color

| 1 | 2 | 3 | 4 | 5 | | 6 | | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| Purple | Red | Reddish pink | Pink | Pinkish grey | Light brown | Medium brown | Dark brown | | |

External Color

| 1 | 2 | 3 | 4 | | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Light grey | Grey | Greyish brown | Light brown | Brown | Dark brown | Brownish black | Black | |

# Appendix C

## Sensory panel response ballot

Sample 1

Initial Tenderness

Very Tough 0 — Very Tender 100

Sustained Tenderness

Very Tough 0 — Very Tender 100

Click to write Choice 1

Overall Tenderness

Very Tough 0 — Very Tender 100

Juiciness

Very Dry 0 — Very Juicy 100

Beefy/Brothy

Not Present
0

Very Intense
100

☐ Not Applicable

Brown/Grilled

Not Present
0

Very Intense
100

☐ Not Applicable

Buttery/Fat

Not Present
0

Very Intense
100

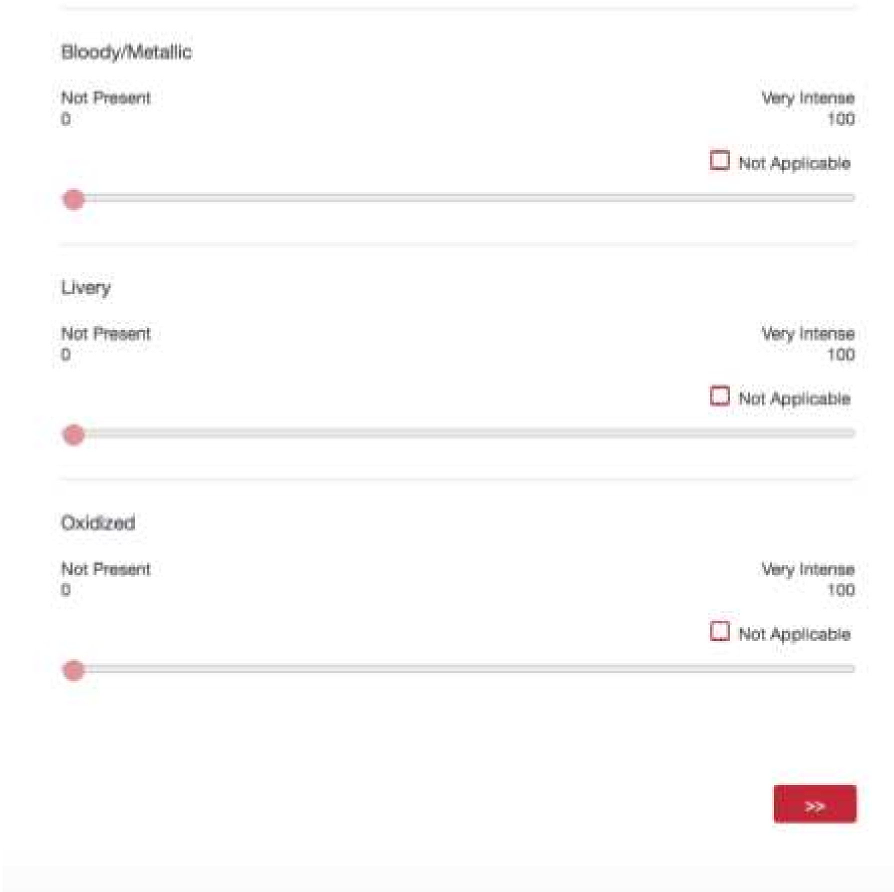
☐ Not Applicable

Burnt

Not Present
0

Very Intense
100

☐ Not Applicable



Bloody/Metallic

Not Present 0

Very Intense 100

Not Applicable

Livery

Not Present 0

Very Intense 100

Not Applicable

Oxidized

Not Present 0

Very Intense 100

Not Applicable

>>

# Appendix D

# Sensory data correlation

| | Initial Tenderness | Sustained Tenderness | Overall Tenderness | Juiciness | Beef/Brothy | Brown/Grilled | Buttery | Burnt | Bloody | Liver |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sustained Tenderness** | 0.95651* | | | | | | | | | |
| **Overall Tenderness** | 0.98078* | 0.99031* | | | | | | | | |
| **Juiciness** | 0.60476* | 0.59834* | 0.59034* | | | | | | | |
| **Beef/Brothy** | -0.0414 | -0.10033 | -0.06116 | -0.19712* | | | | | | |
| **Brown/Grilled** | -0.23966* | -0.25545* | -0.22997* | -0.26223* | 0.37896* | | | | | |
| **Buttery** | 0.39864* | 0.36224* | 0.36448* | 0.53337* | 0.21388* | 0.06415 | | | | |
| **Burnt** | -0.23362* | -0.30282* | -0.2457* | -0.35155* | 0.03068 | 0.43932* | -0.1365 | | | |
| **Bloody** | 0.59934* | 0.59483* | 0.58475* | 0.63054* | -0.29565* | -0.56728* | 0.33088* | -0.45157* | | |
| **Liver** | 0.03891 | -0.08814 | 0.01621 | 0.10635 | 0.14115 | 0.19014* | 0.35731* | 0.26756* | -0.07159 | |
| **Oxidized** | -0.23147* | -0.2395* | -0.23722* | -0.27423* | -0.6301 | 0.0441 | -0.03877 | 0.0401 | -0.15521 | 0.18034 |

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