

THE THERMAL AND PHYSICAL PROPERTIES OF BEEF FROM THREE
USDA-QUALITY GRADES COOKED TO MULTIPLE
DEGREES OF DONENESS

by

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ABSTRACT

The Thermal and Physical Properties of Beef from Three USDA-Quality Grades Cooked to Multiple Degrees of Doneness

by

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This study determined the influence of quality grade (QG) and cooked degree-of-doneness (DOD) on the thermal and physical properties of beef strip steaks. *Beef Longissimus lumborum* steaks from three different QG (USDA prime, low choice, and standard) were tempered or cooked to six DOD (4, 25, 55, 60, 71, 77°C) and subsequently measured for multiple thermal and physical characteristics. The 2-way interaction of QG and DOD impacted Warner-Bratzler shear force (WBSF; $p = 0.008$), springiness ($p = 0.001$), viscoelasticity ($p \leq 0.023$), and protein degradation of myosin and sarcoplasmic proteins ($p = 0.001$). At refrigerated and room temperatures (4 and 25°C) shear force values did not differ ($p > 0.05$) between any quality grades. Prime steaks, regardless of DOD, were more ($p < 0.05$) tender than standard steaks after cooking beyond 60°C. Prime and low choice steaks at 4°C had less springiness ($p < 0.05$) than standard. At 25°C, low choice had higher ($p < 0.05$) springiness compared with prime, while also being similar ($p > 0.05$) in springiness with standard. After cooking,

springiness did not differ between any combination of QG and DOD. For viscoelasticity, low choice steaks cooked to 77°C had the highest ($p < 0.05$) elastic modulus (G') measurement with no difference between any other QG or DOD. Protein degradation of steak myosin and sarcoplasmic proteins (measured in one value) was also affected by quality grade \times DOD. Standard steaks at 25°C had lower ($p < 0.05$) enthalpy than prime or low choice steaks. No other differences were detected regardless of temperature or quality grade. Tenderness is often attributed to perceived consumer perception of eating satisfaction. Our results indicate that differences in protein structure plays an important role for tenderness and that although marbling may be a factor, it is certainly not the only component regarding meat quality. Further studies will need to be done to conclude when divergence occurs and further determine the ultra-structure components that are different between steaks with varying intramuscular fat (IMF) composition.

(90 pages)

PUBLIC ABSTRACT

The Thermal and Physical Properties of Beef from Three USDA-Quality Grades Cooked to Multiple Degrees of Doneness

Jessie McClellan Hadfield

The objective of this study was to determine the influence of quality grade (QG) and degree-of-doneness (DOD) on thermophysical properties of beef strip steaks. The “Prime” eating experience must be marketed to compete with cheaper protein sources, and so palatability is a major concern with beef products. Thermal and physical properties help shed light on the impacts various components have on beef palatability, mainly tenderness and juiciness. Warner-Bratzler shear force (WBSF) and the textural property of springiness are both influenced by a combination of QG and DOD. This is also true for viscoelasticity and the degradation of myosin and sarcoplasmic protein. Although many factors contribute to beef palatability, intra-muscular fat (IMF) content is usually given the most credit when presented to the consumer. However, QG only impacted raw steak weight, cooking duration, cohesiveness, and moisture interactions. DOD influenced more properties including cooking duration and cook loss percent conductivity, various textural properties, protein degradation (even before cooking), and moisture interactions. Generally speaking, these textural properties resulted in less favorable values as DOD increased, but that was not only the case. Thermal properties and protein degradation values simply showed unique differences between DOD (including refrigerated and room-temperature sampling) and did not always follow a

trend. These results show that although over-cooking can be mitigated with high IMF content for tenderness, DOD has more of an effect on many of the palatability characteristics. Furthermore, more research will need to be conducted to fully understand the differences between some of our more intricate tests between QG and DOD.

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LIST OF ACRONYMS

DOD:	Degree of doneness
DSC:	Differential scanning calorimetry
MUFA:	Monounsaturated fatty acid
QG:	Quality grade
RVA:	Rapid visco analyzer
SFA:	Saturated fatty acids
TPA:	Texture profile analysis
USDA:	United States Department of Agriculture
WBSF:	Warner-Bratzler shear force
WHC:	Water-holding capacity

CHAPTER I

INTRODUCTION AND OBJECTIVES

Introduction

Beef products compete against cheaper protein sources and are often viewed by consumers as a “less healthy” option than pork or poultry (Brewer, 2002). Over the past two decades, per capita meat consumption has had an upward trend at the expense of beef due to consumers who are both environmentally and health conscious (Troy & Kerry, 2010). Since 1970, the increased use of poultry over beef products has been the most significant change in the meat industry (Haley, 2001), and in 2016, a study funded by the Pork Checkoff reported that 75% of consumers indicated they had increased their consumption of pork chops over the previous five years. This same study also indicated that the majority of survey respondents preferred pork and chicken over beef. (Lusk et al., 2016) Due to this, the palatability of beef is a critical quality attribute for the viability of the beef industry and has been studied extensively. It is known that during cooking, many thermal and physical changes occur. However, no study has addressed these changes in depth across multiple beef grades. This project was conducted to establish a baseline of the physical and thermal properties of raw and cooked beef steaks within different quality grades (QG). Specifically, the overall objective of this study was to determine the basic thermal and physical alterations that occur during cooking for multiple USDA beef QG, and to increase our understanding of how these alterations affect beef palatability.

The three main palatability attributes are tenderness, juiciness, and flavor (Lyford et al., 2010; McBee & Wiles, 1967; Savell et al., 1987). Of these three characteristics,

tenderness and juiciness are considered physical properties, with tenderness being considered the most important for the American consumer (Huffman et al., 1996; M. F. Miller, Carr, Ramsey, Crockett, & Hoover, 2001; Platter et al., 2003). The beef industry in the U.S. focused its attention on tenderness in the 1990s when consumers complained that beef was tough, fatty, and inconsistent (Brooks et al., 2000). The most recent survey states that the majority of steaks are considered tender, and all but three cuts (the top round, bottom round, and T-bone) have decreased (or improved) in their WBSF values since the previous survey (Savell et al., 2016). This shows the large strides the industry has taken to improve tenderness from a genetic, environmental, and management standpoint (Smith, Savell, et al., 1987). Advances have also been made in teaching consumers how to properly prepare their beef products. Noticeable differences in tenderness and juiciness occur after cooking, and there are numerous studies to support the effects that marbling and cooked degree of doneness have on all three palatability characteristics (Campion, Crouse, & Dikeman, 1975; Lorenzen et al., 1999).

As early as 1916, the USDA began establishing a set standard to determine “quality” in beef products (Harris, Cross, & Savell, 1990). USDA QG use marbling, or intramuscular fat (IMF) alongside maturity scores to determine a universal grade for meat products. Tenderness attributes of beef are known to be influenced by more than just IMF, yet it is the property consumers often use as their only guide to tenderness potential. After selecting products with an acceptable quality grade, consumers take on a major role regarding tenderness. As a steak is cooked to greater internal temperatures or degrees of doneness (DOD), there is a noticeable decrease in tenderness. This concept applies

regardless of fat content within the meat product (Lucherk et al., 2016).

Correlations have been found among palatability, degree of doneness, and USDA quality grade (Lorenzen et al., 1999). However, possible interactions of varying levels of IMF and DOD on thermal, physical, and chemical properties have not been established in a single study (Campion et al., 1975). Furthermore, despite knowing that moisture and fat transfer heat differently (Bengtsson, Jakobsson, & Dagerskog Sik, 1976) the compositional impact of beef, especially IMF content, on the thermal properties is unclear (Cross, 1977; Lowe, 1955; Weir, 1960). At the conclusion of this project, the hope is that a greater understanding of the impact of cooking will be attained. Providing a “prime” beef experience in lower quality products may have important implications for those consumers who prefer the tenderness of prime beef but can only afford low choice or standard beef products. This allows for an increased marketability for products with lower QG.

Hypothesis

For this research, it was hypothesized that the physical and thermal properties pertaining to beef palatability differ per IMF composition and varying cooked degree of doneness.

Objectives

The purpose of this study was to determine how the thermal and physical properties of beef strip steak are affected by fat content and cooked degree of doneness.

CHAPTER II

REVIEW OF LITERATURE

Importance of Tenderness

Beef palatability is the sum of characteristics that lead to a consumer's eating experience. Although juiciness and flavor are components of beef palatability, tenderness is considered the most important (Jeremiah, 1982). Because of the impact that tenderness has in relation to consumer satisfaction, extensive research has been performed on this specific characteristic in beef (Egan, Ferguson, & Thompson, 2001). Studies to determine tenderness have been conducted extensively on the top loin steak. Its popularity among consumers is based on greater palatability as judged against less tender cuts (Savell & Shackelford, 1992). Complaints about beef usually come from an unsatisfactory tenderness level (Bowser, 2001) and in 1997, Boleman et al. showed that 78% of consumers would willingly purchase a product labeled as "guaranteed tender" for a higher price. In order to ensure high levels of satisfaction (98% or higher), steaks need to have a Warner-Bratzler shear force (WBSF) of 4.1 kgf or less (M. F. Miller et al., 2001). This was supported by a 1999 study in which consumers preferred steak that was considered tender according to WBSF values, during blind taste tests (Lusk, Fox, Schroeder, Mintert, & Koohmaraie, 1999). WBSF tests have been extensively conducted on beef, and it is probably the most influential test used as an indication of tenderness. Numerous studies have been able to repeatedly show the correlation between low WBSF values and consumer perception of tenderness. Extensive research has also concluded that

an increase in DOD also increases WBSF values. To the consumer, this means the higher the internal temperature, the less tender the beef strip steak.

Beef tenderness is influenced by many different factors, starting with the animal's genotype and ending with the final cooking methods. Although genetics plays a major role in the potential tenderness of a carcass, this palatability characteristic is more directly influenced by the management prior to and immediately after harvest (Egan et al., 2001). Still, despite all that producers and packers can do for beef tenderness, the actions of consumers ultimately determine the results. Whether a food-service professional or family cook, the end of the line is those who prepare the meat products. Consumers have the most control over the tenderness of their beef products during initial product selection, but the most important factor is the method of preparation, including in consumers' homes (Egan et al., 2001; Lorenzen et al., 1999). Advances have also been made in teaching consumers how to properly prepare their beef products. Noticeable differences in tenderness and juiciness occur after cooking, and there are numerous studies to support the effects that marbling and cooked degree of doneness have on all three palatability characteristics (Campion et al., 1975; Lorenzen et al., 1999). In 2010, the National Beef Tenderness Survey concluded that more than 85% of steaks originating from the rib and loin fall in the "very tender" category (Guelker et al., 2013). Now, the most recent survey states that the majority (70%) of all steaks are considered tender, and all but the top round, bottom round, and T-bone cuts have decreased (or improved) in their WBSF values (Martinez et al., 2017). This shows the large strides the industry has taken to improve tenderness from a genetic, environmental, and management standpoint

(Smith, Savell, et al., 1987).

Meat Composition

Eating quality, or palatability, of beef is influenced by the composition and structural components of muscle (Egan et al., 2001). Meat is made up of protein, fat, and moisture. Each of these components has a specific effect on tenderness in beef steak.

Protein

Approximately 20% of fresh meat is proteins. The proteins of meat provide structure and have instrumental effects on its texture, and thus palatability. The muscle-fiber matrix is held up by four structural proteins: desmin, nebulin, paratropomyosin, and titin. These specific proteins have been shown to impact tenderness. Approximately 24 hours post-harvest, beef is at its least tender stage due to rigor mortis. Several post-harvest practices aid in tenderization and help offset this phenomenon. Among these practices are electrostimulation and hanging, but the practice of aging, or allowing beef carcasses to be stored in a cooler for an extended period of time, is one of the most universally accepted post-harvest tenderizing practices (Smith, Tatum, Belk, & Scanga, 1987). Enzymes within the muscle cells, named the calpain system, have been known to clip these structural proteins and aid in muscle tenderization postmortem the same way that aging does (R. K. Miller, Smith, & Carstens, 2011). Studies have shown that calpain activity may have the biggest impact on muscle tenderness. Several studies have also emphasized the importance of collagen content and collagen type on muscle texture, especially when concerning tenderness (Davey & Gilbert, 1974; Light, Champion, Voyle,

& Bailey, 1985; McCormick, 1994; Nimni & Harkness, 1988). The distribution of collagen throughout muscle in a fine state and the changes to collagen during cooking may have an important role in determining meat palatability (Winegarden et al., 1952). For example, the biceps femoris and semimembranosus have high levels of collagen, and they are decidedly less tender. Muscles considered to be more tender, such as the longissimus dorsi, have less collagen in comparison. These observations are suggestive of collagen being the main factor in tenderness. Nimni and Harkness discussed in detail the nineteen different collagen phenotypes and the roles the primary collagen phenotypes play in muscle texture. However, in contrast, the gluteus medius and psoas major muscles have high collagen concentrations and are still considered very tender (Bailey, 1989). In this respect, Bailey concluded that cooked meat texture was in fact a function of both muscle collagen concentration and the degree of crosslinking of that collagen—not just the types of collagen found in the muscle. Crosslinking is a modification of collagen, and thus Bailey pointed out that crosslinking becomes a major factor in the textural properties of cooked meats, especially pertaining to tenderness.

Intramuscular Fat

Red meat products, including beef, include a number of fats that are important for energy and help with the utilization of fat-soluble vitamins (Daley, Abbott, Doyle, Nader, & Larson, 2010). IMF found within the skeletal muscle, consists of saturated fatty acids (SFA). Approximately 60% of the SFA consumed in the American diet come from animal fats (Daley et al., 2010). In beef, most of these fats are palmitic acid and stearic acid. Beef is also composed of monounsaturated fatty acids (MUFA) such as oleic acid

(Whetsell, Rayburn, & Lozier, 2003). A number of studies have been conducted to analyze and compare the composition of SFA across various types of cattle (Alfaia et al., 2009; Descalzo et al., 2005; Garcia et al., 2008; Gardner & Legako, 2018; Leheska et al., 2008; Nuernberg et al., 2005; Ponnampalam, Mann, & Sinclair, 2006; Realini, Duckett, Brito, Rizza, & De Mattos, 2004). The composition of the fatty acids found in beef is affected by many factors such as age, breed, gender, and nutrition (DeSmet, Raes, & Demeyer, 2004). In 2004, Realini, et al., showed that Hereford steers on grass had 1.68% total lipids per muscle sample and grain fed steers had 3.18%. Later on, Leheska et al. found that mixed cattle ranged from 2.8% to 4.4% total lipids per muscle sample from grass and grain fed cattle, respectively.

The correlation between fat and eating quality is not a new theory. Early civilizations dating back to B.C. records placed value on fat animals (McPeake, 2003; Smith & Carpenter, 1976). Fat in muscle is dependent on many different factors, such as breed, gender, diet, other environmental factors, and age at slaughter (Guerrero, Valero, Campo, & Sañudo, 2013). Dryden and Marchello (1970) reported a significant correlation between muscle lipid content and taste panel tenderness. This has been tested multiple times and is usually found to be true. Trained sensory panels have found that IMF content is positively correlated with flavor (Frank et al., 2016; Legako, Dinh, Miller, & Adhikari, 2016).

As early as 1916, the USDA began establishing a set standard to determine “quality” in beef products (Harris et al., 1990). USDA QG use marbling, or IMF, alongside maturity scores to determine a universal grade for meat products. The QG

developed by the USDA on the basis of marbling levels have weathered some criticism but in general reliably predict consumer acceptability. USDA QG were implemented with the intention of grouping carcasses into cooked beef cuts with similar palatability attributes (Polkinghorne & Thompson, 2010). Since its implementation, this system has been tested in multiple studies. McBee and Wiles (1967) found significant results when evaluating the tenderness differences among prime, choice, good, and standard carcass grades. Campion et al. (1975) conducted a study where U.S. taste-panel results similarly indicated that consumer ratings of tenderness and overall acceptability were related to the USDA QG of the carcass. Numerous studies have supported the finding that panelist-liking scores improve with increased marbling (Lorenzen et al., 1999, 2003; O'Quinn et al., 2012; Savell et al., 1987; Smith, Savell, et al., 1987). However, Lusk et al. (1999) determined that the USDA system poorly influenced consumer confidence in tenderness based on assigned quality grade. Lusk's findings showed that tenderness had considerable variability even within the same quality grade. Voges et al. (2007) reported that consumer preferences for tenderness, as well as juiciness, flavor, and overall liking, did not differ between top loin steaks with marbling scores falling between prime and standard grades.

Since then, Emerson, Woerner, Belk, and Tatum (2012) proclaimed that the system has proven itself as an accurate guide for consumer perception of beef palatability. The relationship between IMF and consumer perception of palatability has been established numerous times. (Corbin et al, 2015; Emerson et al. 2013; Hunt et al., 2014, O'Quinn et al., 2012; Thompson 2004). Therefore, USDA QG are generally recognized as a good indication of overall palatability, and marbling is often referred to

as the most important contributing factor to beef-quality evaluation (Tatum, Smith, & Carpenter, 1982). Furthermore, a decrease in marbling from slightly abundant to traces also showed a decrease in these same palatability attributes, causing an impact on the eating quality of beef (Savell et al., 1987). An even closer inspection showed that USDA Choice carcasses had higher juiciness, tenderness, and flavor than USDA Select carcasses (M. F. Miller et al., 1997). Because increased marbling is an increase in fat content, these studies claim that fat is directly correlated with consumer acceptability in beef. In fact, Corbin et al. (2015) found that juiciness, flavor, and tenderness all increased with an increased fat percentage. However, Savell et al. indicated that tenderness could not adequately be measured using IMF or marbling. Consumers in his study found USDA QG to be inconsistent, with varying degrees of tenderness within each quality grade. The idea that there is a correlation between increased fat levels and consumer perception of juiciness is contradicted by Hedrick et al. (1981) and Brackebusch et al. (1991). Fat content is inversely proportional to moisture content. As fat increases, moisture content will decrease (Von Seggern, Calkins, Johnson, Brickler, & Gwartney, 2005) and should reduce juiciness. Despite this inverse relationship, meat with a higher IMF content tends to lose less moisture during cooking when compared to meat with a lower IMF content (Saffle & Bratzler, 1959). Saffle and Bratzler hypothesized that the presence of fat caused structural changes that enhanced water-holding capacity (WHC) and juiciness of products with high USDA QG. They also stated that products with higher IMF values probably showed a tendency toward higher shrink due to loss of fat, not moisture, during cooking. Contradicting their findings, O'Quinn et al. (2011) suggest that differences in tenderness

may affect sensory findings on juiciness, and that juiciness may not be closely correlated to fat content. Despite its historical value, the actual impact of fat within a meat product is still openly discussed amongst meat experts. More research on this phenomenon will need to be conducted.

Moisture Content

Moisture, or water content, can reach 75% in lean muscle and has an impact on tenderness (Offer & Knight, 1988). In fact, water content and mobility in meat affect all the meat-quality attributes such as tenderness, juiciness, and flavor, as well as firmness and appearance (Trout, 1988). Myowater found within meat is usually found in two places: in the intra-myofibrillar space (between both thick and thin filaments) and in the extra-myofibrillar spaces (in the sarcoplasm, between muscle fibers, and in-between muscle fasciculi) of the meat structure (Hamm, 1975; Offer & Knight, 1988; Offer et al., 1989; Schaefer et al., 2000). It is classified as either protein-associated water, immobilized water, or free water (Pearce, Rosenvold, Andersen, & Hopkins, 2011). WHC is the ability for meat to retain myowater during storage. WHC and tenderness are often considered to have no correlation, but (Pearce et al., 2011) discussed the occurrence of increased WHC and increased tenderness. The mechanisms that make this possible still need to be evaluated, but evidence for it exists. In the past, it has been thought that WHC also affected juiciness, but research has shown that the effects of WHC as well as of other muscle characteristics on juiciness are poorly understood (Pearce et al., 2011). In a study done by Pearce et al. (2008), a high amount intra-myofibrillar water and a low amount of extra-myofibrillar water was thought to be associated with more tender meat.

These results directly contradict those of (Fjelkner-Modig & Tornberg, 1986), and this contrast was attributed to differences in IMF. It is known that during the postmortem process of converting muscle to meat, the water found within the muscle ultrastructure will be reorganized. This reorganization will either increase or decrease the WHC of meat (Pearce et al, 2011). Offer and Trinick (1983) hypothesized that gains or losses of water in meat are due to the swelling or shrinking of myofibrils. This change is brought about by either the expansion or shrinkage of the constituent myofibril lattices (Offer & Trinick, 1983). Offer and Trinick's study also detailed that most water within the compositional properties of muscle was in fact held by capillary forces between the thick and thin filaments. Furthermore, after extracting a large portion of the A-band with an acid, they observed maximum swelling. The inter-filament spacing is the major determinant in WHC of myofibrils and, in turn, has a major impact on the overall WHC of a meat product (Lawrie, 1985). A loss in WHC is attributed to denatured proteins and the increased ability for water to move into extracellular spaces (Lawrie, 1985; Penny, 1977), and WHC increases considerably as pH drops (Rao, Gault, & Kennedy, 1989).

Cooking Impacts on Tenderness and Palatability

After the selection of products with an acceptable quality grade, consumers take on a major role regarding tenderness. As a steak is cooked to greater internal temperatures or DOD, there is a noticeable decrease in tenderness. This concept applies regardless of fat content within the meat product. Applied heat affects inherent physical properties of beef. During the cooking process, heat changes beef through moisture loss,

fat migration, and protein degradation (Smith et al., 1989). Each of these factors affects tenderness as decreased space between muscle fibers produces a less tender product. Lorenzen et al. (1999) showed that cooked beef palatability is affected by many different factors, all relating to meat composition. Smith et al. (1989) found that cooking increased the total percentage of protein and fat in the studied steaks, while the percentage of moisture decreased. In the 1999 study, Lorenzen et al. found significant correlations among tenderness, degree of doneness and USDA quality grade. Sinha et al. (1998) set the standards for degree of doneness with 60°C as rare, 70°C as medium, and 80°C as well done. Consumers detected no tenderness differences between different cooking methods as long as the degree of doneness was medium well or lower. Steaks cooked to well done or greater differed in tenderness according to cooking method. Well done steaks cooked using indoor grilling or pan-frying were tenderer than outdoor grilling or broiling. By USDA quality grade, Choice steaks tended to have higher ratings for tenderness when compared to select steaks. Steaks with a High Select grade were also less tender than Low Choice steaks. However, consumer appreciation of beef is affected by degree of doneness (Cox, Thompson, Cunial, Winter, & Gordon, 1997). Juiciness and flavor ratings were higher at lower DOD regardless of cooking method. Even though early studies showed unclear relationships, marbling and the other factors that make up QG were considered to be the best indication of possible palatability after cooking (Campion et al., 1975). Similar to Campion et al.'s study in 1975, Berry (1992) found that acceptability of cooked ground beef was more heavily influenced by fat content. With tenderness in mind, as fat content decreased, the shear values also increased.

However, this study did not use degree of doneness as a relational factor and instead cooked patties to similar cook loss percentages. Furthermore, in 2001, IMF was found to have a correlation with WBSF values in cooked pork loins, and IMF accounted for 47% of the difference in WBSF values. Protein content alone did not explain differences in tenderness values, and the study concluded that more research needed to be done (van Laack et al., 2001). In contrast, Cross, Berry, and Wells (1980) stated, “Neither collagen content nor total cooking loss was significantly affected by fat level. Sensory ratings and cooking properties were not significantly affected by fat source” (p. 791). Fat obviously has an influence on tenderness in cooked steaks, but the extent of that influence is still under study.

To understand meat quality, it is important to realize that the proteins within the meat undergo intense structural changes during cooking. Because meat structure affects quality, the quality of a meat product is therefore affected by cooking. Three common meat proteins that fall into the fibrous-protein category are actin, myosin, and collagen. Current literature considers collagen the ultrastructural component with the heaviest impact on beef tenderness (Listrat et al., 2016). This may hold true for raw beef, but once the cooking process begins, the effect of collagen becomes unclear. Once meat is cooked, muscle type and cooking conditions produce varying results regardless of collagen content (Dubost et al., 2013, Ngapo et al., 2002). Even the level of cross-linking becomes a less suitable indicator of perceived tenderness when the product undergoes cooking. Davey and Gilbert (1974) suggested that sarcoplasmic proteins also play a role in meat quality, as these proteins would affect cooked meat texture. Sarcoplasmic proteins

typically aggregate between 40 and 60°C, within standard cooking temperature ranges (Tornberg, 2005) After this, several changes happen to the ultrastructure of meat samples, specifically the longissimus studied by Leander et al. (1977). This study found that samples cooked to 68°C had lost all discernable banding features with only the Z-line and A-band region still identifiable. The sarcomere of these samples underwent evident thermal-induced contraction and thus displayed drastic shrinkage. In a separate study, when samples were cooked to 73°C, the sarcomere was reduced by 29% and the A-band region had shrunk in such a way as to cause the sarcomere to have a concave appearance. The Z-line was still identifiable, but only a dense band remained where the A-band region was known to be (Taylor, Geesink, Thompson, Koohmaraie, & Goll, 1995).

Further research regarding muscle ultrastructure may reveal what happens during the cooking process that affects tenderness. It is still unclear which elements of muscle physiology have the greatest impact on consumer perception of tenderness.

Common Instrumental Techniques

Research focused on food science and technology incorporates a wide variety of instrumental techniques. A variety of instruments are used for shelf stability, flavor compounds, texture, and melting point. It's no surprise these instruments and techniques would differ between products such as liquids and solids, but differences are found with research involving the same products as well. In his review of the literature involving meat tenderness, Voisey (1976) found that, "A review of the methods used to measure meat texture indicates considerable confusion in terminology, test conditions, and

interpretation of the readings that makes evaluation of the results a complex task.” It was not until 1997 that an international reference guide for methods to measure Whc, tenderness, and meat color was created (Honikel, 1998). In order to compare research across studies, it’s imperative to have common methods and techniques.

Physical Properties

Because juiciness and tenderness are two main attributes for beef palatability, the texture of beef has been thoroughly analyzed. Although trained sensory panels are beneficial in many studies, a mechanical method of measuring texture was developed to save time and money. The Texture Profile Analysis (TPA) is designed to collect various measurements that replicate a trained consumer. Although the relationship between mechanical data and sensory results is seldom linear, correlations have been made in a variety of foods with different texture properties such as fruits, vegetables, nuts, cheese, hard candy, butter, bread, and meat (Meullenet, Lyon, Carpenter, & Lyon, 1998; Szczesniak, 1987). Now, when sensory studies are conducted, texture measurements are often used to back up the results (Lawless & Heymann, 1998). The ability to consistently measure and quantify eating experience has allowed marketers to develop products and cooking techniques to meet a certain specification (Lyford et al., 2010). Two common methods for studying texture are shear force, specifically WBSF and TPA. Unfortunately, there is a wide variety in the data collected from these mechanical methods and special care should be taken to minimize sample preparation and test conditions (Szczesniak, 1962). Without specific protocol, comparing data from different institutions becomes difficult and often inaccurate. However, in 2010, Der explained that the uniqueness of

each food type in regards to physical characteristics and technical factors calls for the ability to modify instrument setup to be suit each food type, making a strict protocol difficult.

Although WBSF is not the only shear force test found in the literature, it is the most common in studying tenderness (Lanari, Bevilacqua, & Zaritzky, 1987; Zhang & Mittal, 1993). WBSF is also used to determine texture as it relates to meat proteins (Bouton & Harris, 1972). Shear force analysis is an empirical texture test that measures the force required to shear as sample. This method is also designed to read the force needed to puncture a food item (Bourne, Kenny, & Barnard, 1978). A force-time curve is created and peak force can be recorded. The peak force represents the toughness of a sample (Der, 2010).

The TPA is a compression test that measures five texture parameters and results in a force-time curve with two readable peaks. The parameters of force and time are calculated (Bourne et al., 1978). From these parameters, measurements for adhesiveness, chewiness, cohesiveness, fracturability, gumminess, hardness, and springiness can be calculated (Der, 2010). Although this method does not measure mouth-feel, compression-based methods have shown high correlation with sensory-panel juiciness scores on beef rib and loin cuts (Tannor et al., 1943). Of course, all of these parameters will not always apply to each food category. It becomes essential to adjust the settings for meat to accurately retrieve data involving the multi-point analysis of various parameters (Bourne et al., 1978). Across studies, correlations have been found between the TPA and WBSF. However, WBSF tests do not provide an accurate correlation with the TPA when a lot of

connective tissue is present in a sample (Penfield & Meyer, 1975). In 2003, Caine et al. studied the relationship between the TPA, WBSF, and trained sensory characteristics and found that although WBSF is adequate in measuring tenderness, the TPA results explained more of the variation found in sensory perception of tenderness.

Thermal Properties

Two common techniques used for assessing the thermal impacts on protein components involve calorimetry and viscometry. Differential scanning calorimetry (DSC) and Rapid Visco Analyzer (known as RVA) tests are methods used to identify changes in different components of a sample function of temperature (Der, 2010).

The DSC gets a measurement of the energy needed to maintain a consistent (zero difference) between a substance and a reference material against a time or temperature reading. This is accomplished when the two cells containing samples are heated with identical rate and intensity (S. S. Nielsen, 1998). Although it has many practical uses, the DSC is used to detect the denaturation of proteins, or proteins that have had their structure altered or broken down. Parameters include onset temperature (T_o , °C), peak temperature (T_d , °C), and heat of enthalpy (ΔH , J/g; Der, 2010). The parameter of most significance to meat science is enthalpy. Enthalpy must be measured as a change in enthalpy. During the exothermic reaction of protein degradation, the change in enthalpy is the equivalent to the energy released during the reaction (Zemansky 1968).

The different proteins found within a muscle will have different enthalpy values. As the DSC data is recorded, the gives different transition sites between temperatures. The first transition site has been accredited to myosin, and occurs between 54 and 58°C

(Martens & Vold, 1976; Wright & Wilding, 1977). Collagen and the sarcoplasmic proteins are responsible for the next transition site, which occurs around 65 to 67°C (Martens & Vold, 1976; Starbusvik & Marens, 1980; Wright & Wilding., 1977). The last transition, found between 80 and 83°C, is actin (Wright & Wilding 1977).

Composition Affects Texture

Complex chemical changes affect differences seen in texture during various processing practices (Barrett et al., 1998; DeFreitas et al., 1997; He & Sebranek, 1996; Rao & Lund, 1986). These changes deal primarily to the muscle fibers (Rowe, 1974) and connective tissues (Hearne, Penfield, & Goertz, 1978). In regards to temperature, the texture of cooked meat products is generally considered to be affected by changes to connective tissue, soluble proteins, and myofibrillar proteins due to an increase in heat (Zayas & Naewbanij, 1986). The solubility of meat proteins is also affected by heat (Bouton & Harris, 1972) and the cross-linkage that occurs within the connective tissue is related to collagen solubility (Zayas & Naewbanij, 1986). In beef, the correlation between denatured proteins and texture has been reported (Bertola, Bevilacqua, & Zaritzky, 1994; Findlay, Stanley, & Gullet, 1986; Martens, Stabursvik, & Martens, 1982), but, when collecting data for changes to connective tissues under different heat treatments, results varied (Hearne et al., 1978). As a result, there is not a clear understanding of the association between protein that is altered during heating and effect on texture (Bertola et al. 1994; Bouton & Harris, 1972; Bouton, Harris, & Shorthose, 1975; Laakkonen, Wellington, & Sherbon, 1970; Paul, McGrae, & Hofferber, 1973).

CHAPTER III

MATERIALS AND METHODS

Product Selection

Eight “A” maturity (less than 36 months of physiological maturity) beef carcasses from the USDA QG of prime (PR), low choice (LC), and standard (ST) were selected from a commercial processing plant in Utah ($n = 24$). The carcasses were chilled for approximately 24 hours postmortem before being selected using visual appraisal of marbling in comparison to standard issued photographs (National Cattleman’s Beef Association, Centennial, CO) and determining USDA QG and yield grade (YG). Quality grade measurements comprised marbling score (PR with range of Slightly Abundant⁰⁰ or greater, LC with range of Small⁰⁰ to Small¹⁰⁰, and ST with range of Traces¹⁰⁰ or lower [USDA, 1977]), skeletal maturity, and lean maturity. Yield grade measurements incorporated hot carcass weight (kg), external fat thickness (in), rib-eye area (in²), and percentage of internal fat (KPH). Yield Grade was determined using the standard YG equation of $2.50 + [0.0984252 \times \text{fat thickness (mm)}] - [0.0496 \times \text{REA (cm}^2)] + [0.20 \times \text{KPH}\%] + [0.008378 \times \text{HCW (kg)}]$. The left and right strip loins [IMPS 180; North American Meat Processors Association [NAMPP], 2010)] were collected, vacuum packaged, and transported via a refrigerated (4°C) truck. Upon arrival, the paired strip loins were aged 21 days postmortem at 4 °C before fabrication, freezing, and analysis.

Fabrication and Steak Preparation

After being aged 21 days postmortem, steaks were removed from vacuum packaging and fabricated into strip steaks for analysis. Each loin was cut into 2.54-cm thick strip steaks, excluding steaks that contain gluteus medius muscle and purposefully isolating the longissimus lumborum muscle, progressing anterior to posterior using a standard meat slicer (Globe Food Equipment Co., Model 3600N, Dayton, OH). Each steak was randomly assigned to DOD categories and then individually vacuum sealed and frozen at -20°C for storage. DOD categories included refrigerated and room temperature (4 and 25°C, respectively; American Meat Science Association [AMSA], 1995) or cooked internal DOD of rare, medium, medium well, and well done (55, 60, 70, and 77°C respectively; AMSA, 1995).

Cooking Procedures

Frozen steaks were held under refrigerated temperatures (4°C) for approximately 15 hours and allowed to thaw. External fat was removed and the longissimus dorsi was isolated. The precooked weight was taken and steak thickness was measured for uniformity.

Steaks assigned a tested temperature of 4°C were held at this temperature after thawing. Analysis was conducted inside a refrigerated room (4°C). Steaks designated for room temperature (25°C) were allowed to temper inside an incubator (140 Series, Model 12-140E, Quincy Lab, Inc., Chicago, IL) before tests were conducted.

Additional steaks were cooked to an internal DOD of 55, 60, 71, and 77°C

monitored with an Omega Engineering MDSSi8-series benchtop thermometer (Omega Engineering Inc., Stamford, CT) with a 5TC-series thermocouple wire (Omega Engineering Inc., Stamford, CT). Cooked steaks were previously thawed as described above to an internal temperature between 3 and 4°C prior to cooking. Then steaks were placed on a clamshell-style grill (Cuisinart, Griddler Deluxe, Model GR-150, Cuisinart, East Windsor, NJ) with an average grill surface temperature of 245°C. Steaks were removed once the assigned internal temperature was reached. The cook time to the desired internal DOD was recorded and post-cooking weight was measured. All steaks were wrapped in standard plastic wrap to prevent moisture loss and allowed to cool to 25°C before further analysis.

Cook Loss Measurements

After steaks were prepared for tests (external fat trimmed and steaks thawed to 4°C), raw and cooked weights were measured. Cook loss measurements were then

calculated by $\frac{\text{initial weight} - \text{cooked weight}}{\text{initial weight}} \times 100$

Steak Distribution for Analysis

Each steak was divided into segments so that tests were consistent and comparable among steaks. All conductivity and diffusivity tests were conducted in the geometric center of the steak. Food dye was used to mark the reach of the thermal test so that this portion of the steak was not used for other tests. An 8-mm borer was used to obtain 4-5 cores as close to the center of the steak as possible without collecting samples

from steak that may have been damaged from primary thermal measurements (Hot Disk measurements of conductivity and diffusivity are discussed later). These 8-mm cores were used for the rheology measurements and to take DSC samples. A 25.4-mm strip was taken from the anterior portion of each steak and squared off to make three 25.4-mm cubes for textural properties. Cores for WBSF tests were collected next, with an attempt to get a representation of the whole steak. Depending on the steak size, 4-8 cores were collected using a standard boer running parallel to muscle fibers. The remaining portions of steak were cut into pieces for centrifugation used for measurements related to water holding capacity.

Thermal Measurements

Thermal conductivity and diffusivity measurements were collected using a Hot Disk thermal analyzer and Kaplan 10-mm sensor (Hot Disk TPS-500, Gothenburg, Sweden). An incision was made on the interior side of each steak, making a pocket in the geometric center for the sensor to be placed. The steaks were wrapped in standard plastic wrap to avoid moisture loss. Parameters were set at 0.168 watts for 40 seconds, with 10 minutes between each replicate. Diffusivity and conductivity analysis were conducted using the programmed fine-tuned analysis function. As previously stated, steaks assigned a refrigerated (4°C) analysis temperature were kept in a cold storage room and held at the assigned temperature during thermal tests. Steaks assigned to room temperature (25°C) analysis were allowed to temper inside an incubator (140 Series, Model 12-140E, Quincy Lab, Inc., Chicago, IL), where the Hot Disk was placed inside and tests were conducted.

All cooked steaks were measured after cooking and cooling to room temperature.

The thermal behavior of the steak-protein degradation was evaluated using a differential scanning calorimeter (DSC-TA Instruments, Model Q20, Albuquerque, NM). Raw and cooked material samples from both the surface and the center (6-8 mg) were placed into individual high-volume hermetic aluminum pans and heated from case temperature (T_c) of 4 or 25°C to 100°C at 5°C/min to evaluate protein-degradation behavior. The DSC output data presented as the enthalpy, the measure of energy change during protein degradation, as Joules/grams of sample (J/g). In the graphical output, myosin and sarcoplasmic proteins are identified as the graphical peak between 54 and 68°C (Tomaszewska-Gras & Konieczny, 2012) and were recorded in one enthalpy value. The enthalpy for actin, identified as the peak between 71 and 83°C (Tomaszewska-Gras & Konieczny, 2012), was recorded separately. To transpose the data to exhibit the J/g of protein, the following equation was used: (Joules per gram of sample/protein percentage) \times 100. The protein percentage was obtained by thermal combustion in a previous study of these same steak samples (Gardner, 2017). These protein percentages represent the protein of a paired steak, from the same carcass, cooked to the same DOD.

Viscoelasticity

A magnetic-bearing rheometer was used to evaluate the viscoelastic properties of the steak material (TA Instruments, Model ARG2 Rheometer, Albuquerque, NM). Oscillatory tests were performed by strain-sweep step to obtain viscoelastic parameters such as the storage modulus (G'). Experiments were carried out using a parallel-plate

geometry (8 mm diameter) with a temperature-controlled Peltier plate. The temperature of the plate was set at 4°C for refrigerated samples and 25°C for room temperature and cooked samples. For the strain-sweep step, a constant frequency of 1 Hz (6.28 rad/s) was used, and strain values were set from 0.0008 to 10%. Samples were obtained using an 8-mm borer. Four cores were taken as close to the geometric center of the steak as possible. These cores were divided into surface and center samples for viscoelastic measurements.

Water Interactions

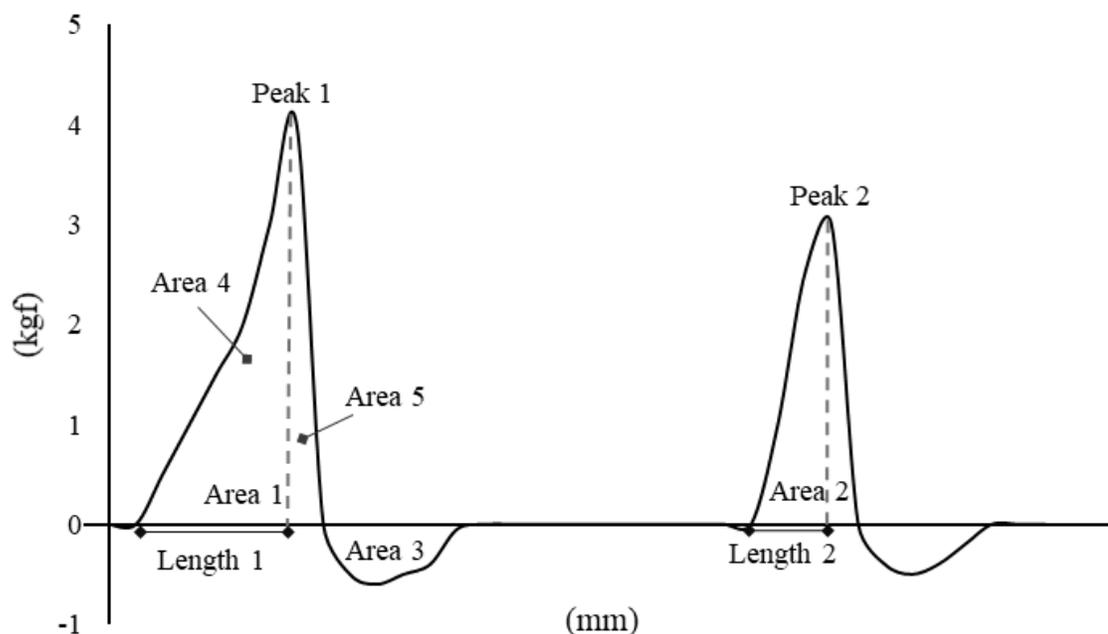
Expressible moisture percent (EM%) and WHC were based on the centrifugation method described by Pietrasik and Janz (2009). Four portions approximately 5 g each were cut from each sample and an initial weight (IW) was recorded. These sub-samples were placed on top of 25 g of 4-mm glass beads (KIMAX Solid Borosilicate Glass Beads, Kimble Chase, Radnor, PA) inside a 50-ml centrifuge tube (VWR Centrifuge Tubes with Flat Caps, VWR International, Radnor, PA) to be centrifuged (Sorvall Model ST 16R Centrifuge, Thermo Scientific, Waltham, MA). Parameters for the centrifuge were set at $900 \times g$ for 10 min. Following centrifugation, the samples were removed, reweighed, and a final weight (FW) was recorded. EM% and WHC was calculated as described by

Pietrasik and Janz (2009), with $EM\% = \frac{IW-FW}{IW} \times 100$ and $WHC = \frac{FW}{IW} \times 100$.

Textural Properties

TPA and WBSF tests were conducted using a TSM-Pro with specialized

attachments (Food Technology Corporation, Model TSM-Pro, Sterling, VA). The 25.4-mm cubes were used for TPA analysis. Cubes were compressed using a 76.2-mm flat geometry in two cycles using a FTC ILC 50-kg load cell and a cross speed of 200 mm/min. Values for adhesion, chewiness, cohesiveness, springiness, and resilience were calculated following the method described by Caine, Aalhus, Best, Dugan, and Jeremiah (2003; Figure 1).



Note. Calculations are as follows: Hardness = Peak 1; Cohesiveness = $\frac{\text{Area 2}}{\text{Area 1}}$; Springiness = $\frac{\text{Length 2}}{\text{Length 1}}$; Resilience = $\frac{\text{Area 1} - \text{Area 2}}{2}$; Chewiness = *Hardness* × *Cohesiveness* × *Springiness*; Adhesion = Area 3.

Figure 1. Graph of TPA measurements.

To analyze shear force, steak cores were collected using a hand-held steel borer, parallel to muscle fibers. Core number was dependent on the surface area of each steak but ranged between four and seven cores per sample. The cores were sheared

perpendicular to the fibers using the same ILC head-cell (50 kg load cell, 200 mm/min crosshead speed) as the compression tests but with a v-shaped WBSF attachment (Caine et al., 2003).

Statistical Analysis

Data was analyzed by use of a split-plot design where QG served as the whole-plot and DOD was the sub-plot. Individual steaks served as the experimental unit. Carcass was included as a random effect. All statistical analyses were done using SAS® version 9.4 (SAS Institute, Cary, NC). Tests of fixed effects were carried out by the GLIMMIX procedure. Denominator degrees of freedom were calculated using the Kenward-Roger approximation. Post-hoc mean comparison was done through use of a protected *t* test using the LSMEANS/PDIFF option. Significance was determined at $P \leq 0.05$ for all comparisons.

CHAPTER IV

RESULTS AND DISCUSSION

Tables 1-5 are placed in the Appendix. Within these tables, all statistical results are presented with corresponding p values. For the purpose of this discussion, figures have been prepared which depict significant ($p \leq 0.05$) interactions or main effects.

General Measurements

The raw weight of steak samples was significant between QG samples ($p < 0.001$; Figure 2). Prime steaks were the lightest ($p < 0.05$), with Low Choice in the middle, and Standard steaks being the heaviest ($p < 0.05$).

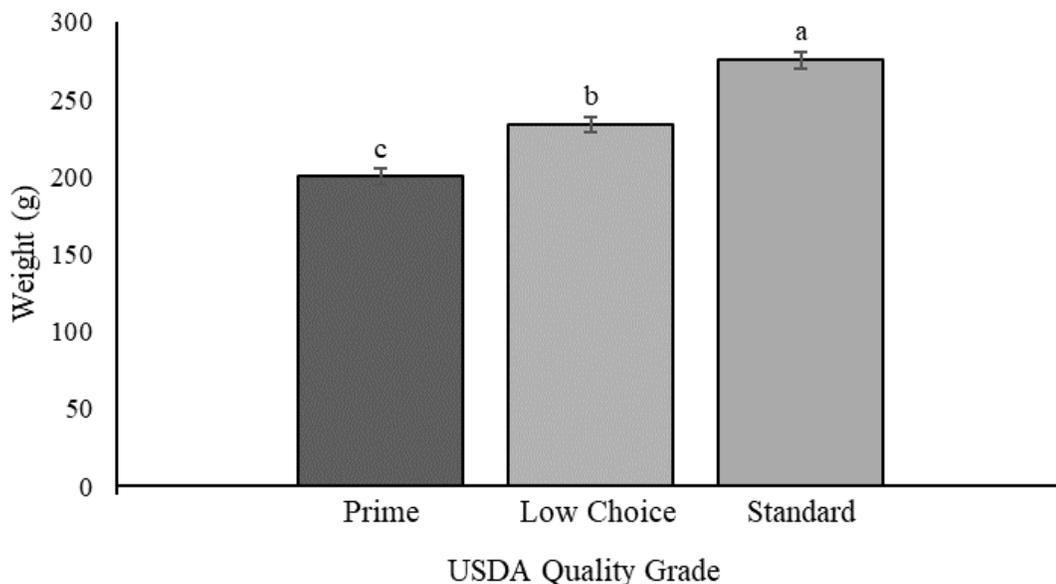


Figure 2. Raw weight of USDA prime, low choice, and standard steaks ($n = 8$) at six degrees-of-doneness (DOD). A main effect (quality grade) was observed ($p = 0.017$).

Prime steaks are the lightest, but also have the smallest surface area. Low choice steaks are intermediate weight and surface area, with standard steaks being the heaviest

and having the largest surface area. This is due to breed type and age of animals that typically grade prime, low choice, and standard. Prime and low choice steaks typically come from British type breeds known for superior marbling and earlier carcass maturation. Standard steaks are often continental type cattle that are later maturing, larger framed, and have less IMF (Moore et al., 2012). The average size of each steak sample sheds light on results that show a main effect with QG such as cooking duration and cook loss percentage.

Cooked Steak Measurements

Cooking duration was affected by the main effects of QG ($p = 0.017$; Figure 3 and DOD ($p < 0.001$; Figure 4) while cook loss only saw the main effect of DOD ($p < 0.001$; Figure 5). Low choice steaks took the longest ($p < 0.05$) to reach designated end internal degree of doneness as compared to prime and standard steaks. Likewise, steaks cooked to 55°C had the lowest cooking duration. Cook times progressively increased with 60°C being the next longest ($p < 0.05$), followed by 71 and 77°C respectively. Similar but not identical trends were seen in cook loss percentage. Steaks cooked to 55 and 60°C had the lowest ($p < 0.05$) cook loss percentage when compared to steaks cooked to 71 and 77°C.

Previous work in our lab has indicated that IMF content influences cooking duration, with greater IMF content slowing cooking rate. The results of this study do not agree with this trend. However, this is likely confounded by the size and weight differences of steaks in this study, where Prime was the smallest. As a steak is cooked to a higher internal temperature, the time to cook also increased. Cook loss, however, is

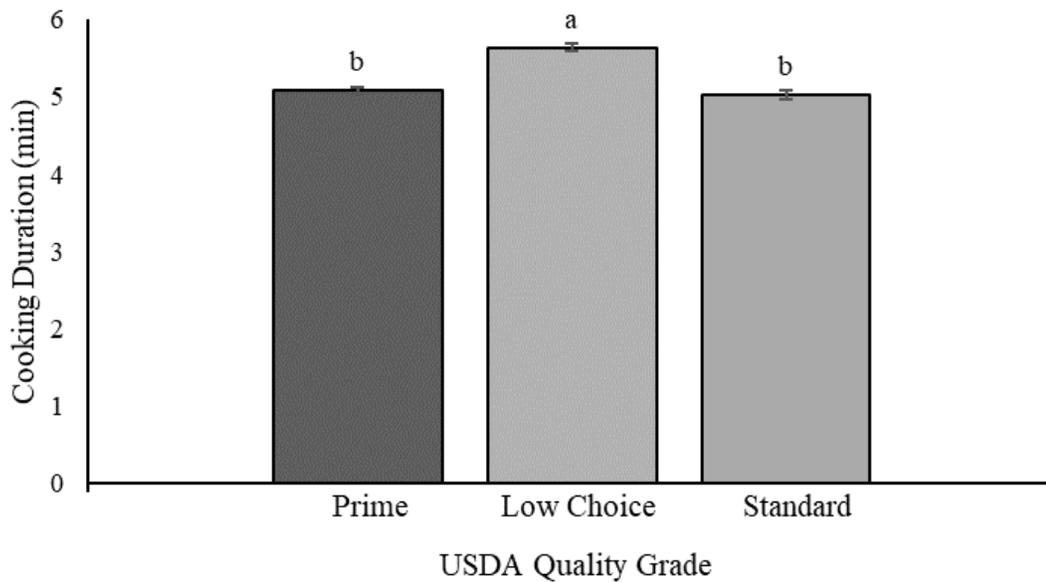


Figure 3. Cooking duration of USDA prime, low choice, and standard steaks ($n = 8$) at six degrees-of-doneness. A main effect (quality grade) was observed ($p = 0.017$).

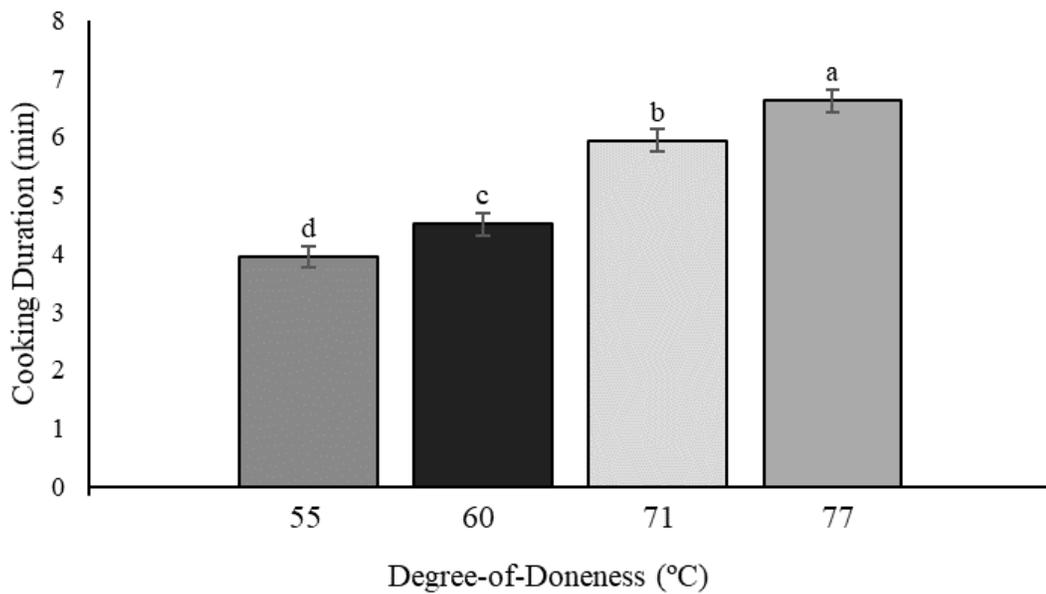


Figure 4. Cooking duration for six degrees-of-doneness (DOD). A main effect (DOD) was observed ($p < 0.001$).

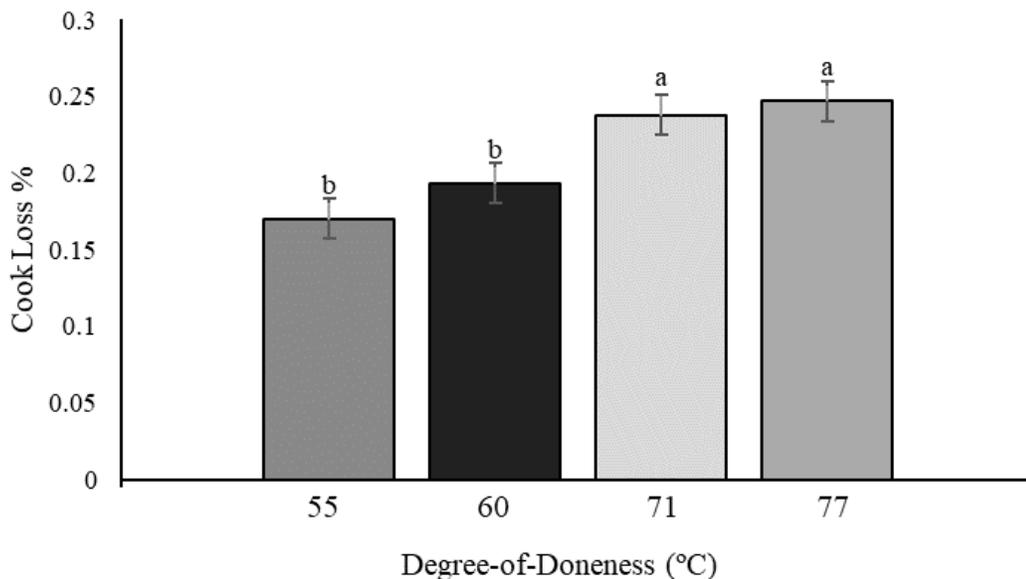


Figure 5. Cooking loss for six degrees-of-doneness (DOD). A main effect (DOD) was observed ($p = 0.011$).

slightly different. Cooking is essential in meat and meat-based products. Numerous studies support that as temperature increases on any product, there will be a degree of cook loss (Murphy & Marks, 2000; Pathare & Roskilly, 2016). This cook loss is the result of evaporating moisture and melting fat, but water is often given credit for the majority of recorded cook loss (Aaslyng et al., 2003; Heymann, Hedrick, Karrasch, Eggeman, & Ellersieck, 1990). Steaks cooked to 77 and 71°C had the highest loss due to cooking, with steaks cooked to 60 and 55°C following with a lower loss. As center heat increases, protein denaturation occurs and allows for water that was previously entrapped within the protein structure to be released. Once the water is “free,” it is easily cooked out. This is a process of both heat and time. As internal DOD increased, so did the time it took for the steak to reach our designated endpoint. Our results show that the increased temperature, and most likely the cooking duration, affected cook loss percentage.

Physical Properties

The interaction of quality grade (QG) and degree of doneness (DOD) impacted WBSF ($p = 0.008$; Figure 6). Prime steaks, regardless of DOD, had lower ($p < 0.05$) WBSF values than low choice and standard steaks cooked to 71°C and 77°C. However, at 60°C, steaks had similar ($p > 0.05$) WBSF values between each of the QG. At refrigerated and room temperatures (4 and 25°C), WBSF values did not differ ($p > 0.05$).

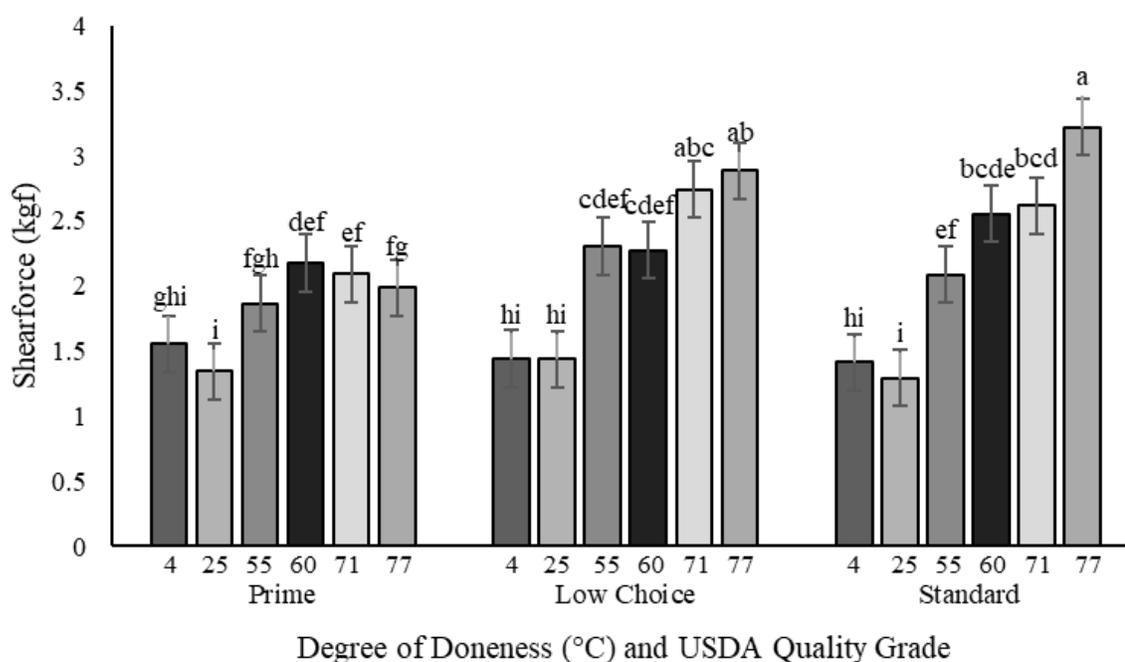


Figure 6. Warner-Bratzler shear force values of USDA prime, low choice, and standard steaks ($n = 8$) at six degrees-of-doneness (DOD). A two-way interaction (quality grade \times DOD) was observed ($p = 0.008$).

Tenderness is known to be influenced by QG (Lorenzen et al., 1999, 2003; O'Quinn et al., 2012; Park et al., 2018; Savell et al., 1987; Smith et al., 1987). Specifically, beef strip steaks with greater IMF or a higher QG, such as a USDA prime or USDA choice as compared to USDA standard, have been determined to be more tender,

according to WBSF values (Campion et al., 1975). The results of this study are in support of these previous findings. However, the impact of QG was dependent on DOD, where DOD was more impactful towards WBSF values at greater DOD of Low Choice and Standard steaks. Alternatively, the WBSF values of Prime steaks varied less due to DOD and were overall lower than Low Choice and Standard at greater DOD. This finding implies that tenderness is more consistent in QG of greater IMF content. Thus, consumers may find more consistent tenderness with Prime steaks across the full spectrum of DOD, in comparison with lower QG steaks.

Among steaks with lower IMF (i.e., low choice and standard), WBSF values were lower at lower DOD. This implies that a toughening occurs in these QG as a result of cooking. Therefore, tenderness issues in lower QG may be overcome by not cooking to greater DOD.

Furthermore, these results clearly reveal that changes in WBSF values begin to occur after cooking. It has been established that the application of heat begins a process of myofibrillar aggregation and collagen shortening (Tornberg, 2005). These physical changes are believed to result in decreased tenderness. The results of this study indicate a decrease in tenderness for low choice and standard at greater DOD. It is, however, unclear why this phenomenon did not occur for Prime steaks. It may be speculated that this QG influence was due to differences in thermal or physical properties of Prime steaks in comparison to lower QG steaks.

The interaction of QG and DOD also impacted the texture property springiness ($p = 0.001$; Figure 7). The springiness of prime and low choice steaks at 4°C were lower (p

< 0.05) than standard steaks. Upon tempering to 25°C, low choice was considered to have lower ($p < 0.05$) springiness compared with prime, while also being similar ($p > 0.05$) in springiness with standard. After cooking springiness did not differ ($p > 0.05$) between any combination of QG and DOD.

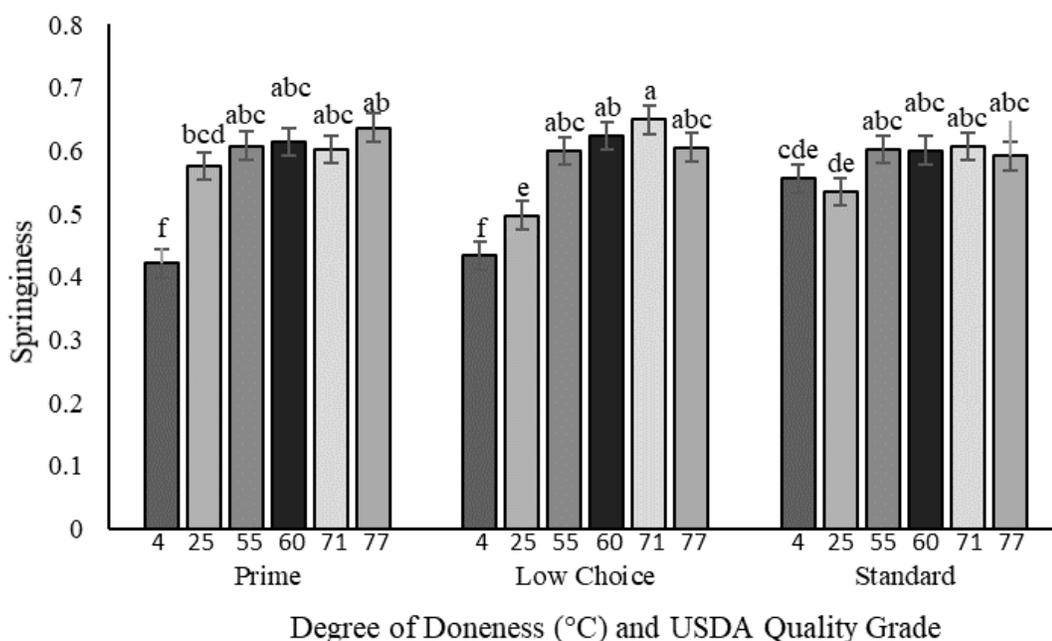


Figure 7. Springiness values of USDA prime, low choice, and standard steaks ($n = 8$) at six degrees-of-doneness (DOD). A two-way interaction (quality grade \times DOD) was observed ($p = 0.001$).

Similar to WBSF, springiness measurements revealed the importance of cooking on textural properties in steak. As previously described, alterations during cooking may impact the physical properties of meat proteins. Springiness values indicate the ability of a medium to return to an original thickness after compression. Overall, the data in this study indicated that cooking increased springiness of beefsteaks. This agrees with observations for WBSF where values increased after cooking. Interestingly, springiness

did not have any clear relationship with QG. The primary factor where QG influenced springiness was in uncooked 4°C steaks, where the springiness of Standard steaks were greater than all other QG of the same temperature. Presently it is unclear why steaks thawed to 4°C would vary in springiness due to QG.

As expected, DOD affected all measured textural properties including adhesion, hardness, chewiness, resilience, and cohesion. The textural property of adhesion was affected by DOD ($p < 0.001$; Figure 8).

Hardness was affected by DOD ($p < 0.001$; Figure 9). Steaks at 4 and 25°C were the lowest ($p < 0.05$) compared to steaks that were cooked. After cooking, steaks cooked to 71°C were highest (kgf; $p < 0.05$) when compared to other cooked temperatures. Steaks at 77°C were next, followed by 55°C.

Chewiness and Resilience similarly each showed an effect from DOD ($p < 0.001$; Figure 10 and Figure 11, respectively). Before cooking (4 and 25°C) showed no difference ($p > 0.05$) and had the lowest values. Steaks cooked to 71°C had the highest value, followed by 60°C and then 55°C.

The only textural measurement to be affected by QG as a main effect alone was cohesiveness ($p = 0.011$; Figure 12), which was also affected by the main effect DOD ($p < 0.001$; Figure 13). Prime steaks were more ($p < 0.05$) cohesive than standard steaks. Low choice was considered similar ($p > 0.05$) to prime and standard. Steaks at 4°C had higher ($p < 0.05$) values when compared to steaks cooked to 55 and 60°C. Steaks tempered to 25°C were considered similar ($p > 0.05$) to 4°C as well as steaks cooked to 71 and 77°C. The last two DOD were also considered similar ($p > 0.05$) to 55 and 60°C.

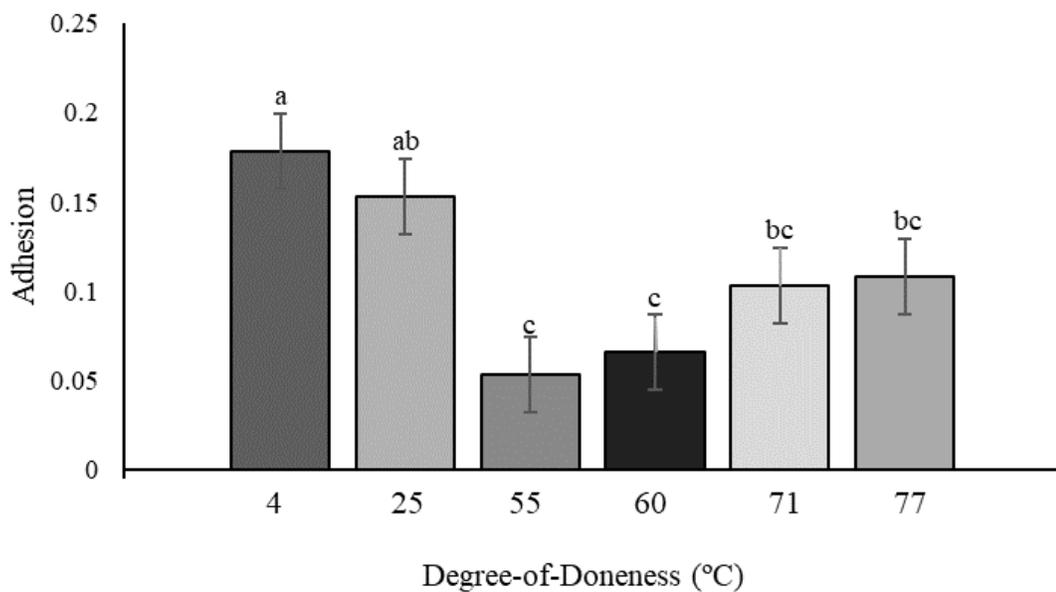


Figure 8. Adhesion of steak samples cooked to six degrees-of-doneness (DOD). A main effect (DOD) was observed ($p < 0.001$).

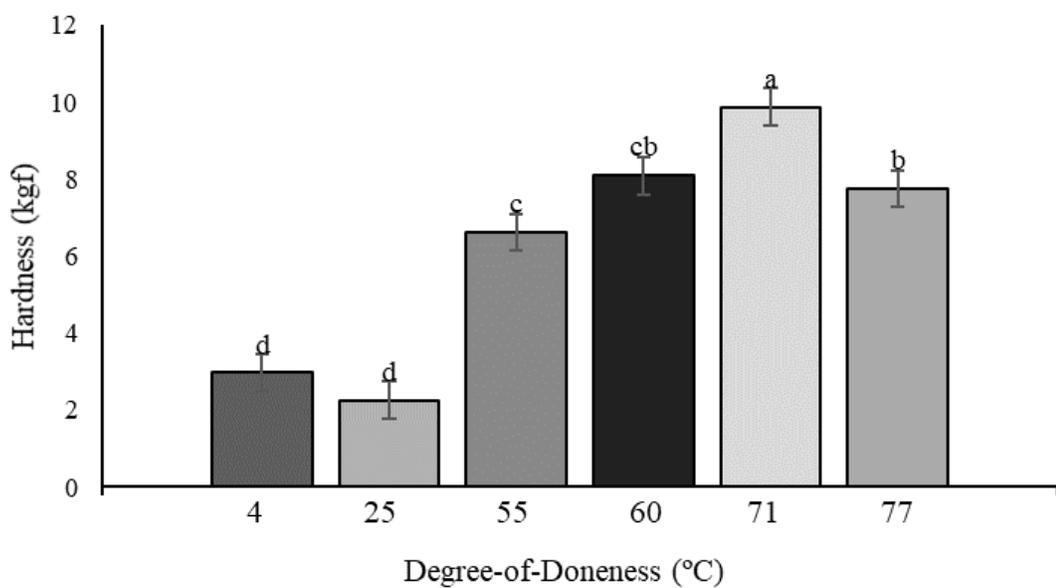


Figure 9. Hardness of steak samples cooked to six degrees-of-doneness (DOD). A main effect (DOD) was observed ($p < 0.001$).

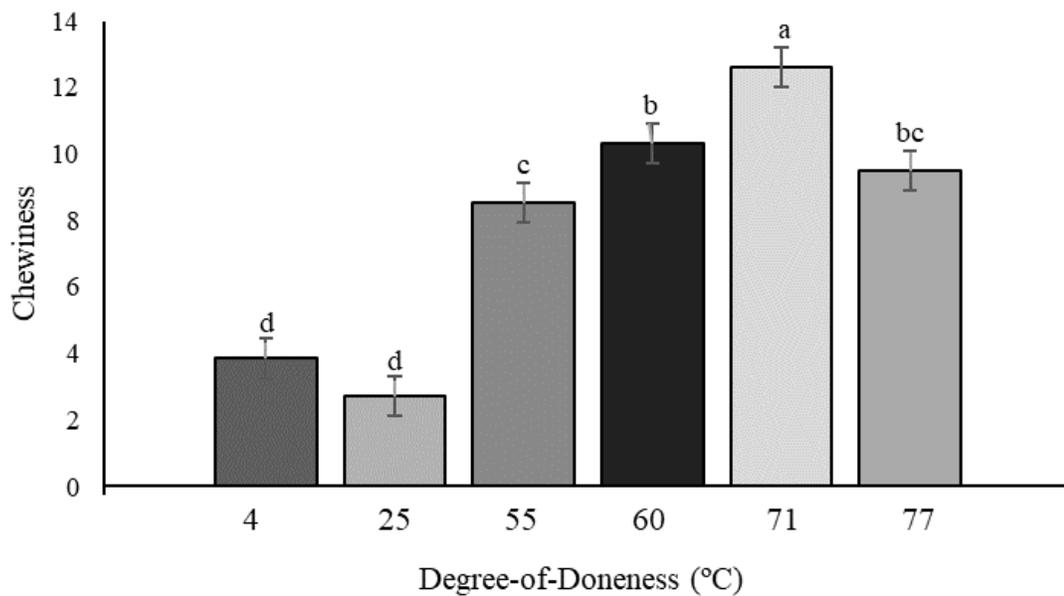


Figure 10. Chewiness of steak samples cooked to six degrees-of-doneness (DOD). A main effect (DOD) was observed ($p < 0.001$).

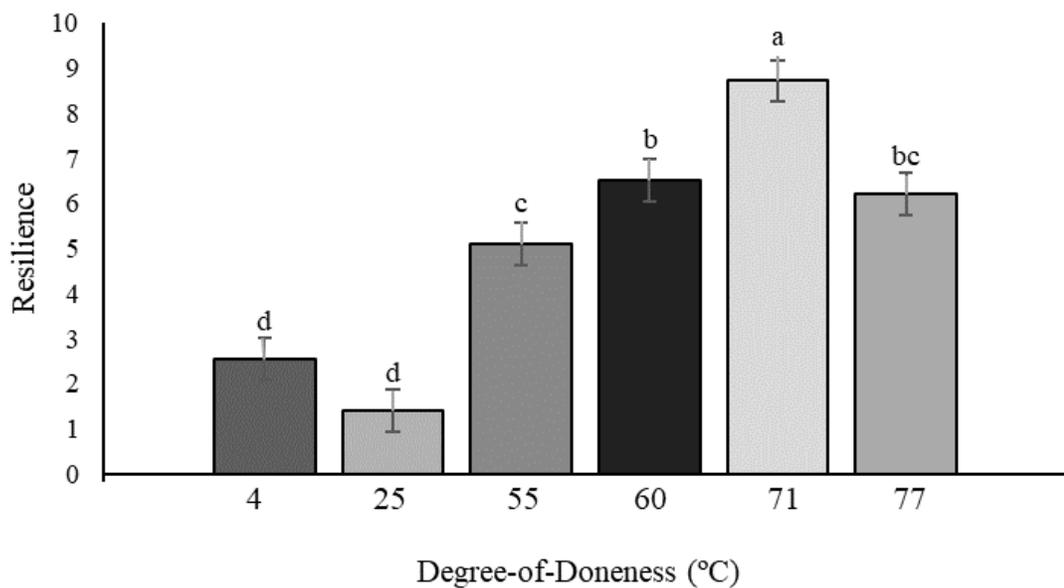


Figure 11. Resilience of steak samples cooked to six degrees-of-doneness (DOD). A main effect (DOD) was observed ($p < 0.001$).

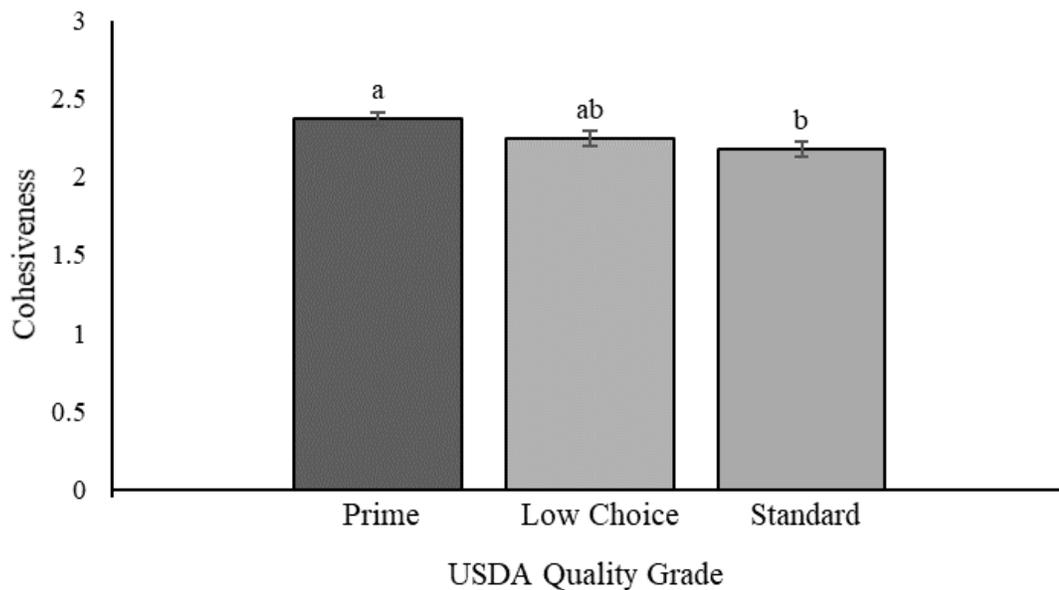


Figure 12. Cohesiveness of USDA prime, low choice, and standard steaks ($n = 8$). A main effect (QG) was observed ($p = 0.011$).

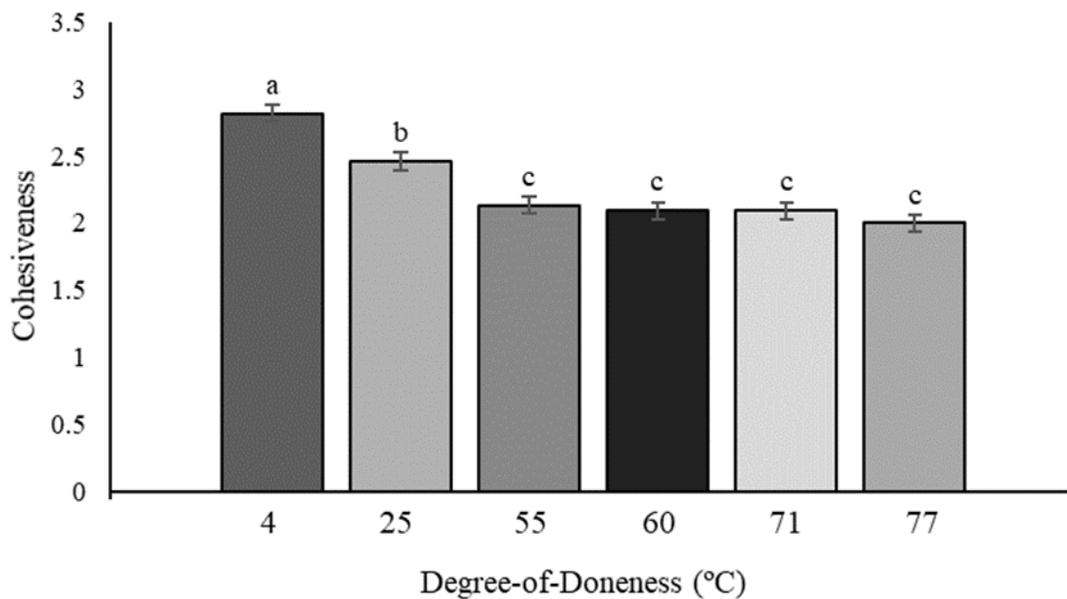


Figure 13. Cohesiveness of steak samples cooked to six degrees-of-doneness (DOD). A main effect (DOD) was observed ($p < 0.001$).

Similar to shear force values, it was expected that DOD would influence multiple textural properties. Adhesion, chewiness, cohesiveness, hardness, and resilience were each ($p < 0.001$) affected by DOD. It is interesting to note that of these values, cohesiveness was the only property to also be impacted ($p = 0.011$) by QG. The effect of cooking on the textural properties of beef is not unusual. Textural properties are tied with composition of beef strip steaks including water content, fat dispersion, and protein structure. Cooking would obviously have an impact on all three components. As a sample is cooked, protein degradation occurs. As exhibited in numerous studies, this degradation reaches a point where the proteins have degraded, and the moisture content still allows for separation of proteins for tenderness, and juiciness. As the cook time and temperature increases, moisture is lost, proteins draw closer together, and steaks will decrease in tenderness and other desirable characteristics. It was expected that refrigerated and room temperature steaks would have less variance than steaks cooked to internal temperatures of 55, 60, 71, and 77°C.

Adhesion is related to connective tissue and fat, and changes in adhesion usually indicate a rearranging of collagen fibers as cooking degraded myofibrillar structure and fat migration occurred (Bouton, Harris, & Shorthose, 1975). Adhesion can be explained as the stickiness of the product, or what a consumer might think of as the way a product sticks to their mouth or teeth while chewing. Refrigerated and room-temperature samples were the most ($p < 0.05$) adhesive compared to samples that had been cooked to 55 and 60°C. Raw samples will always be more adhesive due to the moisture content and lack of crusts and different chemical reactions that occur during cooking. Studies as early as

1952 (Bouton & Harris, 1972) have showed that collagen within a meat product will soften rapidly at temperatures 65°C and above. This softening may explain the difference seen between noncooked steaks and steaks cooked up to 60°C. Muscle fibers rearrange with applied heat, as water is cooked out and fat begins to melt, but before collagen softens. This would initially lower the adhesive properties of the steak. As the collagen softens, adhesive properties became similar to those of raw steaks, but remained similar to those cooked to 55 and 60°C. If researchers wish to study the specific adhesive properties of beef strip steak, the TPA method is not the most reliable. However, for our purposes, the data were still relevant as we were looking for differences and not adhesive properties.

In regard to chewiness and resilience, no difference was seen between raw samples (4 and 25°C), which had the lowest ($p < 0.05$) values. Once cooking began, all chewiness and resilience increased progressively in order from 55 to 71°C. At 77°C, values decreased to become similar to 55 and 60°C. Hardness values showed a similar trend. Raw steaks had the lowest ($p < 0.05$) hardness values. After cooking, steaks cooked to 71°C had the hardest ($p < 0.05$) values, with no difference ($p > 0.05$) between other DOD. To a consumer, these values are all related. Chewiness values are calculated in such a way to mimic a consumer chewing a product, and how much force is required to reach peak force. Resilience is the ability of a product to retain structure (or in a sense, the ability of a product to return to its original shape after pressure occurs). Thus, these two measurements are nearly identical although they serve different purposes. Hardness is the peak force mentioned earlier. Although hardness values mimic WBSF, it is

important to note that hardness values show how much force a product will take, while WBSF are more indicative of how much force is needed to cut the product. Thus, these measurements should be used alongside each other but not as a substitution. Our samples behaved much like current literature describes and correlated with tenderness measurements. Like adhesion, chewiness is often used as a function of collagen and fat content.

Since there were no differences due to QG for chewiness, resilience, or hardness, it is assumed that the content is not the factor so much as what happens to the fat once heat is applied. Before cooking, fat would be intact. After cooking, fat migration will occur and collagen is softened. As internal DOD increases, proteins degrade and develop adhesive properties. Along with softened collagen and fat, a sort of “chewy” glue will form, fortifying samples and giving them the properties measured as chewiness and resilience. At 77°C, where fat has migrated out of a sample and the proteins have hardened as moisture is lost, the samples lose chewiness and resilience. However, this does not hold true for hardness. Studies indicate that as DOD increases, so should hardness values. We see this with our WBSF measurements. However, our samples lose hardness as they reach 77°C.

Cohesive properties are the tendency for products to stick together and maintain form when pressure is applied. To a consumer, products that exhibit cohesive properties take many chews to break down. Our samples were the most ($p < 0.05$) cohesive at 4°C, followed by steaks at room temperature. After cooking no difference ($p > 0.05$) was seen between samples. We know that structural integrity is closely linked to both protein

structure, protein content, and fat content. Our tests related to protein degradation point out that even the lowest heating temperature will degrade proteins, so it was no surprise that cohesive properties were mitigated after cooking. Fat binds to itself and thus would help maintain the structure of a product, prohibiting easy break down. Thus, is also no surprise that fat content is a major contributor to cohesiveness properties of steaks.

Although not typically used to study beef, viscoelasticity tests are more intensive and precise when concerning structure. Values obtained from these tests indicate the amount of force a sample can withstand before it begins to break down, and thus take our interaction between QG and DOD a step further. The solid-like properties of a viscoelastic material are represented with the storage modulus value (G' ; Choi & Chang, 2012).

The viscoelasticity at the surface and center of steaks were influenced by QG dependent on DOD ($p \leq 0.023$; Figures 14 and 15). Surface G' of low choice steaks cooked to 77°C was the greatest ($p < 0.05$). Measurements taken from the center of the steak were affected similarly ($p = 0.023$; Figure 15) with low choice steaks cooked to 77°C being the greatest ($p < 0.05$).

In our study, measurements were taken from the surface and center of each steak sample to take viscoelastic measurements and obtain a G' value. An interaction was found in both surface and center G' measurements between QG and DOD ($p < 0.001$). Low Choice cooked to 77°C had the greatest ($p < 0.05$) values in both surface and center G' . Very little difference was detected amongst the other QG and DOD combos. Prime had no difference regardless of DOD ($p > 0.05$) and Standard steaks only showed

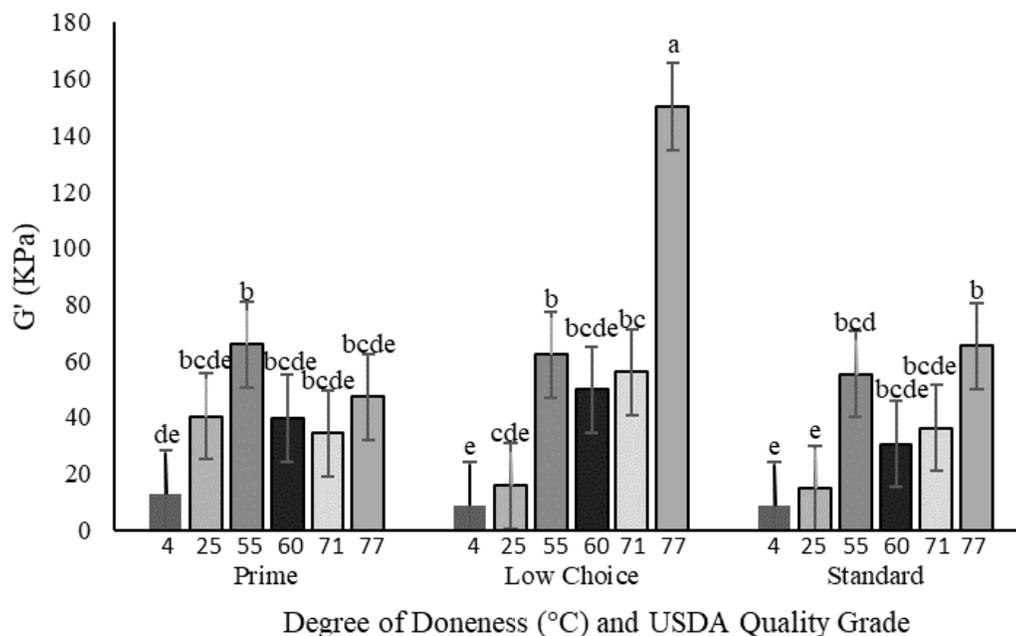


Figure 14. G' values taken from the surface of USDA prime, low choice, and standard steaks ($n = 8$) at six degrees-of-doneness (DOD). A two-way interaction (quality grade \times DOD) was observed ($p = 0.016$).

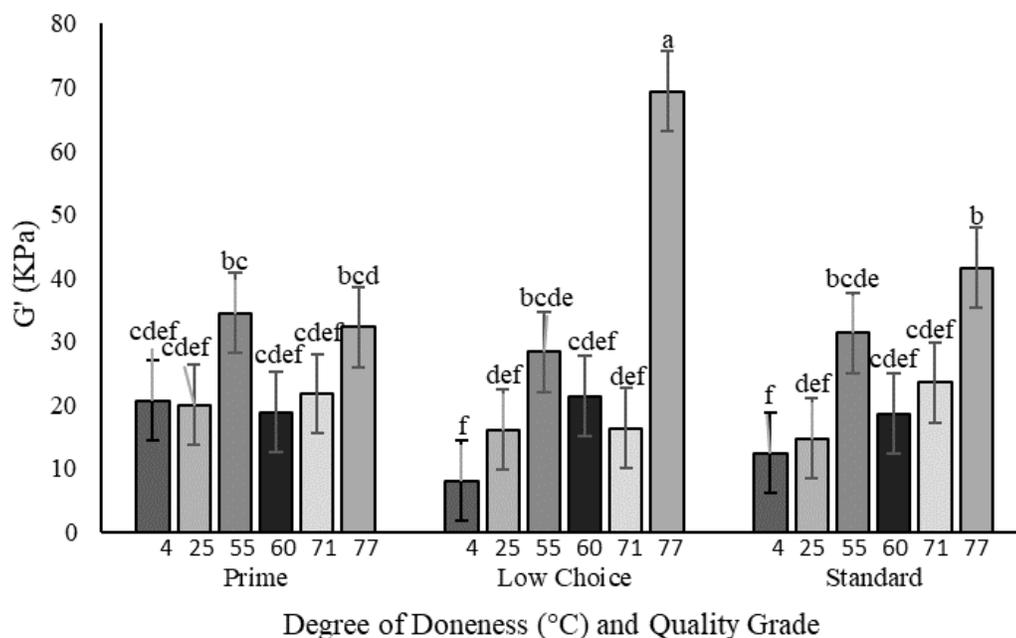


Figure 15. G' values taken from the center of USDA prime, low choice, and standard steaks ($n = 8$) at six degrees-of-doneness (DOD). A two-way interaction (quality grade \times DOD) was observed ($p = 0.023$).

difference between refrigerated steaks and steaks cooked to 77°C where refrigerated steaks were the lowest ($p < 0.05$) and steaks cooked to 77°C were the highest.

Interestingly, these results are generally in agreement with WBSF values, where DOD had little impact on prime but DOD did impact low choice and standard.

Many factors of a steak will affect the G' values. Protein and fat content are major ones, but the temperature and moisture content of each sample will also affect its ability to withstand stress. Protein structure should withstand more stress than a purified fat sample, and thus samples with a higher protein:fat ratio should also exhibit higher G' values. Temperature is also going to play a role. As fat is warmed, it will become less solid, and so cooking the samples would also affect the G' values. When cooked, the integrity of the protein will be compromised as degradation occurs. The fat within a sample will also be affected. Heat will cause fat migration, and could make samples with higher fat content not as significant when tested. Fat could be lost as it is cooked out, but it could also shift and have less of an impact on the samples.

Moisture Interactions

Expressible moisture percent (EM%) and WHC were both affected by the main effect of QG ($p = 0.001$; Figures 16 and 17) and DOD ($p < 0.001$; Figures 18 and 19). Prime steaks had the lowest ($p < 0.05$) EM% compared to low choice and standard steaks. Inversely, prime steaks had the highest ($p < 0.05$) WHC. In regards to DOD steaks cooked to 55°C and 60°C showed no difference ($p < 0.05$) and had the highest ($p < 0.05$) EM%, followed by steaks cooked to 71°C and 77°C. Steaks at refrigerated temperatures were next, followed by room temperature steaks with the lowest ($p < 0.05$) EM%.

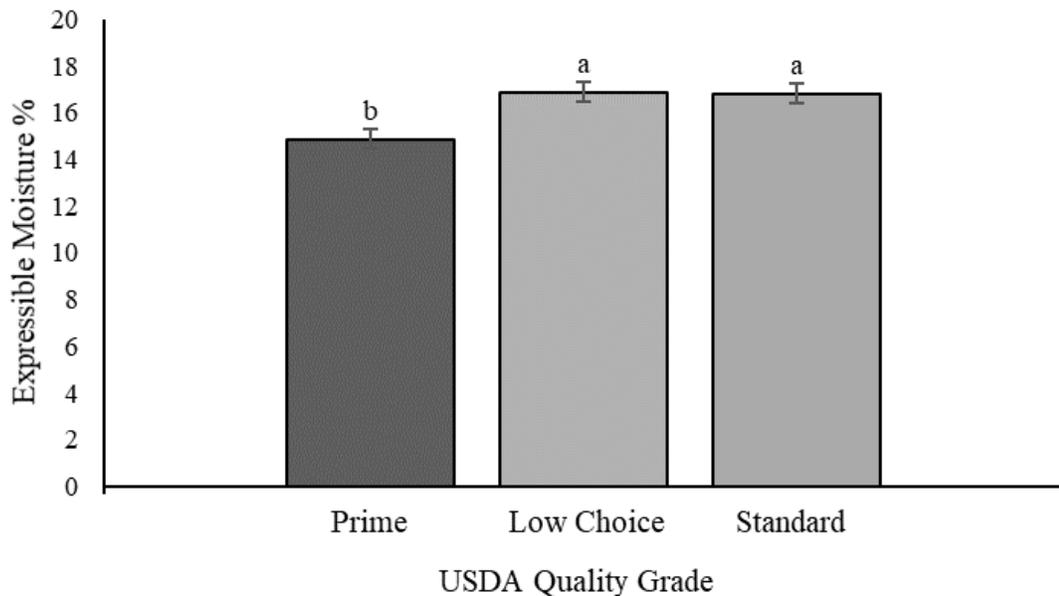


Figure 16. Expressible moisture percentages of USDA prime, low choice, and standard steaks ($n = 8$) at six degrees-of-doneness (DOD). A main effect (quality grade) was observed ($p = 0.001$).

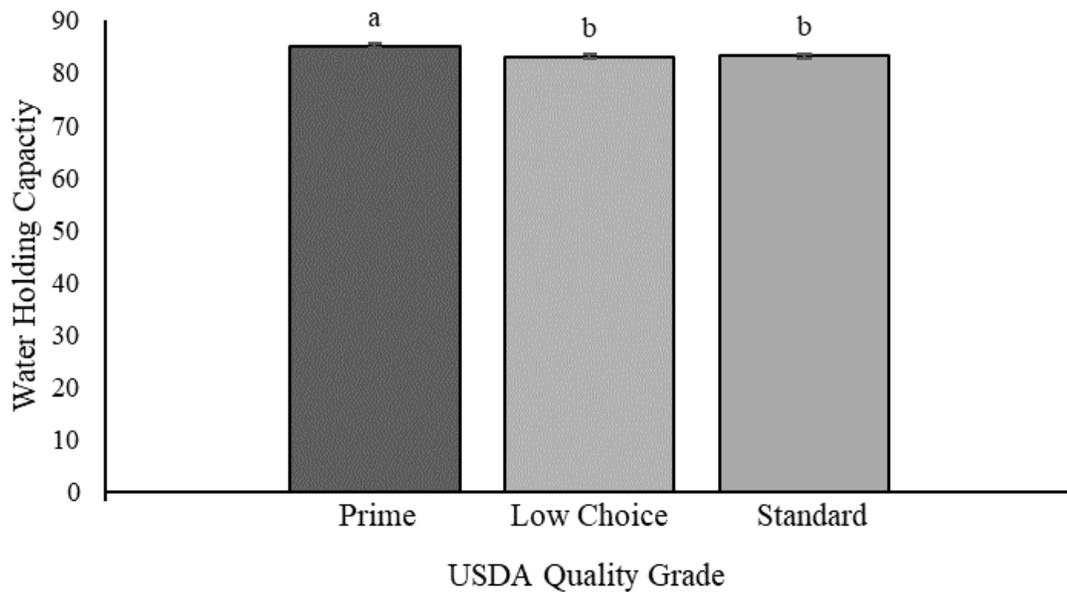


Figure 17. Water-holding capacity of USDA prime, low choice, and standard steaks ($n = 8$) at six degrees-of-doneness (DOD). A main effect (quality grade) was observed ($p = 0.001$).

Inversely, steaks cooked to 55°C and 60°C had the lowest ($p < 0.05$), followed by 71°C and 77°C. Refrigerated steaks were next highest, with room temperature steaks having the highest WHC of all DOD.

In Alias, Omosebi, and Huda (2017), it is discussed that EM% is a component of WHC, and these two measurements will reflect each other. Moisture is a complex topic, especially when related to muscle and meat. Water is a dipole molecule and is thus attracted to the charged proteins that compose muscle. This water is either bound, immobilized, or free water, and each state will affect the composition of muscle and ultimately meat. Bound water is going to be the most resistant to freezing and heating of a meat product. This water will make up less than a tenth of the total water within the muscle. Immobilized water will be held within the intracellular spaces of the meat. This water will not be lost as purge, but can be removed through cooking, pressure, or other means. This immobilized water is the most highly correlated with EM% and WHC and is the most studied in terms of beef palatability and its relation to juiciness and tenderness (Fennema, 1985). Huff-Longeran (2010) discusses that QG does not affect WHC, but our results show a different trend. Although there was no interaction, steaks showed a difference ($p < 0.05$) between QG with WHC and inversely EM%. As fat content increased (QG), WHC also increased. Prime steaks had the highest ($p < 0.05$) WHC and the lowest EM%. Low choice and standard steaks had lower ($p < 0.05$) WHC and higher EM%. The hydrophobic nature of prime steaks makes it believable that there was less free water to be expressed. Instead, the water in these steaks would be bound to proteins and unlikely to be expressed as EM%.

Steaks thawed to room temperature had a greater ($p < 0.05$) WHC and lower ($p < 0.05$) EM% when compared to tests done at refrigerated temperature. Interestingly enough, this curve does not continue upward as steaks are cooked to a greater DOD, similar to our protein degradation analysis. Steaks cooked to medium and well done (71 and 77°C, respectively) DOD followed refrigerated temperature as the next highest WHC, and were higher ($p < 0.05$) than steaks cooked to rare and medium rare (55 and 60°C, respectively) temperatures (see Figures 18 and 19).

Temperature and the pH of a steak will affect WHC and EM%. A high pH will result in higher WHC because the increase in pH also increases the water-binding properties in protein (Calkins & Hodgen, 2007; Meynier & Mottram, 1995). As temperature increases, pH will drop, and there is an increased disassociation with water

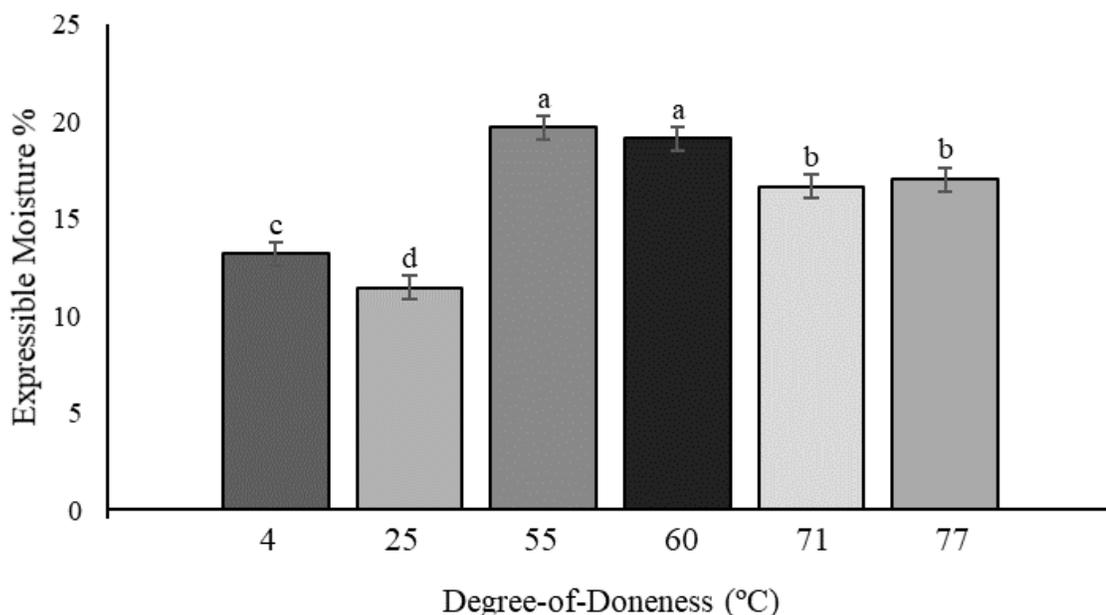


Figure 18. Expressible moisture of steak samples cooked to six degrees-of-doneness (DOD). A main effect (DOD) was observed ($p < 0.001$).

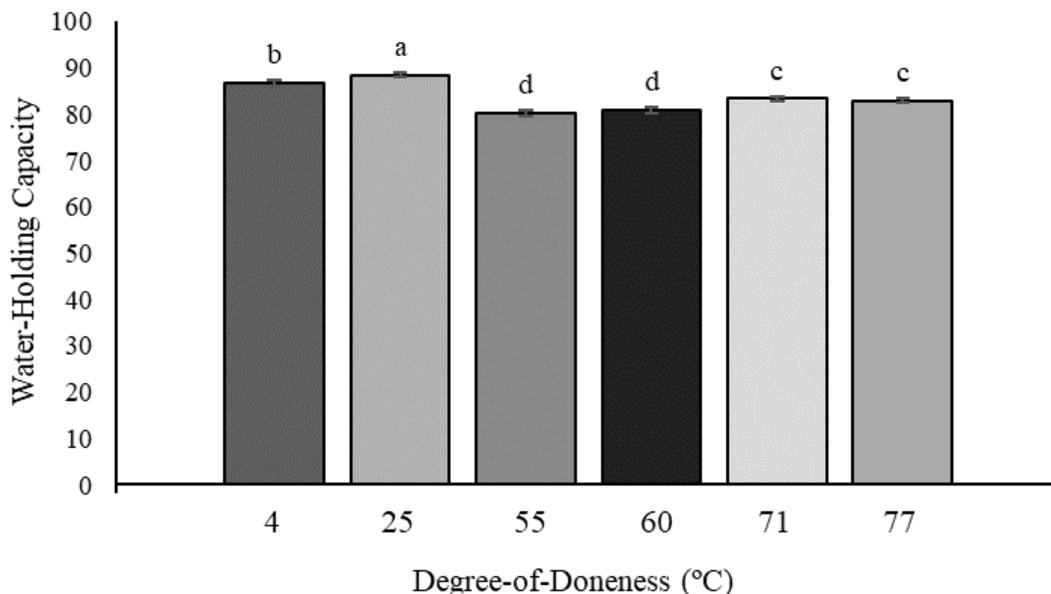


Figure 19. The water-holding capacity of steak samples cooked to six degrees-of-doneness (DOD). A main effect (DOD) was observed ($p < 0.001$).

(van Boekel, 2001). As a sample is cooked, water is freed (and thus lost). As strip steaks are cooked, the proteins would begin to break down, releasing some of the immobilized water within the steak. As the DOD increases, water would be cooked out, leaving less immobilized water, and thus a lower EM%. After steaks are cooked, the water would be mostly cooked out, leaving less water to lose later on. These steaks exhibit the highest WHC, and thus the lowest EM%, because much of the water that could have been expressed has already been released during the cooking process. Further research should be conducted to see what is happening to the proteins that may also be affecting WHC and ability to express moisture.

Thermal Measurements

The interaction of QG and DOD impacted the degradation of myosin and

sarcoplasmic proteins from the center of steak samples ($p = 0.001$; Figure 20). Prime and low choice steaks at 4°C and 25°C were similarly the greatest ($p < 0.05$; J/g). After cooking (DOD of 55°C and above), no difference ($p > 0.05$) was detected. Standard steaks showed a similar trend with room temperature steaks having the greatest ($p < 0.05$) enthalpy, while still being lower ($p < 0.05$) than low choice and prime steaks at room temperature. Standard steaks at 4°C were lower ($p < 0.05$) than refrigerated prime or low choice steaks and greater ($p < 0.05$) than all cooked steaks across quality grade. Like prime and low choice cooked steaks, standard steaks showed no difference between DOD or quality grade after cooking.

Protein degradation plays an important role in the structural integrity of steaks.

Therefore, the use of DSC was logical to help explain what occurs as a steak is cooked.

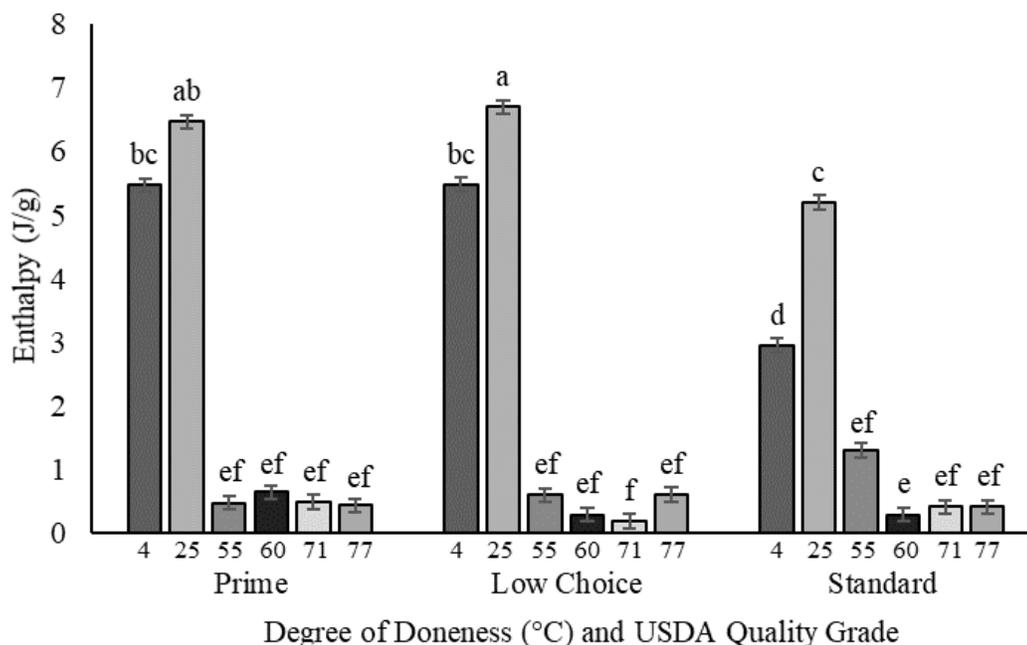


Figure 20. Enthalpy values for the degradation of myosin and sarcoplasmic proteins taken from the center of USDA prime, low choice, and standard steaks ($n = 8$) at six degrees-of-doneness (DOD). A two-way interaction (quality grade \times DOD) was observed ($p = 0.023$).

Similar to viscoelasticity tests, measurements were taken at the surface and center of each steak sample. Of these measurements, two values were obtained: the enthalpy related to the degradation of myosin and sarcoplasmic proteins (MSP) as a combined value and the enthalpy related to the degradation of actin protein (AP). The nature of these tests made our focus mainly on differences of cooked-temperature, as the measurements were done based on amount of protein in each sample. Furthermore, fat melts at a much lower temperature, and fat content differences were excluded from analysis. For this reason, the cooked samples should show a decrease in energy needed to break down the proteins, as the cooking should degrade some if not all the proteins prior to this test. For DSC tests, the most valuable information was obtained from steaks tested at refrigerated and room temperature.

Due to the sensitive nature of the DSC, any protein degradation will affect the results, and any cooking will begin the degradation process. Samples that were not cooked, and thus had little protein degradation previous to testing, showed greater ($p < 0.05$) enthalpy than samples that were cooked to even the lowest DOD (see Figure 21). The data with the most scientific significance is the results from measurements taken from the center of each sample. Measurements of center samples of MSP showed interaction ($p < 0.003$) between QG and DOD. The DOD results are easy to explain. Prime, low choice, and standard steaks with a DOD of 50°C or greater all had a lower ($p < 0.05$) enthalpy for MSP when compared to steaks assigned 4 and 25°C. Once even the lowest cooking temperature was obtained, the process of protein degradation had begun and made the readings similar ($p > 0.05$). The differences between QG is the most

intriguing. The main factor separating QG is IMF content. However, due to the nature of the test, IMF content doesn't affect our results. This is because tests were analyzed with a percent protein basis, and the fat had melted before protein degradation readings were compared. Our study showed that prime and low choice samples at either 4 or 25°C along with standard samples tempered to 25°C showed a greater ($p < 0.05$) enthalpy for MSP than standard 4°C steaks. Standard steaks at refrigerated temperature required less energy to degrade MSP than the other steaks that did not undergo cooking. Samples in this study were not purified, and would thus still be protected by chaperonins, the proteins at room temperature would still be isolated from degradation and should read with similar values as the refrigerated samples from each quality grade (Adina & Abdussalam, 2018). It is challenging to connect this data with WBSF or textural properties. It is, however, likely that some other protein factor, such as collagen, may be varied between the QG in this study. The enthalpies of myofibrillar proteins would not reflect this potential influence of collagen.

The degradation of myosin and sarcoplasmic proteins (MSP) taken from surface samples of steaks were impacted by DOD ($p < 0.001$; Figure 21). Steaks tempered to 25°C had the greatest ($p < 0.05$; J/g), followed by steaks at refrigerated temperatures. After cooking, no difference ($p > 0.05$) was found. Degree of doneness affected the enthalpy measurements of actin proteins taken from the surface of steak samples ($p < 0.001$; Figure 22). Steaks at 4 and 25°C had higher ($p < 0.05$) enthalpy values when compared to all cooked steaks, respectively.

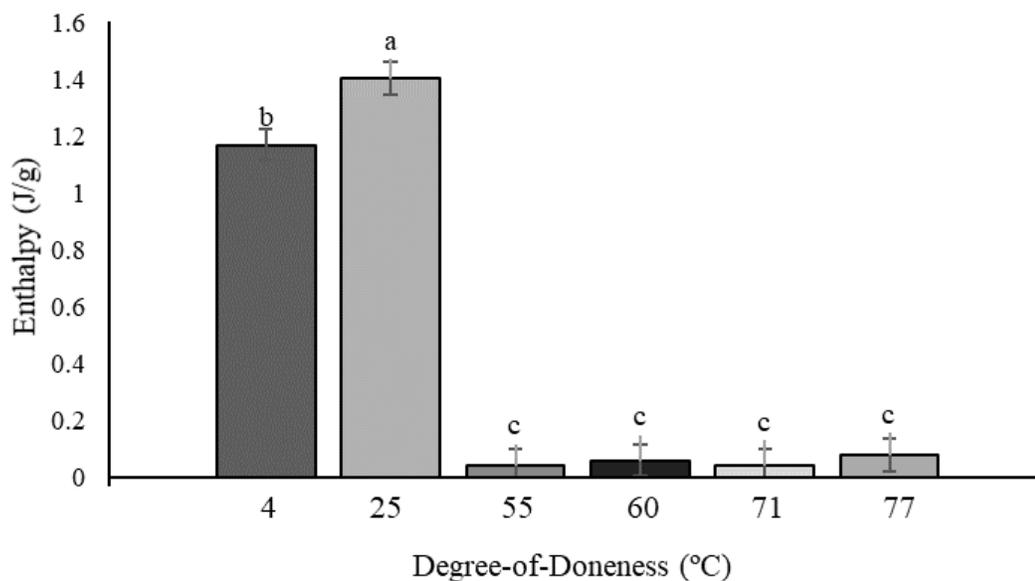


Figure 21. Enthalpy of myosin and sarcoplasmic degradation taken from the surface of steak samples. A main effect (degree of doneness) was observed ($p < 0.001$).

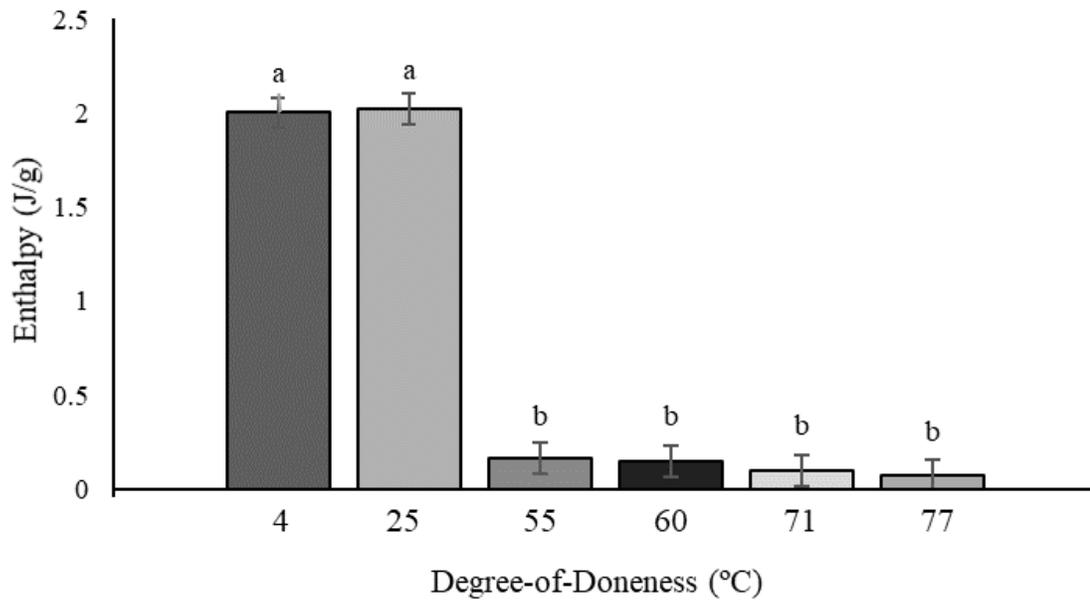


Figure 22. Enthalpy of actin degradation taken from the surface of steak samples. A main effect (degree of doneness) was observed ($p < 0.001$).

Measurements of actin degradation from center steak sampling were also affected by DOD ($p < 0.001$; Figure 23). Steaks at 4 and 25°C and cooked to 71 and 77°C showed no difference and were lower ($p < 0.05$) comparatively than steaks cooked to 55 and 60°C.

Cooking would cause an immediate effect on the steak surface, and so it is no surprise that enthalpy values from cooked surface samples were so low. Enthalpy for actin proteins showed no difference ($p < 0.05$) between raw steaks, and no difference ($p < 0.05$) between cooked steaks. The interesting discussion comes from myosin and sarcoplasmic protein degradation at refrigerated and room temperature steaks. Steaks warmed to room temperature gave off more heat during the exothermic reaction of protein degradation for myosin and sarcoplasmic proteins. Studies have shown that severe denaturation of proteins can occur at room temperature, however our higher

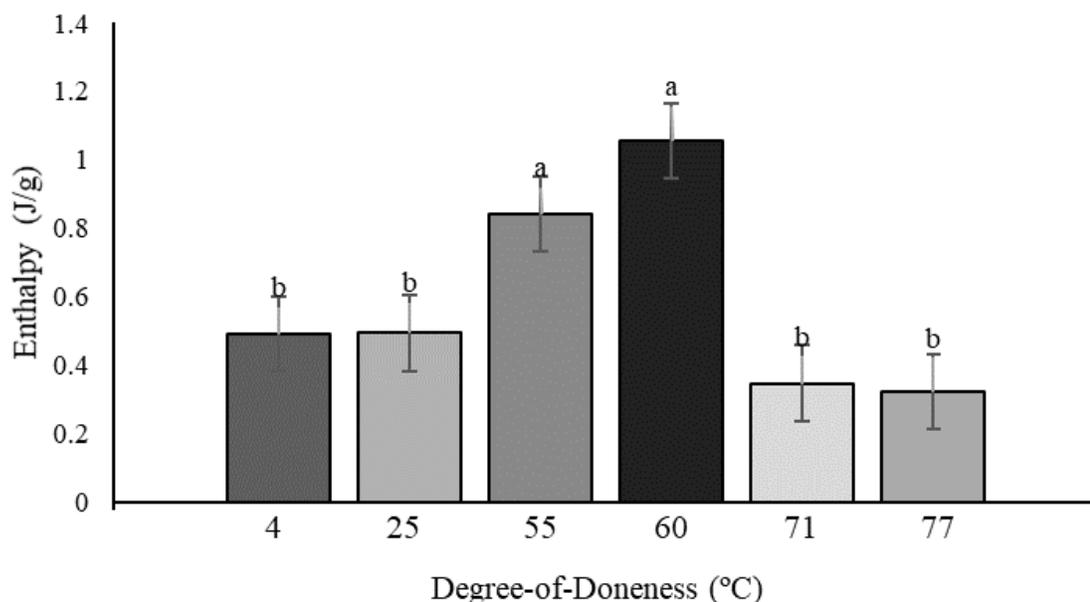


Figure 23. Enthalpy of actin taken from the center of steak samples. A main effect (degree of doneness) was observed ($p < 0.001$).

enthalpy values for myosin and sarcoplasmic degradation suggest that room temperature proteins required more energy to break down than refrigerated proteins. Furthermore, the degradation of actin from center samples did not follow an upward trend according to DOD either. There was a significant difference ($p < 0.05$) between samples assigned different DOD. Steaks with an internal DOD of 55 and 60°C had a lower enthalpy of actin or gave off less heat during the exothermic reaction of protein degradation. However, the difference was not simply cooking as seen previously. Samples tested at 4°C or tempered to 25°C had similar actin enthalpies as samples cooked to 71 and 77°C. Enthalpies for center actin samples aligned with our moisture data more than was expected.

The main effect DOD affected thermal conductivity in steaks ($p = 0.021$; Figure 24). Steaks tempered to 25°C had the highest ($p < 0.05$) when compared to all other measurements (4, 55, 60, 71, and 77°C). Conductivity is the amount of heat that is

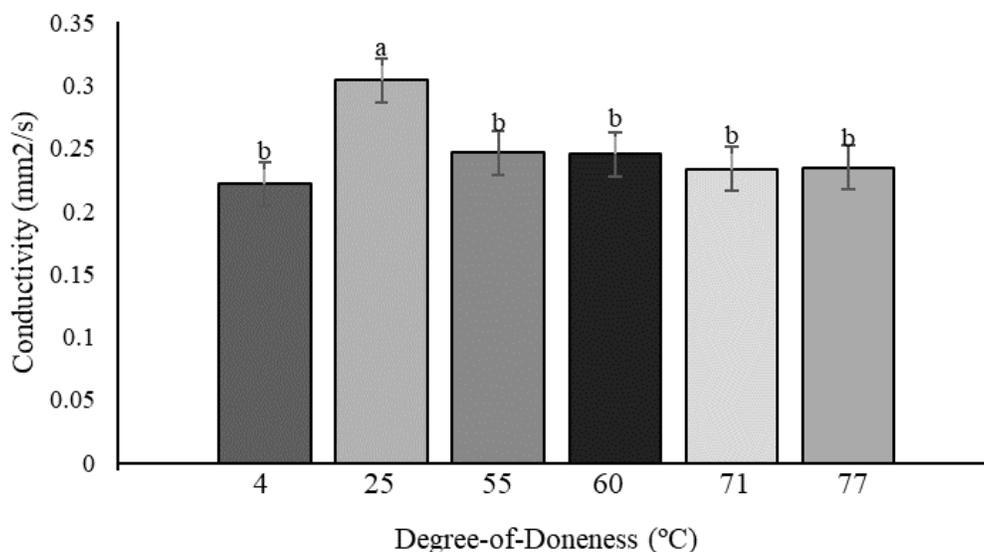


Figure 24. Thermal conductivity for six degrees-of-doneness (DOD). A main effect (DOD) was observed ($p = 0.021$).

transferred through a sample, and the diffusivity is the rate that the heat is transferred from the heat source forward. These two measurements are not dependent on each other.

Despite the differences in IMF and internal cooked DOD, our study concluded that there was no ($p > 0.05$) difference in diffusivity. This would mean that if each steak was the same size and thickness, they would all cook at the same rate, regardless of fat content. Elansari and Hobani (2009) predicted and confirmed that conductivity increases linearly with increased temperature (4-40°C) and moisture content. There was ($p = 0.02$) significance for DOD with conductivity measurements. Samples tempered to 25°C before measurement had the highest conductivity in relation to refrigerated steaks or steaks cooked to 55, 60, 71, or 77°C.

Water is the densest and least conductive at 4°C, so it is no surprise that steaks did not have the highest conductivity under refrigeration. But cooking has a similar effect on conductivity values. When measured during the rate of increase, thermal conductivity will increase with temperature up to 70°C as proteins denature and water is released (Baghe-Khandan & Okos, 1981). Since the remaining steaks were all tested at 25°C, the linear relation between heat and conductivity was not measured. Instead, all the cooked steaks, regardless of DOD endpoint, proved to be less conductive than room-temperature steaks. We have established previously that even low cooking temperatures will degrade proteins and thus release bound water. As our steaks were cooked, the moisture that would have increased conductivity was seen as cook loss after cooling to 25°C. Further research would have to determine when the divergence occurs and if the change in conductivity also affects other physical and thermal factors.

CHAPTER V

CONCLUSION

To compete with protein sources that are cheaper and perceived as healthier by many consumers, the “prime experience” is what sells beef to consumers. Although much can be done in terms of genetics, live animal handling, and post-harvest practice to improve tenderness, the consumer has the greatest impact on the final product. Numerous studies have shown the impact that cooking has on textural properties of steak, with higher cooked degree-of-doneness typically resulting in less favorable physical characteristics. Our study supports this fully. The importance of IMF on palatability factors, especially tenderness, has also been widely studied. Until now, these two factors have not been compared. Our results show that cooking to a high degree of doneness can be overcome with QG containing higher IMF. However, it is not simply the higher fat content causing this observation. Our results indicate that differences in protein structure plays an important role for tenderness and perceived consumer perception of eating satisfaction, and that marbling may need to be reevaluated as the sole source of meat quality. Further research pertaining to the ultra-structure of beef will need to be conducted to pin-point where the divergence lies and what differences other than fat content may be present between typical prime, low choice, and standard steaks. Until that time, consumers would do well to understand that higher QG will still typically be more palatable despite end cooking preferences. Likewise, if the “prime eating” experience without the price tag is desired, refraining from over-cooking steaks will help consumers maintain tenderness and other favorable textural properties in their steak.

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APPENDIX
LS MEANS TABLES

Table A1

Cooking Measurements of Beef Steaks from Three Different Quality Grades and Four Degrees of Doneness

OG	DOD (°C)	Cook time (Min)	Cook loss %
Prime	55	4.231 ^{x\$}	0.196 ^v
	60	4.2663 ^{w\$}	0.194 ^v
	71	5.446 ^{v\$}	0.220 ^u
	77	6.376 ^{u\$}	0.233 ^u
Low choice	55	4.109 ^{x#}	0.164 ^v
	60	4.831 ^{w#}	0.200 ^v
	71	6.429 ^{v#}	0.026 ^u
	77	7.166 ^{u#}	0.260 ^u
Standard	55	3.466 ^{x\$}	0.150 ^v
	60	4.404 ^{w\$}	0.186 ^v
	71	5.939 ^{v\$}	0.239 ^u
	77	6.296 ^{u\$}	0.249 ^u
SEM		0.325	0.015
<i>p</i> values	QG	0.017	0.441
	DOD	< .001	< .001
	QG*DOD	0.519	0.271

Table A2

The Thermal Properties of Beef Steaks from Three Different Quality Grades (QG) and Six Degrees of Doneness (DOD)

QG	DOD (°C)	Diffusivity (W/mK)	Conductivity (mm ² /s)	Myosin, Sarcoplasmic (J/g)		Actin (J/g)	
				Surface enthalpy1	Center enthalpy1	Surface enthalpy2	Center enthalpy2
Prime	4	0.797	0.213 ^v	4.877 ^v	5.467 ^{bc}	1.948 ^u	2.082 ^v
	25	0.477	0.369 ^u	7.050 ^u	6.472 ^{ab}	2.052 ^u	2.170 ^v
	55	0.493	0.233 ^v	0.089 ^w	0.470 ^{le}	0.097 ^v	3.707 ^u
	60	0.489	0.231 ^v	0.288 ^w	0.645 ^{le}	0.119 ^v	5.362 ^u
	71	0.611	0.216 ^v	0.125 ^w	0.488 ^{le}	0.057 ^v	0.619 ^v
	77	0.501	0.233 ^v	0.411 ^w	0.432 ^{le}	0.044 ^v	1.449 ^v
Low choice	4	0.593	0.220 ^v	5.320 ^v	5.477 ^{bc}	2.097 ^u	2.001 ^v
	25	0.588	0.276 ^u	6.387 ^u	6.700 ^u	2.188 ^u	2.091 ^v
	55	0.561	0.244 ^v	0.145 ^w	0.594 ^{le}	0.205 ^v	3.042 ^u
	60	0.498	0.249 ^v	0.137 ^w	0.288 ^{le}	0.127 ^v	3.279 ^u
	71	0.529	0.238 ^v	0.152 ^w	0.185 ^f	0.109 ^v	1.595 ^v
	77	0.579	0.223 ^v	0.281 ^w	0.607 ^{le}	0.085 ^v	0.231 ^v
Standard	4	0.545	0.231 ^v	4.604 ^v	2.946 ^d	1.961 ^u	2.088 ^v
	25	0.591	0.267 ^u	4.584 ^u	5.201 ^c	1.821 ^u	2.009 ^v
	55	0.485	0.263 ^v	0.253 ^w	1.303 ^{le}	0.177 ^v	2.839 ^u
	60	0.511	0.256 ^v	0.279 ^w	1.411 ^e	0.19 ^v	3.435 ^u
	71	0.575	0.246 ^v	0.181 ^w	0.433 ^{le}	0.116 ^v	1.465 ^v
	77	0.554	0.243 ^v	0.120 ^w	0.415 ^{le}	0.096 ^v	1.517 ^v
SEM		0.067	0.030	0.397	0.434	0.101	0.682
<i>p</i> values	QG	0.887	0.886	0.091	0.252	0.296	0.403
	DOD	0.118	0.021	<.001	<.001	<.001	<.001
	QG*DOD	0.301	0.602	0.069	0.001	0.729	0.597

abcde^{gh} Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of QG*DOD.

uvwx Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of DOD. Means not reported if interaction of QG*DOD was found

#% Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of QG. Means not reported if interaction of QG*DOD was found

Table 3

The LS Means for Texture Properties of Beef Steaks from Three Different Quality Grades (QG) and Six Degrees of Doneness (DOD)

QG	DOD (°C)	Adhesion	Chewiness	Cohesiveness	Hardness (kgf)	Shear (kgf)	Springiness	Resilience
Prime	4	0.203 ^u	5.491 ^x	3.065 ^{u,#}	4.210 ^x	1.553 ^{ghi}	0.421 ^f	4.159 ^x
	25	0.166 ^{uv}	2.480 ^x	2.524 [#]	1.786 ^x	1.346 ⁱ	0.575 ^{bcd}	1.236 ^x
	55	0.073 ^w	9.609 ^w	2.220 ^{w,#}	7.161 ^w	1.866 ^{gh}	0.608 ^{abc}	6.224 ^w
	60	0.041 ^w	10.090 ^v	2.116 ^{w,#}	7.831 ^v	2.179 ^{def}	0.614 ^{abc}	6.269 ^v
	71	0.097 ^{vw}	11.549 ^u	2.249 ^{w,#}	8.666 ^u	2.093 ^{ef}	0.601 ^{abc}	8.215 ^u
	77	0.055 ^{vw}	9.462 ^{vw}	2.040 ^{w,#}	7.210 ^{vw}	1.984 ^{fg}	0.636 ^{ab}	6.185 ^{vw}
Low choice	4	0.190 ^u	3.273 ^x	2.829 ^{u,#}	2.716 ^x	1.442 ^{hi}	0.433 ^f	2.093 ^x
	25	0.143 ^{uv}	2.234 ^x	2.476 ^{v,#}	1.983 ^x	1.437 ^{hi}	0.497 ^e	1.200 ^x
	55	0.054 ^w	7.727 ^w	2.057 ^{w,#}	6.256 ^w	2.306 ^{cdef}	0.600 ^{abc}	4.239 ^w
	60	0.070 ^w	10.249 ^v	2.085 ^{w,#}	7.846 ^v	2.276 ^{cdef}	0.624 ^{ab}	6.162 ^v
	71	0.134 ^{vw}	15.302 ^u	2.076 ^{w,#}	11.519 ^u	2.742 ^{abc}	0.649 ^a	10.466 ^u
	77	0.196 ^{vw}	9.533 ^{vw}	1.965 ^{w,#}	8.007 ^{vw}	2.887 ^{ab}	0.605 ^{abc}	6.155 ^{vw}
Standard	4	0.142 ^u	2.772 ^x	2.567 ^{u,\$}	1.973 ^x	1.414 ^{hi}	0.556 ^{cde}	1.365 ^x
	25	0.149 ^{uv}	3.445 ^x	2.377 ^{v,\$}	2.991 ^x	1.293 ⁱ	0.534 ^{de}	1.788 ^x
	55	0.032 ^w	8.218 ^w	2.124 ^{w,\$}	6.445 ^w	2.097 ^{ef}	0.601 ^{abc}	4.838 ^w
	60	0.089 ^w	10.644 ^v	2.074 ^{w,\$}	8.612 ^v	2.553 ^{bcde}	0.600 ^{abc}	7.090 ^v
	71	0.078 ^{vw}	11.000 ^u	1.953 ^{w,\$}	9.422 ^u	2.615 ^{bcd}	0.606 ^{abc}	7.473 ^u
	77	0.073 ^{vw}	9.451 ^{vw}	1.989 ^{w,\$}	8.028 ^{vw}	3.221 ^a	0.591 ^{abcd}	6.268 ^{vw}
SEM		0.037	1.040	0.109	0.840	0.172	0.022	0.807
<i>p</i> values	QG	0.200	0.633	0.011	0.881	< .001	0.570	0.464
	DOD	< .001	< .001	< .001	< .001	< .001	< .001	< .001
	QG*DOD	0.447	0.120	0.653	0.259	0.008	0.001	0.096

^{abcde} Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of QG*DOD.

^{uvwx} Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of DOD. Means not reported if interaction of

QG*DOD was found

^{#%} Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of QG. Means not reported if interaction of

QG*DOD was found

Table 4

The LS Means for Moisture Interactions of Beef Steaks from Three Different Quality Grades (QG) and Six Degrees of Doneness (DOD)

QG	DOD (°C)	EM %	WHC
Prime	4	12.402 ^{w,\$}	87.598 ^{v,#}
	25	10.145 ^{x,\$}	89.772 ^{u,#}
	55	17.608 ^{u,\$}	82.392 ^{x,#}
	60	17.984 ^{u,\$}	82.016 ^{x,#}
	71	14.668 ^{v,\$}	85.333 ^{w,#}
	77	16.389 ^{v,\$}	83.610 ^{w,#}
Low choice	4	13.744 ^{w,#}	86.256 ^{v,\$}
	25	13.306 ^{x,#}	86.694 ^{u,\$}
	55	20.354 ^{u,#}	79.646 ^{x,\$}
	60	19.650 ^{u,#}	80.350 ^{x,\$}
	71	16.172 ^{v,#}	83.828 ^{w,\$}
	77	18.070 ^{v,#}	81.930 ^{w,\$}
Standard	4	13.404 ^{w,#}	86.596 ^{v,\$}
	25	10.912 ^{x,#}	89.088 ^{u,\$}
	55	21.121 ^{u,#}	78.879 ^{x,\$}
	60	19.736 ^{u,#}	80.264 ^{x,\$}
	71	19.118 ^{v,#}	80.882 ^{w,\$}
	77	16.623 ^{v,#}	83.377 ^{w,\$}
SEM		1.038	1.042
<i>p</i> values	QG	0.001	0.001
	DOD	< .001	< .001
	QG*DOD	0.405	0.411

^{abcdefghi} Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of QG*DOD.

^{uvwxx} Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of DOD. Means not reported if interaction of QG*DOD was found

^{#\$%} Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of QG. Means not reported if interaction of QG*DOD was found

Table 5

The LS Means for The Viscoelastic Behavior of Beef Steaks from Three Different Quality Grades (QG) and Six Degrees of Doneness (DOD)

QG	DOD (°C)	SurfaceG' (KPa)	CenterG' (KPa)
Prime	4	12.938 ^{de}	20.628 ^{cdef}
	25	40.241 ^{bcd}	19.910 ^{cdef}
	55	65.793 ^b	34.419 ^{bc}
	60	39.633 ^{bcd}	18.778 ^{cdef}
	71	34.207 ^{bcd}	21.727 ^{cdef}
	77	47.218 ^{bcd}	32.254 ^{bcd}
Low choice	4	8.754 ^e	7.989 ^f
	25	15.642 ^{cde}	16.061 ^{def}
	55	62.174 ^b	28.328 ^{bcd}
	60	49.710 ^{bcd}	21.306 ^{cdef}
	71	55.877 ^{bc}	16.315 ^{def}
	77	150.210 ^a	69.340 ^a
Standard	4	8.713 ^e	12.394 ^f
	25	14.668 ^{de}	14.615 ^{def}
	55	55.176 ^{bcd}	31.317 ^{bcd}
	60	30.420 ^{bcd}	18.622 ^{cdef}
	71	36.072 ^{bcd}	23.556 ^{cdef}
	77	65.331 ^b	41.574 ^b
SEM		15.308	6.312
<i>p</i> values	QG	0.037	0.724
	DOD	< .001	< .001
	QG*DOD	0.016	0.023

^{abcde} Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of QG*DOD.

^{uvwx} Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of DOD. Means not reported if interaction of QG*DOD was found.

^{#S%} Means within a column lacking a common superscript differ ($p < 0.05$) for the interaction of QG. Means not reported if interaction of QG*DOD was found.