TENDERNESS AND JUICINESS OF BEEF STEAKS FROM VARYING HOT CARCASS WEIGHTS

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Michaella Ann Fevold

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By

Michaella Ann Fevold

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

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SUPERVISORY COMMITTEE:

Dr. Robert Maddock
Chair

Dr. Kasey Maddock-Carlin

Dr. Adam Marx

Approved:

4-11-2019
Date

Dr. Marc Bauer
Department Chair

ABSTRACT

The objective of this study was to determine how hot carcass weights affect temperature decline and pH decline of beef carcasses, as well as, tenderness, juiciness and color of beef steaks. Carcasses were selected based on hot carcass weight. Carcasses were separated into either light, medium or heavy weight groups and temperature and pH decline were measured for 24 hours. There were no differences in pH decline, fat thickness, KPH or marbling score, drip loss, cook loss or WBSF among hot carcass weight classes. Light and medium carcasses weight had smaller longissimus areas compared to heavy carcasses. Light weight carcasses had lower USDA final yield grades compared to heavy carcasses. Color data indicated steaks from heavy carcasses were redder than steaks from light carcasses. Hot carcass weight did not have an influence on overall meat quality attributes of steaks, however, hot carcass weight did have an effect on color.

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LIST OF ABBREVIATIONS

ADP.....Adenosine diphosphate

ATP.....Adenosine triphosphate

BF.....Backfat

°C.....Degrees Celsius

cm.....Centimeter

Fe^{2+}.....Ferrous iron

Fe^{3+}.....Ferric iron

g.....Gram

h.....Hour

H^{+}.....Hydrogen ion

HCW.....Hot carcass weight

IMPS.....Institutional meat purchasing specifications

in.....Inches

kg.....Kilogram

KPH.....Kidney, pelvic and heart fat

mm.....Millimeter

NBQA.....National Beef Quality Audit

REA.....Ribeye area

SAS.....Statistical analysis software

SEM.....Standard error of the mean

USDA.....United States Department of Agriculture

WBSF.....Warner-Bratzler shear force

LIST OF SYMBOLS

°...Degree

% ....Percent

CHAPTER 1. LITERATURE REVIEW

Introduction

Tenderness is a main driver in beef consumer satisfaction and encourages return customers (Boleman et al., 1997). Since 1991, the National Beef Quality Audit has been performed every 5 years in order to determine the current status of the industry and to address issues facing the industry. In the six quality audits that have been performed, 'tenderness' or 'eating satisfaction' have been listed as one of the six top priority quality challenge facing the industry at that time (NBQA, 2016). In addition, 55% of packers said they would pay 10% premium for the ability to market a product as "satisfaction guaranteed" (NBQA, 2016) and consumers have reported that they would be willing to pay more for a certified tender product (Boleman et al., 1995*a*). However, it has been difficult to determine what affects final tenderness of beef and it has been difficult to keep up with an ever evolving beef industry.

In 2015 the United States produced more beef than in 1977 with 13 million fewer cattle harvested (Maples et al., 2018). This increase can be attributed to improved production practices including improved genetics and nutrition. However, increasing the efficiency of beef cattle in the United States beef industry also resulted in increased live cattle weights and increased carcass weights, with an increase in carcass weight of almost 45 kg in the past decade (Maples et al., 2018). In 2016, the National Beef Quality Audit reported carcass weight and size was considered a top six priority area, behind food safety, eating satisfaction and lean fat and bone (NBQA, 2016). In addition to the increase in carcass weights, the industry has seen an increase in subcutaneous fat, as well as ribeye sizes (Igo et al., 2013).

While there has been significant research of how chilling rates and pH decline influences overall eating quality, little research evaluating how carcass weights could influence overall

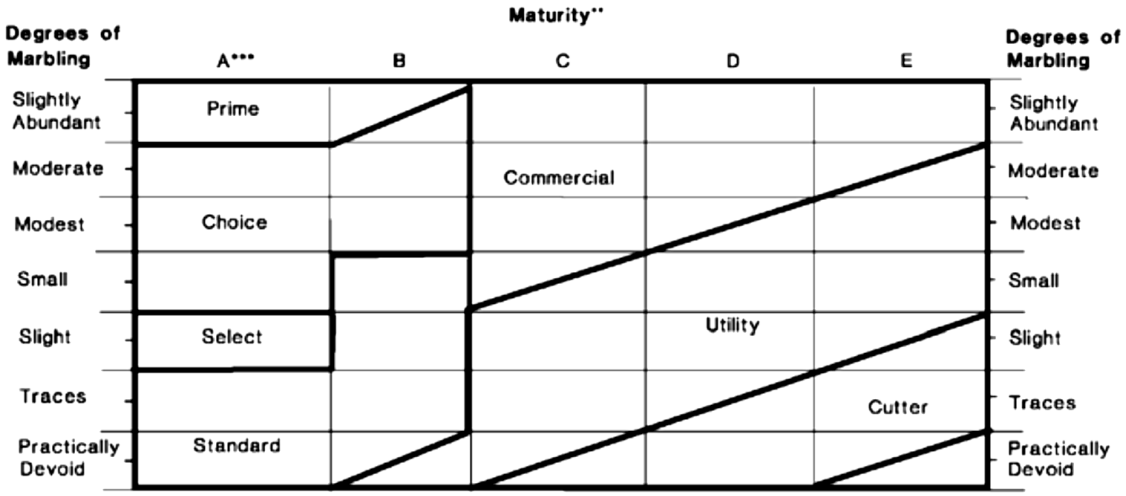
eating quality has been conducted. In addition, much of the research involving chilling rates and pH declines contradict one another, so it is difficult to establish the influences carcass weight have on beef tenderness. The objective of this chapter is to review literature related to carcass chilling, beef tenderness, and meat color.

United States Beef Grading Standards

Beef carcasses in the United States are assigned grades in two separate grading standards, yield grading and quality grading (USDA, 2017). Yield grades are determined using four separate carcass characteristics, including hot carcass weight, 12^{th} rib fat thickness, ribeye area, and kidney, pelvic and heart percentage. The hot carcass weight is the carcass weight prior to chilling. Fat thickness is measured at the exposed interface between the 12^{th} and 13^{th} rib with measurements taken three fourths of the way from the split backbone on the lateral edge of exposed longissimus muscle. Ribeye area is measured in squared inches of the exposed longissimus muscle. Kidney, pelvic and heart fat percentage is measured by estimating the percentage of the hot carcass weight represented by fat around the kidney, in the pelvic area and around the heart. The carcass characteristics are used in an equation to determine the yield grade, the equation is as follows; 2.50 + (2.0 x adjusted fat thickness) + (0.20 x percent kidney, pelvic, and heart fat) + (0.0038 x hot carcass weight) – (0.32 x ribeye area, square inches) (USDA, 2017). The equation is used to determine a numerical yield grade ranging between 1 and 5. A yield grade 1 describes a lean, heavy muscled carcass while a yield grade 5 carcass describes a fat, light muscled carcass.

Quality grading is determined by two factors, marbling and maturity, which interact with each other to determine the final quality grade. Marbling is the white intramuscular fat that is dispersed between the fascicles within the muscle. Degrees of marbling (Abundant, Moderately

Abundant, Slightly Abundant, Moderate, Modest, Small, Slight, Traces and Practically Devoid) correlate to the USDA grades, Prime, Choice, Select, Standard, Commercial, Utility, Cutter, and Canner. Maturity is a combination of both the skeletal maturity (ossification of thoracic buttons) and color maturity. Maturity is classified into A, B, C, D, and E with A maturity being young cattle (less than 30 months) and E maturity (more than 96 months) being old cattle. Maturity can also be established by USDA graders using dentition, age verification or skeletal maturity



(USDA, 2017).

Figure 1.1. Relationship between marbling, maturity and carcass quality grade (USDA, 2017).

Carcass Chilling

There are several types of carcass chilling including delayed chilling, rapid chilling and spray chilling. Delayed chilling is defined as the "process of keeping intact carcasses out of the chill room for some period of time" (Savell et al., 2005). There is conflicting evidence on how delayed chilling affects beef carcass quality, specifically tenderness. Steaks from both steers and cows that were held at 14 – 19 ° C for 20 hours were found to be more tender than carcasses that were chilled conventionally. In addition, steaks from carcasses that were subjected to delayed

chilling also received overall higher consumer acceptability scores (Fields et al., 1976). Additionally, increased tenderness was observed in steaks from carcasses that had been held at a temperature range of 10 – 42 ° C (Martin et al., 1983). However, Will and Henrickson (1976) found that steaks from carcasses subjected to delayed chilling did not show significant improvement in overall tenderness or consumer acceptability.

Rapid chilling (also known as ultra-rapid, blast, or extreme) has not been well defined in literature but is generally accepted as a chilling method which dramatically reduces carcass temperature post mortem (Savell et al., 2005). Again, conflicting results in research makes it difficult to determine the impact of rapid chilling on beef palatability. Joseph (1996) found that carcasses subjected to rapid chill produced retail products with increased toughness and decreased consumer acceptability. However, it has also been argued the use of rapid chilling does not have any significant impact on the consumer acceptability of beef (Bowling et al., 1987).

Spray chilling is the most common and conventional chilling method used in the United States (Greer and Jones, 1997). Spray chilling utilizes chilled water s that is sprayed a few times per hour for 3-8 hours post mortem, in addition to maintaining low temperature conditions and low levels of air circulation (Savell et al., 2005). Spray chilling has been observed across multiple research projects to not significantly impact beef tenderness (Savell et al., 2005). In addition to tenderness, beef color was also observed to not be significantly influenced by the use of spray chilling (Jones and Robertson, 1988).

Beef Tenderness

Tenderness has long been understood to be one of the most important quality attributes in the consumer acceptability in beef products. Additionally, the most common reason for

consumers to find a beef product to be unacceptable was due to toughness (Jeremiah, 1982). In Phase I of the 2011 National Beef Quality Audit, five groups associated with the industry (Government and Allied Industries, Feeders, Packers, Food Service, Distributors and Further Processors and Retailers) were interviewed on what issues and problems their respective industries needed to address in the beef industry. Responses about seven predetermined categories (how and where cattle were raised, lean, fat, and bone, weight and size, cattle and genetics, visual characteristics, food safety and eating satisfaction) were recorded and authors reported the top 3 most frequent answers when asked how they would describe the seven different categories. All five groups ranked 'tenderness' in their top 3 most frequent answers, with Government and Allied Industries answering tenderness 63.8% of the time, Feeders answering tenderness 44.1% of the time, Packers answering tenderness 65.4% of the time, Food Service, Distributors and Further Processors answering tenderness 52.1% of the time, and Retailers answering tenderness 66.7% of the time. These results show beef tenderness is still drives consumer satisfaction of beef products. Several factors can affect the overall tenderness of beef cuts, including muscle fiber types, connective tissue, and genetics and, to some extent, nutrition of the live animal. However, most researchers agree beef tenderness is greatly influenced early in the conversion of muscle to meat.

Conversion of muscle to meat

Conversion of muscle to meat begins immediately postmortem as the muscle tries to maintain homeostasis and due to the lack of oxygen switches metabolism to anaerobic glycolysis. (Maltin et al., 2003). The role of anaerobic glycolysis in muscle after death was first researched by Bate-Smith and Bendall (1949) who found glycogen plays a crucial role in the onset of muscle rigor and muscle pH decline. Using rabbits with varying levels of glycogen (due

to diet), it was found rabbits that had been fed well were more resistant to onset of rigor after death, while those who had been starved had a quicker on set of rigor (Bate-Smith and Bendall, 1949). Anaerobic glycolysis can be defined as the breakdown of glucose without the presence of oxygen. In anaerobic glycolysis, pyruvate is converted to lactate and adenosine triphosphate (ATP) is hydrolyzed to adenosine diphosphate (ADP). The hydrolysis of ATP into ADP results in a free hydrogen ion (H^+) which remains in the tissue. Under aerobic conditions the ADP would undergo rephosphorylation which utilizes the H^+ in order to be converted back into ATP. However, under anaerobic conditions the H^+ remains in the muscle tissue and causes a decrease in muscle pH (Aberle et al., 2012). After ATP has been fully depleted from the muscle, permanent cross-links are formed between myosin and actin which brings the carcass into rigor-mortis and increasing the toughness of the meat (Maltin et al., 2003). These permanent cross-links cause the muscle to become stiff and is known as 'rigor mortis' or 'stiffness of death' (Bate-Smith and Bendall, 1949; Bendall, 1951; Jeacocke, 1982). The myosin-actin cross-links are never resolved but rather postmortem proteolysis degrades structural proteins via endogenous enzymes (Koohmaraie et al., 1996). Postmortem proteolysis will be discussed more in depth in subsequent paragraphs. In addition, electrical stimulation may be used after slaughter to accelerate glycolysis in the muscle, causing a faster pH decline and faster onset of rigor because the ATP in the muscle is used quicker (Martin et al., 1983). Marsh et al. (1987) reported tenderness was most improved when carcasses reached a pH of 6.1 three hours postmortem. However, carcasses with too fast glycolysis can face issues with becoming tough if the pH at three hours postmortem falls below 5.6 (Pike et al., 1993).

Muscle pH decline is not the only factor in the early post mortem period that can influence tenderness of beef products. Lochner et al. (1979) discovered beef tenderness was

highly dependent on longissimus muscle temperature during the 2 – 4 h post mortem time period and points to the theory that well-finished beef is more tender due to the increased temperature, and therefore, a slower temperature decline during the 2 – 4 h post mortem period. Further research has shown carcasses which were considered lean that were held at 37°C for 3 hours post mortem and then moved into a chill cooler were more tender than lean carcasses that were moved directly into a chill cooler (Marsh et al., 1981).

Lastly, more recent research has established a link between muscle pH decline and temperature decline's effects on beef tenderness. Previously it was believed muscle pH should stay as high as possible during the first few hours after exsanguination (Marsh et al., 1981). While it is still true that the goal is to keep pH from declining too rapidly, some researchers believe that a more accurate representation is there is a threshold pH that muscle must reach (5.7) before the temperature drops to below 7° C (Hannula and Puolanne, 2004).

Muscle fiber types

Muscle fiber types may have an impact on overall tenderness in beef due to differences in both the metabolic and contractile natures of the different types of muscle fibers. Most muscle fibers can be classified into three basic types: Type I, slow twitch, oxidative, red; Type IIa, fast twitch, oxidative glycolytic; and Type IIb fast twitch glycolytic, white (Maltin et al., 2003). It can be predicted that due to the metabolic capacity of Type I fibers, muscles with higher amount of Type I fibers would be more tender due to the increased amount of glycogen stored in those fibers versus Type IIb, and to some extent, Type IIa fibers. In addition to the metabolic capacity, Type I fibers are smaller in diameter, while Type IIa and Type IIb fibers are larger in diameter which has been shown to increase in toughness in beef (Maltin et al., 2003). However, researchers in several studies have found it difficult (Morrison et al., 1998; Vestergaard et al.,

2000; Wheeler et al., 2000) to definitively attribute variance in tenderness to specific changes in muscle fiber types and most have determined the relationship is likely heavily influenced by other factors.

Connective tissue

Connective tissue can have significant overall effects on beef tenderness. Connective tissue increases as animals mature through perimysial thickening, endomysial maturation and formation of permanent collagen cross-linking (Robins et al., 1973). Collagen and elastin are both present in the endomysium and perimysium in a matrix of proteoglycan (Lepetit, 2007). Collagen is the most abundant protein in the mammalian body and is found in a triple-helix form. Collagen has multiple genetic forms, with four of these forms being present in muscle (Bailey et al., 1979) with the major forms being Type I and III. It is widely accepted that the two main reasons collagen can influence tenderness is due to its propensity to shrink when heated, as well as its insoluble nature causing the cross-links to be permanent (Light et al., 1985).

Genetics

Researchers are divided on how genetics influences beef tenderness, but most are in agreement that certain breeds can produce more tender meat. In general, cattle of *Bos indicus* breeding will produce less tender meat than cattle of *Bos taurus* breeding (Crouse et al., 1989). However, on average, most cattle breeds will produce meat of similar tenderness. Most likely genetics in *Bos taurus* breeds do not have a significant influence on final tenderness and more weight should be placed on pre and post-harvest management to determine tenderness (Robinson et al., 2001). However, there has been some results suggest tenderness of products from *Bos indicus* could be improved with genetic improvement of certain breeds (Robinson et al., 2001; Johnston et al., 2001).

Nutrition

In general, the idea nutrition could influence beef tenderness is associated with the calpain system. Several studies (Kerth et al., 1995; Boleman et al., 1995*b*; Harris et al., 2001) have shown meat injected with calcium resulted in improved tenderness. However, in other studies (Wiegand et al., 2001; Scanga et al., 2001) cattle were fed increased levels of calcium in an effort to increase the amount of serum calcium and therefore increase the activation of the calpain system. These studies found that while serum calcium was increased, there was no observed improvements in tenderness.

Post Mortem Proteolysis

Post mortem proteolysis has a great effect on the meat tenderization. In 1988, Koohmaraie defined a protease system to be considered to be part of post mortem proteolysis (and thus have a significant role in meat tenderization) it must meet three criteria. The first criteria is the protease must be endogenous in skeletal muscle cells; the second criteria is that *in vitro* the protease must be able to "mimic post mortem changes in the myofibril" (Kemp et al., 2010); The third criteria is the protease must have access to the myofibrils in muscle tissue (Kemp et al., 2010).

Kemp et al., (2010) breaks down possible proteases that serve a role in post mortem proteolysis into four groups; cathepsins, proteasomes, the calpain system and the caspase system. Cathepsins can be grouped into 3 separate families; cysteine, which refers to cathepsin B, H, L and X, aspartic, which refers to cathepsin D and E and serine, which refers to cathepsin G (Kemp et al., 2010). However, researchers doubt cathepsins have an overall significant impact on the tenderness of beef. First, cathepsins reside in lysosomes and must be released from the lysosome in order to act on the myofibrillar proteins, specifically myosin and actin. In addition, there was

very little variation in tenderness of beef samples with varying levels of cathepsin activity (Whipple et al., 1990). Mikami et al (1987) reported cathepsin L was responsible for hydrolyzing troponin T, I and C, nebulin, titin and tropomyosin.

The proteasome is a "multicatalytic protease complex involved in the regulation of a number of basic cellular pathways, by their degradation in the cytosol and nucleus" (Kemp et al., 2010). In order for the proteolysis to occur at least four ubiquitin proteins must attach to the protein that is to be degraded. It was originally believed the proteasome had on impact on post mortem proteolysis (Koohmaraie, 1992). However, it was reported proteasomes in bovine muscle were responsible for post mortem proteolysis of some myofibrillar proteins such as, myosin, actin, tropomyosin and nebulin (Robert et al., 1999).

Calpains are generally accepted as being very important to the tenderization of meat, and account for almost all tenderness changes in postmortem storage of beef (Aberle et al., 2012). Within skeletal muscle there are three known calpains, calpain 1, calpain 2, and p94. Calpain 1 and calpain 2 are both calcium activated. Sorimachi et al (1989) found p94 binds to titin, where proteolysis has been known to occur. However, it has been presented that there was no relationship between p94 and tenderness in pork (Parr et al., 1999). Furthermore, when p94 knockout mice were used to determine the effect of p94 on meat tenderization, no detectable differences were found in myofibrillar proteins, including desmin, nebulin, troponin-T or vinculin (Geesink, Taylor and Koohmaraie, 2005). Calpain 1 is activated in muscle within three days of slaughter, which is within the timeframe where most postmortem proteolysis occurs (Taylor et al., 1995) and is most readily active at pH 7 (Topel et al., 2013). Calpain 1 is considered less stable than calpain 2 and is therefore active for a shorter amount of time with calpain 2 being activated later in the post mortem period (Sensky, et al., 1996). Boehm et al.

reported in 1998 that the calcium concentration in skeletal muscle in the early post mortem period is less than what is needed for the activation of calpain 2. In the past researchers have found it difficult to discover what exact influences calpain 1 and calpain 2 have on meat tenderization.

Researchers believe calpains are the most important in postmortem proteolysis because research shows the infusion of calcium into muscle results in increased tenderness of beef product (Kerth et al., 1995; Boleman et al., 1995*b*; Harris et al., 2001). This is because calpains are activated by calcium while other proteases, such as cathepsins, are not activated by calcium, so it is believed calpains are instrumental in postmortem proteolysis and therefore, final tenderness.

Cold Shortening

It is well-known that the first 24 hours post-mortem are to final palatability and overall acceptability of beef to consumers (Locker and Haygard, 1963; Herring et al., 1965; Hannula and Puollane, 2004). During the first 24 hours several events happen at structural and biochemical levels during the conversion of muscle to meat and some of these events are impacted by how beef carcasses are chilled. Previous to industrial refrigeration carcasses were cooled and kept cool by controlling when the animals were harvested, however, with the rise of technology in refrigeration animals were able to be harvested at any season. However, rise in technology actually created some problems with meat quality when carcasses were chilled to quickly a phenomenon known as 'cold shortening' occurred, which caused an increase in toughness of meat, specifically in beef and lamb (Savell et al., 2005). Cold shortening occurs when there is a very rapid decline in muscle temperature (to less than 14-19° C) before the carcass has entered into the onset of rigor mortis (Locker and Hagyard, 1963). When the muscle is chilled too

quickly the sarcoplasmic reticulum is unable to function correctly leaving calcium ions in the sarcoplasm. Since ATP remains in the system, the muscle is still able to contract resulting in a shortened sarcomere, which is believed to cause the muscle fiber diameter to increase and cause a reduction of tenderness in the meat (Herring, Cassens and Briskey, 1965). It is believed an increase in fat thickness on lamb carcasses can reduce the incidence of cold shortening due to allowing the carcass more time to chill, thereby allowing an increase in biochemical and enzymatic activity (Smith et al., 1976). This relationship has also been theorized in beef with research showing beef carcasses with at least 5-20 mm of subcutaneous fat cover at the 12^{th} thoracic vertebrae had no issues with cold shortening when chilled in a conventional system (Jeremiah and Martin, 1982). Another phenomenon can occur known as thaw rigor if carcasses, especially light weight carcasses, are frozen before the onset of rigor. Thaw rigor occurs when there is a release of calcium ions into the sarcoplasm which can cause contraction during thawing which releases water from the muscle and leads to extreme toughness of meat (Aberle et al., 2012).

Water Holding Capacity

In addition to tenderness, water holding capacity is important to determine fresh meat quality (Huff-Lonergan and Lonergan, 2005). There are three types of water contained within muscle: bound, immobilized and free. Bound water is water bound to the protein in the muscles due to its dipole nature. This water is resistant to freezing, isn't affected by heat and makes up a very small proportion of water in muscle (Huff-Lonergan and Lonergan, 2005). Immobilized water is water trapped between the myofibrils of the muscle and is not able to move during the early postmortem period, however it can be frozen. Immobilized water is most commonly associated with purge (loss of water from meat) and is therefore of the most interest in presenting

moisture loss of fresh meat products (Huff-Lonergan and Lonergan, 2005). Lastly, free water, as the name implies, is water free to move in the muscle and is mostly at the surface of muscle tissue (Huff-Lonergan and Lonergan, 2005).

There are several factors that can affect the ultimate water holding capacity of fresh meat. The first is known as the net charge effect. The net charge effect causes the muscle structure to become more compact and much less capable of binding water. This reduction in space is caused by the muscle reaching its isoelectric point (5.0-5.2 for muscle), or the point where positive and negative charges on the protein are equal meaning. This causes the proteins to no longer repel each other and pack in closer together (Huff-Lonergan and Lonergan, 2005). Another factor is known at the steric or spatial effect. The steric effect influences water holding capacity because about 80% of the water in muscle is held between myofibrils (Aberle et al., 2012) and any changes to the myofibrillar structure can have a significant influence on water holding capacity. During rigor, crosslinks form between myosin and actin which can reduce the amount of space available for water to reside with the spaces between the myofibrils (Offer and Trinick, 1983). With space available for water to reside in the myofibrillar space declining, some of the water may be forced out of the space between myofibrils and into the extramyofibrillar space (Huff-Lonergan and Lonergan, 2005). The loss of water through these spaces is known as drip loss and the water flows out the muscle via drip channels (Topel et al., 2013). However, this water loss can be avoided if the muscle doesn't shrink during the conversion of muscle to meat. This shrinkage can be avoided if the protein (desmin) that connects the myofibrils to the sarcolemma are denatured before shrinkage of the muscle can occur (Topel et al., 2013).

Water holding capacity is arguably more important during the cooking of meat than when it is raw. The inverse relationship between the loss of water during the cooking process and the

juiciness of the cooked product. In addition, there is a positive correlation between juiciness and perceived tenderness in sensory tests (Hughes et al., 2014). This can be interpreted as water being a major determinant of perceived tenderness by consumers. (Hughes et al., 2014).

Meat Color

Kropf (1980) stated meat color at the time of purchase was most likely the single most important driver of United States consumers purchasing decisions at the meat counter. In general, beef is normally thought to be a cherry-red color. In most research settings, muscle color data is collected with a colorimeter which measures the L*, a* and b* values of the muscle which were established in 1976 by the Commission Internationale de l'Eclairage (CIE). L* values determines the lightness of the muscle, with a value of zero being complete blackness. a* values determine the red/green value of the muscle with a more positive value denoting a more red color. a* values are more highly related to determining color stability of meat due to the formation of metmyoglobin on the surface of meat causing the meat to appear more greenish-brown rather than cherry-red (Page et al., 2001). b* values determines the yellow/blue value of the muscle with a more positive value denoting a more yellow color (Xrite, 2016). Consumers have shown beef in a retail case is acceptable when a* values are greater than or equal to 14.5 (Holman, 2017).

Consumer preferred cherry-red color in beef is influenced by the protein myoglobin. Myoglobin is a water-soluble protein that contains a heme ring in the middle that contains 6 binding sites, with 4 sites being used as binding sites for pyyrole nitrogens, one site being used to bind the proximal histidine-93. The last site is used to bind various ligands which can be reversed. These ligands, as well as the valence of iron determine muscle color (Mancini and Hunt, 2005).

There are four major forms of myoglobin which impact meat color, however only three forms will be discussed in this chapter. The first form of myoglobin is deoxymyoglobin, which appears as a dark purple color, occurs when there is no ligand bound to the 6th binding site and heme iron is in the ferrous state (Fe^{2+}). The deoxymyoglobin color is most associated with muscle color when they are first cut, as well as meat that has been in vacuum packaging. (Macini and Hunt, 2005). The second form of myoglobin is oxymyoglobin which appears as the well-known cherry-red color of beef. When the muscle becomes oxygenated (also known as bloom) an oxygen molecule has bound to the 6th binding site of the heme ring, however there is no change in the heme iron from oxymyoglobin and deoxymyoglobin (Macini and Hunt, 2005). The third and final form of myoglobin is metmyoglobin. Metmyoglobin causes the muscle to appear as a muddy brown color. This change in color occurs because of the conversion of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) which is an oxidative reaction (Macini and Hunt, 2005).

Muscle pH can have a significant influence on overall color of beef products. Muscle pH is more correlated to a* and b* values rather than L* values (Wulf and Wise, 1999; Page et al., 2001). Higher muscle pH is associated with beef that is more green and blue in hue, while lower muscle pH is associated with beef that is more red and yellow in hue (Page et al., 2001). This is due to muscle pH affecting how water is bound in the myofibrils and, in turn, influencing how light is reflected off the muscle. Meat with a higher pH will appear darker due to less surface water to reflect light (Page et al., 2001). In addition, muscle with a higher pH may appear darker because enzymes on the surface of the muscle which use oxygen are more active, which could result in less oxygenation of myoglobin (Page et al., 2001).

Implications of Increasing Carcass Weights

In general, as carcass weights increase, the longissimus area also increases linearly (Nour et al., 1983). The increase in longissimus area causes portioned steak thickness to decrease because of the increased surface area (Dunn et al., 2000). The decreases in thickness observed is problematic for the beef industry as consumers show a preference for thicker steaks compared to thinner steaks (Maples et al., 2016). In addition, consumers preferred to decrease the surface area of their steaks (i.e. smaller longissimus muscle size) in order to maintain desired thickness of at least 1 inch (Maples et al., 2016). However, these results are in contrast to research performed by Sweeter et al (2005) which concluded consumers did not have a preference on longissimus muscle size but the preference did trend to larger longissimus muscle size. Interestingly, research has also found while longissimus muscle area increases, muscle areas of other industry important muscles, such as psoas major and semimembranosus, do not necessarily increase (Bass et al., 2009). Furthermore, the relationship between increased longissimus muscle area and other muscle size is most likely cofounded by other variables, such as breed, sex or maturity (Bass et al., 2009).

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CHAPTER 2. TENDERNESS AND JUICINESS OF BEEF STEAKS FROM VARYING HOT CARCASS WEIGHTS

Abstract

Beef hot carcass weights may be related to tenderness and overall eating satisfaction. The objectives of this study were to determine how hot carcass weights affect temperature and pH decline of beef carcasses, as well as, tenderness, juiciness and color of steaks. Beef carcasses (n = 59) were selected at a commercial abattoir based on hot carcass weight and separated into either light, medium or heavy weight groups. Temperature and pH in the longissimus and semimembranosus muscle was measured for 24 hours. After carcasses were chilled for approximately 24 hours, carcass data including ribeye area (REA), 12th rib backfat (BF), kidney, pelvic and heart fat percentage (KPH), marbling score and USDA final yield grade were collected. Ribeye rolls (IMPS 112a) and inside rounds (IMPS 160a) were collected at the plant. Data were analyzed using the mixed procedure of SAS (SAS Institute, Cary, NC). Longissimus muscle temperature of light weight carcasses was lower at 4 h compared to heavy weight carcasses ($P = 0.02$). Semimembranosus muscle temperature of light and medium weight carcasses was lower at 24 h compared to heavy weight carcasses ($P < .0001$). There were no differences in pH decline ($P \geq 0.16$) among carcass groups. There were no differences in fat thickness, KPH or marbling score ($P \geq 0.12$) among carcass groups. There were no differences in drip loss, cook loss or WBSF in either longissimus or semimembranosus muscles ($P \geq 0.10$) among carcass groups. Color data indicated steaks from heavy weight carcasses were redder than steaks from light weight carcasses ($P \leq 0.02$). Hot carcass weight did not have an influence on overall meat quality attributes of steaks, however, hot carcass weight did have an effect on color.

Introduction

Tenderness is a main driver in beef consumer satisfaction and encourages return customers (Boleman et al., 1997). With this knowledge, research needs to be continually conducted in the United States in order to better understand what affects beef tenderness and how the beef industry can deliver a consistent and satisfying products to consumers. In 2015, the United States produced more beef than in 1977 with 13 million fewer cattle harvested (Maples et al., 2018). This increase can be attributed to many improved production methods including better genetics and nutrition. Increasing the efficiency of beef production in the United States has caused live cattle and carcass weights to increase with an increase in carcass weight of almost 45 kg in the past decade (Maples et al., 2018). In 2016, the National Beef Quality Audit reported than carcass weight and size was considered a top six priority area, behind food safety, eating satisfaction and lean fat and bone (NBQA, 2016). In addition to the increase in carcass weights, the industry has seen an increase in subcutaneous fat, as well as ribeye sizes (Igo et al., 2013).

While there has been significant research over the years of how chilling rates and pH decline ultimately affects overall meat quality of beef, there has been little research evaluating how hot carcass weights could impact overall meat quality. The objectives of this research were to evaluate chilling rate and pH decline of carcasses from different weights classes and how they relate to tenderness and juiciness of longissimus and semimembranosus steaks.

Materials and Methods

Experimental design and carcass measurements

Beef carcasses (n = 59) were selected over five different collection days over five months at a commercial abattoir (DemKota Ranch Beef, Aberdeen, SD). Carcasses were selected after completion of the harvest process and before moving into chill coolers. Carcasses were selected

in various weight ranges: light (< 363 kg), medium (363- 408 kg), and heavy (> 408 kg). Approximately 45 minutes following exsanguination, carcasses were moved into chill coolers and muscle pH was immediately measured using a pH meter with a solid glass probe (MPI pH meter, Meat Probes Inc., Topeka, KS) from the center of the semimembranosus and the longissimus between the 12th and 13th rib. Additionally, temperature was taken and recorded for 24 hours with a multilogger thermometer (HH506RA thermometer, Omega Engineering Inc., Stamford, CT). A thermometer probe (Chromega-Alomega KHSS-18G-RSC12, Omega Engineering Inc., Stamford, CT) was inserted into the longissimus muscle on the external fat side at approximately the sixth rib and a second thermometer probe was inserted directly into the center of semimembranosus muscle. Muscle pH measurements were taken in the same location at four and 24 hours after initial measurements.

After carcasses were chilled for approximately 24 hours, carcass data were collected including ribeye area (REA), 12th rib backfat (BF), kidney, pelvic and heart fat percentage (KPH), marbling score and USDA final yield grade. USDA final yield grade was calculated using the following equation, YG = 2.5 + (2.5 x adjusted fat thickness) + (0.2 x KPH %) + (0.0038 x HCW) – (0.32 x REA) (USDA, 2017). Four carcasses with abnormally dark colored lean were identified from the selected carcasses and left in the data set. Ribs and rounds were marked using blue edible grader ink on the external fat surface to track primals to specific test carcasses. Upon fabrication, ribeye rolls (IMPS 112a) and inside rounds (IMPS 160a) were transferred to the North Dakota State University Meat Laboratory in vacuum sealed bags. On day 3 and day 14 postmortem, muscle samples were taken from ribeye rolls and inside rounds for further analysis of protein degradation which is not included in this thesis. Longissimus samples were collected from the cranial end of the ribeye roll. Semimembranosus samples were collected

from the proximal end of the muscle. Samples were packaged in wire closure bags bags and immediately frozen at -80° C. After the day three sample collection, subprimals were repackaged under vacuum to allow for "wet" aging of subprimals.

After subprimals were aged for 14 days, three test steaks were fabricated from each ribeye roll and two tests steaks were fabricated from each inside round. Ribeye steaks were removed from the caudal end of the ribeye roll with one ~1.2 cm face steak which was not utilized for any analysis and three ~2.5 cm test steaks being fabricated. The first test steak was immediately overwrapped in clear cellophane and placed in simulated retail conditions. The second test steak was vacuum sealed and frozen at approximately -18 °C for Warner-Bratzler shear force (WBSF) analysis. The third test steak was used to prepare a 50 g sample for drip loss analysis. Round test steaks were fabricated from the semimembranosus muscle. The muscle was split in half across the muscle fibers with two test steaks being fabricated from the distal end of the muscle. The first test steak was immediately overwrapped in clear cellophane and placed in simulated retail conditions. The second test steak was vacuum sealed and frozen at approximately -18 °C for WBSF analysis. A 50 g sample was taken to for drip loss analysis from the proximal end of the semimembranosus muscle.

Drip loss analysis

Muscle samples from the longissimus and semimembranosus were suspended from a paperclip in a wire closure bag to collect water drip loss over a 24 hour time period. Samples were weighed to approximately 50 g prior to suspension and then reweighed after the 24 hour time period to determine drip loss percentage. Drip loss was determined with the following equation: (1 – ((beginning weight – ending weight) ÷ (beginning weight)).

Meat color

After packaging, longissimus and semimembranosus steaks for simulated retail display were placed on a table under continuous fluorescent lightning in a 0° C cooler (American Fluorescent, Model No. PPS232RC, Waukegan, IL). Two L*, a*, and b* measurements were taken every 24 hours for 10 days on a portion of each steak free of subcutaneous fat. Measurements were taken using a Minolta colorimeter (CR-310 Chromameter, Konica Minolta, Tokyo, Japan) using illuminant D65. Rib and round steaks were randomly rotated on the table each day after measurements were taken.

Warner-Bratzler shear force and cook loss analysis

Steaks for Warner-Bratzler shear force (WBSF) were thawed overnight for approximately 12 hours and were then allowed to equilibrate to approximately 20° C prior to cooking. Steaks were weighed and a thermocouple (Omega Engineering Inc., Stamford, CT) was inserted in the geometric center of the steak. Steaks were cook on clamshell style grills (George Foreman Model No. GRP99, Columbia, MO) to an internal temperature of 71° C and reweighed for cooking loss. Cook loss was determined using the follow equation: (1 – ((raw weight – cooked weight) ÷ (raw weight)). Steaks were then cooled to room temperature. Six 1.27 cm cores were from the center of the steaks parallel to the muscle fibers. Cores were sheared perpendicular to the muscle fibers using a shear force machine (United-Smart 1 test system SSTM500, United Calibration Corporation, Huntington Beach, CA).

Statistical analysis

Data were analyzed using the PROC MIXED procedure of SAS (SAS Institute, Cary, NC) with weight class as the main effect and carcass as the experimental unit. Collection day

was included as a random effect and means were separated using the PDIFF option and were considered significant when $P \leq 0.05$.

Results and Discussion

Temperature decline

Least squares means and standard errors for temperature decline for longissimus muscle and semimembranosus muscle are presented in Table 2.1. No differences were observed among hot carcass weight groups in longissimus muscle temperature at 0 hours ($P = 0.81$) and at 24 hours ($P = 0.64$). In addition, no differences were observed among hot carcass weight groups in semimembranosus muscle temperature at 0 hours ($P = 0.28$) and at 4 hours ($P = 0.13$). Longissimus muscle temperature at 4 hours was lower in carcasses classified as light weight compared to carcasses classified as heavy weight ($P = 0.02$). Additionally, semimembranosus muscle temperature at 24 hours was lower in carcasses classified as light and medium weight compared to carcasses classified as heavy weight ($P < 0.0001$). These differences are in agreement with several papers (Lochner et al., 1979; Jones and Robertson, 1988; Okeudo and Moss, 2005) which observe a difference in muscle temperature decline influenced by fat cover. While 12^{th} rib fat thickness was not statistically significant ($P = 0.12$) there were observed differences in fat thickness between light and heavy weight carcasses. It has also been hypothesized the semimembranosus muscle temperature may be more heavily influenced by spray chilling systems due to the close proximity of the water source to the muscle, as well as having less fat cover over the muscle (Jones and Robertson, 1988).

Table 2.1. Least squares means ± standard error of means of the relationship among hot carcass weight and temperature decline in degrees Celsius of beef longissimus and semimembranosus muscle

	Hot Carcass Weights[1]			
	Light	Medium	Heavy	*P* - value
n	20	19	20	
Longissimus				
0 hours	39.62 ± 0.44	39.57 ± 0.45	39.47 ± 0.44	0.81
4 hours	23.29 ± 2.06[a]	24.24 ± 2.08[ab]	25.99 ± 2.08[b]	0.02
24 hours	9.07 ± 6.86	9.44 ± 6.86	9.53 ± 6.86	0.64
Semimembranosus				
0 hours	39.59 ± 0.53	40.06 ± 0.51	40.03 ± 0.51	0.28
4 hours	31.82 ± 3.38	33.09 ± 3.34	34.04 ± 3.31	0.13
24 hours	14.67 ± 9.05[a]	15.57 ± 9.05[a]	17.83 ± 9.04[b]	< 0.0001

[1] Light < 363 kg, Medium 363-408 kg, Heavy >408 kg
[2] 0 hours is approximately 45 minutes after exsanguination
[a,b] Means with similar superscripts within rows are not significantly different ($P > 0.05$)

Muscle pH decline

Least squares means and standard errors for pH decline for longissimus muscle and semimembranosus muscle are presented in Table 2.2. No differences among hot carcass weight groups were observed for longissimus muscle pH at 0 hours ($P = 0.63$), 4 hours ($P = 0.30$) and at 24 hours ($P = 0.16$). No differences among hot carcass weight groups were observed for semimembranosus muscle pH decline at 0 hours ($P = 0.46$), 4 hours ($P = 0.89$) and at 24 hours ($P = 0.29$). These results were expected as glycogen levels would not be different based on hot carcass weight and therefore would not affect muscle pH decline (Pethick et al., 1995). In addition, temperature decline does not seem to influence the rate of pH decline (O'Halloran, 1996). Rather muscle pH decline is ultimately influenced by the rate of ATP-turnover in post mortem muscle during postmortem glycolysis (Bendall, 1978). Additionally, the pH values of the longissimus muscle were lower in the four hour period compared to the 24 hour period, this could be attributed to how pH measurements were taken (same location repeatedly). When this type of measurement is used muscle that is in still in the pre rigor phase can have its pH altered

due to trauma to the cells which could explain the inconsistency in the measurements (Dutson, 1983).

Table 2.2. Least squares means ± standard error of means of the relationship among hot carcass weight and pH decline of beef longissimus and semimembranosus muscle

	Hot Carcass Weights[1]			
	Light	Medium	Heavy	*P* - value
n	20	19	20	
Longissimus				
0 hours[2]	6.48 ± 0.08	6.49 ± 0.08	6.54 ± 0.08	0.63
4 hours	5.85 ± 0.08	5.94 ± 0.08	5.88 ± 0.08	0.30
24 hours	6.04 ± 0.05	6.07 ± 0.05	5.97 ± 0.05	0.16
Semimembranosus				
0 hours	6.48 ± 0.10	6.39 ± 0.10	6.51 ± 0.10	0.46
4 hours	5.76 ± 0.07	5.77 ± 0.08	5.81 ± 0.07	0.89
24 hours	5.52 ± 0.02	5.54 ± 0.02	5.50 ± 0.02	0.29

[1] Light < 363 kg, Medium 363-408 kg, Heavy>408 kg
[2] 0 hours is approximately 45 minutes after exsanguination

Carcass characteristics

Least squares means and standard errors for carcass characteristics are presented in Table 2.3. No differences were observed among hot carcass weight groups for fat thickness ($P = 0.12$), kidney, pelvic and heart fat percentage ($P = 0.99$) and marbling score ($P = 0.88$). Hot carcass weight was different across the three treatments ($P < 0.0001$), due to experimental design. Longissimus area differed between carcasses classified with light and medium weight groups having smaller longissimus areas than those classified as heavy weight ($P = 0.0002$). In addition, USDA final yield grade differed between carcasses with light weight carcasses having lower USDA yield grades compared to carcasses classified as heavy weight ($P = 0.04$). These results were expected due to the known relationship between increasing hot carcass weight and larger longissimus areas and higher USDA final yield grades (Nour et al., 1983).

Table 2.3. Least squares means of the relationship among hot carcass weight and beef carcass characteristics

	Hot Carcass Weights[1]				
	Light	Medium	Heavy	SEM[2]	*P* - value
n	20	19	20		
HCW, kg	337[a]	385[b]	450[c]	3.8	< 0.0001
12th Rib fat thickness, cm	1.2	1.3	1.6	0.1	0.12
Longissimus area, cm^2	78.5[a]	83.0[a]	91.1[b]	2.6	0.0002
KPH, %	2.3	2.3	2.3	0.2	0.99
USDA final yield grade[3]	3.1[a]	3.4[ab]	3.7[b]	0.3	0.04
Marbling score[4]	452	458	462	18.8	0.88

[1]Light < 363 kg, Medium 363-408 kg, Heavy > 408 kg
[2]Pooled standard errors of the means
[3]USDA Yield Grade determined as 2.5 + (2.5 x 12th rib fat thickness, inches) x (0.2 x KPH, %) + (0.0038 x HCW, pounds) – (0.32 x Longissimus muscle area, square inches)
[4]Small = 400, Modest = 500
[a,b,c] Means with similar superscripts within rows are not significantly different ($P > 0.05$)

Drip loss, tenderness and cook loss

Least squares means and standard errors for drip loss, WBSF and cook loss for steaks from longissimus muscle and semimembranosus muscle are presented in Table 2.4. No differences were observed in drip loss ($P = 0.20$), WBSF ($P = 0.97$), and cook loss ($P = 0.95$) of longissimus muscle among hot carcass weight groups. Additionally, no differences were observed in drip loss ($P = 0.15$), WBSF ($P = 0.10$), and cook loss ($P = 0.34$) of semimembranosus muscle among hot carcass weight groups. Results for drip loss and cook loss are consistent with the literature that water holding capacity of raw and cooked meat is the most compromised when pH falls below the normal range of 5.6-5.8 (Huff-Lonergan, 2010). Since samples were within the normal pH range among all treatments, there is no reason to expect a difference in water holding capacity of steaks. In addition, results for tenderness were also in agreement with current literature, which indicates the rate of pH and temperature decline have a significant influence on beef tenderness (Lochner et al., 1979; Hannula and Puolanne, 2004). In addition, our results show longissimus muscle pH was approaching 5.7 before muscles had fully

cooled to 7° C, indicating there should be no observed detrimental effects on meat tenderness of samples (Hannula and Puolanna, 2004). Since our samples did not differ at 24 hour pH for either longissimus muscle ($P = 0.16$) or semimembranosus muscle ($P = 0.29$), there is no reason to expect a significant difference in WBSF measurements due to pH decline.

Table 2.4. Least squares means ± standard error of means of the relationship among hot carcass weight and drip loss, cook loss and shear force values of beef longissimus and semimembranosus steaks

	Hot Carcass Weights[1]			
	Light	Medium	Heavy	*P* - value
Longissimus				
n	19	19	18	
Drip loss[2], %	0.80 ± 0.10	1.00 ± 0.10	0.70 ± 0.10	0.20
Cook loss[3], %	14.64 ± 1.08	15.07 ± 1.08	14.66 ± 1.08	0.95
WBSF, kg	2.18 ± 0.13	2.19 ± 0.13	2.22 ± 0.14	0.97
Semimembranosus				
n	19	19	19	
Drip loss, %	1.00 ± 0.20	1.00 ± 0.20	0.70 ± 0.20	0.15
Cook loss, %	24.95 ± 1.49	26.62 ± 1.49	24.56 ± 1.47	0.34
WBSF, kg	4.27 ± 0.22	3.83 ± 0.22	3.73 ± 0.22	0.10

[1] Light < 363 kg, Medium 363-408 kg, Heavy >408 kg
[2] Drip loss determined as (beginning weight ÷ ending weight) – 1
[3] Cook loss determined as (raw weight ÷ cooked weight) – 1

Meat color

Least squares means and standard errors for L*, b* and a* values of steaks from longissimus muscle and semimembranosus muscle over 10 days are presented in Table 2.5. Longissimus steak L* values are in Figure 2.1 and semimembranosus steak L* values are in Figure 2.2. Day did not influence longissimus steak L* values ($P = 0.82$) or semimembranosus steak L* values ($P = 0.36$). Longissimus steak L* values did differ among treatments ($P < 0.0001$), with steaks from the light weight group having lower L* values than those from the medium and heavy weight groups. In addition, semimembranosus steak L* values also differed among treatments ($P < 0.0001$), with steaks from the light weight group having lower L* values than those from the medium and heavy weight groups. However, these differences are likely due

to the inclusion of steaks in the analysis that were graded as dark cutters, with three dark cutting steaks in the light weight group. This likely led to lower L* values in the light weight group.

Table 2.5. Least squares means ± standard error of means of the relationship among hot carcass weight and instrumental color scores over 10 days of beef longissimus and semimembranosus steaks

	Hot Carcass Weights[1]			
	Light	Medium	Heavy	*P* - value
n	19	19	18	
Longissimus				
L*	45.94 ± 0.26[a]	48.41± 0.26 [b]	48.11± 0.26 [b]	<0.0001
a*	22.59 ± 0.25[a]	22.16 ± 0.25 [a]	23.55 ± 0.25[b]	.0003
b*	10.51 ± 0.14[a]	10.69 ± 0.14[a]	11.35± 0.14[b]	<0.0001
Semimembranosus				
n	19	19	19	
L*	43.83 ± 0.23[a]	46.94 ± 0.23[b]	46.88 ± 0.22[b]	<0.0001
a*	20.39 ± 0.28[a]	21.30 ± 0.28[b]	21.35 ± 0.27[b]	0.02
b*	10.08 ± 0.13[a]	11.30 ± 0.13[b]	11.28 ± 0.12[b]	<0.0001

[1] Light < 363 kg, Medium 363-408 kg, Heavy >408 kg
[a-b] Means with similar superscripts within rows are not significantly different (*P* > 0.05)

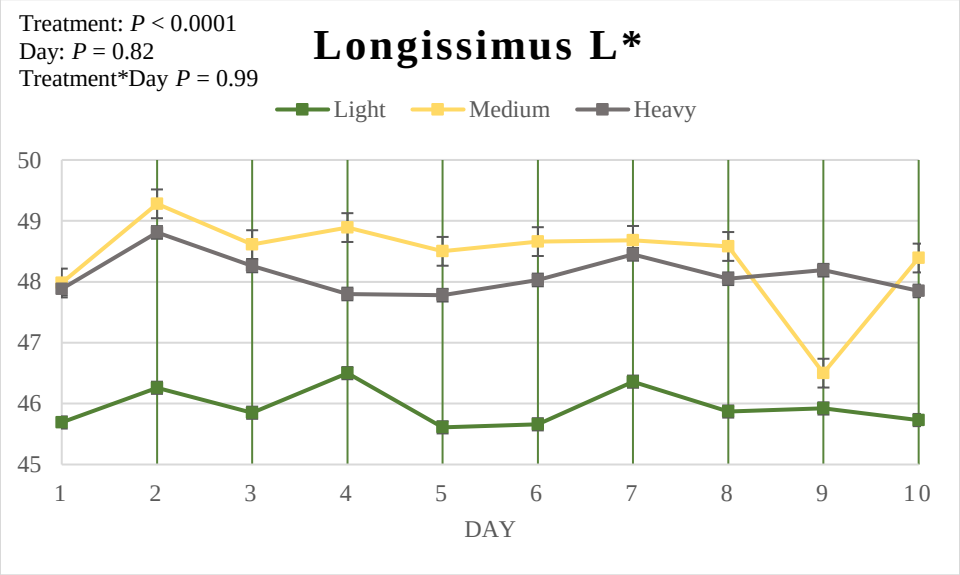

Figure 2.1. Instrumental L* values of beef longissimus steaks from carcasses of varying weight; Light < 363 kg, Medium 363-408 kg, Heavy >408 kg

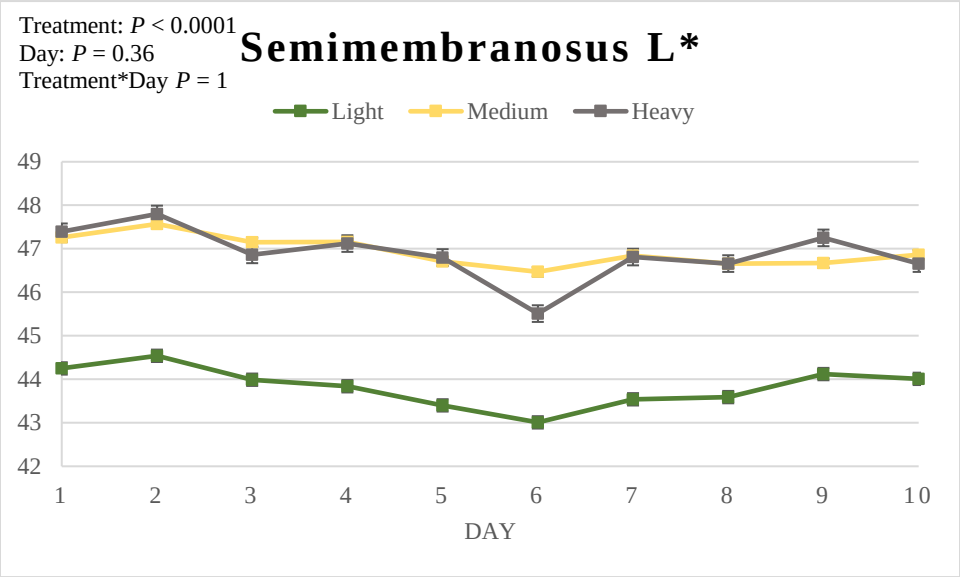

Figure 2.2. Instrumental L* values of beef semimembranosus steaks from carcasses of varying weight; Light < 363 kg, Medium 363-408 kg, Heavy >408 kg

Longissimus steak a* values are in Figure 2.3 and semimembranosus steak a* values are in Figure 2.4. Day was different for longissimus steak a* values ($P < 0.0001$) and semimembranosus steak a* values ($P < 0.0001$). However, this was expected as it is well known that steaks begin to lose color stability as they sit for longer periods of time. Additionally, treatments were different for longissimus steak a* values ($P = 0.0003$) and semimembranosus steak a* values ($P = 0.022$). Longissimus and semimembranosus steaks from carcasses classified as light weight had lower a* values compared to longissimus steak and semimembranosus steak a* values carcasses classified as medium and heavy weight. A lower a* value correlates to a more green color of the steak. These results are in agreement with literature which suggests muscles with a lower pH will have a more desirable cherry-red color longer than muscle with a higher pH, which will turn brownish-green sooner (Wulf and Wise, 1999; Page, et al., 2001). While muscle pH at 24 hours was not significant for longissimus muscle or semimembranosus

muscle, our results do suggest a trend in lower muscle pH having a higher a*, and therefore a more stable red color.

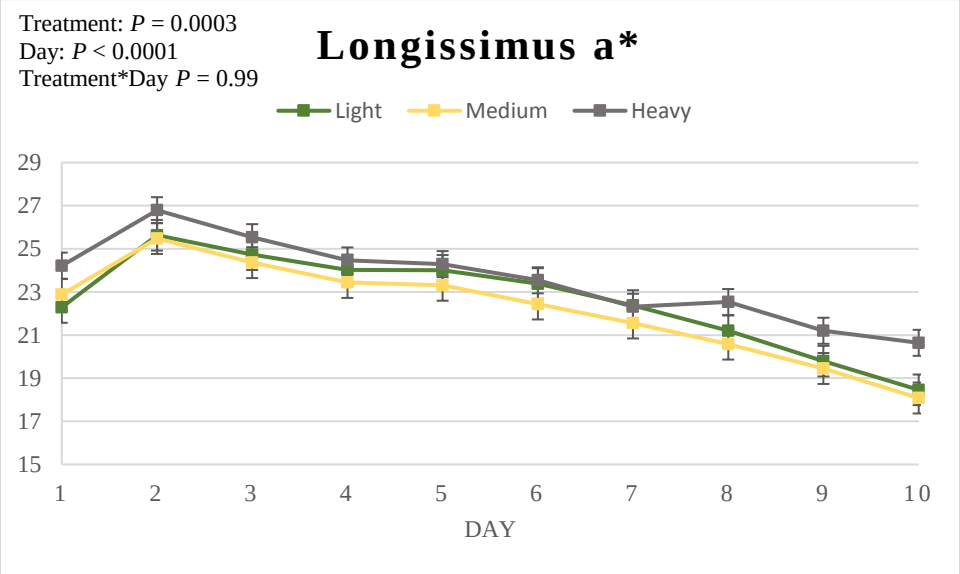

Figure 2.3. Instrumental a* values of beef longissimus steaks from carcasses of varying weight; Light < 363 kg, Medium 363-408 kg, Heavy >408 kg

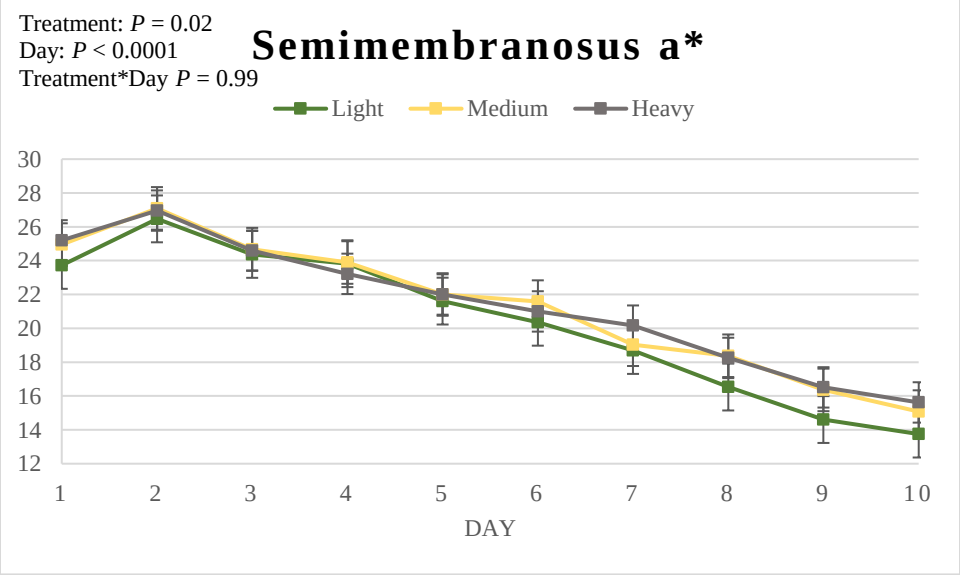

Figure 2.4. Instrumental a* values of beef semimembranosus steaks from carcasses of varying weight; Light < 363 kg, Medium 363-408 kg, Heavy >408 kg

Longissimus steak b* values are in Figure 2.5 and semimembranosus steak b* values are in Figure 2.6. Day was different for longissimus steak b* values ($P < 0.0001$) and semimembranosus steak b* values ($P < 0.0001$). Additionally, treatment was different for longissimus steak b* values ($P < 0.0001$) and semimembranosus steak b* values ($P < 0.0001$). Longissimus steak and semimembranosus steak b* values of carcasses classified as light weight had lower b* values compared to longissimus steak and semimembranosus steak b* values carcasses classified as medium and heavy weight. Lower b* values correlate to a more blue color of steaks. These results are in agreement with literature which suggests muscles with a lower pH will have a more yellow color to the muscle, while muscles with a higher pH, will result in a lower b* value and a more blue color to the muscle (Wulf and Wise, 1999; Page, et al., 2001). While muscle pH at 24 hours was not significant for longissimus muscle or semimembranosus muscle, our results do suggest a trend in lower muscle pH having a higher b*, and therefore a more yellow color to the muscle.

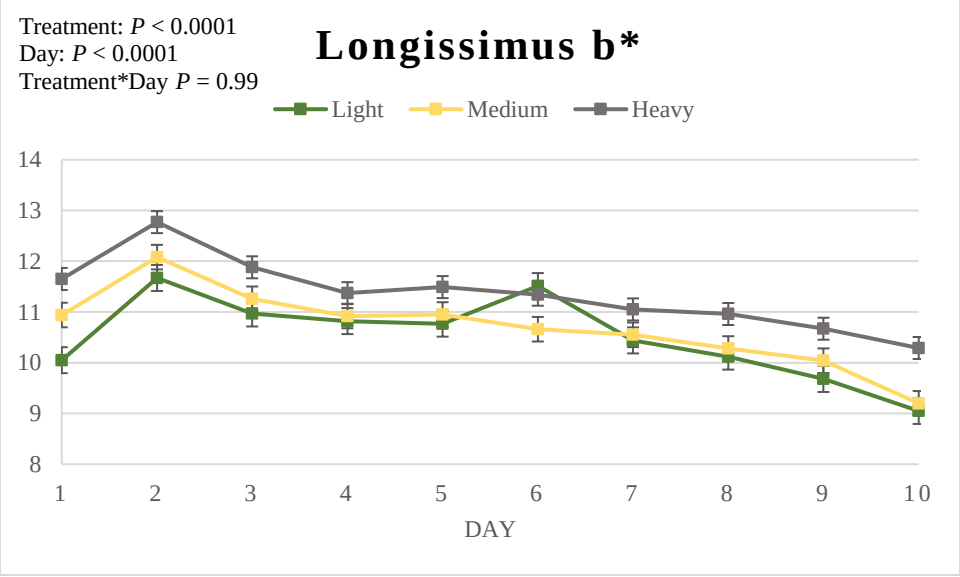

Figure 2.5. Instrumental b* values of beef longissimus steaks from carcasses of varying weight; Light < 363 kg, Medium 363-408 kg, Heavy >408 kg

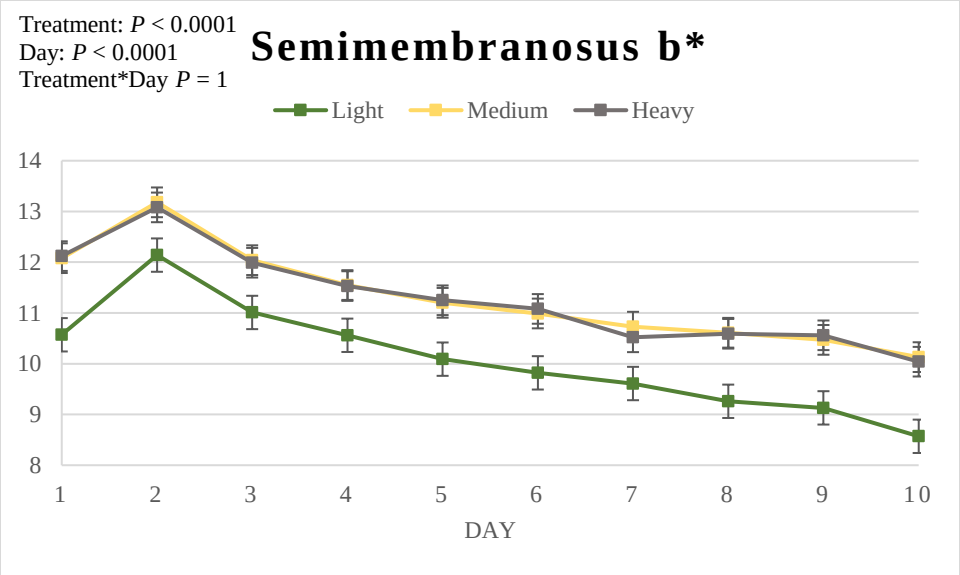

Figure 2.6. Instrumental b* values of beef semimembranosus steaks from carcasses of varying weight; Light < 363 kg, Medium 363-408 kg, Heavy >408 kg

Conclusions

Our results indicate there is some influence on muscle temperature decline due to hot carcass weight. Additionally, our results were in agreement with literature that carcass weights influence longissimus size and final USDA yield grade (Nour et al., 1983). Furthermore, our results indicated muscle pH values may have some influence over meat color, especially a* and b* values. Of particular interest is the steaks from the longissimus muscle and semimembranosus muscle from medium weight and heavy weight carcasses had higher a* values which suggests steaks from medium and heavy weight carcasses may have an advantage in stabilizing a more desirable cherry-red color which most consumers prefer (Kropf, 1980; Holman, 2017). However, our results did not indicate hot carcass weight had any influence over final tenderness of longissimus or semimembranosus steaks. Lastly, it is worth discussing that while there was no influence of hot carcass weight on meat quality attributes, the increase in longissimus area from the heavy carcass weight group could be problematic. Problems may arise because as

surface area of steaks increase (due to increased longissimus muscle size), the thickness of portioned steaks might decrease (Dunn et al., 2000). Consumers have reported a preference for thicker steaks (greater than 1 in) and discriminate against thinner steaks (Maples et al., 2016). Further research is needed in this area in order to keep up with consumer demands.

Our results may mean different things to different segments of the beef industry and consumers of beef products. Beef producers should view our results with caution. While we did not see an influence on tenderness or juiciness of beef steaks due to increased hot carcass weights, producers do need to be aware research is showing that consumers due indirectly discriminate against larger steaks because of thickness of steaks and continued increase in hot carcass weights could result in consumers switching to another protein source such as pork or chicken. Producers may want to be wary of buying feeder calves that have been over selected for carcass traits, such as ribeye size. However, beef producers should also take not that our research indicates fat cover is important in the chilling of beef carcasses and most likely has some influence on producing a more tender product for consumers. Beef packers should also take note of these observations and consider discouraging producers sending under-finished cattle to be harvested in order to avoid an increase in toughness of beef products. Beef packers may also want to consider reaching out to their retail and restaurant customers to gather information on if cut size has been an issue for them in their industries in order to stay ahead of any potential problems their customers may be facing.

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