THE EFFECT OF PACKAGING TYPE AND STORAGE TEMPERATURE ON THE QUALITY CHARACTERISTICS OF BEEF LONGISSIMUS LUMBORUM, GLUTEUS MEDIUS, AND TRICEPS BRACHII MUSCLES AGED FOR EXTENDED STORAGE POSTMORTEM

By

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A THESIS PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2013
To my family
ACKNOWLEDGMENTS

A big thank you first to my parents, whose constant belief in me always helped to reach further in life. To my mother for always being my champion, and for believing in me even when I didn’t believe in myself, and to my father, for being there through everything with love and support and a word of wisdom when I needed it most. Love you both.

I would like to thank everyone at Auburn University for helping me to realize that I was stronger than I ever imagined. Special thanks to the guys (and girls) at the AU Meat lab, especially Barney Wilborn, Pete Holloway, and T.J. Mayfield for helping me get through my college years with a laugh. Thank you especially to Dr. Christy Bratcher for encouraging me to go forward with my education and getting me in contact with Dr. Johnson.

Thank you to everyone in the UF meats lab crew for their unending help with my research and any questions or help I’ve needed. I would also like to thank all the graduate students in the animal sciences department, both past and present, for helping me with anything I may have needed: Dana Schreffler, Mara Brueck, Marisa White, Nick Myers, Justin Crosswhite, and Kyle Johnson. Thank you all for helping me and being an ear for me to fill. I would also like to thank Ryan Dijkhouse for his help with my seemingly never ending data.

I would like to thank Dr. Dwain Johnson for taking a chance and allowing me to come to the University of Florida to further my education. Thank you for answering my unending questions and encouraging me to pursue them further. Thank you also to the other members of my committee, Dr. Chad Carr, and Dr.
Sally Williams for always being there when I came knocking. Thank you to Mr. Larry
Eubanks for his guidance and for keeping me grounded during everything.

Lastly, but never least, I would like to thank Cody Owen. I cannot imagine
where I would be or what a mess my life would look like without him. He has taken
all the craziness I have thrown at him over the past few years and given only love
and support in return. I truly cannot wait to see what happens next in our lives.
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By

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May 2013

Chair: D. Dwain Johnson
Major: Animal Sciences

Packaging type, temperature, and aging were evaluated on palatability, retail color stability, and Warner-Bratzler shear force (WBSF) values of three different subprimals from beef carcasses preselected using USDA-AMS instrumentation data to have marbling scores between Slight$^{50}$ and Small$^{50}$ at the 12$^{th}$/13$^{th}$ rib interface.

Two studies were conducted.

In study one, paired *longissimus lumborum* (LL) muscles (n = 52), and paired *triceps brachii* (TB) muscles (n = 108) were selected from 26, and 54 A-maturity beef carcasses, respectively. Subprimal muscles were aged 21, 32, or 42 days for LL muscles, and 21, 28, or 35 days for TB muscles, in either; DryBag®, traditional vacuum-bag, or no bag at either 0°C or 4°C. Subprimals aged in vacuum-bag packaging retained higher saleable yield. Days 42 and 35 resulted in lighter color in both the LL and TB steaks. The TB steaks that had been aged for 35 days had a higher incidence of off-flavor than other aging periods. The LL steaks from subprimal aged for 32 days had greater WBFS values than steaks from subprimals
aged 42 days, with no significant difference between those steaks aged for 21 or 42 days.

The second study was conducted on the *gluteus medius* (GM) muscle and included the effect of steak location within the muscle on both palatability and WBSF values. Paired GM muscles (*n* = 74) were collected from (*n* = 37) carcasses 24 hours postmortem. One subprimal from each pair was 14, 28, or 42 days at either 0± 2°C or 4± 2°C in either DryBag® or traditional vacuum-bag. Subprimals stored in vacuum-bags had higher saleable yield than the DryBag®. Steaks with the least amount of age (14d) were more red and more yellow, objectively. Tenderness was higher with less connective tissue at 4°C and 0°C for vacuum and DryBag®, respectively. Steaks taken from more posterior locations had lower tenderness compared to steaks from the anterior locations. Outcomes from these studies indicate a need for more research on the GM to further investigate locational tenderness and to continue the search for optimum aging length and conditions to increase quality characteristics of beef.
CHAPTER 1
BACKGROUND INFORMATION

Since 2011 approximately 60% of all beef cattle harvested in the US fall into a marbling score of Slight\(^50\) to Small\(^50\) (Cargill, 2011), but little research has evaluated the effects of postmortem aging on this selection of beef. Generally, cuts from these carcasses will tend to be leaner than those from high Choice carcasses or Prime carcasses. Also important to note is the fact that consumers are demanding leaner and smaller cuts of beef while still holding it to a level of tenderness equal to that of a much higher grade of beef (Menkhaus et al., 1993; Robbins et al., 2003). Consumers that prefer a leaner cut of beef are leading the beef industry to develop steaks from cuts of meat that would previously have been included in roasts (Shackelford et al., 1995).

Aging postmortem continues to be the most commonly used method in the industry to improve the quality and consistency of fresh beef. The 2010 National Beef Tenderness Survey (Guelker et al., 2012) found that no significant changes in tenderness had occurred since the previous survey which stated that tenderness issues are still plaguing various retail cuts from the round and the top sirloin steak (Brooks et al., 2000). A 1999 study reported that approximately 21% of top sirloin steaks and 13% of strip loin steaks purchased from supermarkets had shear force values above 4 kg, putting them in the range of “slightly tough” (George et al., 1999). Additional research must be accomplished to provide better insight into a more reliable method of increasing tenderness and palatability in these cuts.

Currently, there is an effort to develop steaks of equal tenderness and palatability as those from the rib and short loin, but at a lower cost to consumers.
Interest has increased on possible steaks from the chuck especially. Several new steaks have been developed from the chuck that rival muscles from the rib and short loin. These include the Denver steak, the Vegas strip, and the flat iron steaks. The industry must continue to develop these and other cuts to provide for optimal use of the entire carcass while ensuring a tender cut of meat that is acceptable to consumers.

To that effect, only a few studies have evaluated the top sirloin, or gluteus medius steak (Harris et al., 1992; Savell et al., 1999; King et al., 2009) or beef shoulder steak (Shackelford et al., 1995; Rhee et al., 2004; King et al., 2009). However, none of these studies assessed lean color stability during retail display, although it is seen by consumers as vastly important (Gutowski et al., 1979). Consumers prefer a bright cherry red colored beef steak. The visual appearance of steaks while in retail display is the main determinant as to whether a consumer will purchase that product at retail (Wulf and Wise, 1999). Temperature has also been reported to have an impact on postmortem aging and tenderness. Parrish et al., (1969) found that steaks taken from muscles held at higher temperatures were more tender than those steaks from muscles held at a lower temperature (Parrish et al., 1969), and King et al., (2009) reported that slight variations in aging temperature impacted tenderness.

The impact of steak location on palatability and color stability has been investigated within the rib and short loin (Belew et al., 2003; Wheeler et al., 2007), round (Reuter et al., 2002; Sawyer et al., 2007), and chuck (Bratcher et al., 2005). However, the only known work documenting the impact of sirloin steak location on
palatability was by Rhee et al., (2004) which addressed steak location anterior to posterior, but did not address location dorsal to ventral. Purveyors who fabricate center-cut top butts for foodservice cut the subprimal in half anterior to posterior prior to fabricating steaks, but no known publication documents the differences in palatability between the locations.

Therefore, the objective of this study was to evaluate the effects of packaging type, storage temperature, and postmortem aging period on three muscles, the longissimus lumbarum, triceps brachii, and the gluteus medius to develop the most reliable method of enhancing the quality characteristics desired by the consumers, as well as to ascertain locational variations within the gluteus medius to allow for the maximum level of eating satisfaction for beef consumers.
CHAPTER 2
LITERATURE REVIEW

Tenderness

The factors that determine beef palatability are tenderness, juiciness, and flavor. Within these three, tenderness has been stated as the attribute most desired by consumers when eating a steak (Huffman et al., 1996).

Factors Affecting Tenderness

Many factors influence the tenderness of beef, including postmortem proteolysis, intramuscular fat, connective tissue, and the state of muscle contraction (Belew et al., 2003). The mechanisms thought to be responsible for the increase in tenderness resulting from postmortem aging have been studied extensively but still remains unclear. Proteolysis of the myofibrillar protein is considered to be the major influencing contributor to the increased tenderization of postmortem aging. These proteins ensure inter- and intramyofibril linkage and attach myofibrils to sarcolemma by costameres. Proteolysis of these proteins causes weakening of the structures that leads to an increase in tenderness (Koohmaraie, 1996; Sentandreu et al., 2002).

Methods of Measuring Tenderness

Several methods are available to aid in measuring meat tenderness. They are categorized as trained taste panel evaluation by a human panel, and the use of instruments such as ultrasound, shear force evaluation, and trained sensory panel evaluation.

Warner-Bratzler Shear Force. Beef tenderness can be measured objectively using mechanical means, mainly mechanical shear force, which is a measure of myofibril
toughness (Bouton and Harris, 1972). The most common method of mechanical shear force is Warner-Bratzler shear force. This method was first developed by K. F. Warner in the late 1920s and was developed further by L. J. Bratzler in the 1930s (Wheeler et al., 1996). It measures the kilograms of force needed to shear a core sample of a muscle approximately 1.27 cm thick. The samples are cooked to an internal temperature of 71°C, and allowed to cool, and then four to six samples are removed parallel with the fiber direction and sheared across the muscle fiber direction. The more force that is needed to shear the muscle, the tougher the muscle is considered. Several researchers have addressed the need for a standard measurement for evaluating WBSF values.

In the 1990 Beef Tenderness Survey (Morgan et al., 1991) evaluation of 14 cities and numerous beef cuts showed a correlation between a WBSF value of below 3.9 kg, and a confidence level of 68%, with those cuts considered to be at least moderately tender. As the shear force value increased over the 3.9 kg level, steaks were considered to be tough, and confidence level decreased. Devitt et al., (2002) assumed a result of 4.05 kg or less would be classified as tender, and tough meat would be 5.64 kg and greater. Miller et al., (2001) proposed tenderness values of < 3.0, 3.4, 4.0, 4.3 and >4.9 kg would result in 100, 99, 94, 86, and 25% consumer satisfaction for beef tenderness, respectively. Shackelford et al., (1997) classified a carcass as being tender if its longissimus shear value was <6 kg, intermediate at 6 to 9 kg, and tough if the shear value was > 9 kg. In the study, 100% of the carcasses classified as tender had WBSF values below 6 kg after 14 days postmortem. Huffman et al., (1996) stated that a target value of 4.1 kg or less
should be maintained for high levels of consumer acceptability. The National Beef Tenderness Survey (Brooks et al., 2000) used a threshold value of 3.9 kg to differentiate products that were most likely to be considered tender and a 4.6 kg to separate beef that could be considered tough. Several studies have found that WBS values have a strong correlation to consumer sensory panel tenderness scores (Miller et al., 2001; Platter et al., 2003).

Shorthose et al., (1988) found that WBSF did not accurately reflect tenderness differences among various muscles. Regardless of this one study, most researchers use WBSF for an objective measurement of muscle tenderness. Shackelford et al., (1995) and Van Oeckel et al., (1999) stated in their respective studies that assessing the tenderness of cooked meat samples is more easily accomplished using WBSF than by trained sensory panel analysis. They also stated WBSF to be less expensive and less time consuming because of the ability to do multiple samples in the same day without the concern of possible variations within a trained sensory panel.

One of the limitations of WBSF is the lack of information interpreting the results. According to Miller et al., (1995), while WBSF values correlate highly with sensory panel tenderness scores, there is no explanation within the values for “cohesiveness of mass, springiness, number of chews required to segment a meat sample, initial juiciness, sustained juiciness, connective tissue amount, or muscle fiber tenderness.” WBSF lacks an explanation for why a particular piece is tougher than another. For this reason, trained sensory panel evaluation is another important
part of objectively evaluating all quality characteristics of beef cuts (Miller et al., 1995).

**Trained Sensory Evaluation.** Trained sensory panel evaluation is also used as a measurement of beef tenderness as well as other quality characteristics. Smith et al., (1978) demonstrated the correlation between a trained sensory panel and shear force values for 14 muscles to be at $r = 0.48$, suggesting that shear force and trained sensory panel tenderness ratings are sufficiently correlated to justify use of either measure for determining tenderness of muscles in beef (Smith et al., 1978).

While tenderness is considered the most important qualitative characteristic of meat, it is also highly variable and is dependent on many intrinsic and extrinsic factors (Destefanis et al., 2008). While objective measurements like WBSF allows a comparison of different treatments and allows testing of their effects on tenderness, it does not provide information concerning the acceptability of the product or the preference of one kind of meat over another (Wheeler et al., 1996).

**Muscle Location**

The same factors that contribute to the tenderness of individual steaks also contribute to the differences in tenderness between different muscles within the same beef carcass. Those cuts coming from the rib and loin have been shown to be highly marketable while those from the chuck and round are perceived to have tenderness problems and are reduced to ground products or large roasts or cuts that require moist heat to become tender, which decrease their potential value. Belew et al., (2003) studied the WBSF values of 40 bovine muscles to determine the extent of the variation within a carcass. The study found that the historical generalization that states, support muscles are more tender than various locomotive
muscles, are less applicable than previously insinuated. Several muscles from the forearm (biceps brachii) proved to be more tender than some support muscles (longissimus thoracis and longissimus lumborum) and muscles that were in close proximity to one another were markedly varied in tenderness (Belew et al., 2003). Muscle profiling research (NCBA, 2000) identified several individual muscles that possessed desirable tenderness, flavor attributes, or both (Von-Seggern et al., 2005). In a study by Gruber et al., (2006) WBSF values for 17 muscles varied greatly. The study placed the psoas major and the infraspinatus among the most tender muscles, and the semimembranosus as the least tender muscles, regardless of any length of postmortem aging within the study (Gruber et al., 2006)

Shackelford et al., (1995) measured the relationship between shear force and overall tenderness of 10 major beef muscles as well as the relationship between the tenderness of the longissimus and tenderness of other muscles within the same carcass. Steaks were obtained from A-maturity, grain fed, crossbred steers from the supraspinatus (SS), infraspinatus (IS), triceps brachii (TB), longissimus (LD), gluteus medius (GM), psoas major (PM), semimembranosis (SM), semitendinosus (ST), biceps femoris (BF), and quadriceps femoris (QF) at 14 d postmortem. Steaks were measured using Warner-Bratzler Shear force (WBSF) and trained sensory panel evaluation for tenderness and other quality characteristics. The differences found in overall tenderness among the muscles were consistent with previous findings of Ramsbottom and Strandine (1948), Shorthose and Harris (1990), and Morgan et al., (1991) showing PM = IS > TB = LD > ST = GM = SS > BF = SM = QF. In this study, WBSF failed to detect any
correlation between TB, LD, ST, GM, BF, SM, and QF. The data suggests that accurately predicting the tenderness of the LD muscle may not have a large impact on tenderness of other muscles, because of the wide variation in tenderness found (Shackelford et al., 1995).

**Steak Location**

It has been established that a tenderness gradient exists within various muscles of a beef carcass.

Rhee et al., (2004) studied the variations within eleven beef muscles. The eleven muscles were removed from thirty-one Charolais cross, A-maturity steers and aged for 14 days postmortem then frozen at -30°C. Frozen steaks were cut and assigned to either trained sensory panel evaluation or Warner-Bratzler shear force analysis. The study found locational effects for WBSF within the *psoas major* (PM), *semitendinosus* (ST), *biceps femoris* (BF), *semimembranosus* (SM), and *rectus femoris* (RF), with the greatest variation being within the SM. WBSF increased from the proximal to the distal portions of the muscle. The posterior end of the ST had higher shear force than the other locations. The finding within in this study are consistent with those of Shackelford et al., (1997). The study found few correlations among traits were significant. A tenderness gradient also exists within steaks obtained from the *longissimus* muscle (Alsmeyer et al., 1965; Sharrah et al., 1965; Smith et al., 1969). The samples taken from the medial and dorsal portion of the *longissimus dorsi* muscle were more tender than those from the more lateral positions within these studies.
Aging

The aging of fresh beef products has become an integral process of the beef industry in order to meet the ever rising demands and expectations of consumers. The aging process involves storing meat at refrigerated temperatures for a sufficient amount of time in order to maximize palatability characteristics such as tenderness, juiciness, and flavor (Campbell et al., 2001; Laster et al., 2008). It is well documented that aging increases beef tenderness (Bate-Smith., 1948; Smith et al., 1978; Calkins and Seideman, 1988). Multiple factors have been identified that influence beef tenderness, including postmortem proteolysis, intramuscular fat, connective tissue, and the contractile state of the muscle (Belew et al., 2003).

Mechanisms of Aging

The mechanisms that are responsible for the increase in tenderization during postmortem aging are well documented (Koohmaraie, 1988; Quali, 1990; Koohmaraie et al., 1991; Taylor et al., 1995). Z-disk degradation of the myofibrillar structure occurs to increase tenderness, but does not occur until after the first 3-4 days of postmortem aging (Taylor et al., 1995). Calpain is an endogenous, Ca$^{2+}$ dependent proteinase that functions to initiate in-vivo muscle protein degradation, while calpastatin is an endogenous inhibitor that helps to regulate calpains (Page et al., 2002). While calpain is activated by Ca$^{2+}$ and reproduces the postmortem changes in myofibrils that are associated with an increase in meat tenderness (Koohmaraie, 1988), it appears that there is a positive relationship between calpastatin levels and meat toughness that affects the effectiveness of postmortem aging (Johnson et al., 1990; Wulf et al., 1996).
During the aging process, proteolytic and lipolytic enzymes cause modifications within various compounds such as amino acids, peptides, and fatty acids that result in flavor and tenderness modification. Lipid oxidation results in an increase in carbonyl amounts, which can contribute to any off-flavor associated with aging beef (Yancey et al., 2005).

**Methods of Aging**

The environment under which the beef is aged influences the resulting flavors and characteristics of the meat. There are two generally accepted methods of aging meat, wet aging and dry aging (Warren and Kastner, 1992). Dry aging refers to carcasses or subprimal cuts held at a temperature and humidity controlled refrigerated temperature without any type of protective packaging. Dry aging flavor attributes include beefy, brown roasted flavor that differ from the bloody, serumy flavors with metallic notes that can be produced with wet aging (Warren and Kastner, 1992; Campbell et al., 2001). Wet aging is more common and refers to meat that is aged in a vacuum sealed barrier package at refrigerated temperatures. The majority of all beef is vacuum packaged at the packer level then shipped to its destination where it can then be further wet aged or removed from its packaging and dry aged. Wet aging is more common because it will produce the desired increase in tenderness and flavor without the loss of yield and the necessary increase in space associated with dry aging. A consumer sensory study by Sitz et al., (2006) evaluated wet verses dry aging Prime and Choice strip steaks. Consumers rated wet-aged Prime strip steaks significantly higher for flavor and overall acceptability as compared to the dry-aged Prime strip steaks. However, there was no comparable difference in flavor or overall acceptability for dry-aged
versus wet-aged Choice strip steaks. A comparison study by Parrish et al., (1991) determined that little or no cooler shrink was observed with the wet-aged product, and while steaks from both the wet and dry aging method produced very palatable products, steaks that were wet aged had higher scores for tenderness and overall palatability. Similarly, a 2008 study by Laster et al., (2007) found that wet aged ribeye steaks received higher ($P = 0.04$) ratings than their dry aged counterparts for tenderness. There was no significant difference found for overall flavor or juiciness and the effect of aging period had no impact ($P > 0.05$) on any of the consumer sensory attributes of beef ribeye steaks (Laster et al., 2008).

The majority of the research on postmortem aging has been conducted using the *longissimus* or a similarly tender muscle. Smith et al., (1978) reported that 11 or more days of postmortem aging would maximize tenderness of the majority of muscles from the chuck, rib, loin, and round of USDA Choice beef carcasses. Gruber et al., (2006) studied the effect of aging of 17 beef muscles of various USDA quality grades and found tenderness increased with the increasing time of postmortem storage.

The main drawbacks of dry aging beef is the shrink loss and increased cutting times, as well as the need for strict environmentally controlled conditions (Warren and Kastner, 1992; Campbell et al., 2001). A third method of aging beef has recently been introduced to the industry in an attempt to alleviate these issues. The use of a vacuum bag that is highly permeable to water vapor would in theory produce a product with the flavors associated with dry-aged beef without the drastic shrink also associated with dry aging. Researchers (Ahnstrom et al., 2006 and
DeGeer et al., 2009) have demonstrated the effectiveness of this alternative packaging method when aging beef for extended periods of time postmortem but did not include intermediate levels of marbling nor muscles other than the longissimus in their respective studies. Ahnstrom et al., (2006) compared traditional, unpackaged dry aging to dry aging within the highly moisture-permeable bag and found no difference in weight loss between the dry aged and bagged dry aged. However, after 21 d unpackaged subprimalss lost more weight during aging and trimming ($P < 0.05$) than those aged in the bags for 21 d. Also notable in the study was that no differences existed among aging methods or times for cook loss, shear force, or any measured sensory attributes except for astringent flavor (Ahnstrom et al., 2006). The second study (DeGeer et al., 2009) found similar results. No significant differences ($P > 0.05$) in any of the sensory traits between the traditional dry aged and the bagged dry age. The dry aging in a bag created positive effects on the yields and held no negative effects on quality (DeGeer et al., 2009).

Storage Temperature

The temperature at which meat is stored during the postmortem aging period is critically important. While several studies have measured overall tenderness after postmortem age, storage temperatures have varied within these studies, generally from 0°C to 4°C (Miller et al., 1985; Warren and Kastner, 1992; Ahnstrom et al., 2006; Smith et al., 2008; Laster et al., 2007), but the impact of this temperature variation within postmortem aging has not yet been studied extensively.

Busch et al., (1967) demonstrated that steaks held at 16°C for 2 days were more tender than steaks stored at 2°C for 13 days. But while increasing the storage
temperature will increase the enzymatic processes involved in aging, it will also increase the microbial spoilage process (Savell and Rosenthal, 2008).

**Length of Postmortem Age**

Although it is widely accepted that postmortem aging increases tenderness in fresh beef, most researchers disagree on the days of age necessary for optimal tenderness. The 2010 National Beef Tenderness Survey (Guelker et al., 2012) found subprimal post-fabrication storage or aging times at retail establishments averaged 20.5 days while foodservice establishments averaged a time of 28.1 days of postmortem age. Overall average aging periods have decreased on both retail and foodservice establishments from the 2006 National Beef Tenderness Survey (Voges et al., 2007) which found 22.6 and 30.1 days of age, respectively. The range of days found in the 2010 study was also more expansive than that of the 2006 study at 1-358 days to 3-83 d, respectively.

Miller et al., (1997) found that aging beef for 14 days improved beef tenderness consistently and should therefore be recommended as a processing control point for the beef industry. Gruber et al., (2006) showed a decrease in WBSF values of 17 different muscles with increasing time of postmortem storage from days 2 to 28, with the exception of the teres major, but all in different degrees of response. In general, the study found all muscles that had a high or moderately high aging response had a 2 day shear force value greater than 5.5 kg, and muscles with moderately low or low aging responses had 2 day WBSF values less than 5.5 kg. Results from this study show an increased response from postmortem aging in those muscles that would be considered slightly tough to moderately tough. Opposite to those findings, Harris et al., (1992) found that top sirloin steaks did not
respond to postmortem age until 28 days while top loin steaks exhibited increased
tenderness after only 7 days of postmortem aging and continued to increase after
28 days. Top sirloin steaks had higher shear force values than did top loin steaks at
each aging period (Harris et al., 1992).

**Color**

Meat color is considered the most influential factor concerning consumer
purchasing decisions of fresh meat (Kropf, 1980). Consumers rely on color because
they have no other means of measuring the quality and palatability when
purchasing meat. Consumers equate the color of beef to its quality and perceived
wholesomeness, and any deviation from the bright cherry-red color is deemed
unacceptable (MacKinney et al., 1966).

Meat color can range from bright cherry-red, dark purplish red, to a brownish-red color (Faustman and Cassens, 1990). The desirable bright cherry-red color is
dored by oxymyoglobin which has a diatomic oxygen molecule attached at the
sixth coordination site in the ferrous heme iron within the myoglobin molecule
(Mancini and Hunt, 2005). The dark purplish color that meat can obtain is caused by
deoxymyoglobin. This is because deoxymyoglobin lacks a ligand at the sixth
coordination site in the ferrous heme iron (Mancini and Hunt, 2005). The brownish
color is caused by metmyoglobin, and is the most common cause of discoloration in
meat. It occurs when the heme iron oxidizes from the ferrous (Fe2+) state to the
ferric (Fe3+) state. The heme iron is then unable to bind an oxygen ligand at the
sixth coordination site and causes the brown color in the meat (Mancini and Hunt,
2005). Greene et al., (1971) reported that meat with as little as 40% metmyoglobin
caused meat to be rejected by consumers.
Muscle color is one of the contributing factors used to determine USDA quality grades for beef carcasses along with characteristics of marbling and level of carcass maturity (USDA, 1997). Several researchers have demonstrated a relationship between muscle color and meat tenderness (Jeremiah et al., 1991; Wulf et al., 1997), but to what degree it is still unknown. Jeremiah et al., (1991) showed a correlation of 22% or less between shear force values and subjective or objective color measurements over a 10 year carcass data study. Wulf et al., (1996) reported that beef carcasses, excluding dark-cutting carcasses, with dark-colored muscle produced steaks with higher shear force values and lower panel tenderness ratings than carcasses with normal colored muscle, and steaks from pale-colored carcasses having a lower shear force value and higher panel tenderness than normal-colored muscle.

Color can be measured using both subjective and objective analyses. During a subjective color assessment an individual that has been previously trained assigns a numerical value or score to the lean color of the sample. The values usually range from one end associated with a dark purplish color, and the other end being a light red color. In objective color measurement, a colorimeter measures the levels of absorbance of a particular wavelength of color and gives back a numerical equivalent to those levels. The two most commonly used forms of measuring color are Hunter Lab values or CIE L* a* b*. In both forms the scale is identical. L (*) measures the lightness value with 100 being absolute white and 0 being absolute black, a (*) is the redness variable with positive numbers being the redness of the sample, and negative numbers being the greenness of the sample. The b (*) is the
measurement of the yellowness or blueness of a sample, with positive numbers
being yellow and negative numbers being blue (Minolta, 1991). Although the scale
is the same, the numbers for Hunter Lab and CIE L* a* b* are not interchangeable.
Hunter values are quadratic functions and CIE values are cubic functions (Minolta,
1991; Murray, 1995).

Wulf et al., (1997) tested whether objective measures of muscle color could
be used to classify beef carcasses with respect to tenderness. Muscle color was
determined on 317 A-maturity cattle of diverse breeds with a marbling score of
Slight\textsuperscript{00} to Moderately Abundant\textsuperscript{80} at 27 h postmortem on the exposed longissiums
at the 12th/13th rib interface in the L* a* b* color space using a colorimeter. Steaks
were then aged for a set period of time from 1 to 35 days, and tested using Warner-
Bratzler shear force to evaluate tenderness and a trained sensory panel to evaluate
tenderness, juiciness, and flavor intensity. Ultimate pH and calpastatin levels were
also measured. The study found a high correlation between muscle pH, 24-h
calpastatin activities and L*, a*, and b* color scores. Lower muscle pH values were
associated with muscle that had a higher L* value, meaning it was whiter, a higher
a* value, and a higher b* value, and were associated with lower shear force values
and higher taste panel tenderness ratings. In this study, tenderness showed the
highest correlation with b* values (Wulf et al., 1997).

The objective of this study was to evaluate the effects of packaging type,
length of postmortem age, and storage temperature on three muscles, the
longissimus lumborum, the triceps brachii, and the gluteus medius to determine the
most reliable method of enhancing the quality characteristics of fresh beef that
represent the bulk of the supply, as well as to determine if any locational variations in tenderness exist within the *gluteus medius* muscle.
CHAPTER 3
EFFECT OF PACKAGING TYPE AND STORAGE TEMPERATURE ON THE QUALITY CHARACTERISTICS OF BEEF LONGISSIMUS LUMBORUM AND TRICEPS BRACHII MUSCLES AGED FOR EXTENDED STORAGE POSTMORTEM

Introduction

Tenderness has been consistently ranked as the most important aspect of a satisfactory eating experience by consumers (Morgan et al., 1991; Koohmaraie, 1996; Miller et al., 1995). Retail cuts from the rib and loin have been highly marketable; however, those from the chuck and round often are discounted because of real or perceived problems with tenderness (Belew et al., 2003).

Aging is well recognized as a consistent method of increasing the tenderness and palatability of fresh beef (Warner and Kastner, 1992; Miller et al., 1997; Gruber et al., 2006). There are two generally recognized methods of age: wet aging and dry aging (Smith et al., 2008). Dry aging refers to carcasses or subprimal cuts being held at humidity controlled refrigerated temperature without any type of protective packaging. Dry aged flavor attributes of a beefy, brown roasted flavor differ from the bloody, serumy flavors with metallic notes that can be produced with wet aging (Warren and Kastner, 1992; Campbell et al., 2001). Wet aging is more common and refers to meat that is aged in a vacuum sealed barrier package at refrigerated temperatures. The majority of all beef is vacuum packaged at the packer level then shipped to its destination where it can then be further wet aged or removed from its packaging and dry aged. Wet aging is more common because it will produce the desired increase in tenderness and flavor without the loss of yield and the necessary increase in expense associated with dry aging in regards to careful temperature and humidity control. A third method of aging beef has recently been
introduced to the industry in an attempt to alleviate these issues. The use of a vacuum bag that is highly permeable to water vapor would in theory produce a product with the flavors associated with dry-aged beef while blocking oxygen to reduce off-flavors and possibly reduce yield loss (Ahnstrom et al., 2006).

Many studies have explored the effect of postmortem aging on the quality and palatability of steaks from the rib and short loin, however, most focused on products with Modest or greater marbling. Currently, approximately 60 percent of all young beef marketed is between Slight$^{50}$ and Small$^{50}$ degrees of marbling (Cargill, 2011). Although many studies agree that aging increases tenderness and palatability, they disagree on the magnitude of variation among the different aging methods (Parrish et al., 1991; Sitz et al., 2006; Laster et al., 2008). Postmortem aging has also been reported to affect lean color stability and shelf-life of beef (Ledward, 1985; Feldhusen et al., 1995; Tang et al., 2005, King et al., 2012). Meat color is considered one of the most influential factors concerning consumer purchasing decisions at the retail level (Kropf, 1980). Consumers rely on color because they have no other means of measuring quality when purchasing meat. Consumers equate the color of the meat to its palatability and perceived wholesomeness, and any deviation from the bright cherry-red color is deemed unacceptable.

The purpose of the study was to determine the optimal method and length of postmortem aging to consistently increase palatability and color stability of Longissimus lumborum (LL) and Triceps brachii (TB) muscles that represent the bulk of today’s supply.
**Materials and Methods**

**Carcass Collection**

Beef carcasses used for subprimal collection were preselected using USDA-AMS instrumentation data to have marbling scores between Slight$^{50}$ and Small$^{50}$ at the 12$^{th}$/13$^{th}$ rib interface. Paired beef *Longissimus lumborum* (LL) (IMPS# 180; n = 52) and paired *Triceps brachii* (TB) (IMPS # 114E; n = 108) were collected at 24h postmortem from 26, or 54 commercially slaughtered A-maturity beef carcasses, respectively (Table 3-1). Samples were shipped under refrigeration to the University of Florida Meat Processing Center.

**Temperature Variation**

One LL (n = 26), and one TB (n = 54) from each pair were held at 0 ± 2$^\circ$ C in a humidity controlled environment. The other LL and TB muscles from each pair were held at 4 ± 2$^\circ$ C in similar conditions for their respective postmortem aging period.

**Longissimus Lumborum**

Each LL (n = 26 per temperature) was separated into three equal portions and randomly assigned to one of three packaging treatments during storage. Packaging treatments included: DryBag® (B; DryBag®, MacPak, LLC, Wayzata, MN) having a water vapor transmission rate of 2500 g/m$^2$/24 h at 38°C and 50% relative humidity, Traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm$^2$/24 h at 37.8°C and 100% relative humidity, and No packaging (D). Within each loin, the three sections were randomly allotted to aging for 21, 32 or 42 days postmortem. After the assigned postmortem aging period, LL muscles were fabricated into 2.54 cm steaks.
(n = 3) and randomly allocated to sensory, Warner-Bratzler shear force (WBSF) and color stability evaluations.

**Triceps Brachii**

The TB muscles (n = 6) were randomly assigned to one of nine packaging × aging combinations, for each storage temperature. Packaging treatments for TB were the same as described for LL subprimals: B, V, or D and were allotted to postmortem aging periods of 21, 28, or 35 days. After the assigned postmortem aging period, TB muscles were fabricated into 2.54 cm steaks, the most medial steaks (n = 3) were allocated to sensory, WBSF and color stability evaluations.

**Steak Processing**

Steaks for color stability was individually placed on a styrofoam tray containing a Dri-Loc® 40 g white meat pad (Sealed-Air Corporation, Elmwood Park, NJ) and overwrapped with polyvinylchloride film (23,250 mL of O2/m2/24 h°C/90% relative humidity). Sensory and WBSF steaks were vacuum sealed and frozen at -40± 4°C until analysis was completed at a later date.

**Sensory Attributes**

At 24 h prior to cooking, steaks were thawed at 4 ± 2°C. Preheated Hamilton Beach Indoor/Outdoor open top grills (Model 31605, Hamilton Beach Brand, Washington, NC) were used to cook steaks according to the American Meat Science Association guidelines (AMSA, 1995). Steaks were cooked to an internal temperature of 71°C, flipping once at 35°C. Thermocouples (Omega Engineering, Inc., Stanford, CT) were placed in the geometric center of each steak to constantly monitor temperature. Temperatures were recorded using 1100 Labtech Notebook for Windows 7 (Computer Boards Inc., Middleboro, MA) (Computer Boards, Inc.,
Middleboro, MA). The cooked steaks were sliced and served to panelist in warmed, covered containers. Each panelist evaluated 4-6 samples, 2 cubes per sample (1.27 cm$^3$), in individual cubicles within a meat sensory panel room designed with positive pressure air flow, and lighting to ensure an objective assessment. A panel of 7-11 trained members, in accordance with the AMSA sensory guidelines, assessed each sample for 5 attributes. These evaluated sensory traits included: juiciness (1= extremely dry, 2= very dry, 3= moderately dry, 4= slightly dry, 5= slightly juicy, 6= moderately juicy, 7= very juicy, 8= extremely juicy), beef flavor intensity (1= extremely bland, 2= very bland, 3= moderately bland, 4= slightly bland, 5= slightly intense, 6= moderately intense, 7= very intense, 8= extremely intense), overall tenderness (1= extremely tough, 2= very tough, 3= moderately tough, 4= slightly tough, 5= slightly tender, 6= moderately tender, 7= very tender, 8= extremely tender), connective tissue (1= abundant, 2= moderately abundant, 3= slightly abundant, 4= moderate amount, 5= slight amount, 6= traces amount, 7= practically, 8= none detected), and off-flavor (1= extreme off-flavor, 2= strong off-flavor, 3= moderate off-flavor, 4= slight off-flavor, 5= threshold; barely detected, 6= none detected).

**Warner-Bratzler Shear Force Analysis**

Steaks were cooked to the above specifications and were then chilled at 4 ± 2°C for 24 h. After cooling, 6 cores, 1.27 cm in diameter, were removed parallel to the orientation of the muscle fibers. Each core was sheared once, perpendicular to the orientation of the muscle fibers using an Instron Universal Testing Machine (Model 1011, Instron Corporation, Canton, MA) with a Warner-Bratzler shear head at a speed of 200 mm/min.
Color Stability

Steaks were displayed in a Hill (Hill Refrigeration Div., Trenton, NJ) coffin-style retail case at 2 ± 3 °C for 5 d. Cases were illuminated with GE T8 Linear Fluorescent lamps (2,800 lm, 4,100 K; General Electric Company, Fairfield, CT) that emit a case average of 1,148 lx with a 12-h on, 12-h off lighting schedule. Steaks were rotated daily to compensate for uneven temperature and light distribution within the case. Each steak was used for daily visual panel evaluation which included lean color. Following collection of visual data, Hunter L*, a*, and b* reflectance data were collected for each steak. Two measurements per steak were averaged. Visual and objective color data were collected for a five day period for each steak.

Statistical Analysis

The LL muscles were analyzed as a split-plot design with the whole-plot a 2 X 3 factorial representing temperature x aging periods, with packaging treatment as the sub-plot. The TB muscles were analyzed as a split-plot design with the whole-plot a 2 X 3 X 3 factorial design, representing temperature x packaging x aging periods and nested within animal with subprimal as the experimental unit.

Results and Discussion

Saleable Yield

Vacuum packaged subprimals of both muscles had greater saleable yield percentages \((P < 0.001)\) than the other packaging treatments represented (Table 3-2). These results were expected and are consistent with several previous studies (Parrish et al., 1991; Warren and Kastner, 1992; Smith et al., 2008; Laster et al., 2008). Subprimals stored in B packages did not differ from D aged subprimals for
saleable yield percentage for either muscle \( P \geq 0.2 \). These results are similar to those of Ahnstrom et al., (2006) which showed no significant difference between cuts stored in a highly water permeable bag and those dry aged traditionally, regardless of length of postmortem age (Ahnstrom et al., 2006). Storage temperature did not affect \( P > 0.70 \) the saleable yield percentages of LL subprimals but, TB steaks aged at 4°C tended \( P = 0.09 \) to have greater saleable yield than the same muscles stored at 0°C (Table 3-2). For each muscle evaluated, the subprimals fabricated after the shortest postmortem aging period had greater saleable yield percentages \( P \leq 0.05 \) than subprimals fabricated after either of the more extended aging periods, which did not differ \( P > 0.10 \). These results are also consistent with previous studies stating the least amount of aging, regardless of packaging type, results in the least amount of saleable yield lost (Smith et al., 2008; Laster et al., 2008), and increasing postmortem aging time decreases yield and increases trim (Parrish et al., 1991; Ahnstrom et al., 2006).

**Longissimus Lumborum**

**Color Stability**

The LL steaks aged for 42 days began at a lower \( \text{L}^* \) score of 30.9, meaning they appeared darker, than those steaks aged for 21 or 32 days which scored a 34.8 and 34.2, respectively. As the days of retail display progressed, the 42 d steaks became lighter (greater \( \text{L}^* \) values; \( P<0.01 \)) while those steaks with lesser days of postmortem aging trended darker during retail display \( P<0.01; \) Table 3-3). The darker the beef, from red to purple to brown, the less likely the consumer is to purchase the product, regardless of the fact that color had no impact on taste scores (Carpenter et al., 2001). The LL steaks from subprimals aged for 42 d were
less red \((P < 0.01; \text{lower } a^* \text{ values})\) and less yellow \((P < 0.01; \text{lower } b^* \text{ values})\) throughout 3 d of retail display than steaks from subprimals given shorter postmortem aging periods (Figure 3-1). Although the steaks aged for 42 d had a greater overall subjective color score than steaks from 21 or 28 d this can be explained by the increase in lightness \((L^*)\) over the days of retail display also associated with the 42 d steaks, making them appear more red than they objectively scored.

Steaks from subprimals stored in V packaging had greater \((P = 0.01)\) \(b^*\) values than those steaks given D or B storage conditions (Figure 3-2). Subprimal packaging type or storage temperature did not affect \((P \geq 0.39)\) \(L^*\) values of LL steaks during retail display. Storage temperature did not affect \((P = 0.99)\) subjective color scores during retail display (Table 3-3). The LL steaks from subprimals stored in V packages for 32 or 42 d were more yellow \((P < 0.05)\) than steaks from subprimals stored with other packaging types for the same periods (Figure 3-2). The variation in color concerning those steaks from the B or D aging method, as compared to those in the V packaging, is most likely a result of the increased evaporative loss associated with the DryBag® packaging, creating a darker steak.

**Warner-Bratzler Shear Force and Trained Sensory Panel**

Beef tenderness can be measured objectively using mechanical means, mainly mechanical shear force, which is a measure of myofibril toughness (Bouton and Harris, 1972). In this study, LL steaks from subprimals aged for 32 d had greater \((P \leq 0.01)\) WBSF values than steaks from subprimals aged for 42 d which had the lowest \((P \leq 0.01)\) WBSF values of the three aging periods. However, steaks from
subprimals aged for 21 d had lower \((P \leq 0.01)\) WBSF values than steaks aged for 32 d (Table 3-4).

Subprimal packaging type or storage temperature did not affect \((P \geq 0.13)\) WBSF values, or trained sensory panel values for juiciness, beef flavor, or connective tissue of LL steaks (Table 3-4). Trained sensory panelist found LL steaks from muscles aged for 42 d were more tender \((P \leq 0.01)\) than steaks aged for 21 days (Table 3-4). Those steaks that were dry aged (D) had more off-flavors than those steaks that had been aged in either V or D, regardless of length of age or temperature (Table 3-4). Those LL steaks from subprimals stored at 4°C tended \((P = 0.08)\) to have greater sensory panel values for tenderness (Table 3-4). Postmortem aging did not affect \((P \geq 0.38)\) trained sensory panel values for juiciness, beef flavor, off-flavor or connective tissue of LL steaks (Table 3-4). This is similar to Sitz et al., (2006) who found no significant difference between dry- and wet-aged strip loins for flavor, juiciness, or overall acceptability.

**Triceps Brachii**

**Color Stability**

All TB steaks had similar lightness values at the start of retail display, but steaks from subprimals aged for 35 d trended darker (decreasing L* values) throughout display, compared with steaks from subprimals given 21 or 28 d of aging which trended lighter throughout retail display (Figure 3-3). Consumers prefer a bright cherry red colored beef steak, which makes lean color the main determinant as to whether a consumer will purchase that product at retail (Wulf and Wise, 1999).

Subprimal packaging type did not affect \((P \geq 0.28)\) L* values and storage temperature did not affect \((P \geq 0.20)\) a* or b* values for TB steaks during retail display.
display (Table 3-5). As postmortem aging increased, redness and yellowness values of TB steaks during retail display decreased ($P \leq 0.02$) linearly. Usually, this is indicative of an increase in metmyoglobin as the days of retail display increase, resulting in beef that becomes more brown in color.

Opposite to findings with the LL steaks, TB steaks from subprimals aged for 35 d had lower subjective color scores than steaks from subprimals given shorter postmortem aging periods (Figure 3-4), which were similar to results for lightness values and postmortem aging period of TB steaks during retail display. Bright red colored beef outsells discolored beef by a ratio of 2:1 in a retail display case (Hood and Riordan, 1973). For this reason, it is very important to determine the optimal aging, temperature, and packaging scenario for not only tenderness and palatability, but the visual appearance of the steaks as well.

**Warner-Bratzler Shear Force and Trained Sensory Panel**

Subprimal packaging type or storage temperature did not affect ($P \geq 0.23$) trained sensory panel values for juiciness, tenderness, connective tissue or off-flavor of TB steaks (Table 3-6). Additionally, subprimal packaging type did not affect ($P = 0.63$) trained sensory panel values for beef flavor, however, steaks from subprimals stored at 4°C tended ($P = 0.08$) to have greater sensory panel values for beef flavor than steaks from subprimals stored at 0°C (Table 3-6). Length of postmortem age did not affect ($P \geq 0.25$) trained sensory panel values for juiciness, beef flavor, tenderness, or connective tissue of TB steaks (Table 3-6). Trained sensory panelist found TB steaks from muscles aged for 35 d to have more off-flavor ($P < 0.01$) at 5.4 than steaks aged for 21 or 28 days which did not differ at 5.6 (Table 3-6). Although the difference in off-flavor is significantly different from a statistical
standpoint, it is important to mention that the scores of 5.4 to 5.6 are both within the rage of “threshold/barely detected.”

The TB steaks from subprimals aged for 35 d in V packaging had greater \( P \leq 0.01 \) WBSF values than steaks from any other packaging type \( \times \) days of postmortem aging combination (Figure 3-5), suggesting that subprimals which were allocated to this particular combination were innately tougher than subprimals allocated to the other combinations.

**Summary and Conclusions**

Aging has always been considered the best way to tenderize and enhance the flavor of steaks and this research furthers that fact. It also shows that only a limited number of days are needed to be effective for tenderizing a lower valued cut, such as the TB. Tenderness did increase in LL steaks as the length of aging progressed, but the actual difference was marginal. Tenderness in TB steaks was similar throughout the aging process, except for the one subgroup which was speculated to simply being innately tougher. Those LL steaks that were aged for 42 days retained its darker color throughout the retail days, but all steaks decreased at approximately the same rate regardless of age. Those TB steaks aged for 35 days became significantly darker as retail display progressed. More research should be done to corroborate the findings of this study and to further address the need to develop dependable methods to increase desirable tenderness and palatability traits of carcasses indicative of the bulk of the supply today.
Table 3-1. Simple means for carcass traits from which the *longissimus lumborum* and *triceps brachii* were collected.

<table>
<thead>
<tr>
<th>Trait</th>
<th>LL</th>
<th>TB</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of carcasses</td>
<td>26</td>
<td>54</td>
</tr>
<tr>
<td>Hot carcass wt., kg</td>
<td>298.4 ± 30.7</td>
<td>319.7 ± 45.1</td>
</tr>
<tr>
<td>12th-rib fat thickness, cm</td>
<td>0.91 ± 0.4</td>
<td>0.80 ± 0.3</td>
</tr>
<tr>
<td>LM area, cm²</td>
<td>76.7 ± 7.3</td>
<td>82.6 ± 10.8</td>
</tr>
<tr>
<td>USDA YG&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.6 ± 0.6</td>
<td>2.4 ± 0.6</td>
</tr>
<tr>
<td>Marbling&lt;sup&gt;c&lt;/sup&gt;</td>
<td>410.5 ± 30.1</td>
<td>406.1 ± 32.0</td>
</tr>
</tbody>
</table>

<sup>a</sup> *Longissimus lumborum* (LL) (IMPS# 180; n = 52), *Triceps brachii* (TB) (IMPS # 114E; n = 108).

<sup>b</sup> Calculated according to USDA-AMS, 1997.

<sup>c</sup> 300 to 399 = Slight; 400 to 499 = Small; 500 to 599 = Modest.
Table 3-2. Effect of subprimal packaging type, storage temperature, and days of postmortem age on saleable yield % of longissimus lumborum and triceps brachii muscles.

<table>
<thead>
<tr>
<th>Packaging&lt;sup&gt;a&lt;/sup&gt;</th>
<th>P-value</th>
<th>Temperature</th>
<th>P-value</th>
<th>Postmortem age</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>V</td>
<td>D</td>
<td>4°C</td>
<td>0°C</td>
<td>21</td>
</tr>
<tr>
<td>LL</td>
<td>63.8&lt;sup&gt;c&lt;/sup&gt;</td>
<td>79.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>62.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>&lt;0.001</td>
<td>68.1</td>
</tr>
<tr>
<td>TB</td>
<td>60.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>73.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>60.1&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.001</td>
<td>66.3</td>
</tr>
</tbody>
</table>

<sup>a</sup>B; DryBag®, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 2500 g/m<sup>2</sup>/24 h at 38°C and 50% relative humidity, V; Traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm<sup>2</sup>/24 h at 37.8°C and 100% relative humidity; D; No packaging.

<sup>bc</sup>For variables with three treatments, values lacking a common superscript differ (P ≤ 0.05).
Table 3-3. Effect of subprimal packaging type and storage temperature on objective and subjective color values for the *Longissimus lumborum* (LL) steaks during 5 d of retail display.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Packaging&lt;sup&gt;a&lt;/sup&gt;</th>
<th>P-value</th>
<th>Temperature</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trait</td>
<td>B</td>
<td>V</td>
<td>D</td>
</tr>
<tr>
<td>LL</td>
<td>L&lt;sup&gt;b&lt;/sup&gt;</td>
<td>32.6</td>
<td>33.7</td>
<td>32.7</td>
</tr>
<tr>
<td></td>
<td>Subjective Color&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.9&lt;sup&gt;de&lt;/sup&gt;</td>
<td>4.7&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.8&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>B; DryBag®, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 2500 g/m²/24 h at 38°C and 50% relative humidity; V; Traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm²/24 h at 37.8°C and 100% relative humidity; D:= No packaging.

<sup>b</sup>L*; measure of darkness to lightness (larger value indicates a lighter color);

<sup>c</sup>Subjective color: 1; Extremely dark red, 2; Dark red, 3; Moderately dark red, 4; Slightly dark red, 5; Slightly bright cherry red, 6; Moderately bright cherry red, 7; Bright cherry red, 8; Extremely bright cherry red.

<sup>de</sup>For variables with multiple treatments, values lacking a common superscript differ (P ≤ 0.02).
Table 3-4. Effect of subprimal packaging type, storage temperature, and days of postmortem age on Warner-Bratzler shear force (WBSF) and trained sensory panel values for *longissimus lumborum* steaks.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Packaging&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Temperature</th>
<th>Postmortem age</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>V</td>
<td>D</td>
<td>4°C</td>
</tr>
<tr>
<td>WBSF, N</td>
<td>32.7</td>
<td>32.8</td>
<td>32.3</td>
<td>0.92</td>
</tr>
<tr>
<td>Juiciness&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.2</td>
<td>5.1</td>
<td>5.1</td>
<td>0.59</td>
</tr>
<tr>
<td>Beef flavor&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.6</td>
<td>5.4</td>
<td>5.4</td>
<td>0.08</td>
</tr>
<tr>
<td>Tenderness&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.9</td>
<td>5.8</td>
<td>5.7</td>
<td>0.43</td>
</tr>
<tr>
<td>Connective tissue</td>
<td>6.4</td>
<td>6.3</td>
<td>6.4</td>
<td>0.37</td>
</tr>
<tr>
<td>Off-flavor&lt;sup&gt;c&lt;/sup&gt;</td>
<td>5.5&lt;sup&gt;de&lt;/sup&gt;</td>
<td>5.6&lt;sup&gt;d&lt;/sup&gt;</td>
<td>5.3&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.03</td>
</tr>
</tbody>
</table>

<sup>a</sup> B: DryBag, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 2500 g/m²/24 h at 38°C and 50% relative humidity; V: Traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm²/24 h at 37.8°C and 100% relative humidity; D: No packaging.

<sup>b</sup> Juiciness: 1 extremely dry, 2 very dry, 3 moderately dry, 4 slightly dry, 5 slightly juicy, 6 moderately juicy, 7 very juicy, 8 extremely juicy; Beef flavor: 1 extremely bland, 2 very bland, 3 moderately bland, 4 slightly bland, 5 slightly intense 6 moderately intense, 7 very intense 8 extremely intense; Tenderness: 1 extremely tough 2 very tough 3 moderately tough 4 slightly tough 5 slightly tender 6 moderately tender 7 very tender 8 extremely tender; Connective tissue: 1 abundant amount, 2 moderately abundant, 3 slightly abundant, 4 moderate amount, 5 slight amount, 6 traces amount, 7 practically none, 8 none detected.

<sup>c</sup> 1 extreme off-flavor, 2 strong off-flavor, 3 moderate off-flavor, 4 slight off-flavor, 5 threshold, barely detected, 6 none detected.

<sup>d,e,f</sup> For variables with three treatments, values lacking a common superscript differ (P ≤ 0.01).
Table 3-5. Effect of subprimal packaging type, storage temperature, and days of postmortem age on objective color values for the *Triceps brachii* (TB) steaks during 5 d of retail display.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Packaging&lt;sup&gt;a&lt;/sup&gt;</th>
<th>P-value</th>
<th>Temperature</th>
<th>P-value</th>
<th>Postmortem age</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trait</td>
<td>B</td>
<td>V</td>
<td>D</td>
<td>4°C</td>
<td>0°C</td>
</tr>
<tr>
<td>TB</td>
<td>L&lt;sup&gt;b&lt;/sup&gt;</td>
<td>29.7</td>
<td>30.2</td>
<td>29.5</td>
<td>0.9</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>a&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.1</td>
<td>18.9</td>
<td>18.6</td>
<td>0.3</td>
<td>18.8</td>
</tr>
<tr>
<td></td>
<td>b&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.9</td>
<td>10.1</td>
<td>10.9</td>
<td>0.6</td>
<td>10.9</td>
</tr>
</tbody>
</table>

<sup>a</sup>B; DryBag®, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 2500 g/m<sup>2</sup>/24 h at 38°C and 50% relative humidity; V; Traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm<sup>2</sup>/24 h at 37.8°C and 100% relative humidity; D= No packaging.

<sup>b</sup>L<sup>*</sup>; measure of darkness to lightness (larger value indicates a lighter color); a<sup>*</sup>; a measure of redness (larger value indicates a redder color); b<sup>*</sup>; a measure of yellowness (larger value indicates a more yellow color).

<sup>cde</sup>For variables with three treatments, values lacking a common superscript differ (P ≤ 0.02).
Table 3-6. Effect of subprimal packaging type, storage temperature, and days of postmortem age on Warner-Bratzler shear force (WBSF) and trained sensory panel values for *triceps brachii* steaks.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Packaging(^a)</th>
<th>Temperature</th>
<th>Postmortem age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>V</td>
<td>D</td>
</tr>
<tr>
<td>WBSF, N</td>
<td>39.3</td>
<td>40.1</td>
<td>0.68</td>
</tr>
<tr>
<td>Juiciness(^b)</td>
<td>5.2</td>
<td>5.2</td>
<td>5.2</td>
</tr>
<tr>
<td>Beef flavor(^b)</td>
<td>5.6</td>
<td>5.6</td>
<td>5.5</td>
</tr>
<tr>
<td>Tenderness(^b)</td>
<td>5.5</td>
<td>5.4</td>
<td>5.6</td>
</tr>
<tr>
<td>Connective tissue(^b)</td>
<td>6.1</td>
<td>6.0</td>
<td>6.2</td>
</tr>
<tr>
<td>Off-flavor(^c)</td>
<td>5.6</td>
<td>5.5</td>
<td>5.5</td>
</tr>
</tbody>
</table>

\(^a\) B: DryBag, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 2500 g/m²/24 h at 38°C and 50% relative humidity; V: Traditional vacuum-bag (V: 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm²/24 h at 37.8°C and 100% relative humidity; D: No packaging.

\(^b\) Juiciness: 1 extremely dry, 2 very dry, 3 moderately dry, 4 slightly dry, 5 slightly juicy, 6 moderately juicy, 7 very juicy, 8 extremely juicy; Beef flavor: 1 extremely bland, 2 very bland, 3 moderately bland, 4 slightly bland, 5 slightly intense 6 moderately intense, 7 very intense 8 extremely intense; Tenderness: 1 extremely tough 2 very tough 3 moderately tough 4 slightly tough 5 slightly tender 6 moderately tender 7 very tender 8 extremely tender Connective tissue: 1 abundant amount, 2 moderately abundant, 3 slightly abundant, 4 moderate amount, 5 slight amount, 6 traces amount, 7 practically none, 8 none detected.

\(^c\) 1 extreme off-flavor, 2 strong off-flavor, 3 moderate off-flavor, 4 slight off-flavor, 5 threshold; barely detected, 6 none detected.

\(^d,e\) For variables with three treatments, values lacking a common superscript differ (P < 0.001).
Figure 3-1. Interactive effect of days of postmortem age and day of retail display on L*, a*, b* and subjective color score of *longissimus lumborum* steaks. A. lightness (L*) values (P < 0.001), B. redness (a*) values (P < 0.001), C. yellowness (b*) values (P < 0.001), D. Subjective lean color scores\(^a\) (P = 0.06). Notes: \(^a\)1 = Extremely dark red, 2 = Dark red, 3 = Moderately dark red, 4 = Slightly dark red, 5 = Slightly bright cherry red, 6 = Moderately bright cherry red, 7 = Bright cherry red, 8 = Extremely bright cherry red.
Figure 3-2: Interactive effect of subprimal packaging type\(^1\) and days of postmortem age on yellowness (b\(^*\)) values (P = 0.01) of *longissimus lumborum* steaks. Notes: \(^1\) B; DryBag, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 2500 g/m\(^2\)/24 h at 38°C and 50% relative humidity, V Traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm\(^2\)/24 h at 37.8°C and 100% relative humidity; D No packaging. Notes: \(^{a, b, c}\) Values with different letters differ (P < 0.05).
Figure 3-3. Interactive effect of days of postmortem age and subprimal storage temperature on lightness ($L^*$) values ($P = 0.02$) of triceps brachii steaks during 5 d of retail display. Notes: $^1L^*$; measure of darkness to lightness (larger value indicates a lighter color).
Figure 3-4. Interactive effect of days of postmortem age and day of retail display on subjective lean color score\(^a\) values (P = 0.02) of *triceps brachii* steaks.

Notes: \(^a\)1 Extremely dark red, 2 Dark red, 3 Moderately dark red, 4 Slightly dark red, 5 Slightly bright cherry red, 6 Moderately bright cherry red, 7 Bright cherry red, 8 Extremely bright cherry red.
Figure 3-5. Interactive effect of subprimal packaging typed and days of postmortem age on Warner-Bratzler shear force values ($P = 0.01$) of *triceps brachii* steaks. Notes: $^a, ^b, ^c$ Values with different letters differ ($P < 0.0$).$^B$; DryBag, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 88.2oz/in$^2$/24 h at 100.4°F and 50% relative humidity, $V =$ Traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.02–0.03oz/25.2 in$^2$/24 h at 100°F and 100% relative humidity; $D =$ No packaging.
CHAPTER 4
EFFECTS OF PACKAGING TYPE AND STORAGE CHARACTERISTICS AND THE EFFECT OF STEAK LOCATION ON PALATABILITY AND COLOR STABILITY OF CENTER CUT GLUTEUS MEDIUS AGED FOR EXTENDED STORAGE POSTMORTEM

Introduction

Tenderness has been consistently ranked as the most important aspect of a satisfactory eating experience by consumers (Morgan et al., 1991; Koohmaraie, 1996; Miller et al., 1995).

The top sirloin steak is an economical alternative to steaks from the short loin or rib, but only a few studies have evaluated its characteristics, and none of the studies assessed the lean color stability and the effects of post mortem aging on retail display (Harris et al., 1992; Savell et al., 1999; King et al., 2009). Many studies have explored the effects of postmortem age on the quality and palatability of steaks from areas such as the rib and short loin, however, most focused on products with Modest or greater marbling, and few on the top sirloin, or *gluteus medius* muscle. Currently, approximately 60 percent of all young beef marketed is between Slight$^{50}$ and Small$^{50}$ degrees of marbling (Cargill, 2011). Postmortem age has also been reported to affect the process that determines lean color stability and shelf-life of beef (Ledward, 1985; Feldhusen et al., 1995; Tang et al., 2005, King et al., 2012). Meat color is considered one of the most influencing factors concerning consumer purchasing decisions (Kropf, 1980). Consumers rely on color because they have no other means of measuring tenderness when purchasing meat. Consumers equate the color of meat to its quality and perceived wholesomeness, and any deviation from the bright cherry-red color is deemed unacceptable.
Aging is well recognized as a method of increasing the tenderness and palatability of a fresh beef product (Warner and Kastner, 1992; Miller et al., 1997; Gruber et al., 2006). There are two generally recognized methods of postmortem aging: wet aging; storing the beef cuts in highly moisture-impermeable vacuum packages, and dry aging refers to storing the beef carcass or wholesale cuts without any type of protective packaging, and exposing the meat to cooler conditions (Smith et al., 2008). A third type of packing was used in this project, along with wet age, a dry age bag is a highly moisture-permeable bag and makes subprimals more tolerant of variable cooler conditions while decreasing the evaporative loss associated with dry aged beef (Ahnstrom et al., 2006).

The impact of steak location on palatability and color stability has been investigated within the rib and short loin (Belew et al., 2003; Wheeler et al., 2007), round (Reuter et al., 2002; Sawyer et al., 2007), and chuck (Bratcher et al., 2005). However, the only known work documenting the impact of GM steak location on palatability was Rhee et al., (2004) which addressed steak location anterior to posterior, but did not address location dorsal to ventral. Purveyors who fabricate center-cut top butts for foodservice cut the subprimal in half anterior to posterior when fabricating steaks. However, no known publications document the differences in palatability between the locations. The purpose of this study was to determine the best method and length of postmortem aging to consistently increase palatability and color stability on the quality of subprimals that represent the bulk of today’s market.
Materials and Methods

Carcass Collection

Beef carcasses chosen for subprimal collection were preselected using USDA-AMS instrumentation data to have marbling scores between Slight\textsuperscript{50} and Small\textsuperscript{50} at the 12\textsuperscript{th}/13\textsuperscript{th} rib interface. Paired top sirloin butts (IMPS # 184; n = 74) were collected 24 h postmortem from 37 commercially slaughtered A-maturity beef carcasses (Table 4-1). Samples were shipped under refrigeration to the University of Florida Meat Processing Center.

Temperature Variation

One top sirloin butt (n = 37) from each pair was held at 0 ± 2\textdegree C in a humidity and temperature controlled environment. The other side from each pair was held at 4 ± 2\textdegree C in similar conditions for their respective postmortem aging periods.

Aging Conditions

Top sirloin butts (n = 6) were randomly assigned to one of six packaging × aging combinations, for each storage temperature. Packaging treatments were DryBag\textregistered (B; DryBag\textregistered, MacPak, LLC, Wayzata, MN) having a water vapor transmission rate of 2500 g/m2/24 h at 38°C and 50% relative humidity, and traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm2/24 h at 37.8ºC and 100% relative humidity. The packaged muscles were allotted to postmortem aging periods of 14, 28, or 42 days.

After the assigned postmortem aging period, the \textit{biceps femoris} muscles were removed leaving the \textit{gluteus medius} (GM) muscle. The anterior end of the subprimal was then squared and divided in half with a cut anterior to posterior along
the sciatic ligament. Muscles were then fabricated into 2.54 cm steaks and utilized for trained sensory, Warner-Bratzler shear force (WBSF) analysis, and color stability, according to the following diagram (Figure 4-1).

<table>
<thead>
<tr>
<th></th>
<th>Posterior end</th>
<th>Dorsal</th>
<th>WBSF</th>
<th>WBSF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color Stability</td>
<td>Color Stability</td>
<td>Sensory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WBSF</td>
<td>WBSF</td>
<td>WBSF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color Stability</td>
<td>Color Stability</td>
<td>WBSF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WBSF</td>
<td>WBSF</td>
<td>WBSF</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Anterior end

Figure 4-1. Diagram of *gluteus medius* fabrication

**Steak Processing**

Steaks for color stability were individually placed on a Styrofoam tray containing a Dri-Loc 40 g white meat pad (Sealed-Air Corporation, Elmwood Park, NJ) and overwrapped with polyvinylchloride film (23,250 mL of O²/m²/24 h/90% relative humidity). Sensory and WBSF steaks were vacuum sealed and frozen at -40 ± 2°C until analysis was completed at a later date.

**Cooking**

Prior to cooking, steaks were thawed for 12-18 h at 4 ± 2°C. Preheated Hamilton Beach Indoor/Outdoor open top grills (Model 31605, Hamilton Beach Brand, Washington, NC) were used to cook steaks according to the American Meat Science Association guidelines (AMSA, 1995). Steaks were turned once when the internal temperature reached 35 °C and then allowed to finish cooking until they reach an internal temperature of 71 °C (AMSA, 1995). Internal temperatures were monitored by copper-constantan thermocouples (Omega Engineering Inc., Stamford, CT) placed in the geometric center of each steak and recorded using an
Cooking procedures were the same for both sensory and WBSF analysis.

**Sensory Analysis**

Once the steaks reached an internal temperature of 71°C they were readied for sensory analysis. Panelists evaluated 4 steaks during each session. Each steak was trimmed of excess fat then cut into multiple 1.27 cm³ samples, with each panelist receiving 2 samples served in warmed covered containers in a positive pressure ventilated room with lighting and cubicles designed for objective meat sensory analysis. A 7 to 10 member sensory panel trained according to AMSA sensory evaluation guidelines (AMSA, 1995) evaluated each sample for juiciness (1= extremely dry, 2= very dry, 3= moderately dry, 4= slightly dry, 5= slightly juicy, 6= moderately juicy, 7= very juicy, 8= extremely juicy), beef flavor intensity (1= extremely bland, 2= very bland, 3= moderately bland, 4= slightly bland, 5= slightly intense, 6= moderately intense, 7= very intense, 8= extremely intense), overall tenderness (1= extremely tough, 2= very tough, 3= moderately tough, 4= slightly tough, 5= slightly tender, 6= moderately tender, 7= very tender, 8= extremely tender), connective tissue (1= abundant, 2= moderately abundant, 3= slightly abundant, 4= moderate amount, 5= slight amount, 6= traces amount, 7= practically, 8= none detected), and off-flavor (1= extreme off-flavor, 2= strong off-flavor, 3= moderate off-flavor, 4= slight off-flavor, 5= threshold; barely detected, 6= none detected).

**Warner-Bratzler Shear Force**

After cooking, steaks were chilled for 12-18 h at 4 ± 2°C then four to six 1.27-cm-diameter cores were removed parallel to the longitudinal orientation of the muscle
fibers. Then each core was sheared once, perpendicular to the muscle fiber orientation using a Warner-Bratzler shear head attached to an Instron Universal Testing machine (Model 1011; Instron Corporation, Canton, MA) with a cross-head speed of 200 mm/min. The peak force (N) needed to shear each core was recorded, and the mean peak shear force of the cores was used for statistical analysis.

**Color Stability**

Steaks were displayed in a Hill (Hill Refrigeration Div., Trenton, NJ) coffin-style retail case at 2 ± 3 °C for 5 d. Cases were illuminated with GE T8 Linear Fluorescent lamps (2,800 lm, 4,100 K; General Electric Company, Fairfield, CT) that emit a case average of 1,148 lx with a 12-h on, 12-h off lighting schedule. Steaks were rotated daily to compensate for uneven temperature and light distribution within the case. Steaks were evaluated daily, first with a subjective evaluation of lean color. Following collection of visual data, Hunter L*, a*, and b* reflectance data were collected for each steak. Two measurements per steak were taken and the results averaged. Visual and objective color data were collected for a five day period for each steak.

**Statistical Analysis**

The GM muscles were analyzed as a split-plot design with the whole-plot a 2 X 2 X 3 factorial design, representing temperature x packaging x aging periods and nested within animal with individual muscle as the experimental unit. The sub-plot was steak location.
Results

Saleable Yield

Vacuum packaged subprimals had greater saleable yield percentages \( (P < 0.001) \) than those that had been aged in the DryBag® packages (Table 4-2). These results were similar to those studies measuring saleable yield concerning wet aged and dry aged products (Parrish et al., 1991; Warren and Kastner, 1992; Smith et al., 2008; Laster et al., 2008). Storage temperature did not affect \( (P > 0.70) \) the saleable yield percentages. The subprimals fabricated after the shortest postmortem aging period (14 d) had greater saleable yield percentages \( (P \leq 0.03) \) than subprimals fabricated after either of the more extended aging periods, which did not differ \( (P > 0.10) \). These results are also consistent with previous studies stating the least amount of aging, regardless of packaging type, results in the least amount of saleable yield lost (Smith et al., 2007; Laster et al., 2008), and increasing postmortem aging time decreases yield and increases trim (Parrish et al., 1991; Ahnstrom et al., 2006).

Color Stability

Consumers prefer a bright cherry red colored beef steak and the visual appearance of steaks while in retail display is the main determinant as to whether a consumer will purchase that product at retail (Wulf and Wise, 1999). Bright red colored beef outsells discolored beef by a ratio of 2:1 in a retail display case (Hood and Riordan, 1973).

The GM steaks from those muscles aged for 14 d were lighter (greater L* values), more red (greater a* values), and more yellow (greater b* values) throughout retail display than steaks aged for 28 or 42 d, which were similar
throughout display (Figure 4-2). This could be explained by the increased moisture retention involved in vacuum packaged products that could potentially alter the appearance of the steaks. Interestingly, steaks from subprimals aged for 42 d had greater subjective color scores than steaks from subprimals aged for 14 or 28, meaning they were visibly a brighter red color. In a study by Carpenter et al., (2001) consumers were asked to score beef on color and likelihood of purchase. The darker the beef, from red to purple to brown, the less likely the consumer is to purchase the product, regardless of the fact that color had no impact on taste scores (Carpenter et al., 2001).

Steaks from subprimals stored in B packages at 4°C were darker ($P \leq 0.04$; lower L* values) than steaks from subprimals stored in the same packages at 0°C and darker ($P \leq 0.03$; lower L* values) than steaks from subprimals at the same temperature in V packages, at 33.1, 34.6, and 34.6, respectively (Figure 4-3). The variation in color concerning those steaks in the B packaging as compared to those in the V packaging is most likely a result of the increased evaporative loss associated with the DryBag® packaging, creating a darker steak. Packaging type and storage temperature did not affect ($P \geq 0.61$) redness or yellowness values of steaks during retail display.

**Warner-Bratzler Shear Force and Trained Sensory Panel**

Subprimal packaging type and temperature affected both tenderness and connective tissue regardless of length of postmortem age. The data show that the GM muscles stored in the higher temperature, 4°C, and in V packaging resulted in an increase in tenderness as compared to those in the same packaging in the lower temperature, 0°C ($P = 0.05$). Also, for those in B packaging, the steaks from GM
muscles stored at 0°C were more tender than those in the same packaging stored at the higher temperature ($P = 0.04$) (Figure 4-4). The same can be said for sensory panel connective tissue results (Figure 4-4).

Results of the trained sensory panel as well as WBSF for those properties that were not affected by storage conditions can be viewed in Table 4-4. Steaks from subprimals aged for 28 d had greater ($P \leq 0.01$) WBSF values than steaks from subprimals aged for 42 d, but surprisingly steaks from subprimals aged for 14 and 42 d had similar WBSF values ($P > 0.10$). It is also interesting to note that while length of postmortem age did affect the WBSF results, trained sensory panelists could find no variation in tenderness, regardless of length of age (Data not shown). The lack of variation may be an indication that for the GM muscle, a shorter aging period may be just as effective as a longer duration in regards to tenderness.

**Steak Location**

**Trained Sensory Panel**

For those steaks packaged in B packaging, the dorsal side of the GM had a higher occurrence of off-flavor than those from the ventral side ($P = 0.03$). For those in V packaging, steaks from the ventral end of the GM had more off-flavor reported than those from the dorsal end ($P = 0.04$) (Figure 4-5). While statistical significant difference was detected, values were all within the “threshold/barly detected” score for trained sensory panel. Lateral position of the steaks did not did not affect ($P \geq 0.69$) any other trained sensory panel values of the GM steaks. This complements the findings of Rhee et al., (2004) whose study found no difference for trained sensory panel measurements in relation to steak location within the GM muscle.
Warner-Bratzler Shear Force

In the only known research concerning the effect of steak location on the gluteus medius (Rhee et al., 2004) no variation was discovered moving from anterior to posterior of the muscle. In the present study, steaks tended to increase in Warner-Bratzler shear force progressing from anterior to posterior location. The anterior and posterior positioning within the muscle had a greater effect on tenderness than dorsal and ventral steak location. Although steaks were more tender on days 28 and 42 in those steaks from the dorsal side from those steaks taken from the ventral side of the muscle (Figure 4-6). This variation within the muscle needs to be further investigated to determine if steaks or sections of the GM muscle should receive different treatments such as less postmortem aging time for the areas of increased tenderness, or increasing tenderizing techniques, such as blade tenderization for those areas that are known to be innately tougher.

Summary and Conclusions

This research supports the fact that aging is considered the optimal method to tenderize and enhance the flavor of steaks and this research supports that fact. It also shows that only a limited number of days are needed to be effective for tenderizing muscles such as the *gluteus medius* that were previously thought to need extensive aging to increasing tenderness. For GM steaks, there was no significant difference between those steaks aged for 14 days, and those aged for 42 days. The GM steaks aged for 14 days were lighter and remained lighter, more red and more yellow throughout the retail days than those steaks aged for 28 and 42 d. The research has also determined that there is variation within the *gluteus medius* concerning tenderness. The variation in tenderness regarding location could result...
in an increase in the overall profit margin of the top sirloin subprimal. More research should be done to corroborate the findings of this study and to further address the need to develop dependable methods to increase desirable tenderness and palatability traits in the quality of carcasses that lead the industry today.
Table 4-1. Simple means for carcass traits from which the *gluteus medius*\(^a\) was collected.

<table>
<thead>
<tr>
<th>Trait</th>
<th>TB</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of carcasses</td>
<td>37</td>
</tr>
<tr>
<td>Hot carcass wt., kg</td>
<td>296.8 ± 30.0</td>
</tr>
<tr>
<td>12th-rib fat thickness, cm</td>
<td>0.90 ± 0.38</td>
</tr>
<tr>
<td>LM area, cm(^2)</td>
<td>77.8 ± 8.0</td>
</tr>
<tr>
<td>USDA YG(^b)</td>
<td>2.5 ± 0.6</td>
</tr>
<tr>
<td>Marbling(^c)</td>
<td>410.8 ± 31.5</td>
</tr>
</tbody>
</table>

\(^a\) IMPS # 184; n = 74.
\(^b\) Calculated according to USDA-AMS, 1997.
\(^c\) 300 to 399 = Slight; 400 to 499 = Small; 500 to 599 = Modest.
Table 4-2. Effect of subprimal packaging type\(^1\), storage temperature, and days of postmortem age on saleable yields of the gluteus medius.

<table>
<thead>
<tr>
<th>Packaging</th>
<th>Temperature</th>
<th>Postmortem Age (Days)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>V</td>
<td>4°C</td>
<td>0°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>67.2(^{b})</td>
<td>77.9(^{a})</td>
<td>&lt; 0.001</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)B; DryBag, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 2500 g/m\(^2\)/24 h at 38°C and 50% relative humidity, V = Traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm\(^2\)/24 h at 37.8°C and 100% relative humidity.

\(^a\)\(^b\)For variables multiple treatments, values lacking a common superscript differ (\(P \leq 0.05\)).
Table 4-3. Effect of subprimal packaging type, storage temperature, and days of postmortem age on Warner-Bratzler shear force (WBSF) and trained sensory panel values for gluteus medius steaks.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Packaging&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Temperature</th>
<th>Postmortem age</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>V</td>
<td>P-value</td>
</tr>
<tr>
<td>WBSF, N</td>
<td>38.0</td>
<td>38.0</td>
<td>0.99</td>
</tr>
<tr>
<td>Juiciness&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.9</td>
<td>4.9</td>
<td>0.93</td>
</tr>
<tr>
<td>Tenderness&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.1</td>
<td>5.2</td>
<td>0.53</td>
</tr>
<tr>
<td>Beef flavor&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.6</td>
<td>5.6</td>
<td>0.82</td>
</tr>
<tr>
<td>Off-flavor&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.6</td>
<td>5.7</td>
<td>0.43</td>
</tr>
</tbody>
</table>

<sup>a</sup>B; DryBag, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 2500 g/m<sup>2</sup>/24 h at 38°C and 50% relative humidity, V; Traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm<sup>2</sup>/24 h at 37.8°C and 100% relative humidity.

<sup>b</sup>Juiciness: 1 extremely dry, 2 very dry, 3 moderately dry, 4 slightly dry, 5 slightly juicy, 6 moderately juicy, 7 very juicy, 8 extremely juicy; Tenderness: 1 extremely tough 2 very tough 3 moderately tough 4 slightly tough 5 slightly tender 6 moderately tender 7 very tender 8 extremely tender; Beef flavor: 1 extremely bland, 2 very bland, 3 moderately bland, 4 slightly bland, 5 slightly intense 6 moderately intense, 7 very intense 8 extremely intense.

<sup>c</sup>For variables with three treatments, values lacking a common superscript differ (P ≤ 0.01).
Figure 4-2. Interactive effect of days of postmortem age and day of retail display on $L^*$, $a^*$, $b^*$, and subjective color scores of gluteus medius steaks. A. Lightness$^a$ ($L^*$) values ($P < 0.001$), B. Redness$^a$ ($a^*$) values ($P < 0.001$), C. Yellowness$^a$ ($b^*$) values ($P < 0.001$), D. and subjective lean color scores$^b$ ($P < 0.001$). Notes: $^a$L* measure of darkness to lightness (larger value indicates a lighter color); $a^*$ = a measure of redness (larger value indicates a redder color); $b^*$ = a measure of yellowness (larger value indicates a more yellow color). $^b$1 Extremely dark red, 2 Dark red, 3 Moderately dark red, 4 Slightly dark red, 5 Slightly bright cherry red, 6 Moderately bright cherry red, 7 Bright cherry red, 8 Extremely bright cherry red.
Figure 4-3. Interactive effect of packaging\(^1\) and temperature for L\(^*\) values\(^2\). Notes: \(^1\)B; DryBag, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 2500 g/m\(^2\)/24 h at 38°C and 50% relative humidity, V; Traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm\(^2\)/24 h at 37.8°C and 100% relative humidity. \(^2\)L\(^*\) measure of darkness to lightness (larger value indicates a lighter color). \(^{a,b,c}\)Values lacking a common letters differ (\(P \leq 0.04\)).
Figure 4-4. Interactive effect of subprimal packaging type\(^1\) and storage temperature on: A. Trained sensory panel tenderness\(^2\) \((P < 0.01)\) and B. Connective tissue\(^2\) \((P < 0.001)\) values of gluteus medius steaks. Notes: \(^1\)B: DryBag, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 2500 g/m\(^2\)/24 h at 38°C and 50% relative humidity, V: Traditional vacuum-bag (V: 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm\(^2\)/24 h at 37.8°C and 100% relative humidity. \(^2\)Tenderness: 1 extremely tough ,2 very tough, 3 moderately tough, 4 slightly tough, 5 slightly tender, 6 moderately tender, 7 very tender, 8 extremely tender; Connective tissue: 1 abundant amount, 2 moderately abundant, 3 slightly abundant, 4 moderate amount, 5 slight amount, 6 traces amount, 7 practically none, 8 none detected. \(^{a,b,c}\) Values with different letters differ \((P < 0.05)\).
Figure 4-5. Interactive effect of steak location, dorsal and ventral, and packaging type\(^1\) on trained sensory panel off-flavor\(^2\) (P = 0.004) values for gluteus medius steaks. Notes: \(^1\)B; DryBag, MacPak, LLC, Wayzata, MN having a water vapor transmission rate of 2500 g/m\(^2\)/24 h at 38°C and 50% relative humidity, V; Traditional vacuum-bag (V; 8600-14EL, Cryovac-Sealed Air Corporation, Duncan, SC) having a water transmission rate of 0.5–0.6 g/64,516 cm\(^2\)/24 h at 37.8°C and 100% relative humidity.\(^2\): 1 extreme off-flavor, 2 strong off-flavor, 3 moderate off-flavor, 4 slight off-flavor, 5 threshold; barely detected, 6 none detected. \(^{a,b,c}\) Values lacking common letters differ (P ≤ 0.05)
Figure 4-6. Interactive effect of lateral position and days of postmortem age on Warner-Bratzler shear force values ($P < 0.001$) of gluteus medius steaks. Notes: $a$, $b$, $c$ Values with different letters differ ($P < 0.05$).
CHAPTER 5
CONCLUSIONS

Packing type had an influence on yield, but little other influence on the measureable characteristics of the muscles studied. There was substantially greater yield resulting from the subprimals that had been stored in vacuum packaging, regardless of length of age, and temperature, except in the case of the triceps brachii, which had the higher temperature, and a greater yield. Packaging also had no influence on tenderness for any of the muscles in this study, either for the trained sensory panel, or the Warner-Bratzler shear force values. Of the small impact packaging had on color, vacuum packaging had the most positive influence, creating steaks with greater subjective color scores and higher b* values than those of the other packaging types. The impact of temperature on quality characteristics minimal, and varied throughout this study which was perhaps due to the narrow range between the two temperature treatments.

Location within a muscle was found to have an effect on Warner-Bratzler shear force (WBSF) for the gluteus medius, although those results did not coincide with a similar increase in tenderness in trained sensory panel. The variation between the anterior and posterior ends of the gluteus medius indicate the need for addressing locations separately within the muscle, for considerations on postmortem enhancements, such as length of age. The results of this research calls for an exploration to determine if variations within other muscles exist.

Length of postmortem age had an impact on all aspects of this study. As the length of age increased, saleable yield decreased. The resulting increase in tenderness from the increased length of age was not comparable. Except for steaks
from the *longissiums lumborum*, steaks did not increase significantly in tenderness with the longer postmortem aging period, but did increase off-flavor within the *triceps brachii* muscles. The longissimus lumborum muscles did increase in tenderness for both WBSF and sensory evaluation, as the length of age increased.

With respect to tenderness, beef flavor, and overall acceptability, the *triceps brachii* is a viable alternative to the *gluteus medius* as a retail steak. The *gluteus medius*, or top sirloin steak as sold to the consumer, is known as an economical alternative to steaks from the rib or the short loin. This study shows the *triceps brachii*, or “ranch steak” to be an economical alternative to the top sirloin steak.
LIST OF REFERENCES


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BIOGRAPHICAL SKETCH

Amanda Osterhout was born in 1989 to Merrill and Susan Osterhout. She and her family, including one older brother, Charlie, lived in Hernando, Florida. While her family did keep goats on the property, Amanda did not grow up in an agricultural family. After high school, Amanda attended Auburn University, first under the Animal Sciences program, but ultimately ended up in the Poultry Sciences program. While studying at Auburn, Amanda worked as a student worker at the Lambert-Powell Meats Laboratory under Barney Wilborn. It was here that Amanda developed a passion for the meat industry and began looking for an opportunity to further her education in that field. Prior to graduating in 2010, Amanda completed a summer internship at Cagle’s Inc. poultry processing plant in Pine Mountain Valley, Georgia.

Following graduation at Auburn University Amanda was accepted into the graduate program at the University of Florida under the direction of Dr. Dwain Johnson. While working towards her degree, Amanda assisted in the Introduction to Animal Sciences classes as well as assisting with the laboratory sections for the Meats class.