An observation of tenderness, yield, and carcass composition in serially slaughtered steer carcasses implanted with Revalor-XS

by

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ABSTRACT

Tenderness, carcass composition estimates using the 9-10-11th rib sections, and the current USDA yield grading equation were observed and evaluated in serially slaughtered beef steers. These comparisons were made in an effort to better understand evaluations of steers in current marketing processes in the United States. Charolais x Angus steers (*n*=80) were randomized to implant treatments (REV: Revalor-XS on d-0 and d-190 or CON: no implant) and harvest date in a 2 x 10 factorial design. Four pairs of steers were randomly allocated to one of 10 harvest dates and harvested in 42d intervals (0, 42, 84, 126, 168, 210, 252, 294, 336, and 378 days on feed).

Growth promotants are commonly administered to increase rate of weight gain and improve feed efficiency, but in some instances may increase the incidence of tough beef. One objective of this study was to investigate objective mechanical tenderness of serially harvested steers with and without exogenous growth promotant administration. Samples of the *M. longissimus dorsi* from the 13th rib section were obtained from the left side of each carcass, aged for 14d, and frozen at -29ºC. Frozen samples were cut into 2.54-cm-thick steaks for Warner-Bratzler shear force (WBSF) and sliced shear force (SSF) measurements, and vacuum packaged. Samples were thawed for 24h at 2ºC, initial weight was obtained prior to cooking, and steaks were cooked to an internal temperature of 71°C. After a 5 min cooling period, cooked weights were recorded; WBSF samples were cooled 24h at 2ºC prior to coring and shearing. Slice shear force samples were taken immediately following attainment of cooked weight. All samples were sheared according

to AMSA protocol with a texture analyzer and peak shear force data were analyzed via Pearson correlation and mixed models. There were no TRT x DOF interactions ($P \geq 0.51$) observed for objective tenderness determined via WBSF or SSF. Peak force values did not differ between REV and CON for WBSF ($P = 0.10$) or SSF ($P = 0.83$). Peak force did not differ ($P \geq 0.17$) across DOF. Moderate correlation was observed between WBSF and SSF (r = 0.41). Results from this study indicate that growth promotion had little effect on objective tenderness.

Estimates of beef carcass cutability are determined via the USDA yield grade (YG) equation, which has remained unchanged for over 55 years. Previous studies have shown that variables used for predicting YG do not adequately reflect changes in genetics and composition of the current fed beef population. Carcass yields were determined by fabricating carcasses and separating lean, fat, and bone components and weighing to the nearest 0.05 ± 0.005 kg. Linear models were developed to compare predictive red meat yield of steers to the original USDA boneless closely trimmed rib-loin-chuck-round (BCTRLCR) equation and actual BCTRLCR yield. Additionally, ribeye area (REA) to hot carcass weight (HCW) relationship was compared to the standard expected when beef carcasses are graded according to USDA methods. Carcasses less than 317.5 kg in this study had larger REA than required from the USDA REA standard, whereas carcasses greater than 317.5 kg had smaller REA than required. In comparison to HCW, REA trended in a quadratic manner, differing from the original YG equation which is represented in a linear fashion. Yields of BCTRLCR were analyzed without trim fat using a forced intercept of 51.34 from the original USDA YG equation, in order to generate new coefficients for the carcass parameters used to estimate carcass cutability.

Additionally, correlations were calculated between four individual parameters (HCW; REA; fat thickness in inches, (FAT); and percentage kidney pelvic and heart fat, (KPH)) previously determined by the USDA equation, and BCTRLCR outcomes. Calculations of BCTRLCR were strongly correlated (r = -0.86, -0.72, -0.64, -0.82 to HCW, REA, FAT, and KPH respectively) to all individual parameters, indicative of a shift from the original USDA BCTRLCR equation. The new equation would reflect the four original parameters with adjusted coefficients; BCTRLCR = 51.34 – 2.71 (FAT) – 0.848 (KPH) – 0.678 (REA) – 0.0043 (HCW). An updated equation would improve the accuracy in estimating beef carcass cutability.

The third objective was to compare separable lean, fat and bone of samples taken from the ninth-tenth-eleventh rib section to those of the carcass, as well as proximate analysis from each component. Carcass yields were determined by fabricating the right side of each carcass and separating lean, fat, and bone components and weighing to the nearest +/- .05 kg. Ninth-tenth-eleventh rib sections were collected from the left side of each carcass, dissected into lean, fat, and bone, and weighed to the nearest +/- .005 g. Regression models were created to determine linear associations between rib sections and carcass parameters. Carcass fat and lean were strongly correlated (r = 0.87 and 0.80 respectively) to 9-10-11 fat and lean, however carcass bone was only moderately correlated (r = 0.59) to 9-10-11 bone. Correlations between whole carcass parameters and rib sections were more closely correlated when weights of each respective method were compared. Proximate analysis of carcass and rib section components produced varying levels of correlation. A REV × DOF interaction was detected for carcass ash, moisture, and bone (P = 0.04; and 0.05; and < 0.01, respectively) and rib section ether extract (P =

0.05). Both carcass components and rib section differed across DOF ($P < 0.01$) for ether extract, crude protein, moisture, lean, fat, and bone. No treatment effects ($P \geq 0.13$) were observed in rib section components, however ash and ether extract differed ($P < 0.01$) between treatments for carcass components. Results from proximate analysis indicated differences between the 9-10-11th rib and whole carcass parameters.

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am today if it had not been for the immeasurable hours you have taken to guide and care for me. I love you all.

DEDICATION

This thesis is dedicated to my grandparents, parents, and siblings. Dad, thank you for first teaching me how to pick up a show stick and a feed bucket, and instilling my love for beef cattle in the process. I would not be here if it had not been for your compassion and understanding throughout my life. When the time comes, I hope I am half the parent that you didn't have to be. None of this would have been possible without all of your guidance, and I love all of you. Thank you for being there, always.

APPROVAL

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CHAPTER 1

INTRODUCTION

Anabolic steroids are a commonly used strategy to increase growth performance and carcass muscling in cattle of all stages of production, from suckling calves to finishing cattle. In a survey of feedlots from the top 13 cattle feeding states by the USDA National Animal Health Monitoring System (NAHMS, 2011), 84.4% need a better source of all cattle entering the feedlot in locations harboring a minimum of 1,000 cattle were observed to practice growth promoting administration at least once. Revalor-XS (RXS: Merck Animal Health, Madison, NJ), is an anabolic steroid approved (FDA, 2007) for use in feedlot cattle as a strategically delayed, 200 day, slow release implant labeled to increase rate of gain and improve feed efficiency.

Mechanical mechanisms for subjectively determining palatability of meat have been recorded in research since the late 1800s. Researchers have reported that tenderness is the most important attribute to consumer palatability (Shackelford et al., 2001; Voges et al., 2007). There are reports from reviews of literature that the addition of growth promoting hormones may increase toughness (Apple et al., 1991; Garmyn and Miller, 2014; Lean, et al., 2018) whereas others report no change in tenderness between implanted and non-implanted animals (Nichols et al., 2002; Barham et al., 2003; Igo et al., 2011). The purpose of this evaluation was to determine if Revalor-XS administration altered objective tenderness.

The current USDA yield grade equation is based on data from the late 1950's, however much has changed in the industry including genetics and cross breeding, growth promotion technologies, and feed utilization have improved through the decades. Yield grade systems in other countries have been modified and advanced to accommodate changes in beef cattle (Japanese Meat Grading Association, 2000; Canadian Beef Grading Agency, 2020). Previous research on methods of measuring yield grade have suggested the need for an improved equation (Kerth et al., 1999; Farrow et al., 2008; McEvers et al., 2012), allowing more accurate measurements and estimations for both producer and packer.

A review from the USDA Bureau of Animal Industry (1935) stated the efficacy of using the 9-10-11th rib section from heifer and steer carcasses as a method to determine overall body composition as opposed to harvesting a whole carcass for chemical analysis. Hankins and Howe reiterated this method in 1946, establishing several equations from this rib section as a low cost compensatory sample of whole carcass composition. A revision of this method is needed to determine efficacy of these equations from their establishment to present day.

The objectives of this thesis were three fold: to analyze the efficacy of the Hankins and Howe procedure, to review and revise methods of the current yield grade equation calculations, and to observe differences of tenderness of implanted versus non-implanted steers in reference to Revalor-XS.

CHAPTER 2
REVIEW OF THE LITERATURE

2.1. Palatability

Palatability determination by use of sensory panels is a method that has been utilized alongside mechanical shear force and/or stand alone for viability of label claims. Trained panels are useful in determining attributes of meat samples which would otherwise be overlooked, such as determining flavor attributes or aromatic notes (AMSA, 2015). In comparison to tenderness, expected flavor of samples is known to differ based on personal and individual preference (Killinger, 2004; O'Quinn, 2016). Flavor profiles are a complex relationship of animal and feed source; Milopoulos et al. (2019) evaluated the flavor profile and palatability of beef striploins by sensory panel and concluded that consumer perception of meat was related to the quality of forage and feeding period of cattle. Perceived flavor is also impacted by the growth rate of cattle, as lipid development and deposition is influenced by addition of growth technologies and improved feeding methods (Smith et al., 2009). Addition of grains to cattle diets is known to stimulate adipogenesis whereas pasture feeding suppresses adipocytes, which is a major contributor to flavor profile and moisture retention (Smith et al., 2009). The underlying problem in determining juiciness of meat are the many variables associated with retaining moisture. Retained moisture is dependent upon the method of cooking, ultimate pH, fat content, and how long the sample is cooked, among other factors. The lack of research on

juiciness lies within the difficulty of repeatability between sites as well as the perceptions of a consumer panel. Juiciness can be related to the cooking loss from measuring the initial sample weight in comparison to cooked weight, but again this is dependent upon the sample itself.

2.1.1. Factors Effecting Palatability

There are many known factors in the development of meat which can alter palatability. The relationship between some of those factors in the following sections may alter perceived palatability to consumers, influencing selections and preferences. Consumers develop expected flavors and perceptions in beef selection; method of feeding animals prior to slaughter contributes to flavor profiles and development of key fatty acids associated with expected flavors (Smith, 2009). Along with developed flavors during feeding, there are factors to consider during processing from the conversion of muscle to meat which effect palatability.

2.1.2. Cold Shortening

One of the factors known to effect tenderness is the temperature at which carcasses are chilled after harvest. The timing and temperature relationship of cooling a carcass is a key factor in allowing rigor mortis to set in the muscles, as well as allowing optimum time for pH decline, which ultimately effects the overall tenderness of the carcass. When carcasses have been rapidly chilled in 15-16°C conditions, muscles are known to contract and freeze, preventing the onset of rigor, which is known as “cold shortening.” The phenomena has also been associated with disappearance of the I-band in muscle, as well as a physical shortening of muscles when muscles that have been frozen pre-rigor are thawed (Aberle et al., 2012). The association of cold shortening is also

related to leaner carcasses, as fat cover is essential in preventing rapid freezing of external muscle; leaner carcasses are more susceptible to freezing as the lack of fat eliminates the insulation needed to appropriately chill carcasses (Parrish et al., 1979).

Tenderness of cold shortened carcasses was suspected to be directly related to the initial excised length of the of the muscle. Marsh and Leet (1966) observed complex relationships of tenderness and cold shortening, where cold shortened muscle excised under 20% had little effect on tenderness, between 20-40% was reported to increase toughness, and between 55-60% were observed to become more tender. Lochner et al (1979) elaborated on previous research, indicating that the degree of finish of the carcass was more closely related to the degree of cold shortening, and therefore leaner carcasses exemplified higher degrees of cold shortening. Carcasses containing more finish, or fat accumulation, were observed to undergo less instances of cold shortening when compared to leaner carcasses (Lochner et al., 1979; Parrish et al., 1979).

Methods to prevent cold shortening, such as electrical stimulation, have previously been applied in order to increase tenderness. In 1975, Davey et al. reported using the electrical stimulation method to prevent cold shortening, and therefore preventing toughening. Savell et al. (1978) suggested that the physical disruption of the sarcomere length was the implement that improved tenderness, rather than prevention of cold shortening. Electrical stimulation has also been reported to improve tenderness by physically disrupting the contractile bands in meat, along with the stimulation of glycolysis in the muscle prior to rigor mortis and allowing an accelerated pH decline (Aberle et al., 2012).

In conclusion, there are various factors which could affect cold shortening in beef carcasses. Tenderness associated with cold shortened carcasses could depend upon a variety of factors, such as the use of electrical stimulation, pH, sarcomere length, etc. Overall, tenderness and cold shortening have been consistently reported as dependent upon temperature and the time it takes to chill muscles in the carcass as they pertain rigor mortis.

2.1.3. Effect of Sex on Tenderness

Androgens, estrogens, and progesterones are all responsible for the stimulus of muscle growth and maturation of the skeleton (Aberle et al., 2012). Androgens are the principal hormones produced by the testes in intact males, and are responsible for stimulating protein synthesis, whereas estrogen and progesterone are the principal hormones produced by the ovaries and are responsible for promoting fat accretion and skeletal maturity. Essentially, intact females mature earlier than males due to the amount of circulating estrogen in the body, which can ultimately influence the maturation of the carcass (Aberle et al., 2012). Meat from young bulls has been reported to lack uniformity in tenderness and has been known to toughen more quickly than animals of the same age of different sexes, which could be influenced by genetic potential (Aberle et al., 2012). The maturation rates of bulls and heifers is therefore increased as compared to steer or spayed heifers, as the principal hormone source has been removed. Furthermore, Hunsley et al. (1971) reported that age and sex were of equal importance in affecting muscle tenderness, younger animals also had significantly larger *longissimus* muscle areas and less backfat than older animals, regardless of sex. In an evaluation by Choat et al. (2006) it was reported that spayed heifers had smaller *longissimus* areas as compared to intact

heifers and non-hormone treated steers; steaks from steers were reported as superior in palatablilty assessments as compared to either heifer treatment. Zinn et al. (1970) and Choat et al. (2006) observed no differences in steer and heifer tenderness after samples were allowed to age for 14 days, however when aged at 7 days Choat et al. (2006) observed that steaks from spayed and intact heifers were significantly tougher than steaks from steers. It could therefore be hypothesized that initial sex differences in tenderness could change over time with carcass aging practices.

2.1.4. Days on Feed

The length of time cattle are fed an increased concentrate diet can alter palatability of meat, particularly tenderness. Various factors, such as differences in starting live weights, genetic and environmental potential, or physiological age make it difficult to assign an optimum time on feed for cattle between studies. Warner-Bratzler shear force reports from Zinn et al. (1970) indicated that meat from calf-fed Hereford cattle decreased by approximately 1.5 kg of force from 120 to 150 days on feed, and remained unchanged until 240 days on feed when WBSF increased by approximately 1.5 kg. Other studies have reported yearling cattle fed a concentrate diet for 139 days reduced WBSF by 0.44 kg in 139 days as compared to 251 days (Epley et al., 1968). Short et al. (1999) reported that steaks from Charolais crossbred calves were most tender after being fed a concentrate diet for 270 days, whereas other breeds reached an equal level of tenderness at 90 days on the same diet. Other researchers have reported no differences in WBSF of steaks from yearling cattle fed between 100 and 160 days (Van Koevering et al., 1995). While there are differences between studies, the studies previously mentioned

indicate that the optimum time on feed in relation to tenderness is between 90 to 160 days for British breeds, but may include longer feeding periods for Continental breeds.

2.1.5. Growth Promotants

In many studies, use of growth promotant treatments have not proven to increase or decrease tenderness when compared to non-treated animals (Duckett and Andrae, 2001; Nichols et al, 2002; Hutcheson, 2008; Igo et al., 2010). Other studies have reported differences, where growth promotion treatments have decreased tenderness (Apple et al., 1991; Foutz et al., 1997; Garmyn and Miller, 2014). Contradictions in studies may result from a variety of factors, such as aging period, and preparation of samples (Wheeler et al., 1994; Shackelford and Wheeler, 2009).

Beta-adrenergic agonists are non-hormonal compounds fed to beef cattle which can redirect fat metabolism and thereby increase muscle accretion by mimicking the effect of naturally occurring hormones. Use of beta-agonists in cattle do not alter the hormone concentrations in cattle, whereas other forms of growth promotion can slightly change the hormone concentration when implemented. These substances are effective in activating beta receptors in cattle; beta receptors are directly responsible for muscle protein and lipid metabolism (Aberle et al., 2012). Common beta-agonists are ractopamine hyperchloride (Optaflexx) and zilpaterol hydrochloride (Zilmax), which are known to increase muscle size and decrease fat, which can negatively impact tenderness more than other growth promotants (Aberle et al., 2012). The advantage of using beta-agonists are improved weight gain during feeding duration, and increased muscle at harvesting, whereas disadvantages to using beta-agonists are withdrawal times needed to meet USDA standards. Arp et al. (2014) observed increased performance in the round

and loin for both zilpaterol hydrochloride and ractopamine hydrochloride application, as well as lower yield grade and decreased marbling. McEvers et al. (2018) shared similar reports of increased round and loin performance, as well as an ultimate increase in processor revenue of +$138.94/45.4 kg in cattle fed zilpaterol hydrochloride as compared to controls. Greater yields are consistent in research, and therefore improve profitability when beta-agonists are applied.

Anabolic implants are used to reduce the cost of beef production. Implant devices may be comprised of estrogens or androgenic compounds and essentially have two methods of action: estrogentic implants increase circulating levels of somatotropin and insulin-like growth factor-1 (IGF-1), while androgenic compounds such as trenbolone acetate (TBA) do not stimulate somatotropin but increase the circulating IGF-1 and decrease protein loss (Zobell et al., 2006). Implants are an advantageous growth promotant in that they require no withdrawal time prior to slaughter, as they are implanted in the ear and are discarded. Implant products are now available for all stages of production, from suckling calves to grazing cattle, to finishing cattle. Implanted animals have been reported as approximately 20% more efficient on average in terms of daily gain as compared to non-implanted animals (Duckett and Andrae, 2001). Research has indicated that the additional weight gain observed in implanted animals is additive throughout all aforementioned phases of beef production, adding increased live values of approximately $93 per animal (Duckett and Andrae, 2001). While implants did not affect shearing values, the consumer panel in the Igo et al. (2010) research indicated that the quality grade of meat was different for various implant strategies and could be detected; various days of aging were used and it was suggested that aging for 21 days could

minimize palatability differences in implanted animals to improve consumer acceptability. Hutcheson (2008) accounted for the difference in physiological maturity of implanted and non-implanted cattle, as implanted cattle do not accrete fat at the same rate as non-implanted cattle; by allowing implanted cattle to reach physiological maturity, negative effects on marbling could be mitigated. Other research has suggested that the use of implants toughens beef and negatively impacts palatability (Foutz et al., 1997) however, Garmyn and Miller (2014) suggested that instances of toughness could be from misuse of implant strategies. Furthermore, Schnieder et al. (2007) concluded that tenderness of 12 different implant strategies could be improved by postmortem aging periods, regardless of treatment. In summation, implantation strategies may decrease quality grades in carcasses that have not reached physiological maturity, however there are methods which can improve consumer satisfaction and acceptability.

Another technique used by producers is the application of ionophore antibiotics, which alter the fatty acid production levels in the rumen, thereby increasing feeding efficiency. The U.S. Food and Drug Administration approved the use of monensin to improve feed efficiency in 1975. The use of ionophores is now labeled for the reduction of coccidia, and for improved feed efficiency in calves (excluding veal), terminal beef, and in breeding stock (Elanco, 2020). Monensin, is the only approved form of ionophore available to all stages of cattle with the exception of veal (Elanco, 2020). Cross and Dinius (1978) investigated the changes in palatability with the use of monensin and observed that treated cattle had no significant differences in palatability or cooking traits, although the fatty acid levels were significantly different. Goodrich et al. (1984) reported that carcass characteristics were not significantly influenced by monensin, supported by

Hilton et al. (2009) in which effect of zilpaterol hydrochloride, monensin, and tylosin on carcass cutability and palatability were investigated. Hilton et al. (2009) reported little to no effects were observed with the use of monensin, however the addition of zilpaterol hydrochloride increased WBSF values. In conclusion, the different strategies of growth promotion may alter palatability, particularly when beta-agonists are present.

2.1.6. Genetics

Another factor known to effect tenderness is the genetic background of the carcass. It is known that *Bos taurus* animals are reported to be more tender on average than *Bos indicus* animals, regardless of marbling score (Wheeler et al., 1994). Tenderness is improved when enzymes, such as calpains, are activated by calcium released in sarcoplasm during postmortem proteolysis. This calcium release and calpain activation are directly responsible for tenderization during postmortem storage. An inhibitor enzyme, known as calpastatin, is typically observed in greater amounts in bulls and animals of *Bos indicus* lineage. The relationship between calpains and calpastatins is therefore accountable for *Bos taurus* animals presenting as more tender than *Bos indicus* animals. Crossbreeding of *Bos taurus* and *Bos indicus* was developed as a method to increase heterosis; it was reported that crossbred cattle had better rates of gain and were less susceptible to heat stress than pure *Bos taurus* animals, however crossbred herds resulted in less tender beef (Frisch, 1987).

Similar results were reported in common breeds as well, as purebred Angus (British) cattle have lower calpastatin activity when compared to purebred Charolais (Continental) cattle (Shackelford et al., 1994). Genetic analysis of crossbred cattle reported by Riley et al. (2003) reported sire was the source of variation in calpain and

calpastatin interactions. Other studies have supported that calpastatin activity is highly heritable and may increase linearly as the percentage of Brahman (Bos indicus) influence increases (Shackelford et al., 1994; Pringle et al., 1997; Smith et al., 2007).

Other research has suggested that the use of the selection index theory could be used to pass on traits pertaining to tenderness, such as marbling score, muscling score, and genomic breeding value for specific marbling expectations. The selection index theory is used to assess accuracy of selection and expected genetic gain per generation (Hazel, 1943). Pimentel and Konig (2012) used this theory in beef cattle and observed an increased marbling response in offspring belonging to genetic groupings of parents specifically selected for marbling, and determined that the accuracy of genotyping offspring for these traits could be improved by adding ultrasound imaging as well as marbling scores within breeds to improve the accuracy of tenderness traits through breeding and lineage.

Overall, tenderness traits have been influenced by the genetic composition of the sire and may be manipulated directly by specific selection of traits. Sires have been reported as the source of variation in calpain and calpastatin activity regarding purebred as well as crossbred beef animals (Pringle et al., 1997; Riley et al., 2003). Tenderness is highly influenced by the genetic makeup of beef animals and may be improved with the selection of certain traits.

2.1.7. Physiological Age

Another factor which influences palatability is the physiological age of the animal at the time of harvest. It is known that younger slaughter ages are associated with more tender beef (Wulf et al., 1996, Aberle, 2012). Wulf et al. (1996) evaluated the effect of

animal age, marbling, calpastatin activity, and degree of doneness in steers and reported that younger animals had lower calpastatin activity and were therefore more tender. Palatability within age was also observed by Field et al. (1966) and similar results were observed; yearling heifers and steers were more tender than bulls of the same physiological age and moisture was better retained after cooking. Causes for the changes in palatability over physiological time may be reflected in changes of connective tissues over time.

There are many different forms of collagen which have been identified, but the four basic layers in muscle tissue can be classified as the epimysium, perimysium, endomysium, and basement membrane. Each layer is formed by different types and amounts of collagen (Lawrie and Ledward, 2006). As animals age, collagen content is changed; tensile strength of connective tissue such as collagen increases over time because of chemical cross-linking (enzymes allow maturation of fibers in collagen, binding them together to form thermally stable and less soluble forms of collagen) which was first identified in 1968 (Bailey and Peach, 1968). Cross-linking of collagen is responsible for the "muscle toughening" due to age. Steers and heifers between 400-499 days of age were observed to have similar palatability in sensory testing when marbling was held constant, whereas bulls of similar age were indicated as tougher in both sensory testing and shear force testing (Field et al., 1966). In younger animals, collagenases can alter the connective tissue structure which allow degradation of collagen. Over time, the crosslinks can decrease tenderness in the muscle, as when they are heated they shrink, causing moisture loss and greater instances of toughness (Weston et al., 2002). Differences in soluble collagen percentage impact WBSF values, however cattle of

similar age may have differing levels of soluble collagen (Duckett et al., 2007). It has also been reported that not all cross-links impact tenderness in the same way (Lawrie and Ledward, 2006).

2.1.8. Sarcomere Length

Sarcomeres are considered the most basic unit of muscle contraction, defined as the distance between adjacent Z-lines (Lawrie and Ledward, 2006). Sarcomeres are mainly comprised with myosin (thick) and actin (thin) filaments. Myosin and actin filaments are proteins which make up the A-band, an area in which actin and myosin filaments interact for the process of contraction. H-bands are increased in size when the sarcomere is relaxed, and the overlap of actin and myosin is reduced in this stage. The H-band is comprised of myosin, and fills the center space of the sarcomere, also known as the M-line. The I-band, containing actin filaments, is located on each end of the sarcomere and crosses adjacent Z-lines. Myosin filaments are known to be approximately 1.5 μm in length whereas actin filaments are approximately 1 μm in length; together they account for 3.6 μm of a fully stretched sarcomere, or 1.6 μm of a fully contracted sarcomere. There are studies which have reported differing lengths of sarcomeres, indicating that the myosin filament can rupture through the Z-line (Grayson and Lawrence, 2013). Sarcomere length may also differ between muscles (Smulders et al., 1990). Postmortem processes may also effect sarcomere length, as ATP depletion in the muscle causes the permanent formation between actin and myosin (the actomyosin bond), which is also termed rigor mortis (Lawrie and Ledward, 2006). Once in rigor, the bonded sarcomere length cannot change; however, muscle positioning changes sarcomere length before the onset of rigor, allowing sarcomeres to compress or elongate in tension. The

tension and compression may be observed and dependent upon carcass suspension methods.

Different methods of suspending carcasses have been observed in studies, the Achilles carcass suspension method is most commonly used in North America in which the carcass is suspended by the Achilles tendon, to the Tenderstretch carcass suspension in which the carcass is suspended by the *obturator foramen*. Observations between methods have reported shorter sarcomere lengths in the *longissimus dorsi* with the Achilles method as compared to the Tenderstretch method. Another method noted for an increased sarcomere length of the *longissimus* muscle is known as the Tendercut method, where the vertebral column is cut and the weight of the fore-quarter is suspended by the *longissimus* muscle. Additionally, WBSF reports coincide with changes in sarcomere length, longer sarcomeres require less force whereas compressed or shorter sarcomeres require more kg of force to slice (Shackelford et al., 1994). Individual muscles may change according to the aforementioned methods; however, the USDA has established the importance of testing the *longissimus* muscle due to the current methods in which beef grading is evaluated (USDA-AMS, 2015). In conclusion, changes in sarcomere length can impact tenderness, and therefore palatability may coincide with sarcomere length.

2.1.9. pH

Anaerobic glycolysis uses glycogen to produce ATP and lactic acid, causing a decline in muscle pH (Lawrie and Ledward, 2006). Changes in the ultimate pH (UPH, averaging at approximately 5.4-5.8) can cause denaturation of protein in the muscle and change the rate at which proteolysis occurs (Laville et al., 2009). Typically, meat beyond

the isoelectric point (<5.2) is reported as pale, soft, and exudative (PSE), whereas meat with a higher UPH (>5.8) is considered dark, firm, and dry (DFD). Most DFD beef is exported from the United States to Japan, as the product is more desirable to that consumer base. High pH (> 5.9) has been reported to increase WBSF values, regardless of aging times (Purchas et al., 1999; Wulf et al., 2002). Studies have also indicated that calpain and calpastatin interactions may be effected by UPH, as optimal calpain activity ranges from a pH of 7.2-7.8, whereas calpastatin activity decreases below 5.7 (Kendall et al., 1993). The WBSF scores of meat ranging above a UPH of 6.4 have been reported as more tender than that of levels around 5.7 (Kendall et al., 1993, Purchas et al., 1999); researchers have speculated that a UPH could possibly have a role in tenderness when considering the interactions between pH, calpastatin, and calpains, however the consumer perception of how UPH could affect palatability is unknown.

2.1.10. Aging Time

Postmortem aging or conditioning is first associated when Z disks in the muscle begin to degenerate, which causes weakness and fragmentation of myofibrils (Aberle, 2012). Researchers agree that the degradation of cytoskeletal proteins (titin, nebulin, filamin, vinculin, desmin, and dystrophin) is considered to be the main reason meat becomes more tender, upon the onset of the deterioration of the Z-disk. The three proteolysis systems involved in the degradation of cytoskeletal proteins are cathepsins, proteasomes, and calpains; however none of the systems account for all of the postmortem changes in meat tenderness. Protein degradation is also dependent on temperature, as calcium is released from the sarcoplasmic reticulum as temperature decreases, however if the muscles undergo cold shortening, the process is limited

(Aberle, 2012). Proteolysis of the structural proteins causes weakness of the myofibril, which increases tenderness the longer a carcass is held (Laville et al., 2009). Palatability is also influenced by the length of time a carcass is held before processing; greater off-odors and discolorations are observed in carcasses that have been aged longer than 20 days (Jennings et al., 1978).

2.1.11. Marbling

Quality grades of beef are the description of characteristics which predict the palatability of lean (USDA, 2015). Mumford (1902) justified the importance of classifying cattle in the market by grading in which weight, quality, and conformation were used to grade market ready cattle. Federal quality grading was proposed following the Mumford (1902) study. By 1916, the USDA grade specifications for beef were formulated, and by 1924 a federal bulletin was outlined for the official grading standards of dressed beef (Davis and Whalin, 1924). Since the inception of quality grading in beef, standards have adapted over time to allow specific standards for steers, heifers, and cows in the market (USDA, 2017).

Today, steers and heifers are classified into 8 grade categories: Prime, Choice, Select, Standard, Commercial, Utility, Cutter, and Canner (USDA, 2017). The two factors used to determine grades of beef are marbling and maturity of the carcass (USDA, 2017). In order to grade beef in the United States, carcasses are split through the middle of the vertebral column before a cut is made between the 12^{th} and 13^{th} rib, exposing the *longissimus* muscle. The face of the longissimus muscle is allowed to bloom before the quality of lean is determined, through evaluation of the intramuscular fat (marbling) and the firmness of the *longissimus* surface (USDA, 2017). Maturity can be determined

through several methods approved by the USDA (2017), such as dentition (evaluation of the permanent incisors), ossification of bones and cartilage, and evaluation of the color and texture of the *longissimus* surface.

Relationship Between Marbling, Maturity and Carcass Quality Grade[1]

Degrees of Marbling	Maturity[2]				
	A[3]	B	C	D	E
Slightly Abundant	PRIME				
Moderate			COMMERCIAL	COMMERCIAL	
Modest	CHOICE				
Small					
Slight	SELECT		UTILITY	UTILITY	
Traces					
Practically Devoid	STANDARD			CUTTER	

[1]Assumes that firmness of lean is comparably developed with the degrees of marbling and that the carcass is not a "dark cutter."
[2]Maturity increases from left to right (A through E).
[3]The A-maturity portion of the Figure is the only portion applicable to bullock carcasses.

Fig. 2.1. USDA quality grading chart

Palatability is also influenced by fat thickness and marbling, as the accumulation of subcutaneous fat minimizes drying during cooking (Jennings et al., 1978). Steers and heifers of the same quality grade were reported as highly palatable with minimal difference observed in consumer panels (Field et al., 1966). Similarly, relationship of quality grades to palatability were reported by Smith et al. (1987) in which Prime carcasses were more palatable than other grades, and Prime through Standard grades could be identified from predicted flavor, tenderness, and overall palatability from a consumer panel.

2.2. Shear Force History

Tenderness, flavor, and juiciness are the most important factors of meat palatability (Voges et al., 2007). Tenderness has been reported as the most important trait in accordance with consumer preference and satisfaction (Shackelford et al., 2001). The term tenderness as defined by the USDA-AMS (2011) is "the degree of yielding texture possessed by a specimen (for example, steak); ease of which a specimen is torn, cut, or sheared." Scientists rely on a series of methods to determine these meat attributes, such as the Warner-Bratzler Shear Force method, Sliced Shear Force, and also the use of trained and consumer panels. The first known work of mechanical and physical means of measuring tenderness were identified by Lehman, beginning his research in 1897 and first publishing results in 1907. Lehman's method consisted of a simple lever with a blade type end on one side and a lever on the other, a meat sample would be placed on the blade wielding end and pressure would be applied to the lever until the blade separated the meat sample, shear force was recorded by a spring dynamometer (Lehman, 1907).

The need for mechanical determination of tenderness was a prevalent topic of researchers in the 1920's and 30's (Warner, 1929; Bratzler, 1930) who sought a cohesive and systematic approach to objectively measure tenderness. Warner and Baker developed a method known as the "mouse trap" to quantify tenderness, and according to the 1929 progress report from Warner, the mouse trap or miter box mechanical shear had been dispersed to several experiment stations for an observational analysis of how to improve the laboratory testing of mechanical shear. The shear was constructed to run a blade through a meat sample core until the blade passed through and into a miter box, which

would be self-measured and recorded using a spring dynamometer (Warner, 1929). Bratzler, in correlation to this update, associated with Warner's methods to develop a new mechanical device (Fig 2.1.) which would lead to the Warner Bratzler Shear Force (WBSF) method. Bratzler developed an improved miter box mechanism and tested different blade shapes and thicknesses and observed that a triangular shaped blade with a 1.016 mm thickness had the least amount of variations between meat samples. The development of this model also used a palatability committee to analyze perceived differences in samples (Bratzler, 1932).

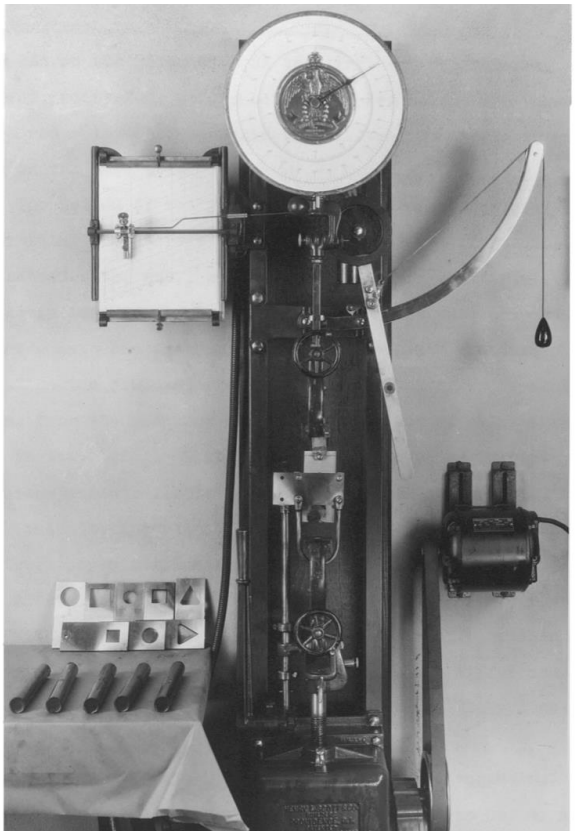

Figure 2.2. Bratzler shearing mechanism, 1932.

2.2.1 Warner-Bratzler Shear Force Sample Preparation

According to AMSA guidelines (2015), WBSF samples should be prepared without freezing whenever possible, however there are guidelines for research when this is not a feasible arrangement. Samples should be vacuum sealed and frozen at the same rates for the same amount of time in order for samples to be uniform. Samples should be thawed in vacuum sealed packages, and the internal temperature should reach between 2 and 5 degrees Celsius before cooking, as internal temperature can influence peak cooked temperature (Wheeler, et al., 1996). Samples should be weighed before preparatory procedures for cooking in order to record initial weight. Temperature monitoring is necessary for samples to reach a consistent recommended internal temperature of 71 degrees Celsius; thermocouples are the suggested temperature monitoring system for WBSF samples. AMSA approved metals for thermocouples are either iron/constantan or copper/constantan <0.05 cm in diameter. Application of these instruments should be applied to the geometric center of the sample. The needle and probe should be pushed through steak samples to create a guide for the thermocouple wire to be run through. Once the wire is exposed on the opposite side of the steak, the needle is removed and the process repeated through the opposing side of the sample steak. The wire should be pushed through to create a loop centering in the steak for appropriate analysis of temperature while the sample is cooked, and the needle and probe should be removed so that the wire remains in the steak. Samples should then be cooked with the appropriate method in accordance with the USDA-AMS and AMSA procedures. Once the sample has reached an internal temperature of 71 degrees Celsius, the final temperature and cooled weight should be recorded. Samples are then cored with a 1.27 cm diameter core device,

either hand held or an automated drill, parallel to the muscle fiber; six core samples are taken from each sample, and should be refrigerated until sheared to maintain consistent temperature and uniformity of the samples (AMSA, 2015). Use of a standardized method of cooking, preparing, and maintaining samples is imperative to ensure repeatability of procedures from varying institutions (Wheeler et al., 1997).

2.3. Slice Shear Force

Sliced Shear Force, introduced by Shackelford, et al. (1999), was developed as a means to determine tenderness in a commercial setting during the grading procedure. Preparations of steaks are based on the belt grill method as described by Wheeler et al. (1998), or the impingement oven (Shackelford, et al., 2009), in which steaks are prepared for sampling in the same method as WBSF until cooking. The SSF method is notably preferable when tenderness of longissimus muscle is being evaluated as results are highly repeatable (AMSA, 2015). The technique substantially increases the laboratory sample output in comparison to WBSF because of the ease of obtaining sample, making this method commercially viable (AMSA, 2015).

2.3.1. Slice Shear Force Sample Preparation

Sample prep for SSF samples is similar in nature to WBSF but have a more rigid protocol per muscle, as described by Wheeler et al. (1996). Samples should be 2.54 cm thick; uniform steak thickness is imperative for cooking purposes and repeatability. An initial weight, before cooking, is recorded as well as beginning temperature to ensure samples are within the 2-5 degree Celsius range as described by the AMSA (2015) guidelines. Steaks should be cooked with the guidelines from Shackleford, et al. (2009), with either a George Foreman Grille for small scale production, or with either a belt grill

or impingement oven for large scale production, and cooked to reach an internal temperature of 71 degrees Celsius (AMSA, 2015). Temperature should be measured with a Digi-Sense thermometer, or a hypodermic temperature probe. Immediately upon cooking, steaks are trimmed 1 to 2 cm from the lateral end of the longissimus muscle before using a sample sizing box and trimming 5 cm parallel to the original cut to create a 5cm section sample steak, which is placed into an orientation box with the steak fibers running parallel to the 45 degree angle cut sections of the box. A knife consisting of two blades 1 cm apart are inserted into an orientation slice box, cutting the 5cm sample steak into a 1 cm thick, 5 cm across slice section with parallel muscle fibers. This section of steak is positioned into the machine, consisting of a 1.1684 mm thick blade. The blade is passed through the sample until the slice is sheared, forces are measured by recording the kg of force taken to shear the sample

2.4. Comparison of Warner-Bratzler Shear Force and Slice Shear Force

In several comparison studies, SSF maintains an overall better repeatability than WBSF (Shackelford and Wheeler, 2009). If time is an important factor, the SSF method is of greater advantage, particularly in large scale experiments. While WBSF samples are a valid measurement, the time and effort needed to chill and prepare the samples for testing are not feasible for some facilities (Shackleford and Wheeler, 2009; Callahan et al., 2013). Callahan et al. (2009) researched correlations between WBSF and SSF within the same steaks and concluded that method of cooking and cooling time had the most influence on both methods, however in comparison to Lorenzen et al. (2010), Callahan exhibited more correlated results, which may be due to endpoint temperatures and cooling of samples. Overall, both methods have been proven effective depending upon

the cooking method and time allowed for cooling; following AMSA guidelines will allow for more uniform and consistent samples amongst various institutions. (Wheeler et al., 1997; AMSA, 2015).

2.2.5. Mechanical Tenderness and Sensory Panels

Warner-Bratzler shear force methods evaluated by untrained sensory panels were reported by Hovenden et al. (1979). They observed higher repeatability in individual judges for tougher beef than for more tender beef; the accuracy of the data did not differ between trained and untrained sensory panels. Similar results were reported by Chambers and Smith (1993) in trained an untrained panels who were administered specific descriptive training guidelines before sensory evaluations, repeatability between panelists were similar regardless of previous experience. Igo et al. (2011) evaluated the effect of trenbolone acetate and estrogen implants (Revalor XS, Revalor IS, and Revalor S) on tenderness with an untrained sensory panel, on steaks aged 14d and 21d. All steaks were tested using WBSF and SSF, as well as sensory evaluation. Correlations of tenderness between WBSF and SSF did not differ between treatments ($P > 0.05$), however sensory evaluations reported that consumers overall scores for flavor, tenderness, and juiciness were effected more by days of post mortem aging rather than implantation strategy; no differences in shear force or sensory analysis were reported for steaks aged 21d regardless of treatment (Igo et al., 2011). Use of growth promotants in beef animals has been consistently unidentifiable between non-implanted and implanted animals, including a consumer perception study by Barham et al. (2003), in which growth promotants were reported to have no difference in tenderness scores with either WBSF or a consumer panel. Shackleford et al. (2001) observed that both trained and untrained panelists rated

longissimus steaks appropriately with corresponding high and low SSF scores. The ability of sensory panelists, regardless of previous experience, is correlated between both WBSF and SSF scores. Subsequently, both objective and subjective methods have been correlated with tenderness levels of beef.

2.2.6. Certified Tender

Certified tenderness claim requirements must be classified with the Warner-Bratzler Shear Force (WBSF) or Slice Shear Force (SSF) methods under the USDA-AMS Beef Tenderness Marketing Claim Standard (2011). Certified tender claims must meet the Minimum Tenderness Threshold Value (MTTV) of 4.4kg of force for WBSF and 20.0kg of force for SSF, as well as qualify as "inherently tender," or meat that has not been enhanced by means of mechanical or chemical tenderization methods (USDA-AMS, 2011). Certified very tender claims must follow the identical claims, however the thresholds for WBSF must exceed the MTTV by 0.5 kg of force and 4.6 kg of force for SSF. Temperature at which steaks were cooked followed guidelines from the Encyclopedia of Meat Sciences (2004), which stated that muscles with little connective tissue should be broiled or oven roasted between 60-70 °C for optimized tenderization and avoidance of excess loss of moisture.

2.2.7. Summary of Mechanical Shearing Methods

Other shear force methods have been developed over the past century of varying instrumentation, with the mutual intent to create a mechanism which simulates the amount of pressure needed for chewing. Methods such as the star probe, a 9mm cylindrical punch with four to six tapered ends 6mm apart, resembling a cherry or olive pitter, had a moderate correlation ($r = -0.54$) to sensory tenderness scores (Nollet and

Toldra, 2010). The star probe is most commonly use in tenderness scores for samples of porcine origin. Another method of mechanical shear is use of a probe needle or blade, to determine tenderness scores in uncooked samples. In a study on the use of mechanical probes in uncooked samples to predict cooked tenderness, correlations between sharp needles and blades on uncooked steaks from the longissimus were 0.85 and 0.88, respectively, in regard to tenderness of the cooked steaks using WBSF (Stephens et al., 2004). While WBSF and SSF are, perhaps, the most common methods of objective tenderness evaluations in beef samples, alternatives can be sought to lower the overall time and cost of evaluation.

2.3. Development of Yield Grade

2.3.1. Beef Yield Grading Estimation System of the United States

The presence of grading systems in beef production have been vital for market reporting systems, uniformity, and consistency of beef products. The USDA published the first Market Classes and Grades of Dressed Beef in August 1924 in response to research from the University of Illinois, and a one year trial run in 1927 was put in place to test the viability of the system in meat packer houses. The Classes and Grades of Dressed Beef were more commonly known as “Prime, Choice, Good, Medium, Common, and Low Cutter.” These standards were designed specifically for meat market reporting, but were eventually adopted by food industries such as restaurants, hotels, and steamship lines. In 1941, an amendment to change grade terms for all beef was applied; “Prime, Choice, Good, Commercial, Cutter, and Canner,” and the 1949 amendment eliminated all references to fat color as a grading implement. Cutability and quality grade systems were

separated on a trial basis in 1962 for one year before permanent separation to allow individual identification of cutability and quality attributes (USDA, 2017).

Cutability, also known as yield grade (YG), has been classified into one of five scores which are calculated from the current USDA YG equation: *YG = 2.5 + (2.5*adjusted fat thickness, inches) + (0.20*estimated percentage kidney, pelvic, and heart fat) + (0.0038*HCW, lbs) – (0.32* longissimus muscle area, inches^2).* The equation was established based on research by Murphey et al. (1960), in which boneless closely trimmed rib-loin-chuck and round (BCTRLCR) were used for estimates of yield. The method currently used by USDA graders to determine yield has been decidedly subjective in nature, largely influenced by the physical human limitations to calculate the individual components of the equation at modern chain speeds of up to 450 carcasses per hour. Hot carcass weights are measured objectively by in-motion scales, whereas fat thickness has been traditionally subjective in nature and measured by visual observations of the longissimus dorsi area once the carcass is ribbed. Fat thickness can also be measured directly with a yield grade ruler. Ribeye area may be either subjectively measured by estimation of the grader, or objectively estimated by a camera or ribeye grid. Kidney, pelvic, and heart fat percentages are based upon estimated visual appearance, however this may be affected by removal of KPH during processing, in which case the processor often assumes a common value of approximately 2.5% of the weight of the carcass. The USDA Agricultural Marketing Service designed a procedure for facilities which remove KPH fat from hot carcasses; carcasses should be weighed before and immediately following the removal of KPH fat and an adjusted calculation is determined

by an AMS agent based on the amount of remaining fat within the carcass (USDA-AMS, 2009). Yield grade descriptions from the USDA guidelines are as follows:

- "*Yield Grade 1.* A carcass in Yield Grade 1 usually has only a thin layer of external fat over the ribs, loins, rumps, and clods, and slight deposits of fat in the flanks and cod or udder. There is usually a very thin layer of fat over the outside of the rounds and over the tops of the shoulders and necks. Muscles are usually visible through the fat in many areas of the carcass.
- *Yield Grade 2.* A carcass in Yield Grade 2 usually is nearly completely covered with fat, but the lean is plainly visible through the fat over the outside of the rounds, the tops of the shoulders, and the necks. There usually is a slightly thin layer of fat over the loins, ribs, and inside rounds and the fat over the rumps, hips, and clods usually is slightly thick. There are usually small deposits of fat in the flanks and cod or udder.
- *Yield Grade 3.* A carcass in Yield Grade 3 usually is completely covered with fat and the lean usually is visible through the fat only on the necks and the lower part of the outside of the rounds. There usually is a slightly thick layer of fat over the loins, ribs, and inside rounds and the fat over the rumps, hips, and clods usually is moderately thick. There usually are slightly large deposits of fat in the flanks and cod or udder.
- *Yield Grade 4.* A carcass in Yield Grade 4 usually is completely covered with fat. The only muscles usually visible are those on the shanks and over the outside of the plates and flanks. There usually is a moderately thick

layer of fat over the loins, ribs, and inside rounds and the fat over the rumps, hips, and clods usually is thick. There usually are large deposits of fat in the flanks and cod or udder.

- *Yield Grade 5.* A carcass in Yield Grade 5 usually has more fat on all of the various parts, a smaller area of ribeye, and more kidney, pelvic, and heart fat than a carcass in Yield Grade 4" (USDA, 2017).

Yield grades may be influenced by several elements, such as management practices, genetics, and nutrition. Ultimately, the USDA yield grade system separates carcasses based on predicted retail product yield, creating a more uniform platform for grid pricing. Discounts and premiums are determined by the beef processor based on this grid system; therefore it is imperative for producers that an accurate equation be in place to produce beef expected by the markets. Past research has identified the relative growth in cattle as both exponential and dependent upon maturity type. In a study on the genetic considerations of growth in beef cattle, Butterfield (1966) identified that maturity within breed selection is a key factor in recognizing when cattle are sufficient for slaughter. Maturity of animals relevant to types of carcasses can be exemplified by dairy type carcasses emerging in the industry. Dairy breeds in comparison to beef are low in terms of red muscle yield in relation to bone, thereby lowering the percentage of retail cuts sold as BCTRLCR, although dairy breeds are superior in terms of leanness. A study conducted by Lawrence et al. (2010) reported the ratio of red meat yields to bones of carcasses in beef type steers averaged 4.32:1 and Holstein steers averaged 3.22:1, reflecting the yield of dairy to beef type carcasses.

It is notable to mention the shift in breed selection from the time the Murphey yield grade was adopted to present day, cattle of the day were typically purebred Hereford whereas today's market is much more versatile from the addition of cross breeding, a method that only became popular in the 1970's after research from the USDA Meat Animal Research Center was published (Cundiff and Gregory, 1977). In 2001, the first adjustment factors in Expected Progeny Differences (EPD's) for cross breeding cattle emerged, allowing producers to calculate the hybrid vigor they could introduce by cross breeding herds.

2.3.2. Previous Yield Grade History

Data from various researchers have discussed the reliability of the current yield grade equation and its efficacy within the industry. Abraham et al. (1980) exhibited in their research that adjusted fat thickness over the ribeye, percentage kidney-pelvic-heart (KPH) fat, and longissimus muscle area (LMA) were the most important factors in predicting carcass yields for BCTRLCR, supporting the equation demonstrated by Murphey et al. (1960), however the measurements of those studies were taken with actual percentages calculated manually whereas the USDA method uses an estimated evaluation of these factors. The USDA equation represents a linear increase of separable fat and lean as yield grade increases, however some researchers have concluded that the relation of fat and lean to yield grade is on a non-linear plane, (Lunt et al., 1985, Lawrence et al., 2004). Lunt et al. (1985) described percentages of lean to fat as 70.56/9.76, 68.61/14.53, and 63.77/20.40% for carcasses of average yield grades of 1.41, 2.08, and 3.02 respectively. Lawrence et al. (2008) reported a quadratic relationship between HCW and LMA, rather than the linear relationship represented by the USDA, and concluded that if the USDA

equation is not updated, the number of yield grade 4 and 5 carcasses will continue to increase as carcass weights increase. These results reflect the natural growth curve of cattle, whereby fat increases at an increasing rate, lean muscle increases at a decreasing rate, and bone is a slow increase until maturity (Boggs et al., 1998). The National Beef Quality Audit (NBQA, 2016) reported an increase in yield grade from an average of 2.9 in both 2005 and 2011 to an average of 3.1 in 2016, as well as an increased fat thickness in inches of carcasses from 0.51 to 0.56, respectively. The audit also reported a steady increase in HCW from an average 308 kg to 390.3 kg from 1995 to 2011, respectively.

Implications from research suggest that the current subjective yield grade method is not adequate for estimating beef carcass values at the speed of commerce. Shackelford et al. (2003) discussed that the application of expertly calculated yield grade is an accurate predictor for carcass composition but the industry demands a more objective method due to the pace of production, and proposed the use of a camera system as a standard to calculate yield grade more accurately on an industrial level. Likewise, a revision of beef carcass grading techniques by Bray (1964) reflected that while outer fat and KPH can be subjectively assessed, this method lowers the accuracy of the equation. Similar results were determined by McEvers et al. (2010), in which Video Image Analysis (VIA) and USDA graders were compared for accuracy. The NBQA reported a decreased frequency of yield grade 2's and increased frequency of yield grade 4's when carcasses were evaluated with an instrument in comparison to USDA graders, reflecting the continual shift in carcass yields mentioned in previous research (Lunt et al., 1985; Lawrence et al., 2008; McEvers et al., 2010).

2.3.3. Beef Yield Grading Estimation System of Canada

The Canadian beef yield grading equation (prior to the recently updated equation of 2019) was determined by dissection of 540 beef carcasses and developed into a regression equation in order to predict total carcass lean: Percent lean = 57.34 – 0.032 (warm carcass weight, kg) + 0.212 (tracing muscle area (LMA), cm^2) - 0.681 (grade fat, mm (fat thickness at the minimum point in the fourth quarter from the vertebrae)). In 1991, governmental researchers with Agriculture Canada began to develop new equation and a grading ruler which would allow Canadian graders to predict lean yields, as the design of the original regression equation was impractical for use at chain speed. In 1996, government mandated carcass grading was determined a private good and was withdrawn from service, passing the responsibility of grading to the agricultural industry; the Canadian Beef Grading Agency (CBGA) was created and all grading services in place were transferred. The CBGA then replaced the previous equation based on research conducted from the early 1990's to 1996. In comparison to the USDA, the CBGA method is simplified to muscle score and grade fat. The CBGA yield grade equation was determined and a four-point muscle score scale was developed from the measurement of the width and length of the longissimus muscle in mm, and thereby a development of a 4 point muscle score to reflect those measurements. Scores on the following matrix below reflect the measurements: 1 width <64 mm, 2 width 64-71 mm, and 3 width >71 mm; 1 length <141mm, 2 length 141-150 mm, and 3 length >150 mm of the longissimus muscle (CBGA, 2020). Yield grade is determined by the following equation:

Percent lean = 63.65+ 1.05 (muscle score) – 0.76 (grade fat)

The grade fat class was developed from the measurement of subcutaneous fat at the thinnest point in the fourth quarter of the ribeye. A 10-point measurement system was devised (Fig. 2.3) Using the values from both tables, the fat class and muscle scores were tabulated as well to illustrate a percent carcass lean for each class, as seen below:

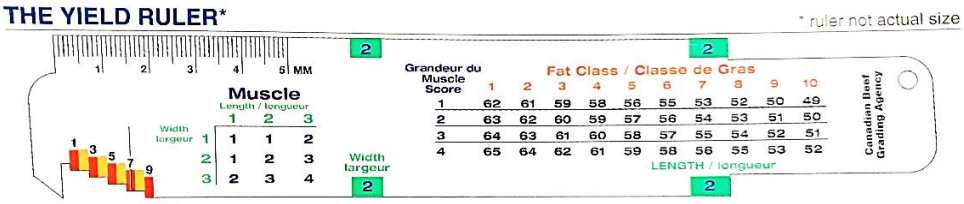

Figure 2.3. Original Canadian yield grading ruler from 1991 to 2019.

On January 15th, 2019, the former Canadian yield grade system was replaced with the U.S. retail grade equation based on the research from Murphey et al., 1960 and adapted by Agriculture and Agri-Food Canada (AAFC), Lacombe Research and Development Center (CGBA, 2020). The equation was adapted with the purpose of developing a uniform grading system in North America in the future. The developed equation is as follows:

Retail Cut Yield % = 53.13 + (0.44*muscle score) – (0.32*fat thickness, mm)

The CBGA continues to use a similar ruler to that of the older style, however it was updated with the addition of the newly adopted system:

Figure 2.4. Current Canadian yield grading ruler implemented in 2019.

2.3.4. Beef Yield Grading Estimation System using EUROP

In the early 1980's, the European Union (EU) created a system known as EUROP to classify beef carcasses. In comparison to the USDA, Japan, and other methods of determining yield, the EUROP system was based upon estimations of conformation or shape of the carcass determined by trained classifiers. These classifications were used to separate carcasses of similar uniformity. From late 2004 to present day, approximately 90% of the carcasses in Europe have been classified by mechanical means of a VIA to measure carcasses more accurately (Ireland Stat, 2010). The system is broken into scores of E, U, R, O, and P:

E - Excellent; all profiles convex to super convex; exceptional muscle development

U - Very Good; profiles on the whole straight, good muscle development

R - Good; profiles straight to concave; good muscle development

O – Fair; profiles straight to concave; average muscle development

P – Poor; profiles straight to concave; poor muscle development

Carcasses are also classified by degree of fat, numbered 1 through 5 in increasing order of fatness. The following images represent the two systems used to classify carcasses with the EUROP system:

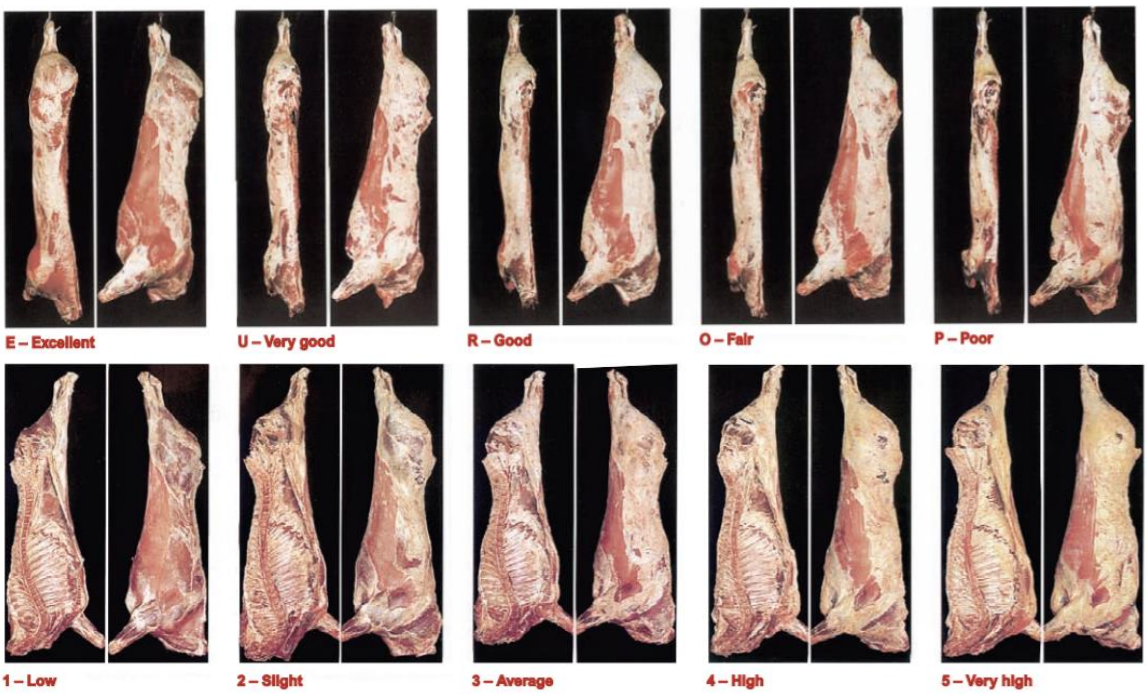

Figure 2.5. EUROP system for yield classification.

It is important to note that each country in Europe may have their own individual method for classification within this system, as the United Kingdom makes specifications for pricing based on cold carcass weights, unlike the USDA method of HCW. Ireland approves plants processing under 150 animals per day to use the 1980's method of trained employees to sufficiently identify carcasses (Ireland Stat, 2010).

2.3.5. Beef Yield Grading Estimation System in Japan

The Japanese yield grading system is administered by the Japanese Meat Grading Association, or JMGA. The JMGA was established in 1975, with a system that compiled yield and quality grades to assign carcass scores. The JMGA updated their system in 1988, with a revision to separate yield and quality scores as independent units of measurement. The current method for yield grading is based on measuring the ribeye area with a grid, while the other measurements are done by scale. The equation measures four factors*: Estimated percentage (%) = 67.37 + (0.130 x longissimus muscle area* cm^2*) +*

(0.667 x longissimus muscle thickness cm) – (0.025 x cold left side weight kg) – (0.896 x subcutaneous fat thickness cm). Estimated yield scores are divided into three classifications, grades A, B, and C. Grade A carcasses have an estimated yield percentage of >72%with a total cut yield above average, B grades are estimated between 69-72% and are considered average in total cut yield, and C grades are <69% and considered below average yield range. These estimated yield grade scores may also be reduced by one rank if the intermuscular or subcutaneous fat layer is considered thick compared to the weight and size of the ribeye area, or if the proportions of the for or hindquarters are considered undesirably thin (Japan Meat Grading Association, 2000). The picture below is representative of the measurements from the 6th and 7th ribs as needed for the JMGA grading system:

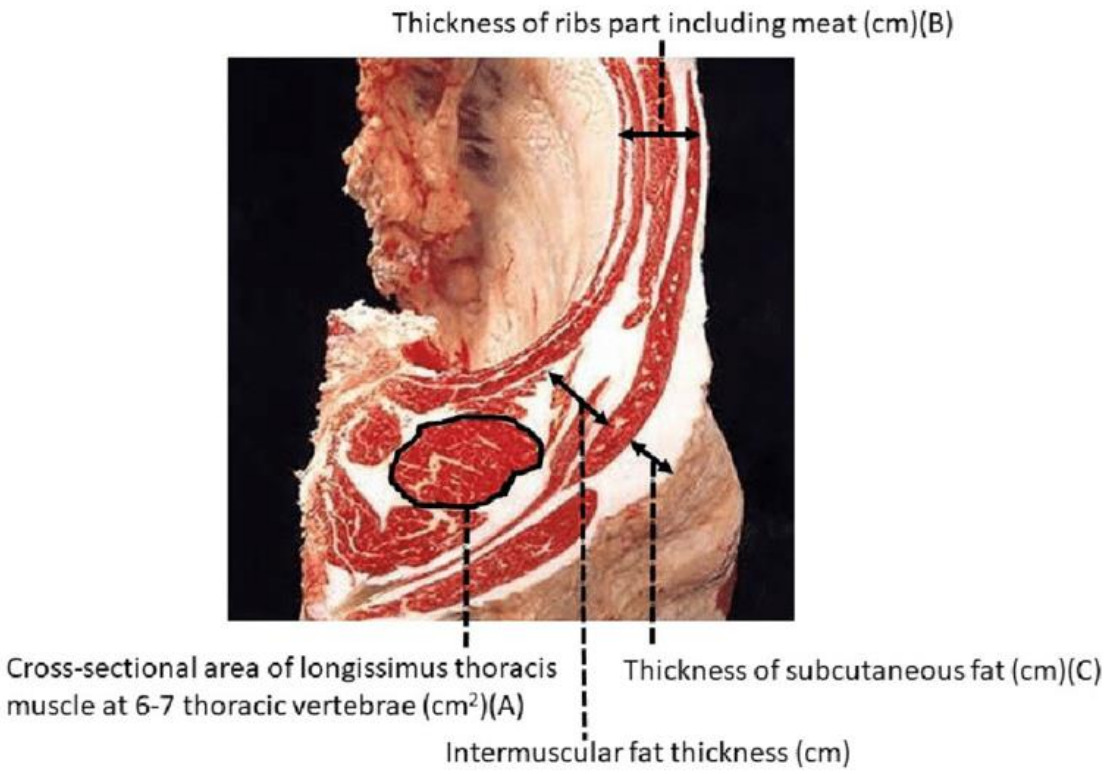

Figure 2.6. Japanese yield grading parameters.

2.4. Beef Body Composition Analysis

The need for an accurate carcass classification system arose to meet industry demands in determining the value of carcasses, as industry uses a value based marketing system. Fat is acknowledged to increase at an increasing rate as animals mature, whereas ash, protein and water have been reported to decrease with age (Nichols, 1991; Boggs et al., 1998). Fat and protein deposition are commonly effected when animals are implanted with a growth promotant treatments, with significant decreases in protein degradation as animals mature, as compared to non-implanted treatments (Nichols, 1991; Duckett and Andrae, 2001). Body composition analysis has been a useful tool for producers to understand the development of bodily components in order to optimize profitable time frames to ship cattle to market, as well as for processors to eliminate the occurrence of over-conditioned carcasses.

Experimental separation of a half or whole beef carcass into lean, fat, bone, and ash was an interest of researchers to understand the relationship of components to beef (Bratzler, 1958). The main problem researchers have faced in obtaining composition information of carcasses is the high cost of using the entire carcass to calculate the percentage of components, and so lower cost methods were pursued. Perhaps the earliest recorded study for determining composition of beef carcasses was published by Lush in 1926, in which he observed several studies from across the country in order to compound a common equation that would reveal the estimated percent of fat from carcasses. In 1946, Hankins and Howe sought to establish a less laborious task of separating a half or whole carcass by using the ninth-tenth-eleventh rib sections as approved in the USDA Report of the Chief of the Bureau of Animal Industry (1935) and to establish a

relationship between physical and chemical composition of the rib section. The rib sections were separated into lean, fat, bone, and ash, thought to be an equivalent representation of whole carcass parameters, based on the research of Hopper (1944).

2.4.1. Hankins and Howe

Hankins and Howe (1946) reported that while fat representation of heifer carcasses dissected by this method were not as accurate as steer carcasses, the separable fat content of the rib section was a sufficient representation of the separable fat of dressed carcasses in steers. They observed lean portions of rib dissection correlations to carcass sides were higher for steers, and that lean meat from the rib was again a poorer correlation in heifers. Ash from meat of the ninth-tenth-eleventh rib section was not sufficiently correlated to carcass measurements (Hankins and Howe, 1946).

Only the right side was used for removing the rib section of the carcasses analyzed. Carcasses should be ribbed as is standard in the USDA grading system. A yardstick and a carpenter's square are necessary to measure the points on the carcass in which to remove the rib section. The A point is the point of the split vertebrae of the carcass, and point B is the cartilage at the thirteenth rib, measured by the yard stick to the nearest mm. The distance between these two cuts is measured with the yard stick to the nearest mm, and multiplied by 0.615 to obtain the measurement of A to C, as point C is 61.5 percent of the measurement taken from A to B. The carpenter's square is then used to measure the distance of C perpendicular to the markers of the yard stick, and point D is the external point perpendicular to point C. Below is the guide in place from Hankins and Howe (1946):

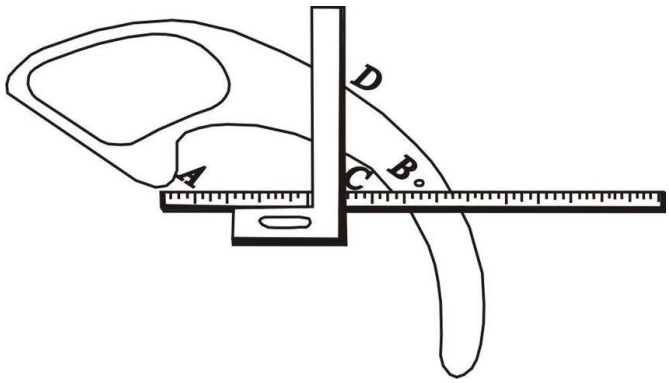

Figure 2.7. Hankins and Howe (1946) measurement methods for rib separation

Equations for the relationships studied in the Hankins and Howe procedure account for the number of animals in the study, and the estimated coefficient of correlation for each corresponding study is therefore vital for determining the accuracy of the equation. The predictability of physical and chemical compositions in further studies depend on their own coefficients added into the original equations, and therefore adjustments in the original equations should determine the accuracy of this method.

Berndt et al. (2017) performed the Hankins and Howe procedure (HH) on Nellore and crossbred bulls and received positive results of compositions from carcass to HH. Nour and Thonney (1994) however reported that adjustments needed to be made for the breed being analyzed in a study that focused on purebred Angus and Holsteins. McEvers et al. (2017) observed the HH model applied to calf-fed Holstein steers; results from this study were different in both chemical and physical composition, likely due to the lack of the Holstein breed utilized for beef at the inception of the method. Walter et al. (2016) reported that the use of the 9-10-11th rib section to determine carcass parameters of Holsteins supplemented with zilpaterol hydrochloride were only moderately related to

chemical composition while lean, fat, and bone were strongly correlated. Updated equations were needed to more accurately address the components from the rib to that of the carcass (Walter et al., 2016). Crouse and Dikeman (1974) when using the Hankins and Howe (1946) method reported that adjusted fat thickness was a more accurate indicator than fat thickness, and rib fat moisture had a greater correlation to carcass moisture than rib protein moisture. Crouse and Dikeman (1974) suggested that fat moisture content may be a better indicator of rib moisture than protein due to the variation of fat in carcasses, which could be a more accurate representation of cattle in present markets. The researchers also observed that the Hankins and Howe equations overestimated carcass moisture and protein while underestimating carcass fat, and that the procedures in their research were only an accurate evaluation for independent sets of data rather than that of market data. More research is needed for further conclusions on changing the current HH model to better suit market needs and to further understand the relationship of carcasses in markets today comparative to the 1940's.

2.4.2. Specific Gravity

There are other methods researchers have used to obtain carcass compositions at lower cost, such as the use of specific gravity (Bratzler, 1958). Specific gravity is the practice of weighing the carcass in the air prior to weighing the submerged carcass in water, and calculating the density and temperature changes of the water (Garrett et al. 1959). Proportions of bone tend to differ between the Hankins and Howe (1946) method and specific gravity (Preston et al., 1974). Carcass composition tends to be more uniform when specific gravity is used, as compared to other uses of carcass weights (Garret,

1968). The equations from Garret et al. (1959) for carcass composition using specific gravity are:

Percent carcass fat = 556.6 – 505.0 * carcass specific gravity

Percent whole body fat = 0.8817 * carcass fat – 1.520

Percent whole body water = 76.89 – 0.8284 * percent whole body fat

Landis (1987) reported the specific gravity of beef carcasses by taking hydrostatic weights of the right side of carcasses before placing them into a water tank; the following equation was used to determine specific gravity of each carcass: specific gravity = weight in air/ weight in air – weight in water. Carcass components were then determined by equations from previous studies (Garret et al., 1959; Lofgreen, et al., 1962) for specific gravity in relation to percent of lean, fat, and bone (Landis, 1987). Specific gravity can be an alternative to predicting carcass composition, with overall better accuracy (specifically when bone is involved) than the Hankins and Howe (1946) method (Preston et al., 1974), however the cost of methods may influence researchers.

2.4.3. Total Body Electrical Conductivity and Bioelectrical Impedance

Electrical conductivity and resistance, or impedance, may be used to assess meat and carcass characteristics (Aberle et al., 2012). Total body electrical conductivity (TOBEC) variable have been reported as the most accurate method of determining carcass composition (Gardner et al., 1997) when applied to the USDA YG equation, however there are disadvantages of using TOBEC, such as the cost and time of assessment. The TOBEC method is noninvasive, the subject is measured by a weak electromagnetic field which can assess the different components of the body. Bioelectrical impedance analysis (BIA) is a more invasive approach in which electrodes

are placed directly into the muscle in specific spots relative to the carcass, and are effective in measuring the composition of lean and fat (Aberle et al., 2012). When the probes are placed in the muscle, pH is analyzed by the detection of water; the conductivity of muscle is less therefore the impedance to electrical flow is greater, and therefore use of BIA can objectively determine meat quality and water holding capacity (Aberle et al., 2012). Zollinger et al. (2010) observed that BIA accounted for 81-84% of variation in salable yield and trimmable fat of beef carcasses. The disadvantage of this application lies in the inconsistency between conductivity of probes, as well as the accuracy needed in placing the probe for appropriate readings (Zollinger et al., 2010; Aberle et al., 2012).

2.4.4. Video Image Analysis

Video image analysis (VIA) is another alternative method to measure carcass composition. The current EUROP beef classification system is largely dependent upon VIA technology, and has improved accuracy and precision in predicting saleable meat yield (Craigie et al., 2012). McEvers et al. (2012) findings also supported the use of VIA as an improvement to salable meat yield for the current USDA and Canadian prediction models. Predictions of fat thickness and yield estimations were improved in both studies (Cragie et al., 2012; McEvers et al., 2012). Camera grading has continued to be promoted, as researchers have observed the continual improved accuracies as compared to current USDA yield grading systems (Jaborek et al., 2020). Camera data has also consistently been able to disprove the efficacy of KPH accuracy in determining yield grade (McEvers et al., 2012; Jaborek, 2020). The use of such technology has become more popular in recent years, as technologies have become more readily available to the

industry (Craigie et al., 2012). In future, the application of VIA could improve the accuracies of the current equation.

2.4.5. Dual Energy X-ray Absorptiometry

Dual energy X-ray absorptiometry (DEXA) is another alternative in determining composition of beef cattle. Originally, DEXA was utilized as a means to measure bone density in human patients to diagnose osteoporosis, however researchers developed the means to evaluate soft tissue as well; typically, the soft tissue amount may be subtracted from the total measurement to evaluate bone density. The DEXA methods Milliken et al. (1996) evaluated the accuracy in predicting composition of ground beef by combining different levels of lean tissue, water, and lard, and observed that the total measured mass by use of DEXA technology was an accurate indicator of all factors. Ribeiro et al. (2011) evaluated the efficacy of measuring the 9-10-11th rib sections from the Hankins and Howe (1946) method as compared to using DEXA technology and observed that DEXA was an accurate predictor of lean and fat. Prados et al. (2016) elaborated that the use of DEXA was improved when equations were specifically developed for individual studies, as compared to Ribeiro et al. (2011), accuracy was improved when body composition of cattle specific to the study were observed. While this method has been used as an alternative evaluation of beef composition, it is most commonly used in humans. The high cost of use and low rate of speed could make the DEXA method more impractical than other methods (Aberle et al., 2012).

2.5. Summary and Conclusions

The use of growth promotant products has differing results between tenderness studies and needs further research for clarification. Tenderness is considered the most

important attribute to consumer preference (Shackleford et al., 2001), and an informative review on how Revalor-XS effects tenderness is needed. The current USDA YG equation needs to be reviewed and analyzed for efficacy in beef animal composition, as YG has been reported at a steadily increasing rate for the past two decades (NBQA, 2017). Further research in these areas will improve production and processing methods, as well as provide consumers a more desirable product.

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CHAPTER 3

Comparison of Warner-Bratzler shear force and slice shear force in serially slaughtered steer carcasses

3.1 Abstract

Growth promotants are commonly administered to increase rate of weight gain and improve feed efficiency, but may increase the incidence of tough beef. The objective of this study was to investigate objective mechanical tenderness of serially harvested steers finished with and without exogenous growth promotants. Charolais x Angus steers (*n*=80) approximately 219 ± 19 days of age were randomized to implant treatments (REV: Revalor-XS on d-0 and d-190 or CON: no implant) and harvest date in a 2 x 10 factorial design. Four pairs of steers were randomly allocated to one of 10 harvest dates and harvested in 42d intervals (0, 42, 84, 126, 168, 210, 252, 294, 336, and 378). Samples of the *M. longissimus dorsi* from the 13th rib section were obtained from the left side of each carcass, aged for 14d, and frozen at -29ºC. Frozen samples were cut into 2.54-cm-thick steaks for Warner-Bratzler shear force (WBSF) and sliced shear force (SSF) measurements, and vacuum packaged. Samples were thawed for 24h at 2ºC, initial weight was obtained prior to cooking, and steaks were cooked to an internal temperature of 71°C. After a 5 min cooling period, cooked weights were recorded; WBSF samples were cooled 24h at 2ºC prior to coring and shearing. Slice shear force samples were taken immediately following attainment of cooked weight. All samples were sheared according to AMSA protocol with a texture analyzer, and peak shear forces were analyzed. Data

were analyzed via Pearson correlation and mixed models. No TRT x DOF interactions ($P \geq 0.51$) were observed for objective tenderness determined via WBSF or SSF. Peak force values did not differ between REV (3.65 kg and 15.12 kg), respectively and CON (3.36 kg and 14.86 kg) for WBSF ($P = 0.10$) or SSF ($P = 0.83$). Peak force via either method was not effected by DOF ($P \geq 0.17$). Weak correlation was observed between WBSF and SSF ($r = 0.41$). Results from this study indicate that growth promotion had little effect on tenderness.

3.2 Introduction

Growth promotion compounds or anabolic agents are a commonly used practice in beef production to improve feed efficiency and increase rate of gain. Estrogenic implants are known to cause increased levels of somatotropin (ST) and insulin-like-growth factor-1 (IGF-1), whereas trenbolone acetate (TBA) increases circulating levels of IGF-1 (ZoBell et al., 2000).

Anabolic implants have been related to an increase in the incidence of toughness in beef, (Apple et al., 1991; Foutz et al., 1997; Garmyn and Miller, 2014). Other studies have reported no difference in beef toughness from exogenous growth promotants (Duckett and Andrae, 2001; Nichols et al., 2002; Hutcheson, 2008; Garmyn et al., 2011). Dikeman's (2007) review on metabolic modifiers suggests that while some studies may observe negative tendencies with tenderness when using growth promotant products, very few reports are statistically significant. By using WBSF and SSF methods, the objective measurements between implanted and non-implanted cattle in this study may be observed and predictions of palatability may be designed.

3.3. Materials and Methods

Eighty Charolais x Angus (*n* = 80) steers were fed and housed together at the Agri-Research Inc. Feedlot in Canyon, Texas. Steers used in this study were under the Institutional Animal Care and Use Committee (IACUC) 01-08-18. Steers were either not implanted (CON) or implanted (REV) with a Revalor-XS (RXS: Merck Animal Health, Madison, NJ; 200 mg trenbolone acetate and 40 mg estradiol), and then paired with an animal of the opposite treatment. Four pairs of steers were randomly allocated to one of 10 harvest dates and harvested in 42d intervals (0, 42, 84, 126, 168, 210, 252, 294, 336, and 378). Remaining REV steers received a second implant on d190 to maintain viability of implantation effects. Estimated final BW, frame scores, days to target body weight, and live growth performance and feeding behaviors were reported by Kirkpatrick (2020). All animals were humanely harvested at the West Texas A&M University Meat Science Lab (Canyon, Texas) on the assigned date (Pillmore, 2020). Carcass components and grading were analyzed and reported by Pillmore (2020). Grading procedures (Pillmore, 2020) followed USDA standard grading procedures (USDA-AMS, 2017). Carcasses were chilled for 48h before processing according to industry standards and previously recorded by Wesley (2020).

3.3.1 WBSF Preparation

After fabrication, samples of the *M. longissimus dorsi* from the 13th rib section were obtained from the left side of each carcass, aged for 14d postmortem, and frozen at -29ºC. Frozen samples were cut into 2.54-cm-thick steaks for Warner-Bratzler shear force (WBSF) and sliced shear force (SSF) measurements, then vacuum packaged. Samples were thawed for 24h at 2ºC. Initial weights of all samples (*n* = 80) were obtained prior to

cooking, and steaks were cooked to an internal temperature of 71°C. Ovens were calibrated before sample preparation, in accordance with AMSA (2015) protocol. Steaks were cooked in a forced-air convection oven (Blodget DFG-100-03, G.S. Blodgett Corporation, Essex Junction, VT) set at 177° until reaching an internal temperature of 71°C. Sample temperature was monitored during cooking via Omega MDSSi8 meter (Omega Engineering Inc., Stamford, CT) and Omega Precision Fine Wire Thermocouples (Omega Engineering Inc., Stamford, CT) consisting of copper/constantan wire and reached an average final temperature of 71.3°C. After a 5 min cooling period, cooked weights were recorded to the nearest 0.005 kg (Catapult C11P9, OHAUS Corp., USA); WBSF samples were plastic wrapped and cooled 24h at 2ºC prior to coring and shearing. Six sample cores (1.27 cm) were taken parallel to the muscle fibers of each steak and were immediately sheared. Cores were sheared (Instron 5944, Instron, Norwood, MA) with a WBSF blade attachment at 250 mm/min and peak shear forces were recorded and analyzed. Shear force blade specifications are reported in the AMSA Research Guidelines (AMSA, 2016).

3.3.2. Slice Shear Force Preparation

Initial weight of all samples (n = 48) were obtained prior to cooking to the nearest 0.005 kg (Catapult C11P9, OHAUS Corp., USA). Differences in sample size between WBSF and SSF were attributed to experimental error in extracting carcass samples, only samples that represented a complete feeding period were represented in this study. Sample steaks were cooked to an internal temperature of 71°C using a timed conveyor impingement oven (Middleby Marshall PS528G, Elgin, IL) calibrated at 204.4°C for 14 minutes, and internal temperature was monitored with a handheld type k thermocouple

(Saf-T-Log Paperless HACCP Thermometer, ThermoWorks, American Fork, UT), average final temperature of samples was 71.5°C. Samples were then prepared for shearing by removing a 2-3 cm section from the end of the *m. longissimus dorsi* before being placed into a sizing box. Samples were cut in the sizing box (G-R Manufacturing Co. LLC., Manhattan, KS) to obtain a 5-cm wide sample for the final slicing box. The 5 cm samples were placed in a 90° slice box (G-R Manufacturing Co. LLC., Manhattan, KS) and sliced parallel to the muscle fiber with a 1-cm spaced double bladed knife (G-R Manufacturing Co. LLC, Manhattan, KS) to obtain a 1-cm thick sample. The 1-cm thick samples were taken immediately following preparation and sheared via Instron texture analyzer (Instron 5944, Instron, Norwood, MA) using a 1.1684 mm flat blade to obtain SSF scores; peak shear force scores were recorded and analyzed in accordance to AMSA (2015) guidelines.

3.3.3. Drip Analysis

Samples (n = 80) from the *longissimus dorsi* were collected approximately 72h postmortem and weighed to approximately 100g. Exact weights were recorded to the nearest ± 0.005g, then placed in a cooler at approximately 34°C for 24h. Sample weights were recorded after 24h to the nearest ± 0.005g. Drip percentage was calculated by taking the final weight of the sample divided by the initial weight of the sample for overall drip loss.

3.3.4. Color Evaluation

Color evaluation was obtained by using a handheld Apiics (Apiics Colortec PCM+, China) colorimeter (400-700nm), which was calibrated each day before use.

Evaluation of L* was recorded from samples (n = 72), excluding d-84 due to colorimeter failure. Color evaluation of a* and b* were also recorded from samples (n = 56); differences in sample size were due to colorimeter failure from d-0 through d-125.

3.3.5. pH

All pH sample (n = 72) values were calculated using an MPI pH meter (MPI pH-Meter, Meat Probes Inc., Topeaka, KS) which was calibrated before use during each feeding period. Samples were tested for pH prior to weighing for drip analysis. Differences in sample size were due to pH meter failure on d-378. All pH recordings were considered as the ultimate pH, as carcasses were allowed to chill for 72h prior to sampling.

3.4. Statistical Analysis

A balanced incomplete block design with a 2 × 10 factorial arrangement was used. The GLIMMIX procedure of SAS was used to analyze fixed effects of treatment, DOF, and the interaction between TRT and DOF with d0 BW used as the covariate. LSMEANS were used to analyze mean estimates; differences were identified using a P-value of 0.05 while tendencies were observed at P-value of 0.06 – 0.10. Shear force methods were compared via Pearson Correlation. Contrasts were analyzed between shear force methods to determine if models were linear or quadratic.

3.5. Results and Discussion

There were no TRT x DOF interactions ($P \geq 0.51$) observed for objective tenderness determined via WBSF or SSF (Table 3.1). Peak force values tended to differ between REV (3.64 kg) and CON (3.36 kg) for WBSF (P = 0.10) but not for SSF (P =

0.83). Results for treatment effects reflect the outcomes of previous studies between tenderness of control samples and samples of animals treated with a growth promotant (Igo et al., 2001; Barhman et al., 2003; Callahan et al., 2009). Zinn et al. (1970) indicated that calf-fed Herefords (British) had lower WBSF values between 120-150 DOF, whereas Short et al. (1999) observed Charolais (Continental) crossbred calves with lower WBSF values after 270 DOF. Results from this study indicated that while peak force did not differ ($P \geq 0.17$) across DOF, steers were most tender between 126-168 DOF. Guidelines for tenderness claims created previously by ASTM International state a minimum tenderness threshold value (MTTV) of 4.4 kg for "Certified Tender," and 3.9 kg for "Certified Very Tender" for WBSF testing. Following those tenderness specifications, 72.5% of REV steers and 77.5% of CON steers were classified as Certified Very Tender whereas 15% of REV and 12.5% CON achieved Certified Tender. Average peak scores for REV and CON steers were 3.64 kg and 3.36 kg for WBSF, and 15.12 kg and 14.86 kg for SSF respectively. Moderate correlation was observed between WBSF and SSF (r = 0.41). The correlation between methods is similar to results from Derrington et al. (2011), who conducted research between the relationships of shear force methods and tenderness and concluded that the correlation between methods performed on the longissimus muscle were moderate (r = 0.64).

Other researchers have reported increased incidence of tough beef when implant technologies were used. Apple et al. 1991 reported a tendency for implanted animals to have increased levels of toughness when evaluated by consumer panels, however WBSF values were similar among treatment groups; it was concluded that the differences between tenderness and palatability were influenced by the protein accretion associated

with implantation. Foutz et al. (1997) observed a tendency for implanted cattle to have higher shear force values, which was concluded to be a result of decreased quality grade in steers that received an implant. Garmyn and Miller (2014) reviewed data from previous studies and hypothesized that the differences in WBSF between implanted and non-implanted animals may be due to improper management of growth promotants. Dikeman (2007) suggested that the negative tendencies in tenderness observed in most studies is not statistically significant. While there are inconsistencies between researchers, results from this study indicated that growth promotion had little effect on tenderness.

Cook loss differed between REV (24.61%) and CON (22.90%) when steaks were cooked using forced-air convection for WBSF ($P = 0.04$) but not when cooked on an impingement oven for SSF ($P = 0.20$). No TRT*DOF interactions were observed ($P \geq 0.30$) for cook loss for steaks cooked for either WBSF or SSF. Differences in cook loss could have been caused by differences in preparation methods (Wheeler et al., 1997). Drip loss did not differ between REV (2.52%) and CON (2.24%), but an interaction was observed between TRT*DOF ($P < 0.01$); drip losses were graphed (Figure. 3.3) and it was concluded that the TRT*DOF interaction was due to experimental error. Girard et al. (2012) also reported differences in drip loss between implanted and non-implanted steers, however it was hypothesized that breed, temperature, and ultimate pH could influence differences in drip loss. Results of this study were similar to those from Thonney et al. (1991) in which implanted (REV) steers were reported as slightly less acceptable in juiciness attributes but were not significantly different across treatments.

There were no differences ($P = 0.14$) in pH between CON and REV steers, although pH differed across DOF ($P < 0.01$). Averages of pH were considered normal (5.3-5.8) as previously described by Honikel (2004) and Aberle et al. (2012). The average pH in this study was consistent with readings from the *longissimus* muscle of steers observed by Page et al. (2001). Colorimeter analysis exhibited a TRT*DOF interaction for L* and b* ($P = 0.05$, respectively). Graphic representations (Fig. 3.1 and 3.2) were created and it was determined that the interactions were due to experimental error. A DOF effect was observed in b* and a* values, similar to results reported by Girard et al. (2012) and Page et al. (2001). Lower a* and b* values are consistent with Page et al. (2001) in which carcasses with more than 0.76 cm of fat thickness had lower a* colorimeter readings, however lower scores were reported in this study.

3.6. Conclusion

While there were minor differences observed between tenderness values of REV and CON steers, there were no significant differences in tenderness between implanted and non-implanted animals. Cooking loss differed between WBSF and SSF, which was hypothesized to be the result of different cooking methods rather than differences in treatment. No significant differences were observed for drip, pH, or color in this study. Results from this study indicate that growth promotants have no significant effects on tenderness.

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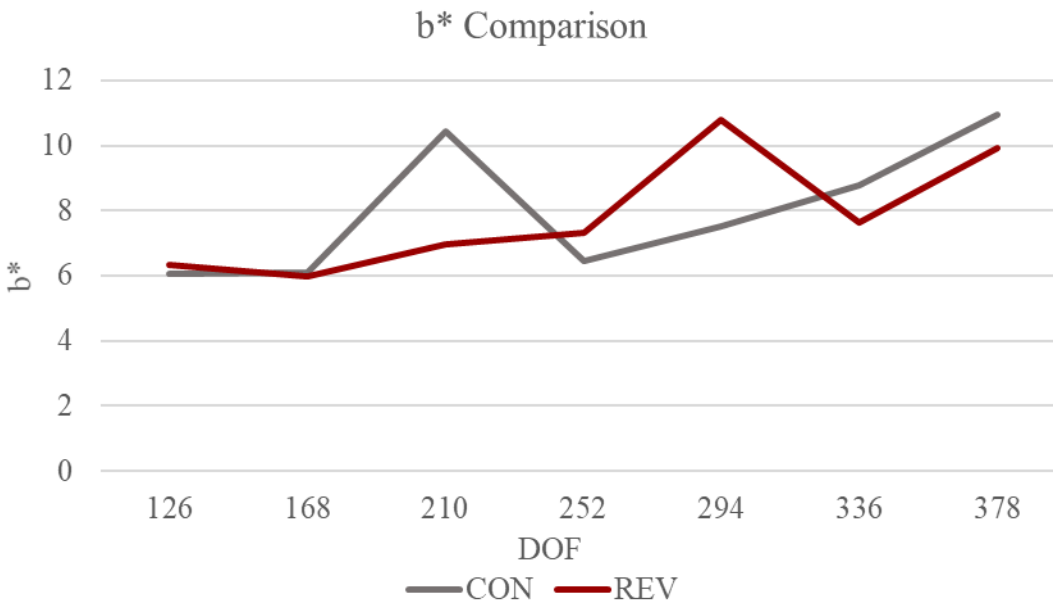

Figure 3.1. Interaction of TRT×DOF on b* values

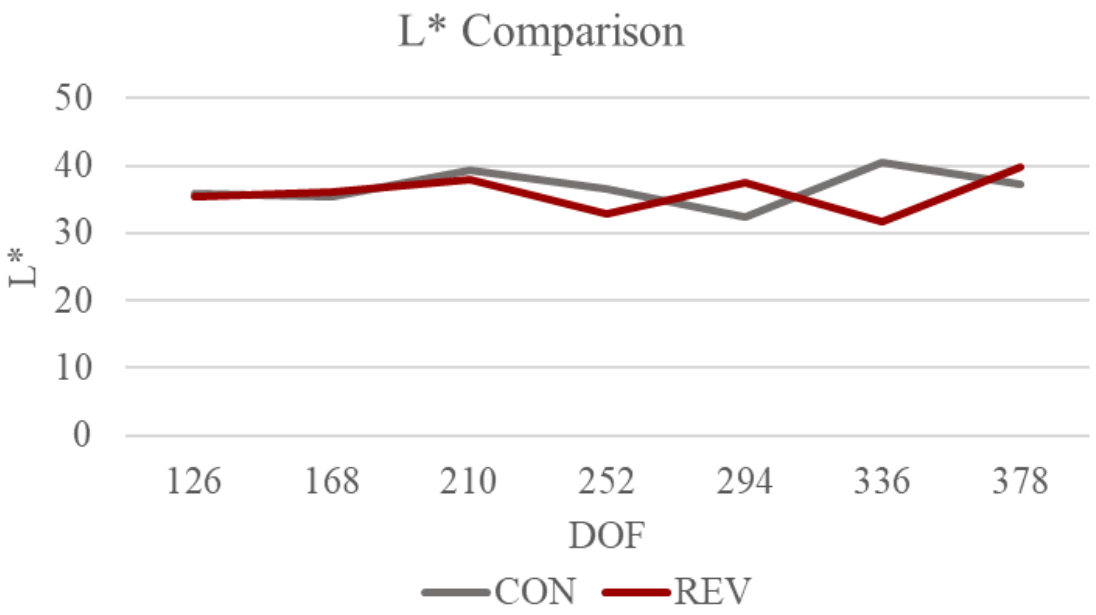

Figure 3.2. Interaction of TRT×DOF on L* values

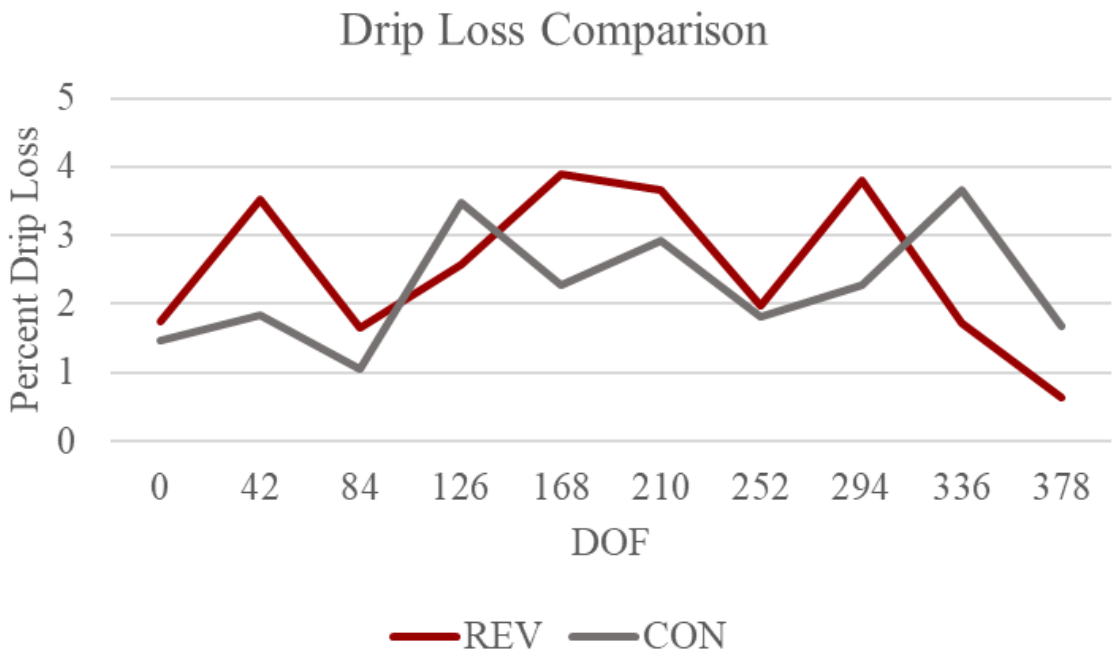

Figure 3.3. Interaction of TRT×DOF on drip loss percentage

Table 3.1. Effect of days on feed (DOF) on WBSF and slice shear force in Angus × Charolais steers in a 378-d serial harvest

	Treatment			DOF										P-Value			
Item	CON	REV	SEM	0	42	84	126	168	210	252	294	336	378	SEM	REV	DOF	REV×DOF
n	40	40	--	8	8	8	8	8	8	8	8	8	8	--	--	--	--
WBSF	3.36	3.64	0.17	3.74	3.32	3.86	3.10	3.08	3.49	3.52	3.12	4.04	3.75	0.29	0.10	0.27	0.51
WBSF Cook Loss	22.90	24.61	0.01	23.42	23.22	24.13	24.20	22.63	25.54	25.22	22.34	26.23	22.58	0.01	0.04	0.46	0.53
SSF[1]	14.86	15.12	1.18	13.4	14.4	18.6	14.1	16.7	12.7	--	--	--	--	1.73	0.83	0.17	0.78
SSF Cook Loss[1]	17.71	18.89	0.01	19.45	19.30	19.23	17.10	17.93	16.79	--	--	--	--	0.01	0.20	0.32	0.30
pH[2]	5.68	5.60	0.03	6.0	5.76	5.78	5.33	5.56	5.59	5.42	5.58	5.76	--	0.03	0.14	<0.01	0.54
Drip Loss	2.24	2.52	0.15	1.61	2.68	1.35	3.03	3.08	3.29	1.90	3.04	2.69	1.16	0.39	0.19	<0.01	<0.01
L*[3]	36.63	35.84	0.62	36.93	34.70	--	35.65	35.74	38.62	34.76	35.00	36.16	38.53	1.32	0.37	0.27	0.05
a*[3]	18.22	18.38	0.32	--	--	--	15.56	16.71	19.63	17.65	18.80	18.74	21.03	0.62	0.72	<0.01	0.52
b*[3]	8.04	7.85	0.36	--	--	--	6.19	6.03	8.71	6.88	9.15	8.20	10.44	0.69	0.71	<0.01	0.05

[1]SSF values were only reported when a full DOF group was represented.
[2] pH values were not reported for d-378 due to pH meter failure.
[3] Colorimeter values not reported from d-0 through d-84 due to colorimeter failure.

CHAPTER 4

Comparison of ninth-tenth-eleventh rib section to carcass components in serially harvested steer carcasses

4.1. Abstract

The objective of this study was to compare separable lean, fat and bone as well as proximate analysis of samples taken from the ninth-tenth-eleventh rib section to those of the carcass. Charolais x Angus steers (*n*=80) were randomized to implant treatments (REV: Revalor-XS on d-0 and d-190 or CON: no implant) and harvest date in a 2 × 10 factorial design. Four pairs of steers were randomly allocated to one of 10 harvest dates and harvested in 42d intervals (0, 42, 84, 126, 168, 210, 252, 294, 336, and 378). Carcass yields were determined by fabricating the right side of each carcass and separating lean, fat, and bone components and weighing to the nearest +/- 0.05 kg. Ninth-tenth-eleventh rib sections were collected from the left side of each carcass, dissected into lean, fat, and bone, and weighed to the nearest +/- 0.005 g. Regression models were created to determine linear associations between rib sections and carcass parameters. Carcass fat and lean were strongly correlated (r = 0.86 and 0.62 respectively) to 9-10-11 fat and lean, however carcass bone was only moderately correlated (r = 0.47) to 9-10-11 bone. Rib sections were representative of a whole carcass supporting use of this method to predict carcass lean, fat, and bone composition of beef cattle, however proximate analysis varied between carcass and rib section components. Interactions between REV × DOF of carcass components were observed for ash, moisture, and bone ($P \leq 0.05$) whereas a rib

section interaction was detected for ether extract ($P = 0.05$). Rib section ether extract was highly correlated (r = 0.88) with the carcass; however, moisture and protein were not as highly correlated as previously reported by Hankins and Howe (1946). Ash was poorly correlated between the rib section and carcass. Both carcass and rib section components differed ($P < 0.01$) across DOF for ether extract, crude protein, moisture, lean, fat, and bone. No treatment effects ($P \geq 0.13$) were observed in rib section components, however ash and ether extract differed ($P < 0.01$) between treatments for carcass evaluations. Results from proximate analysis indicated differences between the 9-10-11th rib and whole carcass parameters. Our results suggest that using the 9-10-11th rib section was a sufficient indicator for fat and ether extract but was not representative of whole carcass composition.

4.2. Introduction

Researchers in the 1920's and 30's recognized the need for estimating proportions of lean, fat, and bone in beef. Lush (1926) was one of the first researchers to identify a method that could quantify these estimations in beef carcasses at the commercial level; he compared studies from multiple locations and created equations that represented the composition of carcasses using the proportions of fat and bone, and concluded that the rib cut was an accurate indicator of carcass composition. In 1935 the USDA report of the chief of the bureau of animal industry indicated that the use of the 9-10-11th rib sections of beef carcasses was a low cost and adequate method of estimating the percentage of bone in animals 10 to 20 months of age. In 1946, Hankins and Howe sought to improve this method of using the 9-10-11th rib dissection from beef carcasses as an accurate composition of lean, fat, and bone in comparison to whole carcass composition. Linear

regression equations were developed to estimate carcass physical and chemical composition from the 9-10-11th rib sections. Correlations for all parameters were greater for steers than that observed in heifer carcasses (Hankins and Howe, 1946). Crouse and Dikeman (1974) reviewed this method of estimation, and suggested that intramuscular fat as well as fat thickness of the rib itself were adequate contributions to improve the variations of carcass chemical composition analyzed in the 1946 research. Crouse and Dikeman (1974) observed that the Hankins and Howe rib chemical analysis procedure coupled with the intramuscular and subcutaneous fat scores accounted for 87, 93, and 97% of variation in carcass moisture, fat, and protein, respectively. A review of the rib techniques was tested again by McEvers et al. (2017), whom observed carcasses to have more separable lean, fat and ash than rib sections, but protein was similar between carcasses and rib sections. Walter et al. (2016) reported proximate analysis on whole carcasses, either treated with zilpaterol hydrochloride for 0 or 20d, and reported that lean, fat, and bone were more accurate than chemical composition when comparing the rib section to the carcass.

The main contradiction between study observations was breed; Hankins and Howe (1946), Crouse and Dikeman (1974), and Walter et al. (2016) observed steers of beef origin whereas McEvers (2017) observed Holstein steers. Shifts in the genetic makeup and management of cattle in the markets may account for the changes in efficacy between studies. Growth promotants are now a common practice in the industry, growth and composition are impacted by the use of these technologies. The purpose of this study was to investigate the efficacy of the Hankins and Howe procedure in implanted and non-implanted cattle.

4.3. Materials and Methods

Eighty Charolais x Angus (n = 80) steers were fed and housed together at the Agri-Research Inc. feedlot in Canyon, Texas. Steers used in this study were under the Institutional Animal Care and Use Committee (IACUC) 01-08-18. Steers were either not implanted (CON) or implanted (REV) with a Revalor-XS (RXS: Merck Animal Health, Madison, NJ; 200 mg trenbolone acetate and 40 mg estradiol), and then paired with an animal of the opposite treatment. Four pairs of steers were randomly allocated to one of 10 harvest dates and harvested in 42d intervals (0, 42, 84, 126, 168, 210, 252, 294, 336, and 378). Estimated final BW, frame scores, days to target body weight, and live growth performance and feeding behaviors were reported by Kirkpatrick (2020). All animals were humanely harvested at the West Texas A&M University Meat Science Lab (Canyon, Texas) on the assigned date. Carcass components and grading were analyzed and reported by Pillmore (2020), all grading was conducted following the 2017 USDA official carcass standards. Carcasses were chilled for 48h before processing according to industry standards, previously recorded by Wesley (2020).

Rib samples were collected from the left half of each carcass. The 9-10-11th rib sections were measured using a meter stick and carpenter square, as described in the Hankins and Howe (1946) procedure;

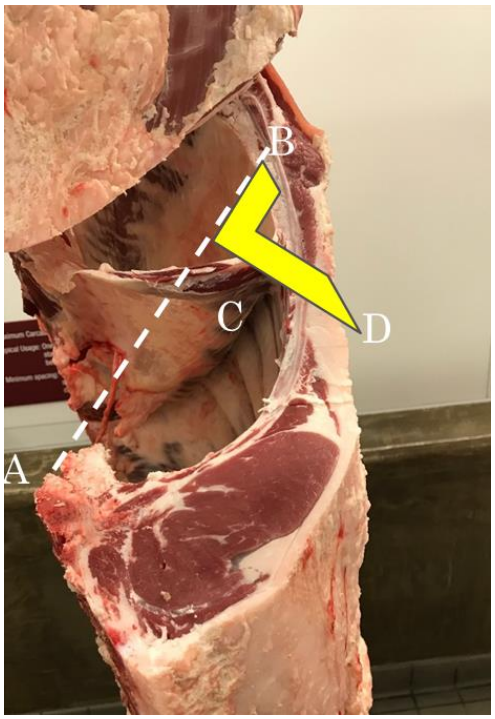

Figure 4.1. Measurements for rib separation

measurements between the topmost point (point A; Figure 4.1.) of the split vertebrae to the cartilage button of the 13th rib (point B) were taken in mm, the third (point C) was calculated as 61.5 percent of the original distance between A and B, and the final point (point D) was marked by placing a carpenter square at the calculated distance to observe the external intersect perpendicular to the external face. The separation was made by cutting the perpendicular line of point D (Hankins and Howe, 1946). Sections were removed with a hand saw, vacuum packaged, and frozen at -29°C until all samples were collected. Samples were allowed to thaw at room temperature, and excess purge was collected and calculated back into sample weights. Rib sections were weighed whole prior to separation into lean, fat, and bone to the nearest 0.05 +/- 0.005 kg (Catapult

C11P9, OHAUS Corp., USA). Subcutaneous, intermuscular, and intramuscular fat were separated from the lean tissue of each sample to equal total fat within the sample, and bone and connective tissue were totaled. Weights were recorded for total lean, fat, and bone plus heavy connective tissue. Lean and fat samples were ground separately for composite samples, bagged, and frozen at -29°C until all samples were ground. Bone was thinly sliced on a band saw until reaching a consistent powder, and then frozen until all samples were collected. Samples were sent to SDK Laboratories (Hutcheson, KS) for proximate analysis.

Proximate analysis of moisture from all carcass and rib sections were determined by drying samples at 105°C for 24 h, and subtracting the weight of the dried sample from the weight of the original sample. Ether extraction of fat was determined via AOAC official method 2003.06 (2006) in which fat was ground to a particle size no greater than 1mm and dried at 102°C for 2 h, and extracted using petroleum ether. Samples were then calculated as the difference between the original weights minus the weight of the tested sample, multiplied by 100. Crude protein was determined by AOAC method 990.30 (2000) in which nitrogen content of the sample was multiplied by 6.25 to calculate crude protein of the sample. Weights were compared for the separated components between right carcass halves and the 9-10-11th rib sections from the left half of the carcass. Ash content, was determined by AOAC official method 942.05 (1943) in which 2 g test portions of samples were placed in porcelain crucibles and exposed to 600°C heat for 2 h. Proximate analysis between samples from the whole carcass and the rib sections were compared to test the efficacy of the Hankins and Howe procedure.

4.4. Statistical Analysis

A balanced incomplete block design with a 2 × 10 factorial arrangement was used. The GLIMMIX procedure of SAS was used to analyze fixed effects of treatment, DOF, and the interaction between TRT and DOF. Correlations and regressions were determined in order to observe the differences in overall composition from rib sections to the whole carcass. Mean estimates were determined by using the LSMEANS procedure; differences were identified using a P-value of 0.05 while tendencies were observed at P-value of 0.06 – 0.10. Contrasts were calculated to observe linear or quadratic tendencies in the data. Comparisons between rib and carcass component weight and chemical analysis were observed.

4.5. Results and Discussion

Correlations of 9-10-11th rib components and carcass components were calculated as a percentage (Table 4.1). Rib ether extract and fat percentage were strongly correlated (r = 0.88 and 0.86 respectively) to the carcass. Fat percentage between the rib section and carcass (Figure 4.2) best resembled the original Hankins and Howe (1946) equation, however our research indicated that fat percentage accounted for 85% of variation when expressed in an exponential equation rather than the linear model originally described, and had the closest relationship between slopes. Ether extract correlations were also similar to the original equation (Figure 4.3); ether extract accounted for 84% of variation when expressed as an exponential equation as opposed to the original linear model, although the exponential slope adequately represented the model. Rib moisture was only moderately correlated (r = 0.78) to the carcass, and the relationship between carcass and rib moisture was linear in both models (Figure 4.4), however the adjusted equation

accounted for 61% variation whereas the Hankins and Howe (1946) equation would have underestimated the percent of moisture in the sample. Rib lean, crude protein, and bone were poorly correlated (r = 0.62, 0.51, and 0.47, respectively) to carcass components; Hankins and Howe (1946) attributed the poor correlation of bone to the impossibility of cutting a carcass perfectly in half during harvesting. Comparison of the composition of lean from the rib section to the carcass (Figure 4.5) was not an adequate method in determining the percentage of lean ($R^2 = 0.31$) in either the original linear equation or the adjusted power curve equation. Rib section crude protein and bone percentage to carcass parameters (Figures 4.6 and 4.7, respectively) were both updated as quadratic equations, however variations were poor ($R^2 = 0.26$ and 0.24, respectively) and indicate that the use of the rib section is not the appropriate method in determining carcass crude protein or bone percentage. Ash was very poorly correlated (r = 0.18) between the rib section and the carcass; no original equation exists from the 1946 data presented by Hankins and Howe, as ash was so poorly related from rib to carcass. A quadratic equation was determined (Figure 4.8), however only accounted for 0.04% of the variation in samples. Rib ash was considered the least predictable component as compared to the carcass in this study.

Similar studies have also reported that the original Hankins and Howe (1946) equations are not adequate predictors for overall composition of either physical or chemical analysis from rib sections to the carcass. Results from this study supported the use of fat from the 9-10-11th rib as an indicator of fat and ether extract in the carcass, but other components varied greatly in accuracy. Crouse and Dikeman (1974) also reported that adjusted fat thickness was a more accurate indicator from rib to carcass comparisons,

and rib fat moisture had a greater correlation to carcass moisture than rib protein moisture. Walter et al., (2016) also reported improved accuracies in lean, fat, and bone when equations were adjusted. Chemical composition has also differed among studies, McEvers et al. (2017) reported a higher correlation of ash as compared to results from this study, Walter et al. (2016) or Crouse and Dikeman (1974). Overall composition appeared to be dependent to each study, rather than fitted to a linear model as suggested by Hankins and Howe (1946). Differences in reported data suggest that using the 9-10-11th rib section component percentages is not always an accurate predictor of carcass components.

Effect of days on feed and implant treatments were analyzed (Table 4.2) for 9-10-11th rib section and carcass physical and chemical components. Chemical analysis of ash were not similar between locations; rib section evaluation had a tendency for TRT*DOF ($P = 0.06$), whereas carcass ash differed between treatments ($P = 0.01$) and had a TRT*DOF interaction ($P = 0.04$). A graph was created (Figure 4.9) to observe the carcass TRT*DOF interaction with ash, it was determined that the relationship observed was due to experimental error. Ether extract analysis differed as well, rib ether extract had a DOF effect as well as a TRT*DOF interaction which was graphed (Figure 4.10) and determined as experimental error. Carcass ether extract exhibited TRT ($P = 0.01$) and DOF ($P < 0.01$) effects, however no interaction was observed. Crude protein had identical DOF effects ($P < 0.01$) between rib sections and carcasses, however there was a tendency for crude protein DOF*TRT interaction ($P = 0.06$) in the rib section but not the carcass. Moisture DOF effects were also identical ($P < 0.01$) however rib and carcass TRT*DOF differed ($P = 0.05$ and 0.08, respectively), but were determined to be caused

by experimental error when graphed (Figure 4.11). Rib section and carcass lean percentages differed, but had DOF effects ($P < 0.01$). Rib lean had a tendency ($P = 0.06$) for TRT*DOF interaction, but carcass did not. Bone exhibited DOF effect ($P < 0.01$) for both rib section and carcass, however only carcass analysis TRT*DOF interaction of bone ($P < 0.01$) was observed; graphic representation of carcass bone interaction (Figure 4.12) was also concluded as experimental error.

Effects of DOF and TRT as well as interactions of TRT*DOF differed between rib sections and carcass components in this experiment. All TRT*DOF interactions were determined as experimental error upon further investigation; the differences observed in this study suggest that interactions observed in the Hankins and Howe (1946) data could have been inconclusive upon further investigation. Koch et al. (1976) suggested that differences in breed could account for differences in lean, fat, and bone percentage. Johnson et al. (1996) reported that frame score and implantation could affect percentages of lean, fat, and bone. Other studies have suggested that body condition score is highly correlated with composition of the 9-10-11th rib in Holsteins, however McEvers et al. (2017) reported differing compositions between rib section and carcass analysis in calf-fed Holsteins. Shackelford et al. (1995) used the 9-10-11th rib section in comparison to wholesale rib cuts as a means to determine carcass cutability, and determined that use of the wholesale rib cut accounted for more variation in equation models than the Hankins and Howe (1946) method. Butler et al. (1956) reported that variation of techniques when fabricating carcasses accounted for differences in composition, it could be hypothesized that differences in extracting lean, fat, and bone from the 9-10-11th rib section as

compared to the separation of the same components in a carcass cause significant differences in physical and chemical analysis.

4.6. Conclusions

Results from this study concluded that while percentage of fat and ether extract seemed to be an accurate indicator between carcass and rib sections, percentage lean, moisture, crude protein, ash, and bone, combined with the chemical analysis of components from each of those parameters provided differing results. Reports from other studies indicate that the use of the 9-10-11th rib section has varying results in the literature. Bone and ash were the poorest indicators of carcass components for this study.

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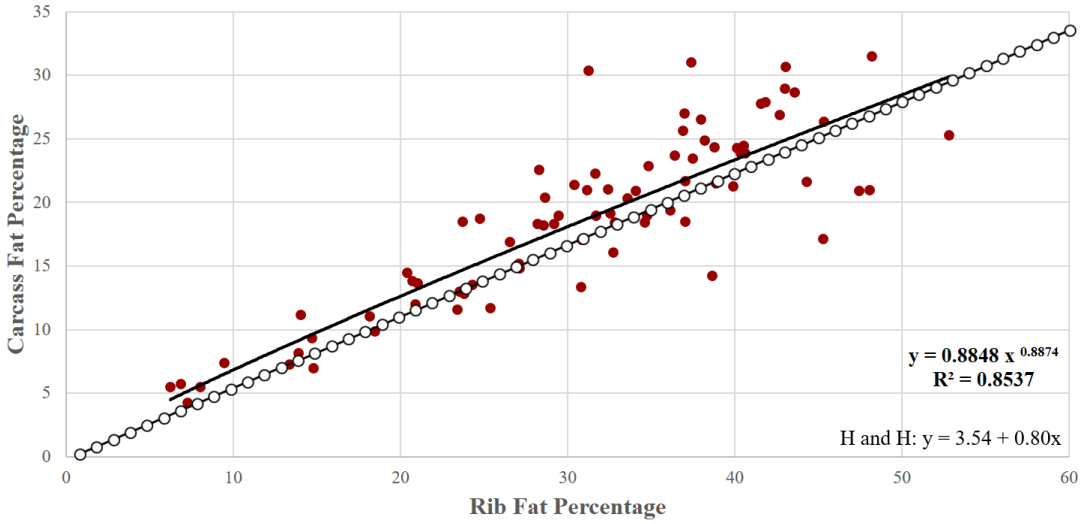

Figure 4.2. Carcass and rib percentage fat (filled) as compared to the original Hankins and Howe (open) equation

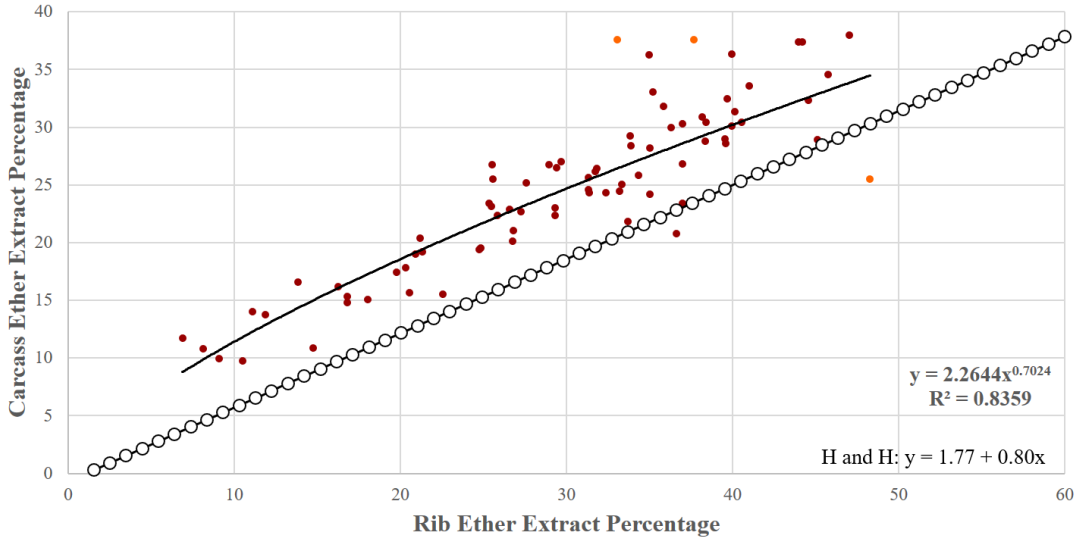

Figure 4.3. Carcass and rib ether extract percentage (filled) as compared to the original Hankins and Howe (open) equation

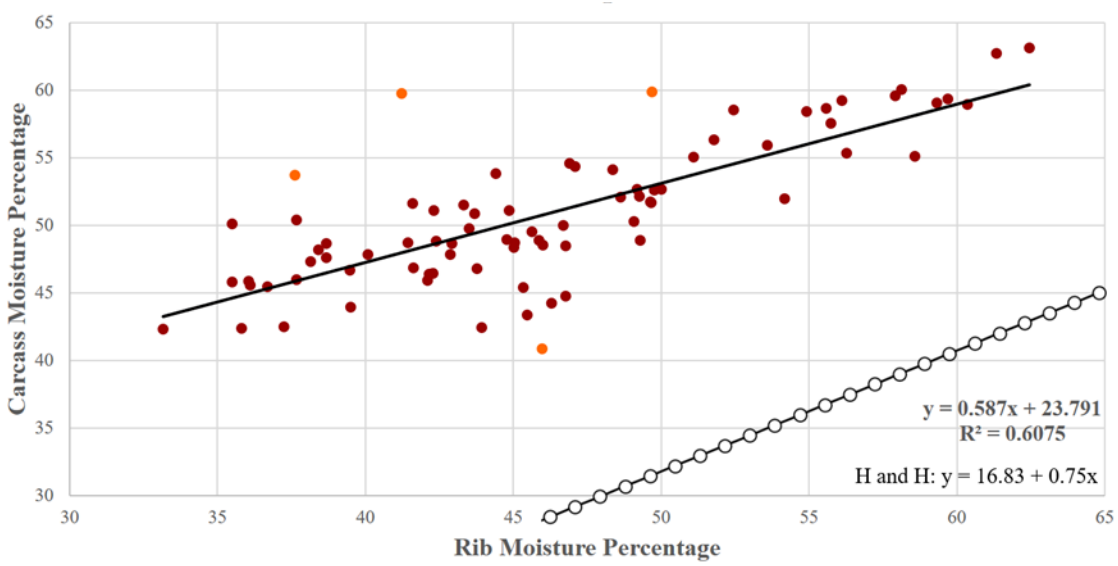

Figure 4.4. Carcass and rib moisture percentage (filled) as compared to the original Hankins and Howe (open) equation

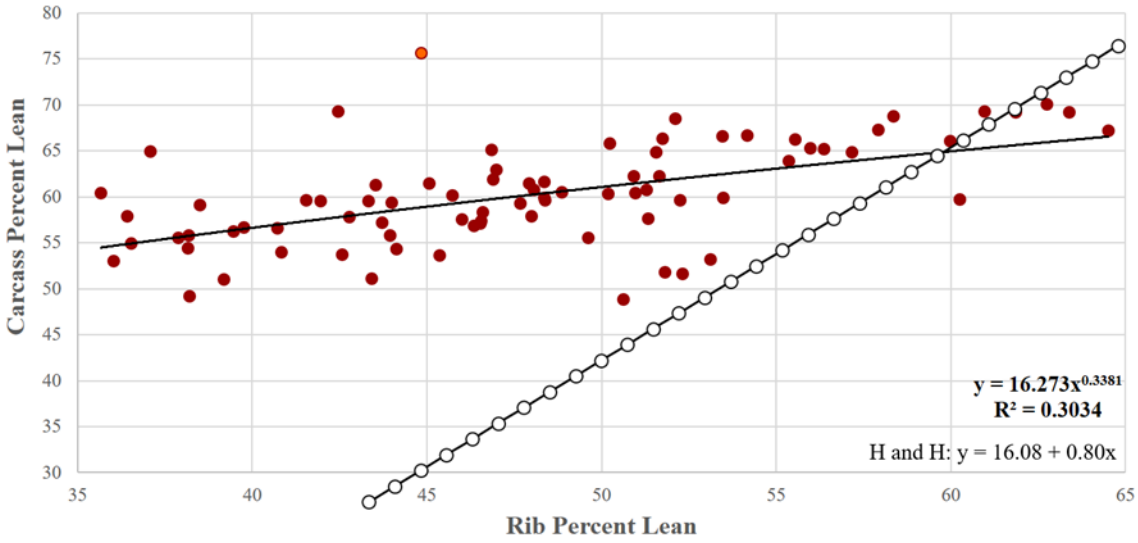

Figure 4.5. Carcass and rib percentage lean (filled) as compared to the original Hankins and Howe (open) equation

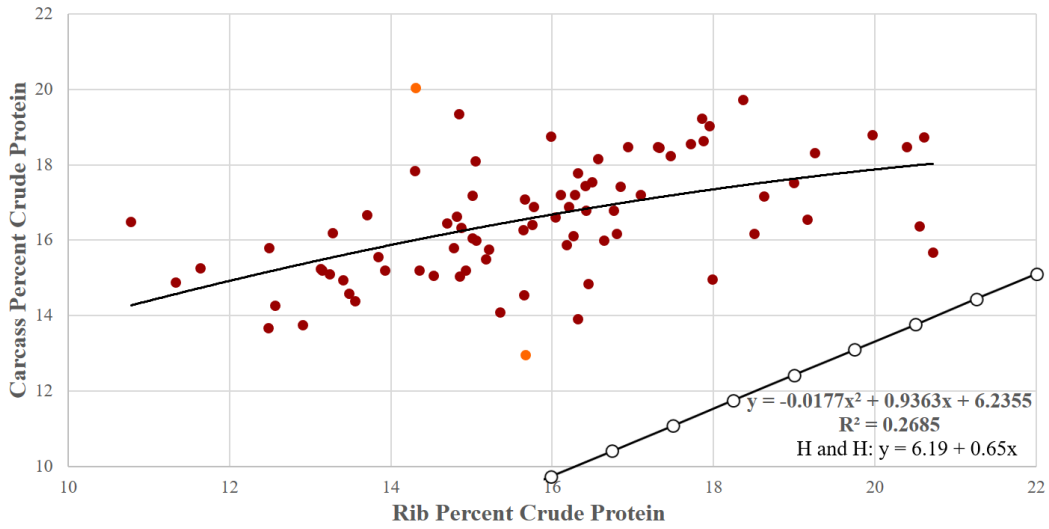

Figure 4.6. Carcass and rib crude fat percentage (filled) as compared to the original Hankins and Howe (open) equation

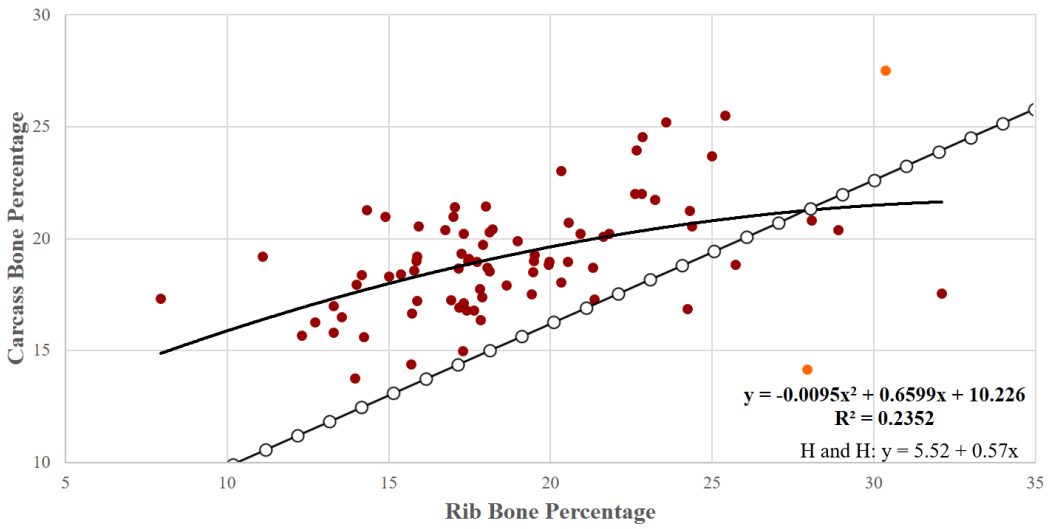

Figure 4.7. Carcass and rib bone percentage (filled) as compared to the original Hankins and Howe (open) equation

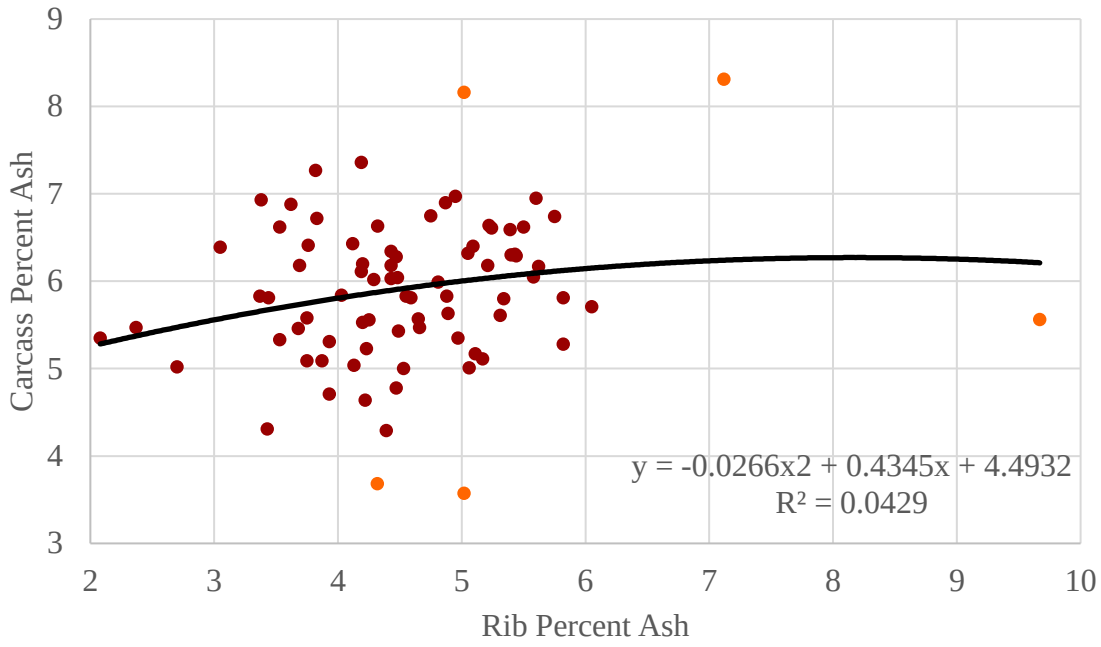

Figure 4.8. Carcass percentage of ash versus rib section percent ash with new equation.

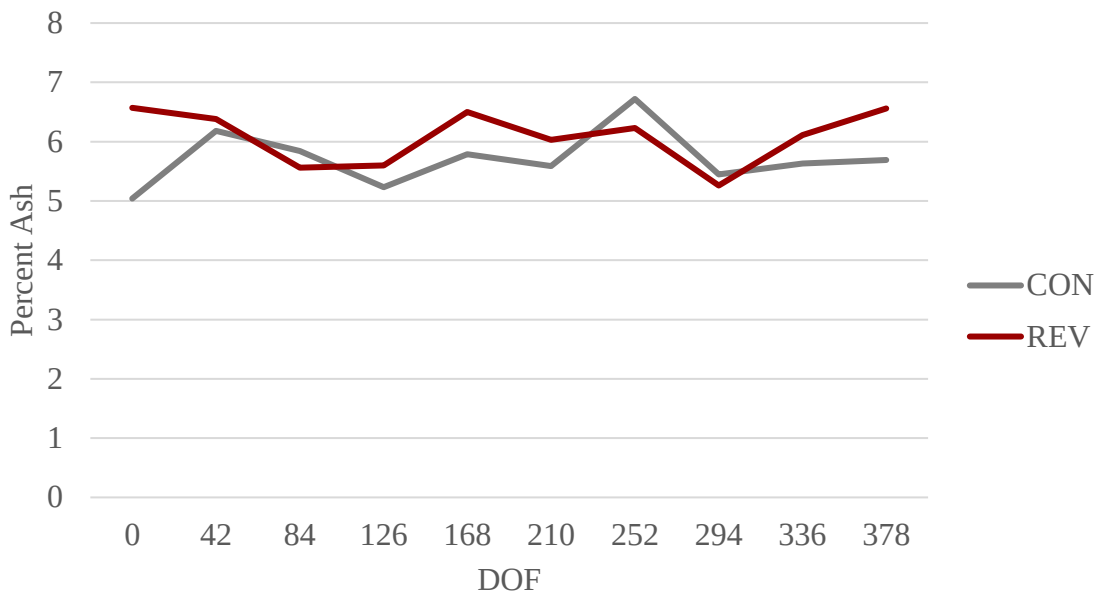

Figure 4.9. Interaction of TRT×DOF for carcass ash.

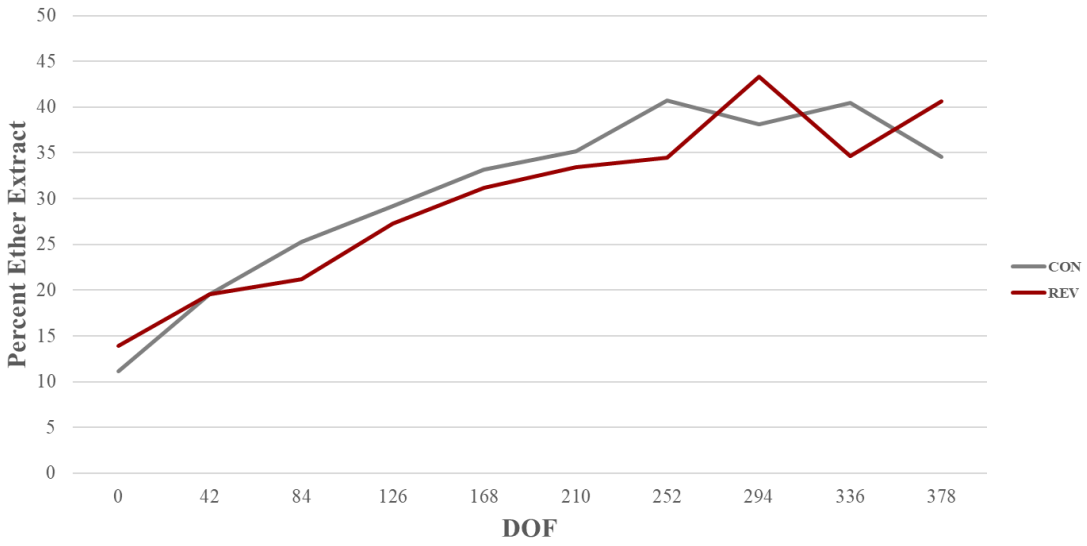

Figure 4.10. Interaction of TRT×DOF for rib section ether extract.

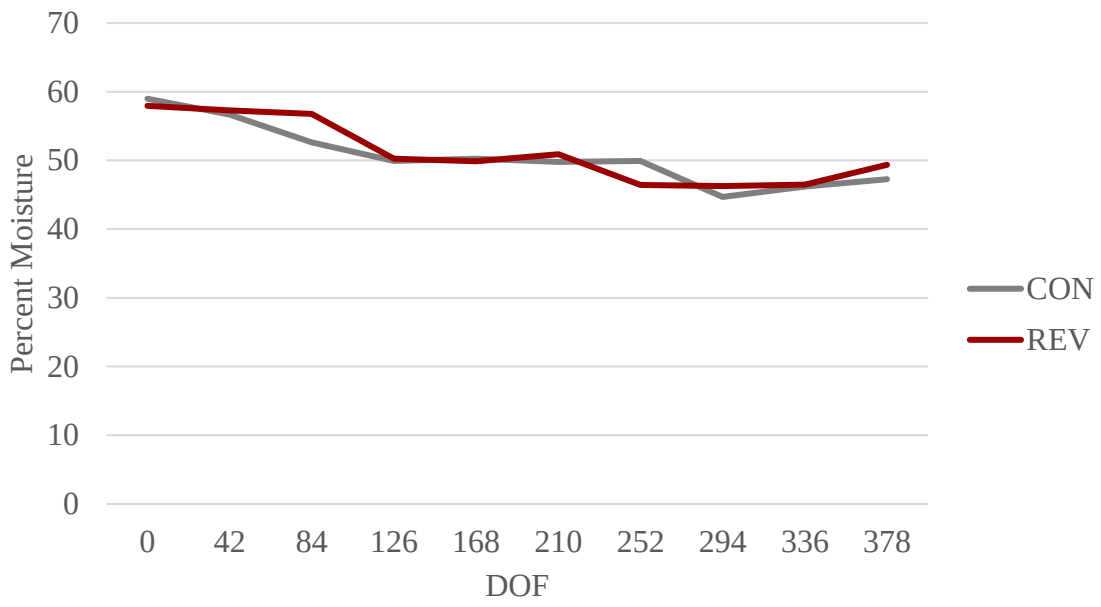

Figure 4.11. Interaction of TRT×DOF for carcass moisture.

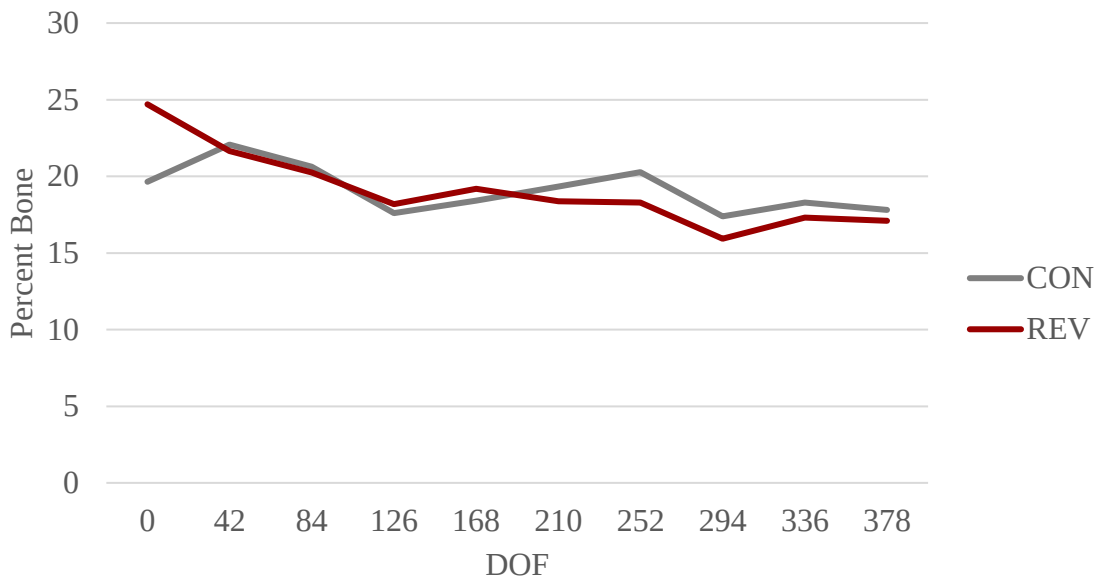

Figure 4.12. Interaction of TRT×DOF for carcass bone

Table 4.1. Simple correlations of rib section components to carcass components as a percent

	Carcass Lean	Carcass Fat	Carcass Bone	Carcass Moisture	Carcass Ether Extract	Carcass Crude Protein	Carcass Ash
Rib Lean	**0.62*** **	-0.81***	0.49***	0.70***	-0.79***	0.51***	0.04
Rib Fat	-0.611***	**0.86*** **	-0.56***	-0.79***	0.86***	-0.58***	-0.03
Rib Bone	0.42***	-0.64***	**0.47*** **	0.56***	-0.63***	0.40***	0.09
Rib Moisture	0.62***	-0.86***	0.57***	**0.78*** **	-0.85***	0.61***	0.08
Rib Ether Extract	-0.62***	0.88***	-0.58***	-0.81***	**0.88*** **	-0.63***	-0.05
Rib Crude Protein	0.54***	-0.79***	0.53***	0.68***	-0.77***	**0.51*** **	0.07
Rib Ash	-0.01	-0.18	0.16	0.01	-0.15	-0.02	**0.18**

$P < 0.001$, ***

Table 4.2. Effects of days on feed (DOF) and Revalor-XS on 9-10-11th rib section and carcass (CX) components of Angus x Charolais steers fed over a 378-d feeding duration

	Treatment			DOF										*P*-value					
Item	CON	REV	SEM	0	42	84	126	168	210	252	294	336	378	SEM	REV	DOF	REV×DOF	Linear	Quadratic
n	40	40	--	8	8	8	8	8	8	8	8	8	8	--	--	--	--	--	--
Rib Ash%	4.60	4.55	0.002	5.34	4.53	4.09	4.01	4.76	4.78	4.36	4.98	4.59	4.29	0.003	0.80	0.19	0.06	0.56	0.35
Rib Ether Extract%	30.74	29.97	0.009	12.54	19.57	23.24	28.24	32.17	34.30	37.57	40.75	37.53	37.61	0.01	0.42	<0.01	0.05	<0.01	<0.01
Rib Crude Protein%	15.92	15.73	0.003	19.54	17.28	17.12	15.84	15.27	15.22	14.60	14.60	14.12	14.66	0.004	0.53	<0.01	0.06	<0.01	<0.01
Rib Moisture%	46.07	46.29	0.005	57.49	53.34	52.48	47.26	44.08	43.11	41.42	39.82	40.02	42.76	0.01	0.77	<0.01	0.08	<0.01	<0.01
Rib Lean%	47.77	48.29	0.01	59.92	53.11	52.16	49.08	44.72	44.93	44.64	42.19	43.69	45.91	0.01	0.61	<0.01	0.11	<0.01	<0.01
Rib Fat%	30.91	30.86	0.008	11.58	20.18	24.34	29.04	34.48	34.95	38.15	40.45	37.49	38.20	0.01	0.97	<0.01	0.06	<0.01	<0.01
Rib Bone%	19.44	18.32	0.007	25.13	22.40	21.31	17.96	18.34	18.11	15.83	17.64	16.11	15.97	0.01	0.13	<0.01	0.18	<0.01	0.01
CX Ash%	5.71	6.08	0.001	5.81	6.28	5.70	5.41	6.16	5.81	6.47	5.36	5.87	6.12	0.003	0.01	0.40	0.04	0.87	0.74
CX Ether Extract%	25.77	23.79	0.007	12.47	17.97	20.02	24.33	23.67	26.79	30.86	32.81	29.65	29.21	0.01	0.01	<0.01	0.15	<0.01	<0.01
CX Crude Protein%	16.33	16.74	0.002	17.65	17.82	18.12	16.82	17.08	15.70	15.98	15.06	15.59	15.51	0.004	0.14	<0.01	0.61	<0.01	0.53
CX Moisture%	50.63	51.16	0.007	58.47	56.99	54.71	50.07	50.07	50.35	48.17	54.48	46.34	48.33	0.01	0.43	<0.01	0.05	<0.01	<0.01
CX Lean%	60.03	60.52	0.009	64.93	65.58	64.21	59.13	58.63	60.07	61.36	54.95	55.44	58.41	0.02	0.59	<0.01	0.54	<0.01	0.18
CX Fat%	19.27	18.16	0.008	7.36	11.59	13.90	19.69	19.50	19.66	20.87	27.08	24.24	23.23	0.01	0.16	<0.01	0.65	<0.01	<0.01
CX Bone%	19.14	19.10	0.003	22.17	21.86	20.44	17.90	18.80	18.86	19.28	16.66	17.79	17.45	0.008	0.87	<0.01	<0.01	<0.01	0.07

CHAPTER 5

Predicting red meat yields in serially harvested steer carcasses using the United States Department of Agriculture calculated boneless closely trimmed rib-loin-chuck-round equation

5.1. Abstract

Estimations of beef carcass cutability are determined via the USDA yield grade (YG) equation which has remained unchanged for over 55 years. Charolais x Angus steers (*n*=80) were randomly allocated to implant treatments and harvest date in a 2 x 10 factorial design. Implant treatments administered were Revalor-XS (REV n=40; 200mg trenbolone acetate/40mg estradiol) on d0 and d190 or no implant as a control group (CON; n=40). Four pairs of steers were randomly allocated to one of 10 harvest dates and harvested every 42 days, beginning on d0 and ending on d378. Carcass yields were determined by fabricating carcasses and separating lean, fat, and bone components and weighing to the nearest 0.05 +/- 0.005 kg. Linear models were developed to compare predictive red meat yield of steers to the original USDA boneless closely trimmed rib-loin-chuck-round (BCTRLCR) equation and actual BCTRLCR yield. Additionally, ribeye area (REA) to hot carcass weight (HCW) relationship was compared to the standard expected when beef carcasses are graded according to USDA methods. Carcasses less than 317.5 kg in this study had larger REA than required from the USDA REA standard, whereas carcasses greater than 317.5 kg had smaller REA than required. Yields of BCTRLCR were analyzed without trim fat using a forced intercept of 51.34

from the intercept used in the original USDA BCTRLCR equation, in order to generate new coefficients for the carcass parameters used to estimate carcass cutability. Additionally, correlations were calculated between four individual parameters (HCW; REA; fat thickness in inches, FAT; and percentage kidney pelvic and heart fat, KPH) previously determined by the USDA equation, and BCTRLCR outcomes. Calculations of BCTRLCR were strongly correlated (r = -0.86, -0.72, -0.64, -0.82 to HCW, REA, FAT, and KPH respectively) to all individual parameters, indicative of a shift from the original USDA YG equation. A new equation would reflect the four original parameters with adjusted coefficients; YG = 51.34 – 2.71 (FAT) – 0.848 (KPH) – 0.678 (REA) – 0.0043 (HCW). An updated equation would improve the accuracy in estimating beef carcass cutability.

5.2. Introduction

In the United States, cutability, or yield grade (YG), has been classified into five scores that are calculated from the boneless closely trimmed rib-loin-chuck and round (BCTRLCR) and are used for estimations of yield, based on the equation: *BCTRLCR = 51.34 - (5.784 * fat thickness, inches) - (0.462 * estimated percentage kidney, pelvic, and heart [KPH] fat) - (0.0093 * HCW, lbs) + (0.74 longissimus muscle area, inches^2)* (Murphey et al., 1960). It has been reported in the literature that the BCTRLCR equation does not adequately represent estimations of yield. Gregory et al. (1962) reported that subjective live scores from USDA graders only accounted for 20-25% of the variation in carcasses that affected the qualitative values of beef carcasses. Farrow et al. (2009) reported higher accuracy in institutions that used weights of KPH from the whole carcass weight and then subtracting the weight of carcasses after the KPH had been removed to

determine actual KPH percentage, and printed the actual percentage on identification tags which USDA graders could more easily use. Other researchers have reviewed methods used worldwide and concluded that while no country has specifically formulated a standard for consumer satisfaction in conjunction with quality and yield grades, it is hypothesized that including consumer satisfaction with current equations would further improve the supply chain (Polkinghorne and Thompson, 2010).

Estimations of red meat yields based on the calculations from the USDA grading system no longer replicate the average carcass red meat yield. Lawrence et al. (2008) reported that the USDA yield grade formula favors light carcasses. Over or underestimations of YG at the grading level consequently effects value of beef carcasses. The objective of this investigation was to study the variables of the current yield grade equation with more fitting coefficients as needed to improve accuracy of beef carcass value.

5.3. Materials and Methods

Eighty Charolais x Angus (n = 80) steers were fed and housed together at the Agri-Research Inc. Feedlot in Canyon, Texas. Steers used in this study were under the Institutional Animal Care and Use Committee (IACUC) 01-08-18. Steers were either not implanted (CON) or implanted (REV) with a Revalor-XS (RXS: Merck Animal Health, Madison, NJ; 200 mg trenbolone acetate and 40 mg estradiol), and then paired with an animal of the opposite treatment. Four pairs of steers were randomly allocated to one of 10 harvest dates and harvested in 42d intervals (0, 42, 84, 126, 168, 210, 252, 294, 336, and 378). REV steers received a second implant on d190 to maintain viability of

implantation effects. Estimated final BW, frame scores, days to target body weight, and live growth performance and feeding behaviors were reported by Kirkpatrick (2020). All animals were humanely harvested at the West Texas A&M University Meat Science Lab (Canyon, Texas) on the assigned date. Carcass components and grading were analyzed and reported by Pillmore (2020), all grading was conducted under the 2017 USDA official carcass standards. Carcasses were chilled for 48h before processing according to industry standards, previously recorded by Wesley (2020).

The BCTRLCR were composed from weights of individual fat and lean primal cuts previously reported by Wesley (2020) for an accurate representation of total lean and fat of each boneless primal for analysis comparisons to the Murphey et al. (1960) equation. Red meat yields were calculated using the estimations from current USDA beef grading and the actual red meat yield from the steer carcasses by Pillmore (2020). Red meat yields were determined in this study by using the separated lean, and creating a linear model of the expected and actual calculations.

5.4. Statistical Analysis

Yields of BCTRLCR were analyzed without trim fat using a forced intercept of 51.34 from the intercept used in the original USDA YG equation, in order to generate new coefficients for the existing carcass parameters used to estimate carcass cutability. Coefficients were determined using parameter estimates from the PROC REG procedure in SAS (SAS Institute Inc., Cary, NC). Additionally, correlations were calculated between the current four individual parameters (HCW; LMA; fat thickness in inches, FAT; and kidney pelvic and heart fat, KPH) via Pearson correlation. The MEANS

procedure was used to calculate descriptive statistics. Linear models were developed to compare predictive and actual red meat yield of steers to the original USDA boneless closely trimmed rib-loin-chuck-round (BCTRLCR), and to represent total red meat percentage of carcasses.

5.5. Results and Discussion

Coefficients for the newly developed equation were based on the original USDA BCTRLCR equation parameters (Table 5.1). Coefficients in the updated equation were all negative, which illustrated the changes over time as cattle aged. The following updated equation represented the four original parameters with adjusted coefficients (Table 5.3):

BCTRLCR = 51.34 – 2.71 (FAT) – 0.848 (KPH) – 0.678 (LMA) – 0.0043 (HCW)

The developed equation differed from the original BCTRLCR equation in that fat thickness was reduced, reflective of the trimmed fat in today's market. As suggested, KPH percentage has not been adequately represented and has been adjusted as a larger percentage than was originally stated in the Murphey et al. (1960) equation. Previous research has reported actual KPH percentage of carcasses was 3.2 ± 0.8 (Dikeman et al., 1998), indicating that the common estimation of 2.5 percent KPH in the USDA YG system has been an underestimation of actual KPH fat. At chain speeds, it is virtually impossible for graders to accurately determine KPH percentage, as they have an average of 7-10 seconds to grade the carcass, therefore an accurate estimation or improved method of determining KPH is necessary both in production and in the current equation.

Gregory et al. (1962) reported that subjective scores from USDA graders only accounted for 20-25% of the variation in carcasses. Other methods have been suggested to improve the accuracy of KPH, as it is currently required in the BCTRLCR and USDA YG equations. The relationship between KPH and HCW was evaluated (Figure 5.4), and only 51% of the variation in KPH could be determined when KPH percentage was evaluated objectively.

Longissimus muscle area as determined for the BCTRLCR and YG equations were calculated in this study by using the USDA LMA standard grid. By using the USDA LMA standard, lighter carcasses have been favored due to having LMA greater than expected, whereas heavier carcasses are unable to meet the LMA expected; the carcass standards that the industry has come to demand do not meet the expectations of the current LMA standard. Carcasses less than 317.5 kg in this study had larger LMA than required from the USDA LMA standard, whereas carcasses greater than 317.5 kg had smaller LMA than required (Figure 5.1). Differences in LMA tendencies were also observed by Lawrence et al. (2008) in which true relations of LMA were quadratic rather than linear, as assumed by the YG equation and longissimus measurement grid. The data from this study suggest that the LMA growth follows a power curve rather than a linear or quadratic model observed in previous research. The negative correlation of LMA in this study determined that the current equation that established the USDA measurement methods of carcasses was inaccurate; the assumption of an exponentially linear growth of LMA was not supported.

The original equation and the new equation were evaluated for calculated and actual red meat yields (Figure 5.2). Actual red meat yields were approximately 20% lower than calculations suggested (Figure 5.2), unlike Crouse et al. (1975) who reported average over and underestimations as 1% or less compared to actual cutability. Results of this study are similar to Lawrence et al. (2008), carcasses were not as the predicted YG model had anticipated. Hot carcass weight in relation to 12^{th} rib fat and KPH was analyzed (Figure 5.3 and 5.4, respectively). Exponential growth of the 12^{th} rib fat was observed, as was reported by Boggs et al. (1998). Only 51% of the variation in KPH was correlated to HCW, in this study KPH was most accurately expressed with a power curve.

Mean, standard deviation, and ranges of traits for all variables used in the model are reported (Table 5.2). Ranges in the data were due to different DOF, which better represented the current market; the cattle population used in the Murphey et al. (1960) research does not reflect cattle in the market today; 21.6% of the carcasses observed in the original study were cows, which is an inadequate representation of USDA market reported beef (USDA, 2017). Changes from primarily purebred to primarily crossbred genetics, widespread use of production practices such as implants and beta agonists, and increased feedstuff variety have also resulted in differences in carcass composition since the induction of the equation (Cundiff and Gregory, 1977). Retail fat trim at the time was approximately 12.7 mm, whereas retail trim in the current market is 3.175 to less than 1 mm to reflect shifting consumer demands. Calculations of BCTRLCR were strongly correlated ($r = -0.86, -0.72, -0.64, -0.82$ to HCW, LMA, FAT, and KPH respectively) to all individual parameters, indicative of a shift from the original USDA YG equation (Table 5.3). This shift exemplifies previously recorded observations of YG

miscalculations with the current systems in place (McEvers et al., 2012). Previous literature has suggested the need for an improved yield grade equation, as correlations between existing parameters has decreased over time (Dikeman et al., 1998; Farrow et al., 2008); the aforementioned authors each conducted studies in which new parameters were calculated and improved variation when compared to the original Murphey et al. (1960) equation.

Kerth et al. (1999) observed an updated evaluation in the USDA quality and yield grading systems which proposed a seven grade yield grading system, however it was reported that on-line USDA graders could not differentiate between the level 4 and 5 YG while computed expert USDA YG were more accurate; the use of the five grade system currently in place was more accurate than the seven grade system. Several studies have determined that the linear regression model that is currently used by the USDA is an inaccurate form of measurement, a reevaluation of the model is needed to better represent beef yields. May et al. (2016) reported that fat thickness of the 12^{th} rib had a linear relationship with DOF, whereas Bruns et al. (2004) reported fat thickness as a quadratic relationship. Farrow et al, (2009) analyzed differing methods and equations of calculating YG and concluded that with available technologies such as video image analysis combined with the existing methodology of YG, a revised equation is both possible and necessary to improve yield grading accuracy.

Video image analysis or VIA is another method which could be used to improve accuracy and consistency of YG and calculated RMY, the VIA-Computer Vision System was approved in 2006, but further research has been conducted to improve these methods

as USDA is still required (Moore et al., 2010). Research comparing USDA graders to video image analysis technologies have concluded classification disagreements of up to 86% as carcass fat increased (McEvers et al., 2012). Understanding how yield has changed to accommodate consumer demands and production changes is imperative for producers and processors to provide suitable products for consumers.

In addition, the accuracy of estimating the total red meat yield of carcasses was examined. As HCW, LMA, 12th rib fat, and KPH have all been determined from the previous equations as predictors of yield, the relationship of those factors was examined (Table 5.4). Hot carcass weight (Figure 5.5) was the best indicator of total red meat yield ($R^2 = 0.33$), however the variation observed was poor. Fat thickness (Figure 5.6) only accounted for 31% of variation in total red meat yield. Longissimus muscle area (Figure 5.7) and KPH (Figure 5.8) had the poorest variations in observing total red meat yield ($R^2 = 0.23$ and 0.19, respectively). The use of HCW, LMA, fat thickness, and KPH percentage were all poor representations of total red meat yield, but follow reports from Lawrence (2010) that total red meat yields are poorly correlated to USDA yield grading systems.

5.6. Conclusions

The equation developed from the coefficients in this study represented the quadratic nature of growth rather than the linear model assumed by the USDA equation, and so is a more accurate predictor of YG and red meat yields. Red meat yields were not observed as calculations had estimated. Red meat percentage was not appropriately estimated, as smaller carcasses were favored in the USDA equation. An updated equation

would address quality concerns of processors, revaluate beef value for future production, and improve the predicted value of beef. More research is needed to determine the most appropriate method of updating the current USDA YG equation.

5.7. Literature Cited

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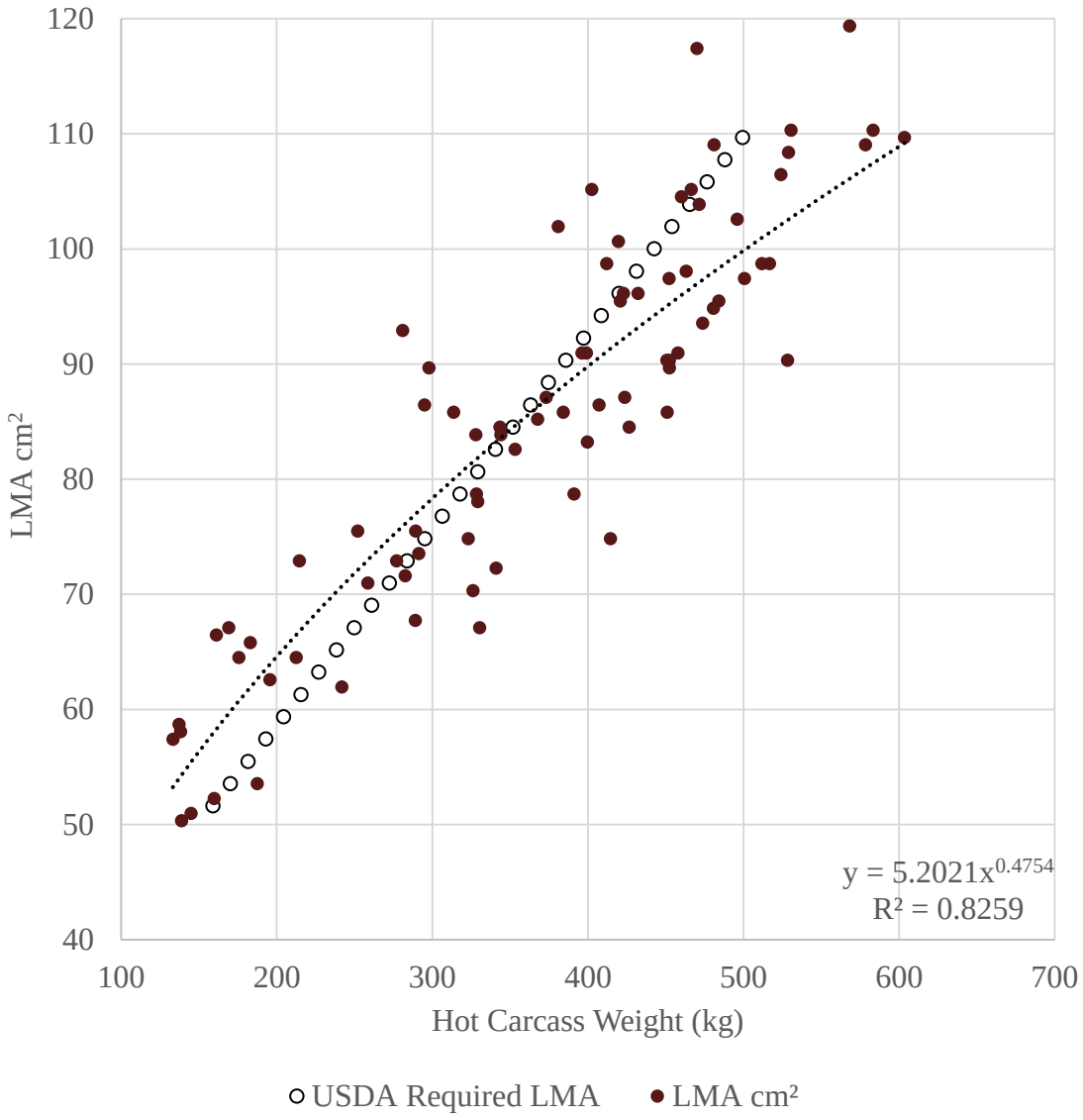

Figure 5.1. Expected LMA from USDA versus actual LMA. USDA required LMA follows a linear trend (open white).

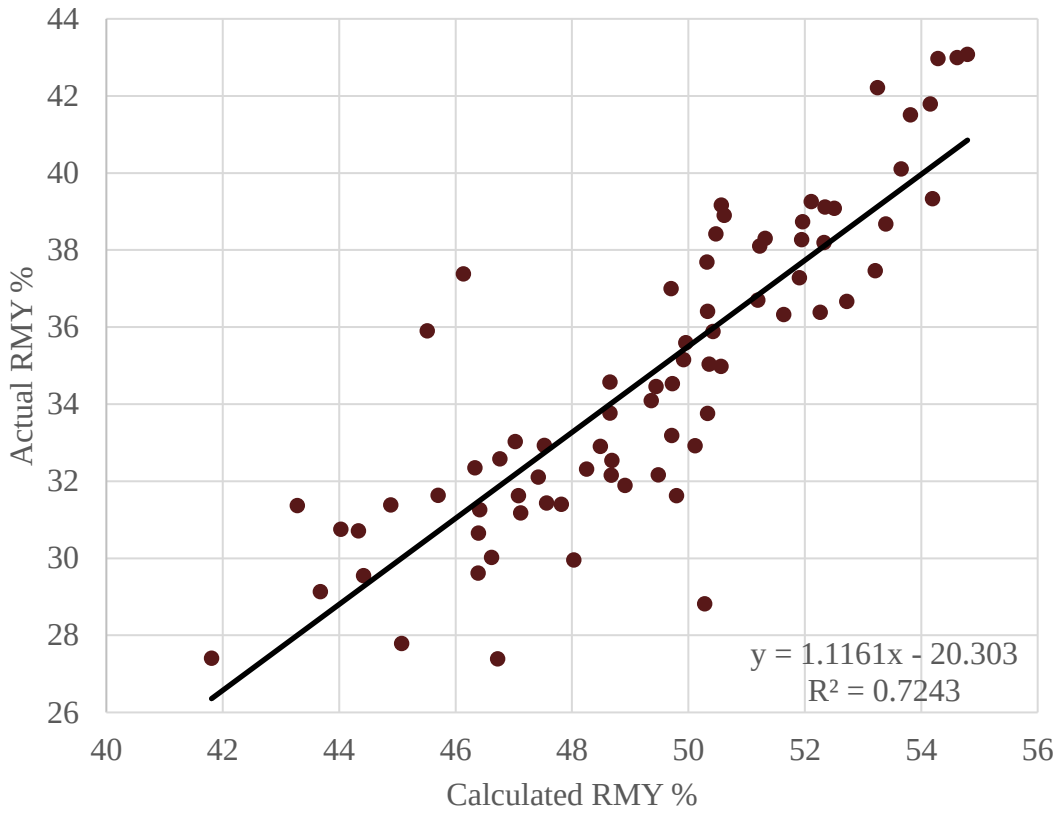

Figure 5.2. BCTRLCR calculated red meat yield versus actual red meat yield percentage.

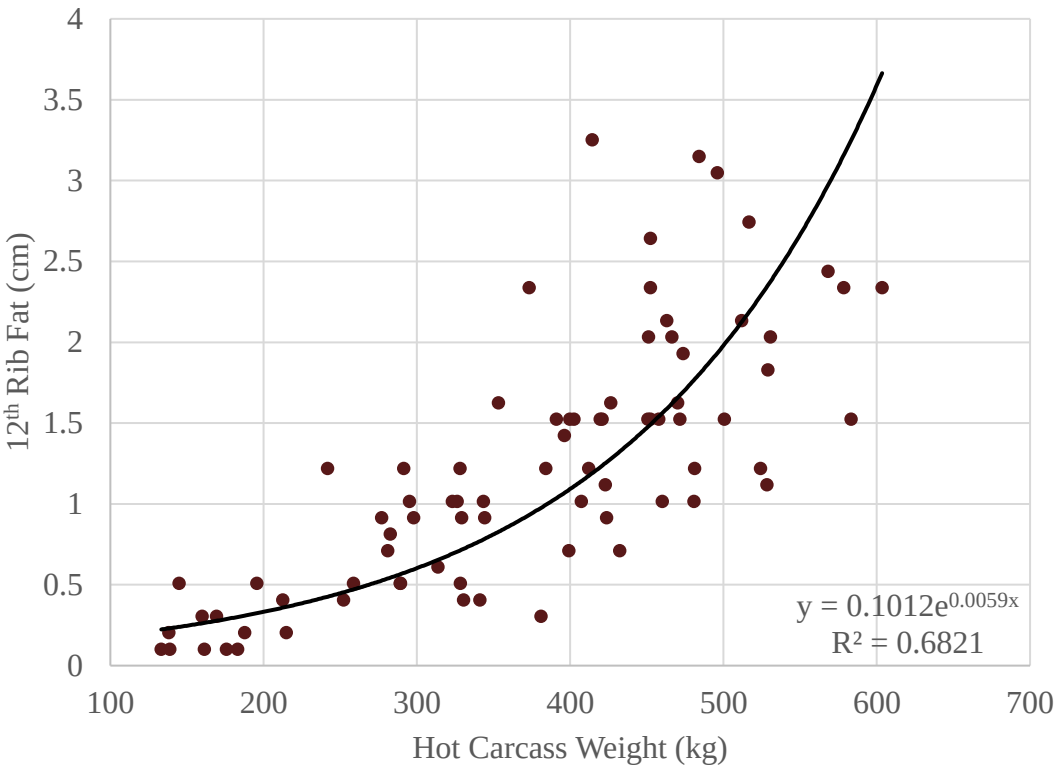

Figure 5.3. Association between hot carcass weight (kg) and 12th rib fat thickness (cm).

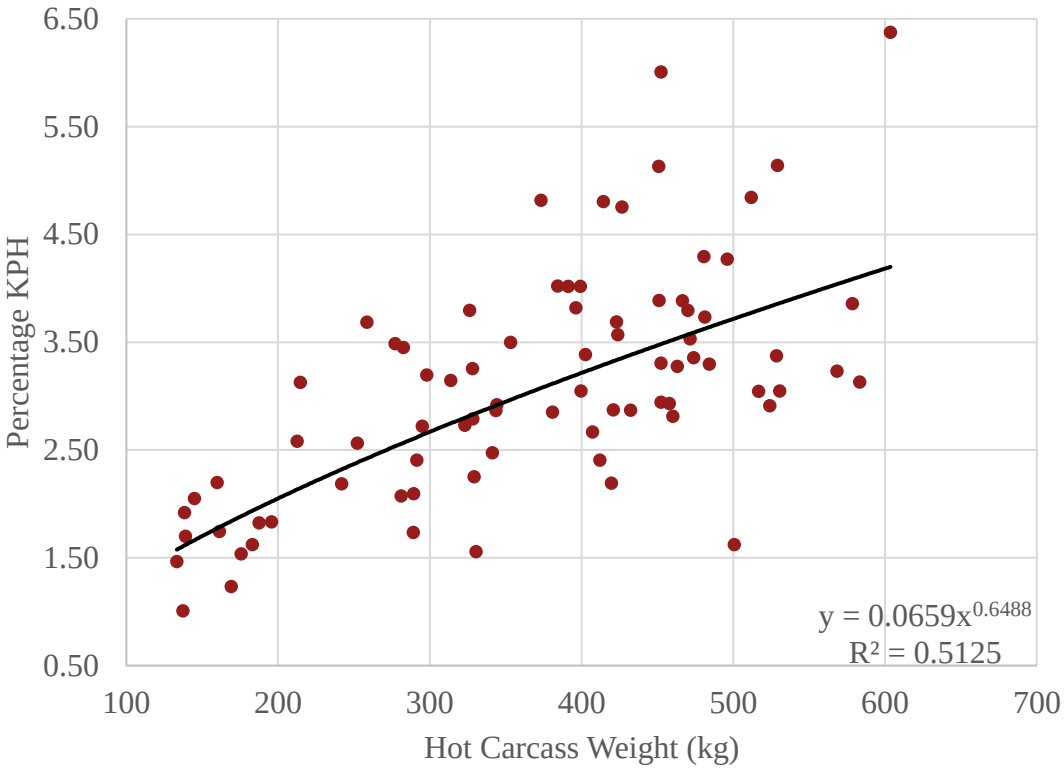

Figure 5.4. Association between hot carcass weight (kg) and percentage KPH.

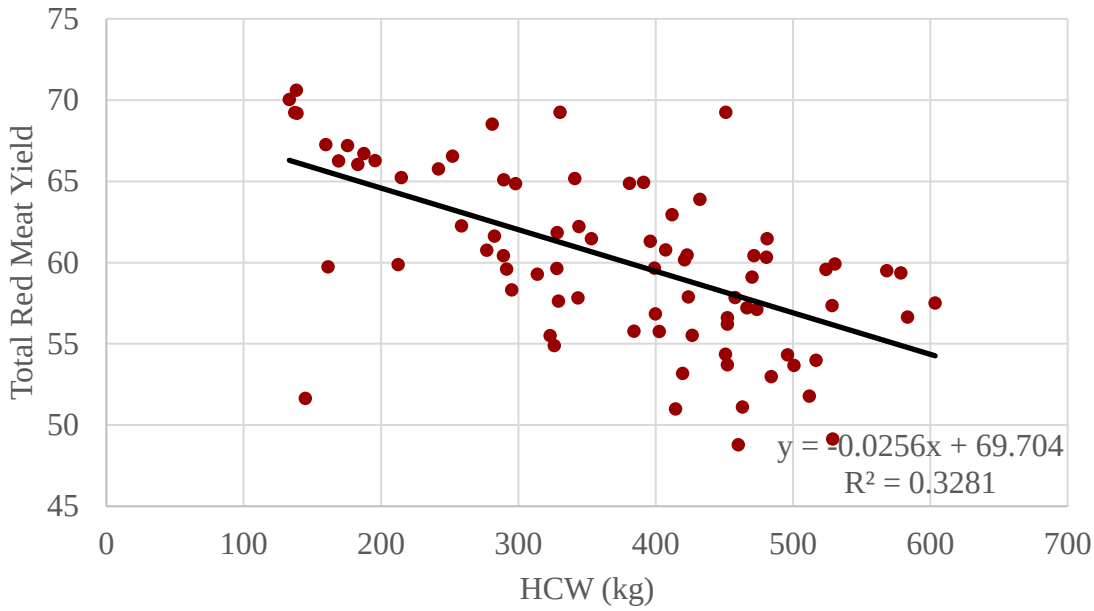

Figure 5.5. Association between hot carcass weight (kg) and total red meat yield .

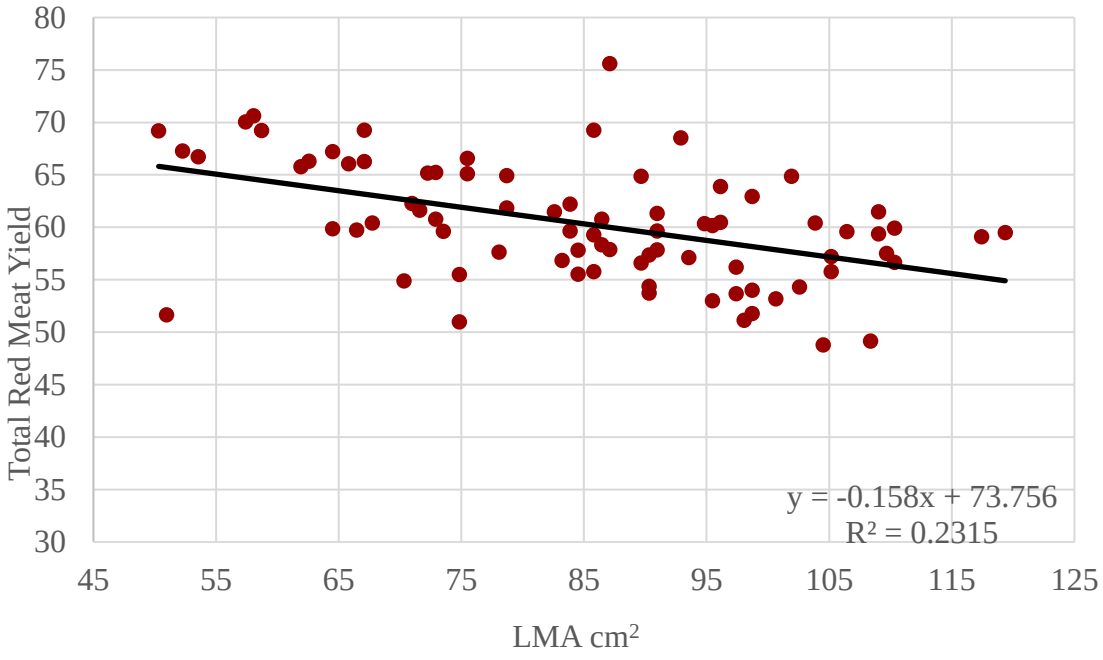

Figure 5.6. Association between longissimus muscle area (cm^2) and total red meat yield.

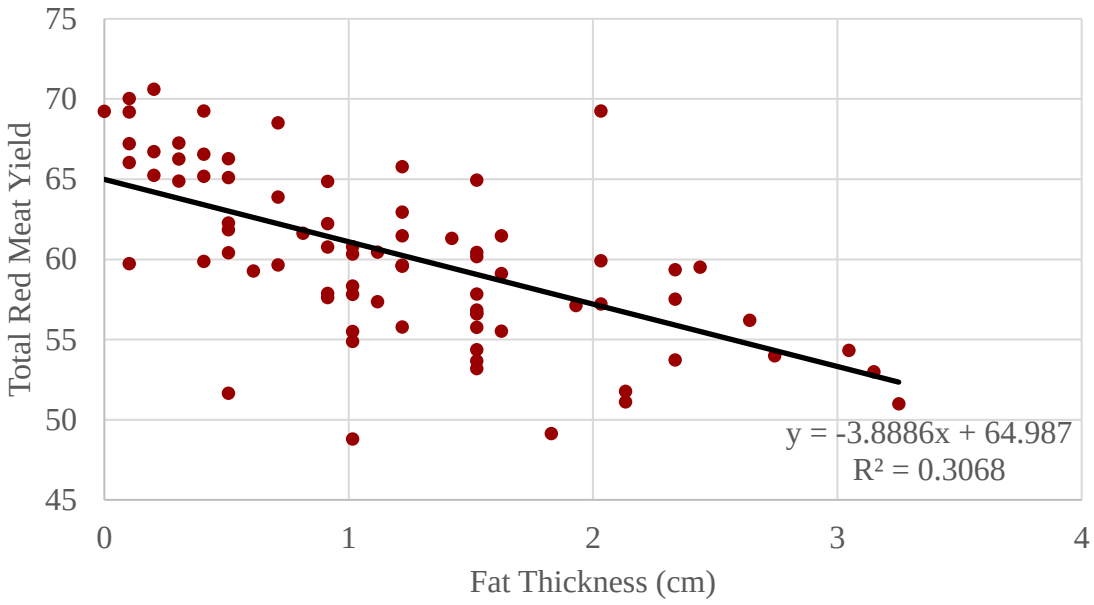

Figure 5.7. Association between 12th rib fat thickness (cm) and total red meat yield.

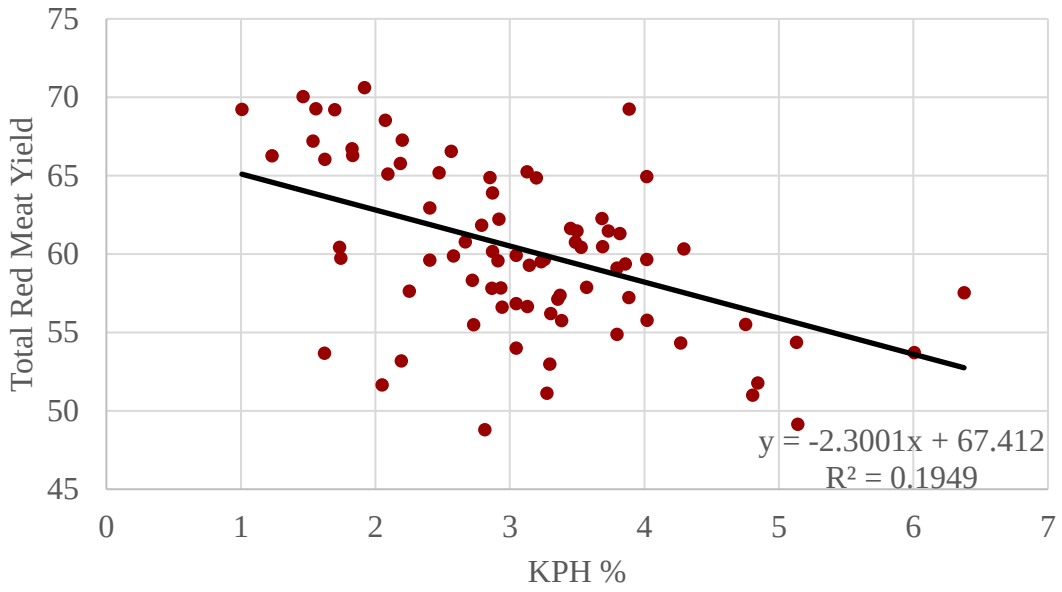

Figure 5.8. Association between percent KPH and total red meat yield.

Table 5.1. Development of new coefficients for original USDA BCTRLCR equation

Item	Original USDA	WTAMU BCTRLCR
Intercept	51.34	51.34
Hot Carcass Weight	-0.0093	-0.0043
Longissimus Muscle Area (in^2)	0.740	-0.678**
KPH	-0.462	-0.848**
Fat (in^2)	-5.78	-2.78

** Indicates P <0.01

Table 5.2. Descriptive statistics of carcass traits

Item	n	Mean	Std. Dev.	Max	Min
HCW, kg	80	367.66	124.01	603.49	133.24
12^{th} rib fat, cm	80	1.21	0.79	3.25	0
KPH %	80	3.09	1.06	6.38	1.01
LMA, cm^2	80	85.22	16.87	119.36	50.32
USDA YG[a]	80	3.16	1.25	6.42	0.94
USDA BCTRLCR[b]	80	49.39	3.01	54.80	41.80
WTAMU BCTRLCR[c]	80	34.99	4.17	43.18	26.19

[a] USDA Yield Grade = 2.5 + (2.5 * fat thickness, in) + (0.0038 * HCW, lbs) + (0.2 * KPH%) – (0.32 * REA, in^2)

[b] USDA Boneless Closely Trimmed Rib Loin Chuck Round = 51.34 – (5.784 * fat thickness, in) – (0.462 * KPH%) – (0.0093 * HCW, lbs) + (0.74 * REA, in^2)

[c] Calculated WTAMU Boneless Closely Trimmed Rib Loin Chuck Round = 51.34 – (2.71 * fat thickness, in) – (0.848 * KPH%) – (0.0043 * HCW, lbs) – (0.678 * REA, in^2)

Table 5.3. Simple correlations between variables used to predict BCTRLCR

	% Red Meat Yield	% Trimmable Fat
HCW, kg	-0.573***	0.775***
LMA, cm^2	-0.481***	0.633***
KPH[a]	-0.441***	0.730***
12^{th} Rib Fat	-0.554***	0.830***

$P < 0.001$***

Table 5.4. Total saleable red meat yield coefficients in relation to HCW, 12th rib fat, LMA, and KPH

	Coefficients	**SEM**
Intercept	67.24	--
HCW (kg)	0.042	0.07
12th Rib Fat (cm)	-0.021	0.01
LMA (cm^2)	-1.712	1.09
KPH %	-0.235	0.67