AN EVALUATION OF GRADING PARAMETERS AND FABRICATION YIELDS OF BEEF CARCASSES

By

Angela N. Schmitz

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ABSTRACT

Two experiments were performed to evaluate grading parameters and fabrication yields of beef carcasses. In Exp.1, single-sired beef steers (n=56) were blocked (n=28 per block) by implant status and sorted into pairs by weight. Each pair was then randomly assigned to a harvest day (0, 28, or 56) and dietary intake level [maintenance (M) or *ad libitum* (AL)] that was applied within d 28 and 56. Additionally, supplementation of zilpaterol hydrochloride (ZH) was randomly applied within a pair for each of M and AL diet levels. Steers that were randomly assigned to a treatment were fed ZH continuously at 90 mg for 20 d following a withdrawal period of 4 d before harvest. Steers (BW= 603.5 ± 48.1 kg) were harvested at a commercial processing facility, allowed a 24 h chill period, and then left carcass sides were transported to the West Texas A&M University Meat Laboratory for fabrication. Each side was fabricated into subprimals to determine individual red meat yield (RMY), trimmable fat yield (TFY), and bone yield (BY). Results indicated that RMY tended ($P < 0.07$) to differ by harvest day (0= 64.0, 28= 63.3, 56= 62.5 %), intake (M= 63.4, AL= 62.1 %), and treatment (C= 61.4, ZH= 63.7 %). Comparatively, TFY was impacted ($P < 0.04$) by harvest day (0= 20.9, 28= 21.0, 56= 22.4 %), intake (M= 20.5, AL= 23.3 %), and treatment (C= 23.5, ZH= 21.3 %). In Exp.2, the ability of the United States Department of Agriculture (USDA), Canadian Beef Grading Agency (CBGA), and Japanese Meat Grading Association (JMGA) grading

systems as well as bioelectrical impendence technology (BIA) to accurately predict red meat yield and trimmable fat yield were evaluated using fabrication results from Exp 1. Pearson correlations were generated between the actual RMY% and each grading system and BIA. Resulting correlations indicate that the equation for boneless closely trimmed retail cuts from the round, loin, rib and chuck from the USDA grading system demonstrated the highest correlation (r = 0.71) followed by the Canadian yield equation (r = 0.61), and lastly the Japanese estimated yield equation (r = 0.36). Moreover, the equation developed from this study using BIA measurements, accounted for 72% of the variation in RMY%, respectively. These results indicate that the USDA grading system provides the best prediction of RMY and BIA technology can be used as an accurate, noninvasive predictor of beef carcass composition.

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APPROVAL

Chairman, Thesis Committee Date

Member, Thesis Committee Date

Member, Thesis Committee Date

Head, Department of Agriculture Date

Dean, Graduate School Date

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CHAPTER 1

INTRODUCTION

Estimating beef carcass composition in order to determine the true cutability and value of a carcass has been extensively researched for many years. Crucial to the beef industry are the accurate prediction of carcass composition endpoints and the proportion of important tissues such as muscle, fat and bone. The proportion of these tissues can be altered by several factors including age, weight, breed, gender or nutrition (Berg and Butterfield, 1968). In recent years, the addition of feed additives such as zilpaterol hydrochloride (ZH) in the diets of feedlot cattle, have resulted in a change in carcass composition as well.

Zilpaterol hydrochloride, a β_2 adrenergic agonist, is used in the cattle feeding industry as a method to improve the efficiency of animal production (Lawrence et al., 2011). Zilpaterol hydrochloride functions as a repartitioning agent which has the ability to increase the proportion of lean muscle while decreasing fat deposition, thereby altering the carcass composition (Hilton et al., 2009). The administration of ZH most commonly occurs during the finishing period in which cattle are allowed *ad libitum* access to feed.

However, cattle demonstrate an improvement in feed efficiency and carcass composition when fed at a maintenance dietary intake level (Murphey and Loerch, 1994). Therefore, a need exists to examine the effects of ZH administered during a maintenance dietary intake level on beef carcass composition.

To account for these factors and their ability to alter carcass composition, extensive research has been conducted using a variety of methods, equations and grading systems to accurately predict carcass composition. Powell and Huffman (1968) stated the most accurate estimate of carcass yield is a chemical analysis of the whole carcass. However, whole carcass analysis is impractical in commercial applications because it is time consuming and expensive, therefore it is not used. Further research was conducted utilizing other methods to predict carcass composition such as the 9-10-11th rib dissection (Hankins and Howe, 1946), linear measures and regression equations (Murphey et al., 1960; Cole et al., 1962; Brungardt and Bray, 1963), video image analysis (Cross et al., 1983; Wassenburg et al., 1986), bioelectrical impedance analysis (Berg et al., 1996; Marchello et al., 1999; Zollinger et al., 2010), ultrasound (Wallace et al., 1977; Cross and Whittaker, 1992), X-ray computer-assisted tomography (Skjervold et al., 1980; Karamichou et al., 2006), and total body electrical conductivity (Forrest et al., 1988; Berg et al., 1994).

Other systems exist throughout different countries that utilize a variety of different grading parameters to estimate the yield of a beef carcass and provide an overall value for that carcass. However, current grading systems utilize camera-based technologies or subjective methods to derive an estimation of beef cutability. Therefore, the beef industry needs an updated system that can objectively and accurately estimate the carcass composition from modern livestock raised via today's standards.

This thesis had two objectives: 1) evaluate the fabrication yields of carcasses from over-finished beef steers supplemented ZH and fed at maintenance or *ad libitum* dietary intake levels and 2) evaluate the ability of the three different grading systems as well as bioelectrical impedance technology to predict red meat yield and trimmable fat yield of over-finished beef carcasses.

CHAPTER II

LITERATURE REVIEW

2.1. Beef Composition

Crucial to the meat animal industry is the accurate prediction of live animal and carcass composition endpoints (Miller et al., 1988). Knowing the carcass composition endpoint is important to producers as they strive to reduce excess carcass fat in order to meet the consumer's demands for lean meat products across all species. The composition of a carcass refers to the proportion of the major tissues (muscle, fat and bone) that can be altered by several factors such as age, weight, breed, gender or nutrition (Berg and Butterfield, 1968). The proportion of skeletal muscle, adipose tissue and bone and how certain factors influence these, has been of interest for many years. These three tissues are of primary importance as they comprise the carcass and represent approximately 46-50% (muscle), 25-35% (fat) and 12-15% (bone) of the total weight of the meat animal (Beermann, 2004). It is important to understand the normal pattern of growth among these tissues in order to interpret the influences of external factors that alter carcass composition (Berg and Butterfield, 1968).

Gerrard and Grant, 2003, described growth as an expansion of size that is produced by an accretion of tissues similar to that of the original tissue or organ. This expansion in size is aided by certain cellular processes known as hypertrophy, an increase in cell size and hyperplasia, an increase in cell number. True growth is characterized as increase in skeletal muscle cells and bone cells while an accumulation of adipose tissue (fat) is referred to as fattening. To examine the true patterns of growth, animals can be slaughtered and dissected over a wide range of ages and weights (Berg and Butterfield, 1968). Live weight or average daily gain is the most commonly measured parameter to estimate the growth of an animal. Jones (2004) described the normal growth curve of a meat animal as a sigmoid line or an "S" shaped curve if live weights are accurately recorded throughout the life span of that animal. Furthermore, when the curve reaches a point of zero increase, the animal has reached its maturity, or the point where the animal will receive little weight change with little to no change in fat content (Jones, 2004). Therefore, the development and growth of bone is considered to be early developing, muscle to be intermediate and fat accumulation to be late developing.

2.1.1 Growth of bone

At birth, bone accounts for a higher proportion of the carcass weight in order to provide the framework to support the soft tissues and protect vital organs, thus the reason for being early developing. The growth of bone during the prenatal phase will ultimately determine the length of the individual muscles, therefore playing a crucial role in overall muscle growth (Jones, 2004). The growth of bones occurs longitudinally and radially; bone maturity results from ossification of the cartilage into bone (Berg and Butterfield, 1974). This process is highly influenced by certain factors such as age, sex, hormones and nutrition. For most species, the female will display a smaller structure and lighter weight compared to males and will exhibit earlier time patterns for bone growth maturity (Beermann, 2004).

2.1.2. *Growth of muscle tissue*

As an animal continues to grow once the bone structure has developed, it must then develop muscles to assist with survival mechanisms. Muscles are composed of individual muscle fibers that can be altered from hypertrophy of those muscle fibers to result in muscle growth (Gerrard and Grant, 2003). Muscles can be classified as early developing such as muscles found in the jaw to aid with suckling or late developing which consists of abdominal muscles to support the gut later in life. Berg and Butterfield (1968) classified muscles into growth impetus groups based on the idea that individual muscles have been shown to follow different growth patterns. Muscles that are categorized as "low impetus" are those that grow at a slower rate in proportion to total body muscle. Jones (2004) described the low impetus muscles as very critical for movement of the animal and contribute to the distal portion of the limbs. Furthermore, those muscles that function uniformly throughout the life span of the animal are considered to have an "average impetus". Finally, the "high impetus" muscles are those that grow more rapidly to meet certain demands placed on them such as weight gain (Jones, 2004). The differentiation of these muscle impetus groups were studied by anatomical dissections of animals at different ages and the results indicated that the major differentiation occurs soon after birth during the first three months of age (Butterfield and Berg, 1966a).

The relative growth of muscles may be altered by other factors such as sex, breed, or nutrition. Nutrition plays an important role in the development and growth of muscles and can have a larger impact throughout various stages of growth and age (Jones, 2004). Butterfield and Berg (1966b) studied the effects of low and high planes of nutrition on the growth of muscles from calves. Data from this study indicated that inadequate nutrition in the early post-natal stage of life affected the muscle-weight distribution and resulted in body weight loss. It is during this stage of life that the effects of nutrition on muscle growth are more apparent. Dwyer et al. (1994) demonstrated the effects of maternal nutrition on muscle fiber development in the porcine fetus and on postnatal growth of the litter. By increasing maternal feed intake and plane of nutrition, a significant increase in muscle fiber hyperplasia occurred in the litter from that sow. Increased muscle fiber count had a significant effect on growth rate and feed conversion in the later stages of growth (Dwyer et al., 1994). Thus, adequate nutrition is needed and performs a crucial role in the formation of muscle fibers which has subsequent results on the overall growth of muscle in a variety of species.

The breed of each species is an additional factor that alters the growth of muscles. Muscle fiber number is different among breeds and is typically found in greater numbers in the faster-growing breeds (Gerrard and Grant, 2003). For example, the Pietrain breed exhibit extremely muscular statures because they possess a greater quantity of muscle fibers compared to other pig breeds (Gerrard and Grant, 2003). Additionally, when comparing the growth of beef (Hereford) breeds of cattle to dairy (Friesian) breeds, beef breeds demonstrate an increased muscle to bone ratio (Berg and Butterfield, 1968). Similarly, the sex of an animal can influence the number of muscle fibers. Muscle fibers tend to be increased in males compared to females in some species such as cattle and chickens but gender has no effect in pigs (Gerrard and Grant, 2003).

2.1.3. Growth of adipose tissue

The final major tissue discussed is adipose tissue or fat, which can be influenced by the same factors that influence muscle growth. The deposition of fat provides a type of energy source for survival of the animal. Growth of adipose tissue is considered to be "late-developing" and occurs at specific sites in the body and throughout different times and rates (Gerrard and Grant, 2003). Fat deposition appears first around viscera such as the kidney and fat deposition occurs later in between the muscles, beneath the skin, and finally between the muscle bundles to form marbling (Andrews, 1958). Fat deposited between the muscles is more commonly referred to as intermuscular fat, the fat beneath the skin as subcutaneous fat and finally the fat within the muscle as intramuscular fat or marbling. Nürnberg et al. (1998) stated that energy balance and the deposition of adipose tissue result from the maintenance of a balance between energy intake and energy expenditure. Therefore, as an animal is placed on a nutrient-restricted diet, the first depot to reduce in size is the depot that had been deposited last, such as intramuscular fat followed by subcutaneous fat and intermuscular fat (Jones, 2004).

2.2. Methods to estimate carcass composition

The accurate prediction of live animal and carcass composition has been under investigation for years. The estimation of carcass composition has been extensively investigated using a variety of methods, equations and grading systems. Powell and Huffman (1968) stated the most accurate estimation of carcass yield is a chemical analysis of the whole carcass although this technique is time consuming and impractical for commercial applications. Several methods and equations developed in the 1940's and the years following (Hankins and Howe, 1946; Murphey et al., 1960; Cole et al., 1962; Vance et al., 1971; Crouse and Dikeman., 1974) are still being used today to estimate the overall composition of beef carcasses despite the change in overall body composition of livestock raised via today's standards. These methods of predicting body composition can be accomplished via physical, electrical, and chemical procedures.

2.3. Physical methods to estimate carcass composition

2.3.1. 9-10-11th rib dissection

Hankins and Howe (1946) developed equations for predicting carcass composition based on rib composition when it was discovered that the separable physical components and chemical composition of the 9-10-11th rib cut of beef steers were associated with the composition of the entire carcass. This procedure developed by Hankins and Howe (1946) requires the prime-rib cut to be divided by ribs to separate the 9-10-11th rib section from the remaining primal. The rib section is then separated into the three portions of lean tissue, fat tissue, and bone and weighed separately for physical analysis. Composite samples from the lean tissue and fat tissue are used for chemical analysis to determine protein, fat, water and ash following A.O.A.C (1960) procedures. Equations were developed from these results to estimate separable fat, separable lean and separable bone from the 9-10-11th rib dissection and have been the focus of many studies thereafter.

Cole et al. (1962) conducted a study to determine the relationship of the pounds of separable lean from the left side of steer carcasses with carcass measurements such as carcass length, carcass weight, fat thickness, and *longissimus dorsi* area in order to develop equations for predicting pounds of lean in the carcass. The values predicted from these equations as well as equations developed by Hankins and Howe (1946) was compared to the actual values. Results from this study indicated that the developed equations which utilized only fat thickness and carcass weight were comparable in accuracy with the Hankins and Howe equation which utilized percentage lean from the 9-10-11th rib section. The Hankins and Howe (1946) equation showed a high association with the actual pounds of lean in the left side (r=0.95), however, the equation over-estimated percentage lean in 66 of the 81 carcasses. Although the equation over-estimated lean and provided serious limitations such as extra labor, time and expense, it was still a suitable predictor of carcass leanness (Cole et al., 1962).

In a similar study, Powell and Huffman (1968) evaluated the accuracy of the Hankins and Howe (1946) equations and other methods of predicting carcass lean with the chemical analysis of the entire right side of beef carcasses. Results from this study were similar to that of Cole et al. (1962) in which equations from Hankins and Howe (1946) method of dissecting the 9-10-11th rib section most accurately predicted carcass fat (r = 0.94) and carcass protein (r = -0.96). However, the same limitations occurred and this method was the least practical of all the methods used.

Crouse and Dikeman (1974) investigated the accuracy of equations developed by Hankins and Howe (1946) using a population of steer carcasses derived from different breeds (Hereford, Simmental, Limousin X Angus) compared to those used by Hankins and Howe (1946). The 9-10-11th rib section equation over-estimated carcass moisture and protein while under-estimating carcass fat. A bias was observed in the Hankins and Howe (1946) study among the breed groups used for predicted carcass protein which compared to the errors observed amongst the breed differences in this study (Crouse and Dikeman, 1974). It was concluded that the Hankins and Howe (1946) method could provide prediction equations for the breeds used in this study but with a constant error provided over all subclasses (Crouse and Dikeman, 1974).

To determine if different breed types affected the accuracy of the equations developed by Hankins and Howe (1946), Nour and Thonney (1994) conducted a study to evaluate the differences of Angus and Holstein breeds. Results from this study were similar to previous studies in which 9-10-11th rib sections were accurate predictors for the entire carcass composition. However, the Hankins and Howe (1946) equations over-predicted the percentage of protein for Holstein steers. Moreover, prediction equations for percentage protein were different in the study for Angus and Holsteins. Therefore, it was concluded that the equations developed by Hankins and Howe (1946) could be used to predict carcass composition; however, breed type should be considered for greater accuracy (Nour and Thonney, 1994).

A similar study conducted by Marcondes et al. (2012) evaluated the accuracy of 9-10-11th rib methods using crossbred Nellore cattle. In this study, physical composition of the rib section containing fat, lean and bone was influenced by breed type but the predictions still remained satisfactory. Additional equations to the Hankins and Howe equations were developed and are recommended to be used only with these breeds (Marcondes et al., 2012).

Lunt et al. (1985) conducted a study to determine the accuracy of prediction methods, including 9-10-11th rib dissection methods, on estimating carcass composition of beef steers (n=32) given a forage-based or grain-based diet. Differences in fat, lean, and bone percentages were detected in forage-fed steers compared to grain-fed steers at later slaughter periods and the physical-chemical composition of the 9-10-11th rib section proved to be the most useful method for explaining the variability in carcass compositions (Lunt et al., 1985).

Similarly, Miller et al. (1988) used beef cattle with varying carcass compositions and different ages to determine if age played a role in accurately predicting carcass compositions. It was found that the 9-10-11th rib section was the most accurate and precise method to estimate beef carcass composition across all age classes (Miller et al., 1988).

These studies have confirmed the accuracy of the method developed by Hankins and Howe to predict carcass composition by using the 9-10-11th rib section. Although this method is still being used in research, it requires more time, labor and costs which results in being an impractical method of predicting carcass composition in today's industry. Additionally, these equations developed before the 1980's have limited application to modern cattle because of the changes in potential growth of cattle (Marcondes et al., 2012). Therefore, alternative methods that can rapidly and accurately predict carcass composition have been developed and extensively researched since the development of the Hankins and Howe (1946) method.

2.3.2. United States Department of Agriculture grading system

An alternative and common estimation of beef cutability in the industry is through the use of the United States Department of Agriculture (USDA) yield grade standards. The first tentative grades of beef carcasses in the U.S. were established in 1916 to provide a uniform report of dressed beef markets and were further refined in 1926, 1939, 1941, 1949, 1950, 1956, 1965, 1973, 1975, 1980, 1987, 1989, and finally in 1997 as the official carcass grades (USDA, 1997). Murphey et al. (1960) developed a regression equation for estimating percentage boneless, closely trimmed, retail cuts from the round, loin, rib, and chuck which became the basis for the USDA yield grade standards for beef. The most useful equation developed by Murphey at al. (1960) was: percentage boneless retail cuts from round, loin, rib, and chuck= 51.304 – 5.78 (12^{th} rib fat thickness, in.) - 0.462 (percentage kidney, pelvic, and heart fat) + 0.740 (area of rib eye, in^2) - 0.0093 (hot carcass wt., lbs.). This equation was used to determine a yield score based on a numerical scale of one to ten to indicate a range of 2.3% in yield of retail cuts (Murphey et al., 1960). Further studies (Cole et al., 1962; Brungardt and Bray, 1963) were conducted and additional equations were developed independently of the equation developed by Murphey et al. (1960) for estimating carcass cutability. Powell and Huffman (1968) and Cross et al. (1973) compared the USDA yield grades with other methods of estimating beef carcass cutability and reported that the USDA yield grade equation was the most accurate and practical method of predicting cutability.

In 1965, USDA adopted the standards developed by Murphey et al. (1960) following a trial period where modifications were applied based on industry experiences and this effort became a part of a dual-grading system involving separate identification of differences in cutability and quality. The modifications applied included an updated equation that served as a multiple linear regression model to predict a percentage of boneless closely trimmed retail cuts expected to be derived from the round, loin, rib, and chuck (Lawrence et al., 2010). The modified equation determines the USDA yield grade (1to 5) of a beef carcass on the basis of the following equation: yield grade = 2.50 + (2.50

x 12^{th} rib fat thickness, inches) + (0.20 x percentage kidney, pelvic, and heart fat) + (0.0038 x hot carcass weight, pounds) - (0.32 x area ribeye, in^2) (USDA, 1997).

The yield grade of a beef carcass is determined by considering four characteristics: the amount of external fat, the amount of kidney, pelvic, and heart fat, the area of the ribeye muscle, and the carcass weight (USDA, 1997). The amount of external fat present on a beef carcass is measured perpendicular to the outside surface of the ribeye muscle at a point three-fourths of the ventral length of the ribeye muscle. This measurement can be adjusted to reflect the amount of fat covering other parts of the carcass. Moreover the amount of kidney, pelvic, and heart fat is evaluated subjectively and is expressed as a percentage of the carcass weight. The area of the ribeye may be measured subjectively or by means of grid calibrated in tenths of a square inch (USDA, 1997). From these measurements, including the carcass weight, a semi-objective yield grade can thus be determined. The USDA calculated yield grade equation is still used in current beef marketing methods to estimate the red meat yield of beef carcasses. Subsequently, the efficacy of the USDA yield grade equation to accurately predict red meat yield of beef carcasses has been the subject of many studies in the following years since its adoption.

Ramsey et al. (1962) implemented one of the first studies that tested the relationship of the newly proposed USDA calculated yield grades with separable lean, fat and bone of steers (n=133) from eight breeds. Results indicated that the yield grades were strongly correlated to separable lean (r= -0.82) and separable fat (r= 0.80) percentage of the sample carcasses. In addition, ribeye area was omitted from the yield grade calculations to indicate that the resulting yield grades were more closely related to separable lean and fat than when ribeye area was included (Ramsey et al., 1962). In a study by Crouse et al. (1975), relationships among variables in the yield grade equation were studied when applied to a variety of breeds newly introduced to the United States at that time. Results from this study indicated that the fat thickness at the 12th rib was the most useful variable in predicting cutability in the yield grade equation regardless of breed type. Similar to the findings of Ramsey et al. (1962), the ribeye area or *longissimus* muscle area had the lowest predictive value of the four variables used in the yield grade equation. Moreover, the yield grade equation demonstrated significant differences between breed groups and tended to either underestimate or overestimate actual cutability, depending on breed group (Crouse et al., 1975).

Abraham et al. (1980) conducted a study with the purpose of comparing the results from the original USDA yield grade study with data from a new beef population and to provide data for revising the yield grade standards to improve the accuracy of the yield grades. A regression equation was developed from this study and compared to the original equation to indicate that the new equation was only slightly more correlated with cutability. Therefore, it was concluded in this study that little advantage would occur from revising the present USDA yield grade equation. In agreement with the previous studies, Lunt et al. (1985) evaluated techniques for predicting beef carcass composition and concluded that USDA yield grades were useful and more accurate than other methods studied.

However, as the number of research studies pertaining to the USDA yield equation increased, the more the industry and USDA learned of the inaccuracies and discriminations of the system. One of the first issues discovered with the yield grade equation was its inability to predict carcass cutability of the exotic breed types (i.e. Charolais, Limousin, and Simmental) by underestimating their cutability relative to other breed types (Crouse et al. 1975). In agreement, Charles and Johnson (1976) reported breed differences in amount and distribution of carcass dissectible fat. It was reported that different breeds could have the same thickness of fat over the ribeye but differed in external fat compared to intermuscular fat. Moreover, Hereford carcasses were reported to have significantly more subcutaneous fat and less kidney and pelvic fat than other breeds (Charles and Johnson, 1976). Rather than evaluating the differences in breed type, Abraham et al. (1980) evaluated differences in carcasses due to sex (steer, heifer or cow) on the basis of weight, fat thickness and muscling. Results indicated that the Murphey (1960) equation used to predict cutability did in fact underestimate the average cutability of cows while overestimating the average cutability of heifers and very closely predicting the cutability of steers. The results from this study indicate the variation among steers, heifers and cows in the rate at which they deposit fat in the carcass and the effectiveness of the predictive equations to reflect these differences (Abraham et al., 1980). In addition to these issues, Cross et al. (1980) reported inaccuracies with the USDA yield grade equation when used in actual application. Pressure is exerted onto the USDA grader by the beef processors to upgrade carcasses and increase grading speed which leads to errors caused by subjective evaluation (Cross et al., 1980). As a result, the USDA began seeking more objective and accurate means of determining yield grades.

2.3.3. Video image analysis system

In response for the need of a more objective and accurate method to measure beef carcass characteristics, the USDA, in cooperation with the National Aeronautics and

Space Administration (NASA) and the Jet Propulsion Laboratory, began a project in 1978 to develop an instrument that could objectively evaluate carcass yield grade traits (Cross et al., 1983). Video image analysis (VIA) was identified as a technology that could enhance the accuracy and increase the speed and efficiency in carcass grading. The VIA instrument was tested from 1981 to 1983 at the USDA's Meat Animal Research Center in cooperation with staff at Kansas State University (Cross and Whittaker, 1992). The VIA system was designed as a camera/computer system that assessed the chilled, ribbed surface of the muscle and fat areas at the $12/13^{th}$ rib interface to measure subcutaneous fat depth, the total number and area of marbling pieces, and lean color (Cross and Whittaker, 1992).

Cross et al. (1983) performed a study to compare the ability of the VIA system to predict the composition of the $9\text{-}10\text{-}11^{th}$ beef rib section with the grader's application of the factors used in the USDA yield grade equation. The results generated from this study indicated that developed equations from instrument-measured traits predicted rib composition more accurately than the equation developed from non-instrument carcass measured traits (Cross et al., 1983). Therefore, this study indicated the potential of VIA as a yield grading device for commercial purposes. In a similar study VIA proved to be a reliable method for carcass grading and predicting the total weight and the percentage of primal lean and fat yield of beef carcasses (Wassenburg et al., 1986).

In 1994, the National Beef Instrument Assessment Planning Symposium was held to evaluate the status of instrument technology; VIA was considered as one of the most promising methods for carcass evaluation. In agreement, Cross and Belk (1994) reviewed objective methods for predicting yield of beef carcasses and stated that the VIA system was more accurate than physically measured traits; however, because beef carcasses are presented to graders at line speeds of 200 to 450 carcasses per hour, the chances of grading error are increased. It became problematic to consistently position a camera and record proper image of the entire muscle and fat on a high speed grading line. It was concluded in 1996 that consensus was to be established before any specific instrument such as VIA was capable of replacing USDA graders and had the ability to augment application of beef carcass grades (Belk et al., 1996). The proposed idea by Belk et al. (1996) would allow USDA graders to provide input that is not reproducible by an instrument such as adjusted preliminary yield grade (APYG) while allowing the instrument to provide information that cannot be accurately evaluated by graders at chain speed such as longissimus muscle area. A study conducted by Steiner et al. (2003) suggested that VIA systems can however operate at industry speeds while effectively augmenting official USDA yield grades of beef carcasses. The VIA system is still in current use for determining beef carcass yield grades and will only be replaced if a more accurate technology is developed.

2.3.4. Canadian Beef Grading Agency grading system

As the United States Department of Agriculture (USDA) made advances in the prediction equations and technology used to estimate the cutability of beef carcasses, several other countries developed their own systems for doing the same. The Canadian grading system was introduced in 1929 as an optional service and still remains that way today. The newly developed system contained only two grades for quality without any acknowledgment of the cutability of the carcass. To address the developing problems with excess fat, new standards were developed in 1958 that contained a grade slot

(Canada Commercial-Class 3) for carcasses considered to have an excess proportion of fat (Gracey, 2014). In 1972, it became apparent there was a preference for lean carcasses which led to a change in the grading system to describe leaner carcasses as “Canada A1” or “Canada A2”. However, many were displeased with the new grading system and felt that quality was being sacrificed for carcass leanness (Gracey, 2014). This led to the final change in the grading system in 1992 with an adjustment of quality grades in 1996 and the creation of the grading service known as the Canadian Beef Grading Agency (CBGA). The new grading standards introduced a dual grading system where quality and yield attributes were determined independently (Gracey, 2014). The addition of a yield grade system was a very important advancement for the CBGA as in the previous standards, carcasses were classified as A1, A2, A3, and A4 based on a subjective measurement of fat content.

The updated yield grading system measures the amount of lean or muscle in the carcass in conjunction with fat classes assigned to the carcasses to obtain a yield grade (Canada 1, Canada 2, and Canada 3). A carcass that met the quality standards to qualify for the Canadian A grades, is also assessed in terms of cutability and assigned a yield grade. These three yield grades are assessed on the basis of lean yield percentage that is calculated from measurements obtained by a grading ruler that was developed by the Agriculture and Agri-Food Canada Lacombe Research Station (CBGA, 1996). The measurements obtained by the grading ruler are assessed at the Canadian grading site (between the 12th and 13th rib) where the fat class and muscle score are determined. The fat class (1-10) is a measurement of the backfat depth at the minimum point of thickness (mm) perpendicular to the outside surface and within the fourth quarter of the longissimus muscle (Dubeski et al., 1997). Fat classes are assigned in 2-mm increments whereby a fat class of 1 is 2 or 3 mm, a fat class of 2 is 4 or 5 mm and so on (Aalhus et al., 2014). To obtain a muscle score, the grading ruler is used to measure the ribeye length and width which are combined using a matrix located on the ruler to reach a final muscle score of 1, 2, 3, or 4. With these measurements, yield grades are assigned based on the cutability equation (percentage lean= 63.65 + 1.05 × muscle score – 0.76 × grade fat, mm) whereby yield= 1 if percent lean ≥ 59%, yield= 2 if percent lean ≤ 58% and ≥ 54%, and yield= 3 if percent lean ≤ 53% (Dubeski et al., 1997). The Canadian yield algorithms used are based on data from a Canadian National Beef cut-out in 1993 (Aalhus et al., 2014).

Similar to the USDA, the Canadian beef industry is pursuing the implementation of objective methods for grading beef carcasses to be used in commercial grading systems. Although a majority of the research pertains to the improvement of objective methods for quality grading, efforts have been made to quantify total or saleable meat yield (Tong et al., 1997) in addition to establishing grading equivalencies between multiple grading systems (Dubeski et al., 1997). Furthermore, new technologies for improving beef grading in Canada are being implemented in the major commercial plants. Camera/software systems have been developed to photograph the ribeye at the grading site and output additional information such as marbling, ribeye area, and fat depths (Aalhus et al., 2014). These cameras can rapidly obtain measurements and when combined with yield prediction equations embedded in the software, an estimate of saleable lean meat yield is generated. However, further research and more accurate yield equations are needed to improve the overall estimations of saleable lean. Further calibrations and validations of new algorithms should be performed because the current yield equations in use were established from much earlier Canadian and US carcass cut-outs (Aalhus et al., 2014). The Canadian beef industry faces many challenges to improve production efficiency as well as the current grading system while maintaining the quality traits consumers' desire. The changing market and addition of new technologies will assist the Canadian beef grading system to make the necessary improvements.

2.3.5. Japanese Meat Grading Association grading system

In Japan, the need for a carcass grading system became apparent throughout the 1960's and leading into the 1970's. To resolve this issue and to assume all of the grading responsibilities, the Japanese Meat Grading Association (JMGA) was established in 1975 (Polkinghorne and Johnson, 2010). The grading standards that were established in 1975 were revised in 1976, 1979, and finally in 1988 where separate quality and yield grades were adopted. Similar to the previous grading systems established (USDA, CBGA) Japanese yield grades are determined by a regression equation to estimate yield percentage utilizing the ribeye area, rib thickness (measured muscle thickness above the rib), cold left side weight and subcutaneous fat thickness. All of these measurements are obtained at the 6^{th} and 7^{th} rib section and used in the following regression equation: estimated yield percentage= 67.37 + (0.130 × ribeye area, cm^2) + (0.667 × rib thickness, cm) – (0.025 × cold left side weight, kg) – (0.896 × subcutaneous fat thickness, cm) (JMGA, 1988). If the carcass is from the Wagyu breed, an additional value of 2.049 will be added to the estimated yield index. Furthermore, yield grades are assigned on the basis of the estimated yield percentage whereby yield= A if estimated yield is 72% or greater, yield= B if estimated yield is 69% to 72%, and yield= C if estimated yield is less than 69% (JMGA, 1988).

The Japanese yield grading system was developed to estimate the yield of carcasses from the Wagyu breed of cattle common to the country of Japan. This breed is unique for their genetic ability to deposit marbling and in order to reach an endpoint highly desired by the Japanese market, cattle are fed a diet high in roughage for longer periods of time relative to common feeding practices in the US (Cameron et al., 1993). Consequently, excessive amounts of external fat are produced from this management practice that results in poor carcass cutability even though they only account for 17% of the meat produced in Japan (Cameron et al., 1993). Therefore, a high proportion of the beef consumed in Japan is imported from Australia and the US to meet the domestic demands (Lunt et al., 1993). This has led to several studies (Cameron et al., 1993; Harris et al., 1995; Radunz et al., 2009) conducted to determine if a relationship exists between grading systems that can accurately predict the cutability as well as meet the demand for an equitable pricing system.

Harris et al. (1995) performed a study to provide a comparison of Japanese and USDA beef quality and yield grades and to determine if there was a possibility to predict a Japanese grade based on twelfth rib evaluation. Steers (n= 78) in this study produced carcasses with excessive fat and heavy weights for the US beef industry while also not producing exceptionally high marbling scores despite the feeding regimen they experienced resembling Japanese practices. Furthermore, Harris et al. (1995) reported the inability of the twelfth rib traits from the USDA grading system to predict Japanese grade characteristics effectively. It was concluded in this study that a compromise between grading systems involving the twelfth rib and sixth rib carcass measurements needs to occur in order for carcasses to be equitably priced and traded between the US and Japan.

2.3.6. Additional grading systems

In addition to the grading systems previously mentioned, multiple other systems exist throughout the world that are designed to grade and classify beef carcasses based on different demands prominent in those beef industries. In contrast to the USDA, Canadian, and JMGA grading systems, the EUROP system adopted in many European countries has primary emphasis on yield estimation. This system utilizes a grid describing carcass conformation on one axis and external fat level on the other (Polkinghorne and Thompson, 2010). The conformation axis is divided into five classes E, U, R, O, and P with extremely muscled classified as E and very poor muscling classified as P. The fat axis also contains fives classes that are designated numerically from 1 (very lean) to 5 (very fat; Polkinghorne and Thompson, 2010).

In Australia, the AUS MEAT system was created in 1987 to replace subjective grading measurements already in place with specific assessments of sex, dentition, and carcass weights to grade beef carcasses. However, this system was altered in 1995 due to the Meat Standards Australia (MSA) and consumer testing. The components previously assessed (sex, dentition, and carcass weight) proved to be ineffective with the MSA system which replaced carcass grades with grades describing their predicted eating quality based on factors such as *Bos indicus* content, hormone growth promotant administration, carcass suspension method (conventional or tenderstretch), post-mortem pH/temperature decline, ageing, and cooking method (Polkinghorne and Thompson, 2010). The same muscle portion could have a different grade depending on the date of consumption and cooking method thus, leading to a consumer grading system unlike most other grading systems around the world.

Several other grading systems exist around the world that utilize physical methods to estimate the yield of beef carcasses. The beef grading system is evolving through the development of instrument grading and other procedures outside of physical methods that use equations developed many years ago on cattle differing from those raised via today's standards.

2.4. Electrical methods to estimate carcass composition

2.4.1. Bioelectrical impedance analysis

The need for an updated grading system that could objectively and accurately estimate the composition of beef carcasses and provide a means of value-based pricing became evident once certain flaws were discovered with previous grading systems. Berg and Marchello (1994) summarized the criteria a grading system must meet in order to be successful as having an objective method to determine value, can be implemented at the time of slaughter, be applicable to on the rail trading and can be readily adopted in a processing facility.

Research using bioelectrical impedance (BIA) technology began to show promising results throughout the 1990's as a noninvasive, quick and simple method to estimate body composition in a variety of species including humans. Bioelectrical impedance analysis measures the opposition of body tissues to a small alternating current in order to determine the total body water which can then estimate the fat free mass (FFM) and body fat (NIH, 1994). The BIA technology utilizes transdermal attachment of electrodes to introduce the alternating electrical current throughout body tissues to result in an opposition measurement or impedance. Impedance measures vary with the frequency of the current used (typically 50 kHz) and is a function of two components: the resistance (R) of the tissues themselves and the additional opposition which is known as reactance (X; NIH, 1994). The current that passes between the two electrodes, often called the detector and source terminals, generates a voltage and passes through all conducting material present in the body between the electrodes. Materials in the body such as blood and urine produce a high conductivity; muscle is intermediate and material such as bone, fat or air has a low conductivity (NIH, 1994).

Lukaski et al. (1985) first reported the use of BIA technology to estimate fat free mass (FFM) in humans in order to determine overall body composition. It was discovered that this technology was reliable and safe when estimating human body composition. Further research indicated that BIA can be utilized to estimate body and carcass composition on a variety of species such as rats (Cornish et al., 1992), lambs and lamb carcasses (Berg and Marchello, 1994; Slanger et al., 1994; Berg et al., 1996) swine and pork carcasses (Swantek et al., 1992; Marchello at al., 1999), cattle and beef carcasses (Marchello et al., 1994, 1999; Velazco et al., 1999; Zollinger et al., 2010) and horses (Latman et al., 2011). Results from these studies suggest that use of BIA technology can present an alternative for assessment of carcass yield by using objective measurements to more accurately approximate carcass yield in contrast with the current carcass yield evaluation systems that rely on subjective appraisal (Zollinger et al., 2010). Furthermore, it was concluded that BIA technology has the potential to provide a rapid, noninvasive procedure to predict saleable product from live animals as well as processed carcasses which could facilitate the implementation of changes needed for carcass merit programs (Swantek et al., 1992; Marchello et al., 1994, 1999; Zollinger et al., 2010). Berg and Marchello (1994) indicated that a system that utilizes BIA technology could easily be incorporated into existing industrial meat processors. However, this technology currently lacks the standardization needed for the acceptance from the industry but with further research, this issue could be resolved.

2.4.2. Ultrasound

Ultrasound was shown to be an accurate tool for measuring fat thickness and muscling in cattle as early as the 1950's (Wallace et al., 1977). Ultrasonic evaluations were conducted by using devices that could capture images of the *longissimus* muscle area and fat thickness between the 12^{th} and 13^{th} ribs of live animals. These images could be interpreted and used to predict carcass yield. Wallace et al. (1977) studied the relationships of ultrasonic and carcass measurements with retail yield in beef cattle and discovered that fat thickness measurements from the ultrasonic method was more highly correlated to yield compared to the *longissimus* muscle area in beef steers. Eventually, ultrasound technology was identified at the technology with the greatest potential for predicting yield of beef carcasses (Cross and Whittaker, 1992). More recently, results from a study conducted by Greiner at al. (2003) indicated that live animal equations using ultrasonic measurements were similar in accuracy to carcass measurements for predicting beef carcass composition. Therefore, it was concluded from this study that live animal ultrasound measurements are useful predictors of retail yield. Cross et al. (1994) explained the advantages of ultrasound imaging as being low cost, ease of use and the potential to estimate both yield and quality traits.

2.4.3. X-Ray computer assisted tomography

The use of X-ray computer-assisted tomography, commonly referred to as CAT scanning, was another method under evaluation for its ability to estimate carcass composition. This technology has the ability to present anatomical information by computer synthesis of an image of X-ray transmission data obtained from various regions under consideration (Leymaster, 1986). Skjervold et al. (1980) performed one of the first studies utilizing X-ray technology to estimate body composition in pigs. The results obtained in this study demonstrated promising advancements with the technology but required much more development before it could be used in the animal industry. More recent research has been conducted utilizing X-ray technology to estimate carcass composition in sheep and has also received promising results (Jones et al., 2002; Karamichou et al., 2006). However, due to the expense of adopting such a system in commercial production facilities, very little research has been conducted to develop grading systems utilizing the technology (Cross and Belk, 1994).

2.4.4. *Total body electrical conductivity (TOBEC)*

Another technique for the assessment of body composition is through the use of electromagnetic scanning, commonly referred to as total body electrical conductivity (TOBEC). This method was used originally to determine the body composition of humans and entails measuring the total-body electrical conductivity of individuals as they are passed through an electromagnetic field (Van Loan et al., 1987). Tissues within the body have different electrical conductivity and affect the magnetic field, thus allowing estimation of composition (Cross and Belk, 1994). The efforts by the pork industry to establish product evaluation equipment led to the development of an accurate, rapid on-line grading system using TOBEC (Cross and Belk, 1994). Similarly, Forrest et al. (1988) indicated that TOBEC technology provided an accurate, rapid method for determining carcass composition of pork. Berg et al. (1994) discovered that electromagnetic scanning (TOBEC) was also effective in accurately predicting lamb carcass composition. Although research is limited on the development of on-line electromagnetic grading systems for beef, results to date on various species are very promising for the beef industry (Cross and Belk, 1994).

2.5. Methods to estimate carcass quality

In conjunction with the assessment of carcass composition and yield estimation, grading systems evaluate quality attributes which are currently used to segregate and price beef carcasses (Wulf and Page, 2000). In the US the quality of a beef carcass is evaluated by considering its marbling and firmness in a cut muscle surface in relation to physiological maturity and is ultimately used to describe the characteristics of the meat which predict overall palatability (USDA, 1997). Smith et al. (2008) summarized palatability as the aggregated effects of difference in flavor, juiciness and tenderness which are contributed to many factors with one of them being the amount of intramuscular fat or marbling in the muscle. Delivering a quality eating experience is essential for the beef industry by maintaining consumer demand for beef products. Therefore, multiple grading systems and methods to assess quality attributes have been developed to provide a means of a value based system for beef carcasses.

2.5.1. United States Department of Agriculture and Canadian Beef Grading Agency grading systems

In 1916, the United States Department of Agriculture developed the first tentative beef carcass grades as a basis for the National Meat Marketing Reporting Service. These standards were refined and became the official standards in 1926 to provide the basis for grading when the voluntary beef grading and stamping service was begun in 1927 (USDA, 1997). Since then, the official standards went through several amendments and modifications to become what it is today. The USDA quality grade is determined by assessing the degree of intramuscular fat (marbling) and firmness of the cut surface of the *longissimus dorsi* in relation to the carcass maturity (USDA, 1997). In order to determine the quality grade of a carcass, it must be split down the back into two equal halves and must be partially separated into a hindquarter and forequarter by cutting it with a saw and knife (USDA, 1997). The cut is made perpendicular to the long axis of the vertebral column across the 12th thoracic vertebra in order to expose the *longissimus dorsi* muscle between the 12th and 13th ribs.

There are currently eight beef quality grades that are applicable to steer and heifer carcasses: Prime, Choice, Select, Standard, Commercial, Utility, Cutter and Canner. Bulls are ineligible for USDA quality grading and cows are ineligible for the Prime grade. These quality grades contain nine marbling levels that progress from the low end of practically devoid through traces, slight, small, modest, moderate, slightly abundant, and moderately abundant with abundant being the highest level of marbling. There are five maturity groups, A, B, C, D, and E which are normally from animals harvested at 9-30, 30-42, 42-72, 72-96, and >96 months of age, respectively (Smith et al., 2008). These maturity groups are determined by evaluating the skeletal maturity and cartilage ossification in conjunction with lean color and texture. Ossification (conversion of cartilage to bone) usually occurs earliest in the posterior vertebrae (sacral), later in the middle vertebrae (lumbar) and latest in the anterior vertebrae (thoracic) and the rib bones grow wider and flatter with age. Moreover, the color of lean becomes progressively darker red and the lean texture becomes progressively course in more mature carcasses (Smith et al., 2008).

Similar to the USDA grading system, the Canadian grading system which was introduced on 1929 utilizes maturity and marbling to assign a quality grade. The Canadian grading system went through extensive modifications in 1992 and was later adjusted in 1996 to align with the marbling standards of the USDA system (Polkinghorne and Thompson, 2010). There are four quality grades for youthful cattle: Prime, AAA, AA, and A in addition to mature carcass grades. These four grades mirror that of the USDA Prime (slightly abundant), Choice (small), Select (slight) and Standard (traces). Additionally, there are four D grades that are designated by muscling, fat depth, and fat color for cows and an E grade for bulls. Unlike the USDA system, the Canadian quality grades exclude carcasses with yellow fat and require good or better muscling and firm lean texture (Polkinghorne and Thompson, 2010). Meat color is assessed at the *longissimus dorsi* muscle between the 12^{th} and 13^{th} ribs and fat color is assessed with meat texture and carcass confirmation.

2.5.2. *Japanese Meat Grading Association grading system*

In contrast to the grading systems applied in North America (USDA and CBGA), the Japanese grading system utilizes different standards and parameters to assign beef carcasses a quality grade. The Japanese Meat Grading Association (JMGA) was established in 1975 and grades were also revised several times at which point separate quality and yield grades were adopted in 1988 (Polkinghorne and Thompson, 2010). Under the Japanese grading system, carcasses are assigned scores for marbling, meat color, fat color and quality, and meat texture and the lowest of these scores determines the quality grade (JMGA, 1988). In Japan, attributes such as meat texture and fat quality are important to consumers and under traditional cooking methods, well marbled beef with a firm texture is required in order to cut into very thin slices (Dubeski et al., 1997).

The Japanese quality grade parameters are assessed after quartering between the 5th and 6th ribs. There are twelve beef marbling scores (BMS) that increase numerically from 1 to 12 that are used to evaluate marbling. The BMS scores are related to five beef marbling grades which consist of excellent (BMS 8-12), good (BMS 5-7), average (BMS 3-4), below average (BMS 2), and poor (BMS 1) (JMGA, 1988). Moreover, there are five beef color and brightness grades (very good, good, average, below average, and inferior) where beef color is evaluated by Beef Color Standards (BCS) and brightness is evaluated by visual appraisal. In addition, firmness and texture of meat is classified as very good, good, average, below average and inferior for firmness and very fine, fine, average, below average, and course for texture. Finally, the fat of beef carcasses is classified as well on the basis of color, luster, and quality. Using the Beef Fat Standards (BFS) and visual appraisal of fat luster and quality, fat color can be given one of seven grades which consist of excellent (BFS 1-4), good (BFS 1-5), average (BFS 1-6), below average BFS 1-7), and inferior (A grade; JMGA, 1988). The marbling, meat color and brightness, firmness and texture and fat color, luster and quality grades are then all considered in assigning the carcass quality grade that are designated as the 1 being the lowest and 5 being the highest quality (Polkinghorne and Thompson, 2010).

These three grading systems to assign beef quality grades are among many systems in place around the world to access quality attributes. Cross and Belk (1994) stated that it will be crucial to reward quality, conformity and consistency, and penalize the product of non-conformity and quality shortfall in order to fully implement and utilize a value and quality based marketing system. Nonetheless, the beef industry is also experiencing the impact of subjective methods to assign quality grades of beef carcasses and thus, similar to the estimation of beef yield grades, objective and accurate methods of carcass evaluation for quality grades are needed as well.

2.6. Methods to fabricate and merchandize beef carcasses

Meeting the demands of customers is crucial for the beef industry and competing in today's marketplace (Savell, 1993). Cross and Savell (1994) stated that the beef industry was in need of a value-based marketing system where producers must be paid for producing what the consumers demand. Although many still believe the beef industry needs to improve value-based marketing, several crucial events occurred in history that has led to the advancements representative of today's market place.

2.6.1. History and development of boxed beef in the United States

In the early 1900's, the beef industry rapidly grew due to the development of new technologies and ways to transport beef products such as refrigerated trucks. In addition, new processing plants were developed outside of the "corn belt" and further south where cattle were being raised. Traditionally, cattle were slaughtered and carcass sides were transported to “breakers” who disassembled the carcasses into primal cuts (Azzam, 1998). The increase in labor costs, emerging technologies and new demands by hotels, restaurants and retail stores contributed to the need for a revised system of marketing carcasses (Azzam, 1998). Therefore, Iowa Beef Processors (IBP) was founded in 1961 and developed the first large-scale boxed beef production. The first plant was built in 1967 in Dakota City, NE where beef carcasses were broken, boned, and cut into primals and sub-primals and individual cuts that could be vacuum packed in plastic and shipped in boxes to customers. The development of boxed beef revolutionized the beef industry and allowed for a more efficient system and increased the market for beef products.

2.6.2. History and development of Institutional Meat Purchase Specifications

In addition to the development of boxed beef, the development of The Meat Buyer’s Guide in 1961 and the development of Institutional Meat Purchase Specifications (IMPS) were crucial to the beef industry. The Meat Buyer’s Guide has been the premiere resource for the many people who have dealt with production, sales and purchasing of meat products. Many years later, maintained by the Agricultural Marketing Service (AMS), IMPS were designed as a set of standard meat specifications that are valid for North America. These specifications are a result of a decision by the Canadian Meat Council and the American Institutional Meat Purchasing Specifications Council to harmonize their systems in order to reduce confusion between producers and retail buyers (AMS, 2013). Moreover, IMPS provides a reference for users so that they have a standard description for meat primals, wholesale cuts, subprimals, and potion cuts.

2.6.3. Cutting methods

The term “fabrication” or to “fabricate” is used to describe the process of reducing beef carcasses into smaller sections that can be handled more easily, packaged, and shipped to end users (Savell, 2014). Fabrication of beef can be accomplished through the process of hot, warm or cold boning; the separation of meat from bone at different carcass temperatures. Hot boning refers to the processing while the carcass temperature is still close to that of the live animal whereas cold boning occurs after the meat has progressed into a full state of rigor and the carcass has been subjected to an external cooling regimen (Davies, 2004). Warm boning occurs at an intermediate position between hot and cold boning. Chilling of carcasses prior to boning has become the normal processing method due to various technological advances that has allowed the processing of large quantities of meat for immediate and future use (Davies, 2004).

Traditional boning methods occurred on a table where butchers would begin the fabrication process by making knife cuts and manipulating the joint in order to remove the bone. In conjunction with the removal of bones, cuts of meat are removed and transferred to another group of workers to carry out general trimming before final packaging (Davies, 2004). With the introduction of chain and rail systems to meat processing facilities, identified cuts are removed from the side or quarter of the carcass while it hangs from the rail, referred to as rail boning. The cuts removed from the carcass via these boning methods can be accomplished by using the guidelines of various beef cutting styles. The variation among cutting styles such as the Chicago style, New York style, Philadelphia style, and Boston style exist because of the preferences desired in these different regions. The hindquarter consists of a higher percentage of table cuts such as steaks and roasts when compared to the forequarter. Therefore, these variations in cuts were developed with the purpose of including a larger percentage of either the round or chuck in with the loin and rib cuts so that more steaks can be acquired (Aldrich, 1922).

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CHAPTER III

EFFECT OF ZILPATEROL HYDROCHLORIDE SUPPLEMENTATION AND DIETARY INTAKE LEVEL ON BEEF CARCASS FABRICATION YIELDS

3.1. Abstract

An experiment was conducted to evaluate the fabrication yields of carcasses from over-finished beef steers supplemented zilpaterol hydrochloride (ZH) and fed at maintenance (M) or *ad libitum* (AL) intake levels. Single-sired beef steers (n=56) were blocked (n=28 per block) by growth implant status and sorted into pairs by BW. Each pair was then assigned randomly to a harvest day (0, 28, or 56) and dietary intake level (M or AL) that was applied within d 28 and 56. Additionally, supplementation of ZH (continuously at 90 mg for 20 d following a withdrawal period of 4 d) was applied randomly within a pair for each of M and AL intake levels. Steers (BW= 603.5 ± 48.1 kg) were harvested at a commercial processing facility. After a 24 h chill period, standard USDA grading procedures were used to derive a calculated yield grade and quality grade. Following grading, the left carcass sides were transported to the West Texas A&M University Meat Laboratory for fabrication. Each side was fabricated into subprimals to determine individual red meat yield (RMY), trimmable fat yield (TFY), and bone yield

(BY). A mixed model was used for analysis; fixed effects included treatment combinations and random effects included block and pairs. Single df contrasts tested d 0 vs. 28, d 0 vs. 56, d 28 vs. 56, M vs. AL, and control (C) vs. ZH. Yield of chuck eye roll differed ($P < 0.05$) by harvest day (0= 4.1, 28= 4.1, 56= 4.6 %), intake (M= 4.41, AL= 4.40 %), and treatment (C= 4.6, ZH= 4.5 %). Similarly, eye of round yield was impacted ($P \leq 0.02$) by harvest day (0= 1.5, 28= 1.4, 56= 1.4 %), intake (M= 1.4, AL= 1.3 %), and treatment (C= 1.3, ZH= 1.4 %). Additionally, brisket yield was altered ($P < 0.01$) by harvest day (0= 4.1, 28= 3.6, 56= 3.5 %), intake (M= 3.47, AL= 3.54 %), and treatment (C= 3.4, ZH= 3.6 %). Days on feed, intake and treatment tended ($P < 0.09$) to alter shoulder clod yield (0= 2.2, 28= 2.0, 56= 2.0 %; M= 2.0, AL= 1.9 %; C= 1.9, ZH= 2.1 %). For remaining subprimals, no differences ($P \geq 0.15$) were detected. Furthermore, results indicated that RMY tended ($P \leq 0.07$) to differ by harvest day (0= 64.0, 28= 63.3, 56= 62.5 %), intake (M= 63.4, AL= 62.1 %), and treatment (C= 61.4, ZH= 63.7 %). Comparatively, TFY was impacted ($P < 0.04$) by harvest day (0= 20.9, 28= 21.0, 56= 22.4 %), intake (M= 20.5, AL= 23.3 %), and treatment (C= 23.5, ZH= 21.3 %).Results from this study indicate that intake level during the last 56 days of the finishing period and ZH supplementation affect subprimal yields as well as carcass RMY and FY of beef steers.

3.2. INTRODUCTION

Zilpaterol hydrochloride (ZH), a β_2 adrenergic agonist, has been used in the cattle feeding industry as a method to improve the efficiency of animal production (Lawrence et al., 2011). Previous research in cattle has reported that ZH enhanced growth performance and red meat yield by increasing HCW, dressed carcass yield, and LM area

(Montgomery et al., 2009, Garmyn et al., 2010, Rathmann et al., 2012). In addition, ZH has been reported to increase sub-primal weights and cutting yields of calf-fed Holstein and native steers when fed during the last 20 d of the feeding period (Avendaño-Reyes et al., 2006; Boler et al., 2009, Hilton et al., 2009; Hilton et al., 2010; Leheska et al., 2009, Neill et al., 2009; Robles-Estrada et al., 2009; Scramlin et al., 2010). Similarly, Lawrence et al. (2011) reported an improvement in feeding performance, carcass yield characteristics, and fabrication values of cull cows fed ZH 20 d prior to slaughter. Zilpaterol hydrochloride is administered during the end of the finishing period in which cattle are allowed AL access to feed. However, Murphey and Loerch (1994) demonstrated an improvement in feed efficiency and carcass composition when cattle were fed at a M dietary intake level. There has been little research pertaining to the fabrication and sub-primal yields of beef steers fed at different dietary intake levels (i.e., M vs. AL) and supplemented ZH prior to slaughter. Therefore, the objective of this study was to evaluate the fabrication yields of carcasses from over-finished beef steers supplemented ZH and fed at M or AL dietary intake levels.

3.3. MATERIALS AND METHODS

No live animals were used in this experiment and therefore required no approval from the Animal Care and Use Committee at West Texas A&M University. The live phase portion of the experiment adhered to all guidelines described in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (Federation of Animal Science Societies, 2010, Savoy, IL) and was approved by the West Texas A&M University Institutional Animal Care and Use Committee (#02-06-14).

3.3.1. Animals

The live phase portion of the experiment involving the transportation, blocking, penning and feeding of the steers are described by Walter et al. (2016). Steers used in the carcass phase of the experiment were obtained throughout four separate harvest dates. Upon completion of the feeding period, steers were transported to a commercial beef processor for slaughter.

Following completion of the slaughter process, HCW and KPH weight were recorded for each carcass. Carcasses were allowed a 24 hour post-slaughter chill period before each left carcass side was ribbed between the 12^{th} and 13^{th} ribs for standard (USDA, 1997) grading procedures. Grading included the evaluation of marbling score, skeletal and lean maturity, 12^{th} rib subcutaneous fat thickness and LM area. A final quality grade and calculated yield grade were determined for each carcass (n = 55) with the exception of one carcass due to excessive trimming which resulted in unattainable yield and quality grade measurements and was therefore excluded from the remainder of the study. Following all grading procedures, the left carcass sides were transported the West Texas A&M University Meat Laboratory for further processing procedures.

3.3.2. Carcass Fabrication

Left carcass sides were fabricated into the following primal cuts according to guidelines of the North American Meat Processors Association (NAMP, 2010): round (NAMP #158), loin (NAMP #172) /flank (NAMP #193), rib (NAMP #103) /plate (NAMP #121) and chuck (NAMP #113)/ brisket (NAMP #120). All primals were weighed individually and summed to determine cold carcass side weights (CSW) then fabricated into trimmed subprimals. Each trimmed subprimal, bone, fat and lean trim (visual 80/20) was weighed individually to be calculated as a percentage of CSW.

The round primal was separated into the knuckle (NAMP #167A), top (inside) round (NAMP #168), bottom (outside) round (NAMP #171B), eye of round (NAMP #171C), heel meat (NAMP # 171F) and boneless shank meat.

The loin/flank primal was separated into the strip loin (NAMP #180), top sirloin butt (NAMP #184C), bottom sirloin tri-tip (NAMP #185D), peeled tenderloin, side on (NAMP #189D), and bottom sirloin ball tip (NAMP #185B). The flank steak was separated from the fat and bone as well as the bottom sirloin flap (NAMP #185A) and elephant ear.

The rib/plate primal was separated into the ribeye roll, lip on (NAMP #112A), back ribs (NAMP #124), rib blade meat (NAMP #109B), inside skirt (NAMP #121D), outside skirt (NAMP #121C) and hanging tender (NAMP #140).

The chuck primal was separated into the shoulder clod (NAMP #114), top blade (NAMP #114D), shoulder tender (NAMP #114F), chuck-eye roll (NAMP #116D), mock tender (NAMP #116B), short rib (NAMP #130A), pectoral meat (NAMP #115D), whole brisket (NAMP #120) and foreshank (NAMP #117).

After each subprimal, lean trim, fat and bone was weighed; lean trim and subprimals were combined and weighed to determine the red meat yield percentage (RMY%) of each carcass. Furthermore, all fat and bone was combined and weighed to calculate the fat yield percentage (FY%) and bone yield percentage (BY%).

3.3.3. Statistical Analysis

The experiment was developed as a multi-factorial design which included three harvest dates, two dietary intake levels and ZH supplementation or control (C) and is discussed in further detail by Walter et al. (2016). Fabrication data were analyzed using the MIXED model procedures (SAS Inst. Inc., Cary, NC). Fixed effects included the treatment combinations of d 0, d 28 M, d 28 A, d 56 MC, d 56 MZ, d 56 AC and d 56 AZ and random effects included block and pairs. Each individual side carcass was an experimental unit. Single df contrasts were constructed to test comparisons of d 0 vs. 28, d 0 vs. 56, d 28 vs. 56, M vs. A, and control (C) vs. ZH. Differences were considered significant at a *P*-value of ≤0.05 and trends at a *P*-value of ≤0.10 but >0.05.

3.4. RESULTS

3.4.1. Carcass data

The frequencies of carcass yield and quality grades among the 55 carcasses are represented in Table 1. Throughout the study, carcasses did not exhibit yield grades lower than 2.0. The calculated yield grade with the greatest frequency was 3.0 to 3.9 (52.82 %) followed by yield grade 4.0 to 4.9 (12, 21.82%), 2.0 to 2.9 (9, 16.36%), and finally ≥ 5.0 (5, 9.09 %). Furthermore, the overall quality grades remained within select (12, 21.82%) and choice (43, 78.18%). Of the select quality grade, carcasses resulted in 5 (9.09%) yield grade 3.0 to 3.9, 3 (5.45%) yield grade 2.0 to 2.9, 2 (3.64%) yield grade 4.0 to 4.9, and 2 (3.64%) yield grade ≥ 5.0. Within the choice quality grade, carcasses resulted in 24 (42.63%) yield grade 3.0 to 3.9, 10 (18.18%) yield grade 4.0 to 4.9, 6 (10.91%) yield grade 2.0 to 2.9, and 3 (5.45%) yield grade ≥ 5.0, respectively.

Harvest day, dietary intake level and ZH treatment effected CSW ($P < 0.01$), absolute and percentage fat yield ($P \leq 0.04$), and absolute red meat yield ($P < 0.01$; Table 2). Cold carcass side weight was 14.27 kg greater ($P = 0.04$) when harvested on d 56 vs. 0 and 10.44 kg greater ($P = 0.05$) when harvested on d 56 vs. 28. Cold carcass side weight was also 17.41 kg greater ($P <0.01$) for steers that were fed at the AL dietary intake level compared to the steers fed at M. Cold carcass weights tended ($P = 0.08$) to increase by 8.34 kg when steers were supplemented ZH in the last 20 d of the feeding period. Absolute fat yield tended ($P \leq 0.09$) to increase as DOF increased (0= 36.54, 28= 37.64, 56= 43.50 kg). Steers receiving AL dietary intake level had 10.22 kg greater ($P < 0.01$) absolute fat yield (2.89% as a percentage of the CSW) compared to steers fed the M diet. Absolute red meat yield was 11.34 kg greater ($P < 0.01$) for steers fed an AL diet level; however, no difference ($P = 0.20$) was detected as a percentage of CSW. Zilpaterol hydrochloride treatment increased ($P < 0.05$) red meat yield by 10.29 kg and tended ($P = 0.06$) to increase red meat yield by 2.32% as a percentage of CSW. In addition, there was a tendency ($P = 0.06$) for increased red meat yield of 8.99 kg for d 56 vs. 0 as well as an increase ($P < 0.05$) of 8.01 kg for d 56 vs. 28. Days on feed, dietary intake level, or ZH treatment had no effect ($P \geq 0.38$) on bone yield.

3.4.2. Round

Round sub-primal values were altered by harvest day, dietary intake level and ZH treatment (Table 3). Harvest day impacted ($P \leq 0.05$) absolute knuckle weight (0= 5.21, 28= 4.89, 56= 5.44 kg), top (inside) round (0= 8.43, 28= 8.92, 56= 9.38 kg), bottom (outside) round (0= 5.36, 28= 5.29, 56= 5.85 kg), and heel meat (0= 2.00, 28= 2.02, 56= 2.22 kg). Similarly, eye of round yield as a percentage of CSW was impacted ($P \leq 0.03$) by harvest day (0= 1.51, 28= 1.37, 56= 1.36 %). Steers fed at AL diet levels had heavier weights from the knuckle (0.45 kg; $P = 0.01$), top (inside) round (0.61 kg; $P = 0.01$), bottom (outside) round (0.37 kg; $P = 0.03$), and heel meat (0.12 kg; $P = 0.03$). Additionally, the eye of round ($P = 0.09$) tended to be 0.13 kg heavier in steers fed at AL intake levels. However, heel meat was increased ($P = 0.04$) by 0.16% as a percentage of

CSW when fed at M. Steers that were supplemented ZH demonstrated heavier weights of top (inside) round (0.68 kg; $P = 0.01$), bottom (outside) round (0.40 kg; $P = 0.04$), eye of round (0.52 kg; $P < 0.01$), and heel meat (0.21 kg; $P < 0.01$). The knuckle ($P = 0.06$) tended to be 0.41 kg heavier for steers supplemented ZH. The eye of round tended ($P = 0.06$) to increase by 0.18% as a percentage of CSW when steers were supplemented ZH. Furthermore, the round produced 2.42% fat trim after being separated into subprimal cuts. No difference ($P= 0.26$) was detected in shank meat as a percentage of CSW.

3.4.3. Loin/Flank

Dietary intake level and ZH treatment tended to have the greatest impact on sub-primal yields from the loin (Table 4). The top sirloin butt ($P < 0.01$) was 0.74 kg heavier for steers fed at AL intake. The bottom sirloin tri-tip increased ($P = 0.03$) as a percentage of CSW by 0.04% when steers were fed at M intake. Supplementation of ZH resulted in a top sirloin butt that was 0.32 kg heavier ($P = 0.01$) than C steers. The peeled tenderloin was 0.11% greater ($P = 0.10$) as a percentage of CSW from cattle treated with ZH. Harvest day altered ($P = 0.01$) the bottom sirloin tri-tip as a percentage of CSW (d 0 = 0.79, 28 = 0.69, 56 = 0.69 %). No difference was detected for the strip loin ($P= 0.13$), bottom sirloin flap ($P= 0.18$), and bottom sirloin ball tip ($P=0.84$). Flank subprimals (flank steak, elephant ear) were not affected ($P \geq 0.12$) by harvest day, dietary intake level or ZH treatment.

3.4.4. Rib/Plate

Harvest day and dietary intake level tended to have the greatest effect on rib and plate sub-primal yields (Table 5). Harvest day altered ($P \leq 0.01$) weights of back ribs (0= 1.81, 28= 1.99, 56= 2.16 kg), inside skirt (0= 1.18, 28= 0.81, 56= 0.68 kg) and outside skirt (0= 0.65, 28= 0.82, 56= 1.03 kg). When expressed as a percentage of CSW, harvest day impacted ($P \leq 0.01$) the inside skirt (0= 0.68, 28= 0.46, 56= 0.36 %) and outside skirt (0= 0.37, 28= 0.46, 56= 0.55 %). Steers that were fed at AL intake had greater weight of ribeye roll (0.60 kg; $P < 0.01$), back ribs (0.22 kg; $P < 0.01$), and blade meat (0.22 kg; $P = 0.04$). Blade meat from the rib displayed the only increase in absolute weight (0.37 kg; $P = 0.01$) as well as a percentage of CSW (0.13%; $P = 0.05$) when steers were supplemented ZH. The outside skirt ($P = 0.03$) from the plate was 0.14 kg heavier for steers fed AL intake and tended ($P = 0.06$) to decrease as a percentage of CSW by 0.07% when steers were supplemented ZH. The inside skirt was not affected by dietary intake level ($P \geq 0.63$) or ZH supplementation ($P \geq 0.46$).

3.4.5. Chuck/Brisket

Sub-primal weights from the chuck and brisket were affected by harvest day, dietary intake level and ZH treatment (Table 6). Harvest day impacted ($P < 0.01$) absolute weights from the shoulder tender (0= 0.34, 28= 0.39, 56= 0.43 kg), chuck eye roll (0= 7.23, 28= 7.36, 56= 8.59 kg) and brisket (0= 7.12, 28= 6.37, 56= 6.68 kg). When expressed as a percentage of the CSW, harvest day altered the chuck eye roll (0= 4.14, 28= 4.11, 56= 4.55 %) and brisket (0= 4.08, 28= 3.56, 56= 3.48 %). Steers fed AL intake had greater weight of shoulder tender (0.04 kg; $P = 0.04$), chuck eye roll (0.74 kg; $P = 0.01$), and top blade (0.15 kg; $P = 0.05$). The shoulder clod ($P = 0.06$) tended to increase as a percentage of CSW by 0.16% when fed at M intake. Zilpaterol hydrochloride treatment increased the weights of the shoulder tender (0.05 kg; $P = 0.03$) and top blade (0.27 kg; $P < 0.01$) with a tendency to alter the weights of the shoulder clod (0.53 kg; $P < 0.01$) and mock tender (0.13 kg; $P = 0.03$). As a percentage of CSW, the shoulder clod tended (P = 0.05) to increase by 0.20% when ZH was supplemented. Short rib and pectoral meat from the chuck were not affected by treatment ($P \geq 0.23$). The brisket (P < 0.01) was increased by 0.87 kg when steers were fed AL intake and was increased by 0.99 kg when ZH was supplemented. When expressed as a percentage of CSW, the brisket (P = 0.01) was increased by 0.27% when ZH was supplemented.

3.5. DISCUSSION

Several studies have reported the effects of zilpaterol hydrochloride on growth performance and carcass yield of native steers as well as calf-fed Holstein steers (Avendaño-Reyes et al., 2006; Boler et al., 2009, Hilton et al., 2009, 2010; Leheska et al., 2009; Neill et al., 2009; Robles-Estrada et al., 2009; Scramlin et al., 2010). One of the first studies on the supplementation of ZH demonstrated the beneficial effects on carcass weight and increased subprimal weights when fed during the last 20 d of the feeding period. Plascencia et al. (1999) first reported an increase in carcass weight as well as an increase of (bone- and trim-in) primal cuts, boneless closely trimmed primal cuts and boneless closely trimmed retail cuts from cattle supplemented ZH.

A study conducted by Avendaño-Reyes et al. (2006) reported an increase in carcass weights by 7% which resulted in an increase of carcass yield from steers supplemented ZH. Boler et al. (2009) and Hilton et al. (2010) reported similar results of an increase of chilled side weight (CSW) as well as saleable yield when ZH was included in the diet. Chilled side weight was increased by 6.22 kg which resulted in an increased saleable yield of 6.40 kg. In the present study, cold carcass side weight (CSW), similar to chilled side weight, was increased by 8.34 kg and percentage of red meat yield (RMY%)

was increased by 10.29 kg as well as by 2.32% as a percentage of CSW from steers supplemented ZH.

There were no differences detected in fat yield and bone yield when expressed as an absolute value or as a percentage of cold carcass side weight when ZH was included in the diet. In agreement, Avendaño-Reyes et al. (2006), Boler et al. (2009), and Leheska et al. (2009) reported no effect on fat yield when steers were supplemented ZH. However, Hilton et al. (2010) detected no difference in the quantity of fat trim but did detect a decrease in fat yield by 0.58 percentage units as a percentage of CSW with ZH supplementation. Unlike the current study and the studies that reported no differences in fat yield, the study by Hilton et al. (2010) demonstrated a larger sample size (n=801) which may explain why differences existed in these traits between studies.

The supplementation of ZH in the diet has also demonstrated an increase in weight of various subprimals when expressed as an absolute weight as well as a percentage of carcass weight. Plascencia et al. (1999) reported increased weights from retail cuts that include the knuckle, inside skirt, neck, inside round, and triangle. Similarly, Hilton et al. (2009) reported increased subprimal yields of the shoulder clod, chuck tender, knuckle, top round, outside round, eye of round, strip loin, top sirloin butt, bottom sirloin butt ball tip, full tenderloin, and flank steak with the supplementation of ZH. In the present study, similar results occurred in which subprimal weights were increased due to the inclusion of ZH in the diet. These subprimals affected by ZH include the knuckle, top (inside) round, bottom (outside) round, eye of round, heel meat, top sirloin butt, peeled tenderloin, rib blade meat, chuck shoulder clod, chuck shoulder tender, chuck (mock) tender, chuck flat iron, and the brisket. Subprimal weights from the round demonstrated the greatest effects from ZH supplementation, which coincide with results from previous studies. Boler et al. (2009) and Hilton et al. (2010) both reported increased weights from the knuckle, inside round, eye of round and heel which agree with results from the present study. When expressed as a percentage of cold carcass weight, ZH increased the eye of round, peeled tenderloin, rib blade meat, outside skirt, chuck shoulder clod, and the brisket.

In the present study, the results support the use of the β adrenergic agonist ZH functioning as an efficacious repartitioning agent in beef cattle. This function of ZH has been reported (Leheska et al., 2009) as an increase in protein and muscle deposition indicative of an improvement in carcass composition. However, Hilton et al, (2009) describes the repartitioning capacity of ZH as an increase in carcass protein and moisture and a decrease in carcass fat. Although the present study detected no decrease in fat yield, it is evident that ZH is responsible for protein and muscle deposition due to the absolute increase in weight of several economically important subprimal cuts.

3.6. CONCLUSION

Days on feed, dietary intake level and ZH treatment all demonstrated effects on sub-primal yields. Sub-primal weights were significantly increased from steers fed an *ad libitum* dietary intake level as well as steers supplemented ZH. Zilpaterol hydrochloride demonstrated the greatest effect on the round primal by increasing the weight of each sub-primal cut while tending to increase the percentage of red meat yield and decreasing the percentage of fat yield. The percentage of trimmable fat yield was also impacted by days on feed as well as dietary intake level. These results indicate that intake level during the last 56 days of the finishing period and ZH supplementation affect sub-primal yields. This information provides producers with the opportunity to efficiently produce more saleable product and increase carcass value.

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Table 1. Values (relative frequency, %) of carcass yield[1] and quality[2] traits among fifty-five carcasses.

Calculated Yield Grade	Choice	Select	Total
1.0-1.9	-	-	-
2.0-2.9	6 (10.91%)	3 (5.45%)	9 (16.36%)
3.0-3.9	24 (42.63%)	5 (9.09%)	29 (52.72%)
4.0-4.9	10 (18.18%)	2 (3.64%)	12 (21.82%)
≥ 5.0	3 (5.45%)	2 (3.64%)	5 (9.09%)
Total	43 (78.18%)	12 (21.82%)	55 (100.00%)

[1] Based on USDA Beef Carcass Grading Standards (USDA, 1997); Yield grade= 2.5+ (2.50 x adjusted fat thickness, inches) + (0.20 x percent kidney, pelvic, and heart fat) + (0.0038 x hot carcass weight, pounds) – (0.32 x area ribeye, square inches).

[2] Based on USDA Beef Carcass Grading Standards (USDA, 1997); Quality grades: Select = Slight$^{0\text{-}49}$, Slight$^{50\text{-}100}$ and Choice= Small$^{00\text{-}100}$, Modest$^{00\text{-}100}$, Moderate$^{00\text{-}100}$.

Table 2. Effect of feeding beef steers for 0, 28, or 56 days on a maintenance (M) or *ad libitum* (A) dietary intake level and given a control (C) or zilpaterol hydrochloride[1] (Z) treatment on carcass fabrication yields.

Item	Treatment Combination							SEM	*P*- Value					
	0	28 M	28 A	56 MC	56 MZ	56 AC	56 AZ		Overall	0 vs. 28	0 vs. 56	28 vs. 56	M vs. A	C vs. Z
Cold Side Weight (CSW) kg	174.64[c]	171.29[c]	185.64[bc]	175.36[c]	183.51[bc]	194.12[ac]	202.64[a]	5.49	<0.01	0.62	0.04	0.05	<0.01	0.08
Fat Yield, kg	36.54[bc]	33.87[c]	41.40[bc]	35.71[c]	39.72[bc]	53.76[a]	44.80[b]	3.75	0.01	0.80	0.09	0.07	<0.01	0.49
% CSW	20.93[b]	19.87[b]	21.96[b]	20.40[b]	21.06[b]	26.51[a]	21.51[b]	1.36	0.04	1.00	0.34	0.22	0.01	0.12
Bone Yield, kg	25.98	27.60	27.59	27.45	29.18	28.16	29.28	1.15	0.38					
% CSW	15.50	16.75	15.25	16.50	16.50	14.50	15.75	1.07	0.80					
Red Meat Yield, kg	111.59[bc]	107.86[c]	117.27[bc]	111.20[bc]	117.66[b]	119.68[b]	133.79[a]	4.01	<0.01	0.85	0.06	0.03	<0.01	0.02
% CSW	64.01	63.66	62.86	63.59	62.92	59.10	64.42	1.23	0.07	0.60	0.26	0.46	0.20	0.06

[1] Merck Animal Health, Summit, NJ.

[2] Means within a row with different superscripts differ (P< 0.05).

Table 3. Effect of feeding beef steers for 0, 28, or 56 days on a maintenance (M) or *ad libitum* (A) dietary intake level and given a control (C) or zilpaterol hydrochloride[1] (Z) treatment on round primal yields.

	Treatment Combination									***P*- Value**				
Item	0	28 M	28 A	56 MC	56 MZ	56 AC	56 AZ	SEM	Overall	0 vs. 28	0 vs. 56	28 vs. 56	M vs. A	C vs. Z
Knuckle (peeled), kg	5.21^{b}	4.64^{c}	5.13^{bc}	5.17^{b}	5.28^{b}	5.30^{b}	6.01^{a}	0.21	<0.01	0.21	0.34	<0.01	0.01	0.06
% CSW	2.99	2.70	2.83	2.96	2.88	2.74	2.97	0.11	0.36					
Top (inside) round, kg	8.43^{c}	8.66^{bc}	9.18^{b}	8.94^{bc}	9.17^{b}	9.14^{b}	10.26^{a}	0.27	<0.01	0.15	<0.01	0.05	0.01	0.01
% CSW	4.83	5.07	4.91	5.10	5.00	4.72	5.07	0.13	0.34					
Bottom (outside) round, kg	5.36^{bc}	5.03^{c}	5.55^{bc}	5.64^{b}	5.76^{b}	5.66^{b}	6.33^{a}	0.22	0.01	0.81	0.05	0.01	0.03	0.04
% CSW	3.07	2.94	2.98	3.22	3.14	2.92	3.13	0.08	0.15					
Eye of round, kg	2.64^{ab}	2.40^{c}	2.50^{bc}	2.42^{bc}	2.56^{bc}	2.42^{bc}	2.86^{a}	0.10	0.02	0.14	0.50	0.19	0.09	<0.01
% CSW	1.51^{a}	1.40^{ab}	1.34^{bc}	1.38^{b}	1.40^{b}	1.25^{c}	1.41^{ab}	0.05	0.02	0.03	0.01	0.71	0.14	0.06
Heel Meat, kg	2.00^{cd}	1.91^{d}	2.12^{bc}	2.13^{bc}	2.23^{b}	2.10^{bc}	2.40^{a}	0.06	<0.01	0.79	<0.01	<0.01	0.03	<0.01
% CSW	1.15^{abc}	1.12^{bc}	1.11^{bc}	1.21^{a}	1.22^{a}	1.09^{c}	1.19^{ab}	0.03	0.03	0.45	0.39	0.04	0.04	0.12
Shank Meat, kg	2.01	2.01	2.12	2.11	2.12	2.09	2.22	0.07	0.45					
% CSW	1.15	1.18	1.12	1.20	1.16	1.08	1.10	0.04	0.26					

[1] Merck Animal Health, Summit, NJ.

[2] Means within a row with different superscripts differ (*P*< 0.05).

Table 4. Effect of feeding beef steers for 0, 28, or 56 days on a maintenance (M) or *ad libitum* (A) dietary intake level and given a control (C) or zilpaterol hydrochloride[1] (Z) treatment on loin and flank primal yields.

	Treatment Combination									*P*- Value				
Item	0	28 M	28 A	56 MC	56 MZ	56 AC	56 AZ	SEM	Overall	0 vs. 28	0 vs. 56	28 vs. 56	M vs. A	C vs. Z
Strip loin, kg	4.56	4.26	4.73	4.42	4.59	4.80	5.09	0.21	0.13					
% CSW	2.61	2.49	2.56	2.52	2.50	2.48	2.53	0.11	0.98					
Top sirloin butt, kg	5.69[c]	5.60[c]	6.32[ab]	5.69[c]	5.90[bc]	6.32[bc]	6.76[a]	0.22	0.01	0.26	0.12	0.67	<0.01	0.01
% CSW	3.26	3.35	3.36	3.25	3.23	3.10	3.33	0.13	0.67					
Bottom sirloin flap, kg	2.02	1.58	1.77	1.79	1.87	1.84	2.09	0.17	0.18					
% CSW	1.16	0.92	0.95	1.02	1.01	0.95	1.03	0.07	0.27					
Bottom sirloin ball tip, kg	0.52	0.67	1.75	0.51	0.54	0.49	0.70	0.17	0.84					
% CSW	0.30	0.39	0.27	0.28	0.29	0.25	0.34	0.07	0.83					
Bottom sirloin tri-tip, kg	1.37	1.20	1.29	1.28	1.30	1.26	1.36	0.07	0.60					
% CSW	0.79[a]	0.70[bcd]	0.68[bcd]	0.73[ab]	0.71[bc]	0.65[d]	0.67[cd]	0.03	0.01	<0.01	<0.01	0.88	0.03	0.98
Peeled tenderloin, kg	2.14	2.15	2.15	2.20	2.27	2.01	2.59	0.15	0.10	0.94	0.44	0.37	0.69	0.01
% CSW	1.22	1.25	1.14	1.25	1.24	1.04	1.28	0.07	0.16					
Flank steak, kg	0.92	0.79	0.89	0.83	0.83	0.89	0.96	0.05	0.12					
% CSW	0.53	0.46	0.42	0.47	0.45	0.46	0.47	0.03	0.17					
Elephant ear, kg	1.70	1.24	1.28	1.48	1.35	1.60	1.56	0.20	0.47					
% CSW	0.98	0.72	0.68	0.84	0.73	0.82	0.77	0.10	0.36					

[1] Merck Animal Health, Summit, NJ.

[2] Means within a row with different superscripts differ ($P < 0.05$).

Table 5. Effect of feeding beef steers for 0, 28, or 56 days on a maintenance (M) or *ad libitum* (A) dietary intake level and given a control (C) or zilpaterol hydrochloride[1] (Z) treatment on rib and plate primal yields.

	Treatment Combination									***P*- Value**				
Item	0	28 M	28 A	56 MC	56 MZ	56 AC	56 AZ	SEM	Overall	0 vs. 28	0 vs. 56	28 vs. 56	M vs. A	C vs. Z
Ribeye roll, lip on, kg	5.67	5.56	5.93	5.56	5.41	6.04	6.34	0.27	0.07	0.79	0.52	0.66	<0.01	0.70
% CSW	3.25	3.24	3.20	3.17	2.94	3.11	3.13	0.10						
Rib back ribs, kg	1.81[c]	1.86[bc]	2.11[ab]	2.08[ab]	2.04[b]	2.28[a]	2.25[a]	0.10	<0.01	0.09	<0.01	0.02	<0.01	0.70
% CSW	1.03	1.09	1.14	1.19	1.11	1.18	1.11	0.05	0.15					
Rib blade meat, kg	1.98[b]	1.93[b]	2.27[b]	2.16[b]	2.18[b]	1.98[b]	2.69[a]	0.15	<0.01	0.51	0.10	0.21	0.04	0.01
% CSW	1.14	1.13	1.22	1.23	1.19	1.02	1.33	0.08	0.09	0.69	0.49	0.76	0.90	0.05
Inside skirt, kg	1.18[a]	0.81[b]	0.80[b]	0.62[b]	0.68[b]	0.77[b]	0.63[b]	0.11	0.01	0.01	<0.01	0.13	0.69	0.63
% CSW	0.68[a]	0.48[b]	0.43[bc]	0.36[bc]	0.37[bc]	0.40[bc]	0.31[bc]	0.06	<0.01	0.01	<0.01	0.06	0.63	0.46
Outside skirt, kg	0.65[e]	0.75[de]	0.88[bcde]	1.04[abc]	0.88[cd]	1.11[a]	1.09[ab]	0.09	<0.01	0.14	<0.01	0.01	0.03	0.22
% CSW	0.37[d]	0.44[cd]	0.47[bcd]	0.59[a]	0.48[c]	0.57[ab]	0.54[abc]	0.05	0.01	0.18	<0.01	0.03	0.45	0.06

[1] Merck Animal Health, Summit, NJ.

[2] Means within a row with different superscripts differ (*P*< 0.05).

Table 6. Effect of feeding beef steers for 0, 28, or 56 days on a maintenance (M) or *ad libitum* (A) dietary intake level and given a control (C) or zilpaterol hydrochloride[1] (Z) treatment on chuck and brisket primal yields.

	Treatment Combination								*P*- Value					
Item	0	28 M	28 A	56 MC	56 MZ	56 AC	56 AZ	SEM	Overall	0 vs. 28	0 vs. 56	28 vs. 56	M vs. A	C vs. Z
Chuck shoulder clod, kg	3.87	3.48	3.53	3.38	4.02	3.56	3.98	0.21	0.06	0.12	0.50	0.15	0.66	<0.01
% CSW	2.22	2.04	1.90	1.94	2.20	1.83	1.97	0.13	0.09	0.08	0.06	0.87	0.06	0.05
Chuck shoulder tender, kg	0.34[d]	0.37[cd]	0.41[bc]	0.40[bcd]	0.43[ab]	0.42[bc]	0.48[a]	0.02	<0.01	0.08	<0.01	0.04	0.04	0.03
% CSW	0.20	0.22	0.22	0.23	0.23	0.21	0.24	0.01	0.21					
Chuck eye roll, kg	7.23[d]	7.05[d]	7.66[cd]	8.06[bcd]	8.32[abc]	9.03[a]	8.96[ab]	0.57	<0.01	0.79	<0.01	<0.01	0.01	0.77
% CSW	4.14[b]	4.11[b]	4.11[b]	4.58[a]	4.54[a]	4.66[a]	4.42[ab]	0.25	0.05	0.88	0.03	<0.01	0.90	0.34
Chuck (mock) tender, kg	1.33	1.32	1.39	1.34	1.44	1.40	1.55	0.07	0.10	0.82	0.19	0.17	0.11	0.03
% CSW	0.77	0.77	0.75	0.77	0.79	0.72	0.77	0.04	0.79					
Chuck short rib, kg	1.43	1.33	1.50	1.43	1.43	1.55	1.64	0.09	0.24					
% CSW	0.82	0.77	0.80	0.82	0.78	0.81	0.81	0.05	0.98					
Chuck top blade, kg	2.15[b]	2.07[b]	2.23[b]	2.09[b]	2.29[ab]	2.16[b]	2.51[a]	0.10	0.03	1.00	0.31	0.20	0.05	<0.01
% CSW	1.23	1.22	1.21	1.19	1.25	1.12	1.24	0.07	0.68					
Pectoral Meat, kg	0.80	0.72	0.83	0.69	0.75	0.69	0.64	0.09	0.68					
% CSW	0.46	0.43	0.45	0.39	0.41	0.36	0.32	0.05	0.23					
Brisket, whole boneless, kg	7.12[ab]	6.09[cd]	6.64[abc]	5.71[d]	6.62[bc]	6.66[abc]	7.73[a]	0.28	<0.01	0.03	0.08	0.36	<0.01	<0.01
% CSW	4.08[a]	3.56[b]	3.56[b]	3.25[c]	3.60[b]	3.43[bc]	3.62[b]	0.11	<0.01	<0.01	<0.01	0.38	0.44	0.01

[1] Merck Animal Health, Summit, NJ.

[2] Means within a row with different superscripts differ ($P < 0.05$).

CHAPTER IV

AN EVALUATION OF THREE DIFFERENT GRADING SYSTEMS AND BIOELECTRICAL IMPEDANCE ANALYSIS TECHNOLOGY TO ACCURATELY PREDICT RED MEAT YIELD OF BEEF STEERS

4.1. ABSTRACT

An experiment was conducted to evaluate the ability of the United States Department of Agriculture (USDA), Canadian Beef Grading Agency (CBGA), and Japanese Meat Grading Association (JMGA) grading systems as well as bioelectrical impendence technology (BIA) to accurately predict red meat yield and trimmable fat yield of beef steers. Fifty five single-sired steers were fed a finishing diet until an average slaughter weight of 603.5 ± 48.1 kg was achieved. Steers were transported to a commercial processing facility where they were harvested and allowed a 24 h chill period. The left sides of each carcass were ribbed between the 12th and 13th ribs for USDA and CBGA grading procedures. The right side carcasses remained intact for BIA measurements. The left side carcasses were then transported to the West Texas A&M University Meat Laboratory where they were ribbed in between the 6th and 7th ribs for JMGA grading procedures. Upon completion of all grading procedures, each left side carcass was fabricated into primals and then further into subprimals to obtain weights in order to determine the percentage of red meat yield (RMY%) for each carcass. Data was

analyzed to determine correlations between grading variables as well as BIA measurements to the actual red meat yield. In addition, equations were developed to predict RMY%. Resulting correlations indicate that the equation for boneless closely trimmed retail cuts from the round, loin, rib and chuck from the USDA grading system demonstrated the highest correlation of (r = 0.71) followed by the Canadian yield equation (r = 0.61), and lastly the Japanese estimated yield equation (r = 0.36). Moreover, the developed equation from this study using the BIA measurements, accounted for 72% of the variation in RMY%, respectively. These results indicate that the USDA grading system provides the best prediction of red meat yield percentage from beef carcasses based on our data. Furthermore, BIA technology can be used as an accurate, noninvasive predictor of beef carcass composition.

4.2 INTRODUCTION

Efforts to devise a system that can accurately and objectively determine the true value of beef carcasses has been attempted through recent years. Current grading systems utilize camera-based technologies and/or subjective methods to derive a calculated yield grade or an estimation of overall beef cutability. Grading systems vary globally and utilize a variety of grading variables and standards to derive an overall value for that carcass based upon the estimated yield it would provide (Polkinghorne and Thompson, 2010).

Beef carcass yield grades (USDA, 1997) were designed as a way to estimate the percentage of boneless closely trimmed (1.27cm fat) retail cuts derived from the round, loin, rib and chuck (BCTRLRC) of a carcass based upon data compiled in the 1950’s (Murphey et al., 1960). This data was conducted on carcasses with different compositional proportions and cutability in comparison to beef carcasses produced via today's standards. Extensive research has been conducted to evaluate the USDA yield grade and its accuracy (Abraham et al., 1980).

Other grading systems such as the Canadian Beef Grading Agency (CBGA) and Japanese Meat Grading Association (JMGA) utilize their own yield grades to estimate the percentage of red meat. The CBGA was introduced 1929 but was later adjusted in 1996 to align with USDA quality grading standards (CBGA, 1996). In contrast the yield grade system used by CBGA utilizes the Canadian Yield Ruler to determine an estimated lean by measuring fat classes and muscle scores. The JMGA was established in 1975 and utilizes a variety of different grading factors and location when compared to the USDA and CBGA systems.

An additional system that provides a rapid, noninvasive method to estimate body composition is through the use of bioelectrical impedance (BIA) technology. This technology utilizes resistance and reactance assessment to determine the fat-free mass (FFM) and body fat of an organism by introducing an alternating current into the body via electrodes. Bioelectrical impedance analysis (BIA) has been shown to be an accurate predictor of carcass yield estimates throughout a variety of species including humans, cattle, lambs, and pigs (Lukaski et al., 1985; Berg and Marchello, 1994; Berg et al., 1996; Swantek et al., 1992, 1999; Marchello et al., 1999, Velazco et al., 1999; Zollinger et al., 2009).

The beef industry needs an updated system that can objectively and accurately quantify yield from modern livestock animals raised via today's standards. Therefore, the objective of this study was to evaluate the ability of the USDA, CBGA, and JMGA grading systems as well as BIA technology to predict red meat yield and trimmable fat yield of beef carcasses.

4.3. MATERIALS AND METHODS

No live animals were used in this experiment and therefore required no approval from the Animal Care and Use Committee at West Texas A&M University. The live phase portion of the experiment adhered to all guidelines described in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (Federation of Animal Science Societies, 2010, Savoy, IL) and was approved by the Institutional Animal Care and Use Committee (#02-06-14).

4.3.1. Animals

Fifty six single-sired steers were fed a finishing ration until average slaughter weights (BW = 603.5 ± 48.1 kg) were reached. Steers were transported (1,944 km) to a commercial processing facility for harvest; hot carcass weight (HCW) and kidney, pelvic and heart fat (KPH) were recorded immediately post-slaughter. Carcasses were allowed a 24 hour chill period and were then ribbed between the 12^{th} and 13^{th} ribs for USDA and CBGA grading procedures. All left side carcasses were transported to the West Texas A&M Meat Laboratory to be ribbed again between the 6^{th} and 7^{th} ribs for JMGA grading procedures and fabrication. All right side carcasses remained intact for BIA measurements at the commercial processing facility.

4.3.2. Carcass Measurements

Standard USDA yield grading procedures were assessed between the 12^{th} and 13^{th} ribs which included the measurement of 12^{th} rib back fat thickness (FT) and LM area along with obtaining the HCW and KPH to calculate a final yield grade. The USDA yield grade was calculated using the following equation: yield grade = 2.5 + (2.5 × 12^{th} rib fat thickness, in) + (0.0038 × hot carcass weight, lb) + (0.2 × % kidney, pelvic, heart fat) – 0.32 × ribeye area, in^2; USDA, 1997). Additionally, the data was used to estimate the percent of BCTRLRC using the equation: [BCTRLRC % = 51.34 – (5.78 × 12^{th} rib fat thickness, in) – (0.0093 × hot carcass wt., lbs) – (0.462 × % kidney, pelvic, heart fat) + (0.740 × ribeye area, in^2)] (Murphey et al. 1960). A final quality grade (standard, select, choice or prime) was determined by assessing a marbling score in conjunction with overall maturity score (A, B, C, D, E) by visually evaluating skeletal maturity and lean color and texture.

The CBGA grading procedures were assessed using the Canadian Yield Ruler (CBGA) to determine the yield grade. The yield grade was determined by measuring the length and width of the LM area to derive a muscle score (1, 2, 3 or 4) using a matrix located on the yield rule. The muscle score was then combined with the fat class score (1to10) measured at the minimum point of fat thickness (mm) perpendicular to the outside surface and within the fourth quarter of the LM area. Canadian yield grades were assigned based on the equation (% lean= 63.65 = 1.05 × muscle score – 0.76 × grade fat, mm), where yield= 1 if percent lean $\geq$ 59%, yield 2= if percent lean $\leq$ 58% and $\geq$ 54%, and yield =3 if percent lean $\leq$ 53%. Other measurements included a marbling and maturity score that is similar to that of the USDA standards to determine a final quality grade.

The bioelectrical impedance analysis (BIA) measurements were conducted on the intact right side carcasses at the beef processing facility using a Quantum X body composition analyzer 24 hours postmortem. Only 55 of 56 carcasses were used for BIA measurements because one carcass was trimmed extensively due to unknown defect. Two electrode holders equipped with positive (detector) and negative (source) terminals, in which stainless steel needles were attached and used as electrodes, were inserted into the carcass. One electrode holder was placed between the 2^{nd} and 4^{th} ribs and the other posterior to the pubis. An alternating electrical current (425 µA at 50 kHz) was introduced between the positive (detector) and negative (source) electrodes to quantify resistance (Rs; ohms) and reactance (Xc; ohms) to determine fat-free mass (FFM) and body fat of each carcass. Resistance measures the opposition of electrical flow in the tissues themselves whereas reactance measures the additional opposition of the membranes, tissue interfaces, and nonionic tissues to derive an estimation of total body water (TBW; National Institutes of Health, 1994). The resistance and reactance variables were used to calculate an impedance [$I= (Rs^2 + Xc^2)^{5}$] value to determine the overall resistance of body tissues. Other measured variables included the temperature (Tp; ºC) recorded from the longissimus muscle at the 12^{th} rib, length between electrodes (L; cm) and right side carcass weight (RSW; kg). Using these variables, additional values were calculated: electrical volume ($EVOL= L^2/Rs$), resistive density [$RsD= RSW^2/ (L^2/Rs)$] and reactive density [$XcD= RSW^2/ (L^2/XC)$].

Following completion of USDA, CBGA, and BIA grading procedures, all left side carcasses were transported (60 km) from the commercial processing facility to the West Texas A&M University Meat Laboratory via refrigerated truck. Carcasses were then ribbed between the 6^{th} and 7^{th} ribs for Japanese grading procedures. Japanese yield grading information included the cold left side carcass weight, LM area, rib thickness, and subcutaneous fat thickness to estimate the percentage yield of boneless wholesale cuts (JMGA, 1988). The Japanese estimated yield was calculated as [estimated yield (%) = 67.37 + (0.130 × ribeye area, cm^2) + (0.677 × rib thickness, cm) – (0.025 × cold left side wt, kg) – (0.896 × subcutaneous fat, cm)]. Based on estimated yield, three Japanese yield grades were assigned; A= ≥72%, B= ≥69% and < 72%, C= <69%. Furthermore, a quality score was determined by assessment of marbling (1= no marbling, 12= extreme) in the LM area via the Japanese beef marbling standards (BMS) as well as fat color (1= brilliant white, 7= beige), lean color (1= lightest, 7= darkest), lean firmness and lean texture (1= coarse, 5= extremely fine).

4.3.3. *Carcass fabrication and sample analysis*

Following all grading and BIA procedures, left side carcasses were fabricated into primal cuts of the round (NAMP #158), loin (NAMP #172) /flank (NAMP #193), rib (NAMP #103) /plate (NAMP #121) and chuck (NAMP #113)/ brisket (NAMP #120) according to the guidelines of the North American Meat Processors (NAMP) Association (NAMP, 2010). Primals were further fabricated into subprimals and weighed. Further detail on the fabrication process is described in a separate manuscript (Schmitz et al., 2016). All of the lean product, including the subprimals, fat product and bone were weighed to determine the percent red meat yield (RMY%), percent trimmable fat yield (TFY%), and percent bone yield (BY%) for each carcass. All soft tissue was ground through a fine grind plate. Samples from each carcass were collected and analyzed at for moisture, lipid and protein content. Procedures to determine carcass composition were described in a previous article (Walter et al., 2016).

4.3.4. Statistical Analysis

This study was designed as an observational study to examine the capability of the USDA, CBGA and JMGA grading systems as well as BIA to predict the RMY% of beef carcasses. The means were calculated for each of the grading variables as well as the BIA variables. Data were analyzed using the CORR procedure of SAS (SAS Inst. Inc., Cary, NC). Correlations were determined between the prediction equations and the calculated RMY% determined from the fabrication process. Pearson correlation coefficients among the prediction equation and calculated RMY% for a given variable were considered significant if a P-value was ≤ 0.05.

Data from BIA measurements were analyzed separately using the REG procedure of SAS. The model statement included the calculated RMY and through the stepwise selection procedure, variables were eliminated from the model at the $P > 0.05$ level. Nine variables were evaluated for use in a model to predict percentage red meat yield with 4 being eliminated. Models were then evaluated for their adjusted coefficient of determination (Adj. R^2), root mean square error (RMSE), and mallows Cp statistic (Cp; Mallows, 1973).

4.4. RESULTS AND DISCUSSION

4.4.1. Carcass characteristics

Descriptive statistics (Table 1) were evaluated for each of the variables necessary for each of the grading systems as well as BIA measurements. For the USDA system, mean (±SD) for HCW, LMA, FT, KPH, calculated yield grade, and BCTRLRC were 381.42 (±33.00 kg), 88.65 (±7.05 cm^2), 2.02 (±0.66 cm), 7.99 (±1.89 kg), 3.71 (±0.89), and 48.13 (±2.06 %), respectively. In comparison, the 2011 National Beef Quality Audit

(Moore et al. 2012) reported means of 374.0 (±46.5 kg), 88.8 (±11.7 cm^2), 1.30 (±0.52 cm), and 2.9 (±0.9) for HCW, LMA, FT and calculated yield grade, respectively. Calculated red meat yield from this study could not be compared to the National Beef Quality Audit as that data was not collected during the audit. In a study similar to the present one, carcasses weighing 680 kg from Hereford and Angus steers produced means of 82.9 cm^2 and 5.74 for LMA and calculated yield grade (Dubeski et al. 1997). Table 2 illustrates the percentage of USDA yield and quality grades presented in this study. Yield grades ranged from 2.0 to > 5.0 and quality grades remained within the Select and Choice grades.

Canadian grading variables produced medians of 2 (±0.5), 2 (±0.0), 2 (±0.5), 8 (±1.5), 3 (±0.5), and a mean of 64.3 (±0.6 %) for ribeye length and width, muscle score, fat class, calculated yield grade, and calculated yield, respectively. In comparison, Dubeski et al. (1997) reported a mean of 2.30 for muscle score and 46.4% for calculated yield. With respect to JMGA grading variables, mean cold left side weight, REA, rib thickness, subcutaneous fat thickness, and yield estimation were 186.9 (±16.2 kg), 48.0 (±5.2 cm^2), 7.8 (±1.1 cm), 3.1 (±0.9 cm), and 72.3 (±1.9 %), respectively.

Bioelectrical impedance measurement mean values (±SD) for Rs, Xc, I, L, Tp, EVOL, RsD, and XcD were 161.52 (±13.37 ohms), 44.88 (±4.17 ohms), 167.66 (±3.83 ohms), 118.51 (±4.87 cm), 3.07 (±0.70 °C), 87.58 (±9.38), 396.65 (±54.89), and 109.99 (±14.18; Table 1). In a similar study, Marchello et al. (1999) reported means (±SD) of 167.4 (±16.2 ohms), 49.9 (±5.9 ohms), 112.8 (±4.5 cm), 2.3 (±0.8 °C), and 76.9 (±9.8) for Rs, Xc, L, T, and EVOL for beef carcasses (n = 50). No derived values for I, RsD, and XcD were reported in that study. In comparison, a more recent study (Zollinger et al.,

2010) reported means for Rs, XC, I, L, EVOL, RsD, and XcD of 172.5 (±18.0 ohms), 47.2 (±7.4 ohms), 178.9 (±18.8 ohms), 124.7 (±7.4 cm), 91.9 (±17.0), 346.5 (±75.2), and 93.3 (±16.8).

Simple correlation coefficients between grading variables measured in this study and the calculated RMY% are presented in Table 2. Results indicate that some variables and prediction equations from the various grading methods were correlated to RMY%. The USDA grading parameters correlated ($P < 0.01$) to RMY% were hot carcass weight (r = -0.38), fat thickness (r = -0.65), KPH (r = -0.39), calculated yield grade (r = 0.71), and BCTRLRC (r = 0.71). Longissimus muscle area tended ($P = 0.09$) to be correlated to RMY% (r = 0.23). Of the CBGA parameters, fat class, calculated yield grade, and calculated yield were correlated ($P < 0.01$) to RMY% (r = -0.59, -0.47, and 0.61, respectively). Ribeye length, width, and muscle score demonstrated no correlation ($P > 0.05$) with RMY% (r = 0.10, 0.17, and 0.13, respectively). The Japanese grading parameters that indicated a correlation ($P \leq 0.01$) with RMY% were the cold left side weight (r = -0.39), subcutaneous fat thickness (r = -0.61), and yield estimation (r = 0.36). No correlation ($P > 0.05$) was detected for ribeye area and rib thickness (r = -0.04 and 0.07). Of the prediction equations from each grading system, the USDA equation demonstrated the highest correlation (r = 0.71) followed by CBGA (r = 0.61) and then JMGA (r = 0.36) to RMY%.

With respect to BIA measurements, Pearson correlation coefficients (Table 3) indicate that temperature, electrical volume, resistive density, reactive density and right side weight displayed a correlation ($P < 0.05$) with RMY% (r = -0.45, 0.28, -0.67, -0.50, and -0.36, respectively). This is in agreement Marchello et al. (1999) who reported volume to be correlated with beef IMPS cuts as well as Zollinger et al. (2010) who demonstrated a correlation between resistive density and reactive density to saleable yield of beef carcasses. Resistance and impedance tended ($P \leq 0.10$) to relate to RMY% (r = -0.25 and -0.23). Swantek et al. (1992) reported Rs to be correlated to measurements related to RMY% in market pork whereas Zollinger et al. (2010) demonstrated non-significant correlations between Rs and saleable yield of beef carcasses. Reactance and length demonstrated no correlation ($P > 0.05$) with RMY% (r = 0.06 and 0.11). In contrast, Slanger et al. (1994) reported Xc to have a positive correlation with total weight of retail ready lamb cuts as well as Marchello et al. (1999) and Zollinger et al. (2010) whom reported Xc to be positively correlated with beef IMPS cuts and carcass salable yield percentage, respectively. Data from Zollinger et al. (2010) suggested that an increase in Xc results from carcass composition shifting from a greater trimmable fat content to a leaner product. The negative correlation between Xc and RMY% in the present study may be due to the increased fat content exhibited from these beef carcasses.

Correlation of resistance, reactance, impedance, length, temperature, electrical volume, resistive density, reactive density, and right side weight with trimmable fat yield (kg) were correlated ($P \leq 0.01$) with coefficients of -0.59, -0.46, -0.59, 0.40, 0.35, 0.76, 0.50, 0.60, and 0.88, respectively. When expressed as percentage of trimmable fat yield, temperature, resistive density, reactive density, and right side weight demonstrated a positive correlation ($P \leq 0.001$) with coefficients of 0.50, 0.77, 0.59, and 0.55. Zollinger et al. (2010) also reported a positive correlation ($P \leq 0.001$) of fat trim percentage with resistive density, reactive density and carcass side weight (0.74, 0.54, and 0.56).

However, in contrast to the present study, Zollinger et al. (2010) reported a correlation ($P < 0.01$) of reactance with fat trim percentage (-0.45).

Of the carcass soft tissue composition, moisture and lipid percentage demonstrated a correlation with multiple BIA measurements whereas protein percentage revealed only one correlation. Temperature, resistive density, reactive density, and right side weight were correlated ($P \leq 0.05$) with moisture and lipid percentage with coefficients of -0.31, -0.65, -0.52, -0.39, respectively, for moisture and 0.32, 0.70, 0.53, and 0.44, respectively, for lipid percentage. Resistive density revealed the only correlation ($P \leq 0.05$) with protein percentage with a coefficient of -0.26. Previous research (Velazco et al., 1999) demonstrated correlations between all BIA measurements and carcass soft tissue composition, in contrast to the present study. Velazco et al. (2010) reported correlations between length, resistance, reactance, electrical volume, and impedance with carcass moisture, lipid and protein (kg).

The association of calculated RMY% with prediction equations from the USDA, CBGA, and JMGA grading systems are shown in Figure 1. The USDA prediction equation of BCTRLRC demonstrated an under-estimation of RMY%. However, this equation only accounts for the round, loin, rib, and chuck while disregarding the remaining carcass such as the flank, plate, and brisket. Therefore, it is not surprising that this equation would underestimate RMY%. The Canadian calculated yield equation also demonstrated under-estimation of RMY% but not to the extent of the USDA yield grade equation. In contrast, the Japanese yield estimation equation tended to over-estimate RMY%.

4.4.2. BIA prediction model

Multiple regression models were developed to predict RMY% using BIA measurements. Model selection criteria included the models adjusted coefficient of determination (Adj. R^2), root mean square error (RMSE) and Mallows Cp statistic (Cp). The best fit equation that was selected for RMY% had the greatest Adj. R^2, least RMSE and a Mallows Cp statistic representing the closest number of variables included in the model. Table 3 exhibits the best model for prediction of RMY%. The best model accounted for 69% of the variation in RMY% and included the variables Rs, EVOL, XcD, RsD and Tp. The model for RMY% = 78.58- (0.047 × Rs) + (0.049 × EVOL) + (0.15 × XcD) – (0.060 × RsD) – (1.525 × Tp). The Adj. R^2, Cp, and RMSE for the model were 0.69, 3.47, and 0.01, respectively. The accuracy of the BIA method to predict RMY%, depicted in Figure 2, illustrates the relationship between our calculated and predicted data. Prediction accuracy of the RMY% was indicated by an r-value of 0.72, a root mean square error of 0.01, and a model *P*-value <0.0001. Slanger et al. (1994) and Marchello et al. (1999) demonstrated excellent correlations (R^2 = 0.92 and 0.97) for saleable product of lambs and beef. In addition, Swantek et al. (1992) and Zollinger et al. (2010) reported adequate correlations (R^2 = 0.84 and 0.81) for saleable yield of pork and beef carcasses. The increased content of carcass fat may explain the differences in the R^2 value of the present study compared to previous studies where beef carcasses produced more lean content. In addition, variation among external moisture and temperature of carcasses from the present study compared to previous studies may explain reported differences as well.

4.5. CONCLUSION

The beef steers in this study provided carcasses that were suitable for the USDA grading standards and Canadian grading procedures but were lacking the fat depth and content for typical Japanese grading standards. The USDA grading system demonstrated the most accurate equation for predicting the percentage of red meat yield in beef steers while still tending to underestimate the red meat yield. Similarly, the Canadian grading system equation tended to underestimate the red meat yield of beef carcasses but accounted for less of the variation when compared to the USDA equation. The Japanese equation for estimating lean demonstrated an overestimation of red meat yield and accounted for the least variation between all three grading systems. This data provides insight to the accuracy of three different grading systems currently used in today's industry.

Bioelectrical impedance technology has proven to provide an accurate, objective method for estimating body tissue of carcasses by a rapid, non-invasive process. In the present study, the use of BIA technology provided objective measurements that could accurately and quickly predict the red meat yield of the beef carcasses used. Additional research is needed in order to standardize this technology for industry acceptance and use.

4.6. REFERENCES

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Table 1. Descriptive statistics of grading and bioelectrical impedance parameters for beef carcasses.

Item	*n*	Mean	SD	Median	QD	Min.	Max.
USDA							
Hot carcass weight, kg	55	381.42	33.00			321.40	471.12
Longissimus muscle area, cm^2	55	88.65	7.05			72.26	104.52
12^{th} rib fat thickness, cm	55	2.02	0.66			1.02	3.86
Kidney, pelvic, heart fat, %	55	2.08	0.46			1.31	3.74
Marbling score[a]	55	432	53			310	530
Calculated yield grade[b]	55	3.71	0.89			2.00	6.70
BCTRLRC, %[c]	55	48.13	2.06			41.16	52.08
CBGA							
Ribeye length[d]	55			2	0.5	1	3
Ribeye width[d]	55			2	0	1	3
Muscle score[d]	55			2	0.5	1	4
Fat Class[d]	55			8	1.5	4	10
Lean Color	55			5	0	3	8
Fat Color	55			5	0	5	5
Lean Texture	55			5	0	4	5
Calculated yield grade[e]	55			3	0.5	1	3
Calculated yield, %[e]	55	64.31	0.60			63.18	66.04
JMGA							
Cold left side weight, kg	55	186.93	16.06			157.85	231.33
Ribeye area, cm^2	55	48.00	5.17			36.10	59.40
Rib thickness, cm	55	7.75	1.12			5.60	9.90
Subcutaneous fat thickness, cm	55	3.13	0.93			1.50	6.90
Marbling score[f]	55			2	0	2	3
Lean color[f]	55			1	0.5	1	2
Fat color[f]	55			1	0	1	2
Yield estimation, %[f]	55	72.33	1.88			69.46	77.29
BIA							
Resistance (Rs), ohms	55	161.52	13.37			131.80	193.90
Reactance (Xc), ohms	55	44.88	4.17			36.00	52.90
Impedance (I), ohms[g]	55	167.66	13.83			137.30	200.90
Length (L), cm[h]	55	118.51	4.87			108.00	132.10
Temperature (Tp), °C	55	3.07	0.70			1.28	4.78
Electrical Volume (EVOL)[i]	55	87.58	9.38			68.20	109.90
Resistive Density (RsD)[j]	55	396.65	54.89			289.60	540.90
Reactive Density (XcD)[k]	55	109.99	14.18			80.30	138.20

[a] Marbling score: 300 = slight, 400 = small, 500 = modest.
[b] Calculated yield grade = 2.5 + (2.5 x fat thickness, in.) + (0.0038 x HCW, lb) + (0.2 x KPH%) – (0.32 x REA, $in.^2$).
[c] BCTRLRC, % = Percent boneless closely trimmed retail cuts from round, loin, rib, and chuck = 51.34 – 5.78 (single fat thickness over ribeye, in.) - .462 (percent kidney fat) + .740 (area of ribeye, sq. in.) - .0093 (carcass wt., lbs.).
[d] Canadian ribeye length and width, muscle score and fat class calculated using the Canadian Yield Ruler (CBGA, 1996).
[e] Canadian yield grade calculated as estimated yield percent using Yield ruler where 59% or > = YG1, 54 – 58% = YG2 and 53% or < = YG3; Canadian calculated yield, % = 63.65 + 1.05 (muscle score) – 0.76 (grade fat); Calculated yield grade
[f] Japanese marbling score determined using Beef Marbling Standards (BMS) with a scale of 1-12; Lean and fat colored determined using Beef Color Standard (BCS) 1-7 and Beef Fat Standard (BFS) 1-7; Yield estimation, % = 67.37 + (0.130 x ribeye area, cm^2) + (0.667 x rib thickness, cm) – (0.025 x cold left side weight, kg) – (0.896 x subcutaneous fat thickness, cm) (JMGA, 1975).
[g] Impedance= $(\text{Resistance}^2 + \text{Reactance}^2)^5$.
[h] Distance between detector electrodes (cm).
[i] Electrical volume= $\text{Length}^2/\text{Resistance}$.
[j] Resistive Density= Right side $\text{weight}^2/(\text{Length}^2/\text{Resistance})$.
[l] Reactive Density= Right side $\text{weight}^2/(\text{Length}^2/\text{Reactance})$.
[f] All BIA measurements were taken on the right carcass side.

Table 2. Simple correlation coefficients between USDA, CBGA, JMGA and Bioelectrical Impedance measurements and percentage red meat yield of beef carcasses.

	Red Meat Yield (%)	
Item	**Coefficient**	***P*- Value**
USDA		
Hot carcass weight, kg	-0.38	<0.01
Longissimus muscle area, cm^2	0.23	0.09
12^{th} rib fat thickness, cm	-0.65	<0.01
Kidney, pelvic, heart fat, kg	-0.39	<0.01
Calculated yield grade[a]	0.71	<0.01
BCTRLRC, %[b]	**0.71**	**<0.01**
CBGA		
Ribeye length	0.10	0.45
Ribeye width	0.17	0.22
Muscle score	0.13	0.33
Fat Class	-0.59	<0.01
Calculated yield grade	-0.47	<0.01
Calculated yield, %[c]	**0.61**	**<0.01**
JMGA		
Cold left side weight, kg	-0.39	<0.01
Ribeye area, cm^2	-0.04	0.75
Rib thickness, cm	0.07	0.61
Subcutaneous fat thickness, cm	-0.61	<0.01
Yield estimation, %[d]	**0.36**	**0.01**

[a] Calculated yield grade= 2.5 + (2.5 x fat thickness, in.) + (0.0038 x HCW, lb) + (0.2 x KPH%) – (0.32 x REA, $in.^2$).
[b] BCTRLRC, % = Percent boneless closely trimmed retail cuts from round, loin, rib, and chuck = 51.34 – 5.78 (single fat thickness over ribeye, in.) - .462 (percent kidney fat) + .740 (area of ribeye, sq. in.) - .0093 (carcass wt., lbs.).
[c] Canadian calculated yield, % = 63.65 + 1.05 (muscle score) – 0.76 (grade fat).
[d] Japanese yield estimation, % = 67.37 + (0.130 x ribeye area, cm^2) + (0.667 x rib thickness, cm) – (0.025 x cold left side weight, kg) – (0.896 x subcutaneous fat thickness, cm).

Table 3. Simple correlation coefficients between bioelectrical impedance measurements and carcass composition of beef carcasses.

					Soft carcass tissue, %		
Item[a]	**RMY, kg**	**RMY,%**	**TFY, kg**	**TFY, %**	**Moisture**	**Lipid**	**Protein**
Resistance (Rs), ohms	-0.11	-0.25	-0.59***	0.06	-0.19	0.17	-0.01
Reactance (Xc), ohms	-0.35**	0.06	-0.46***	-0.25	0.06	-0.14	0.21
Impedance (I), ohms	-0.14	-0.23	-0.59***	0.04	-0.17	0.15	0.01
Length (L), cm	0.10	0.11	0.40**	-0.05	0.06	-0.07	0.19
Temperature (Tp), °C	0.58***	-0.45***	0.35**	0.50***	-0.31*	0.32*	-0.08
Electrical Volume (EVOL)	0.17	0.28*	0.76***	-0.09	0.20	-0.19	0.14
Resistive Density (RsD)	0.88***	-0.67***	0.50***	0.77***	-0.65***	0.70***	-0.26*
Reactive Density (XcD)	0.76***	-0.50***	0.60***	0.59***	-0.52***	0.53***	-0.12
Right side weight, kg	0.80***	-0.36**	0.88***	0.55***	-0.39**	0.44***	-0.11

[a] See Table 1 footnote for description of items.

* $P \leq 0.05$

** $P \leq 0.01$

*** $P \leq 0.001$

Table 4. Regression model for predicting percentage red meat yield (RMY%) using BIA measurements.[ab]

Model	Adj. R^2	Cp	RMSE
RMY% = 78.58- (0.047 * Rs) + (0.049 * EVOL) + (0.15 * XcD) – (0.060 * RsD) – (1.525 * Tp)	0.69	3.47	0.01

[a] Rs=Resistance; EVOL=Electrical volume; XcD=Reactive Density; RsD=Resistive Density; Tp=Temperature.
[b] Adj. R^2= Adjusted R^2 analysis; Cp=Mallows' statistic calculated with the s^2 for all five variables used; RMSE= Residual mean square error.

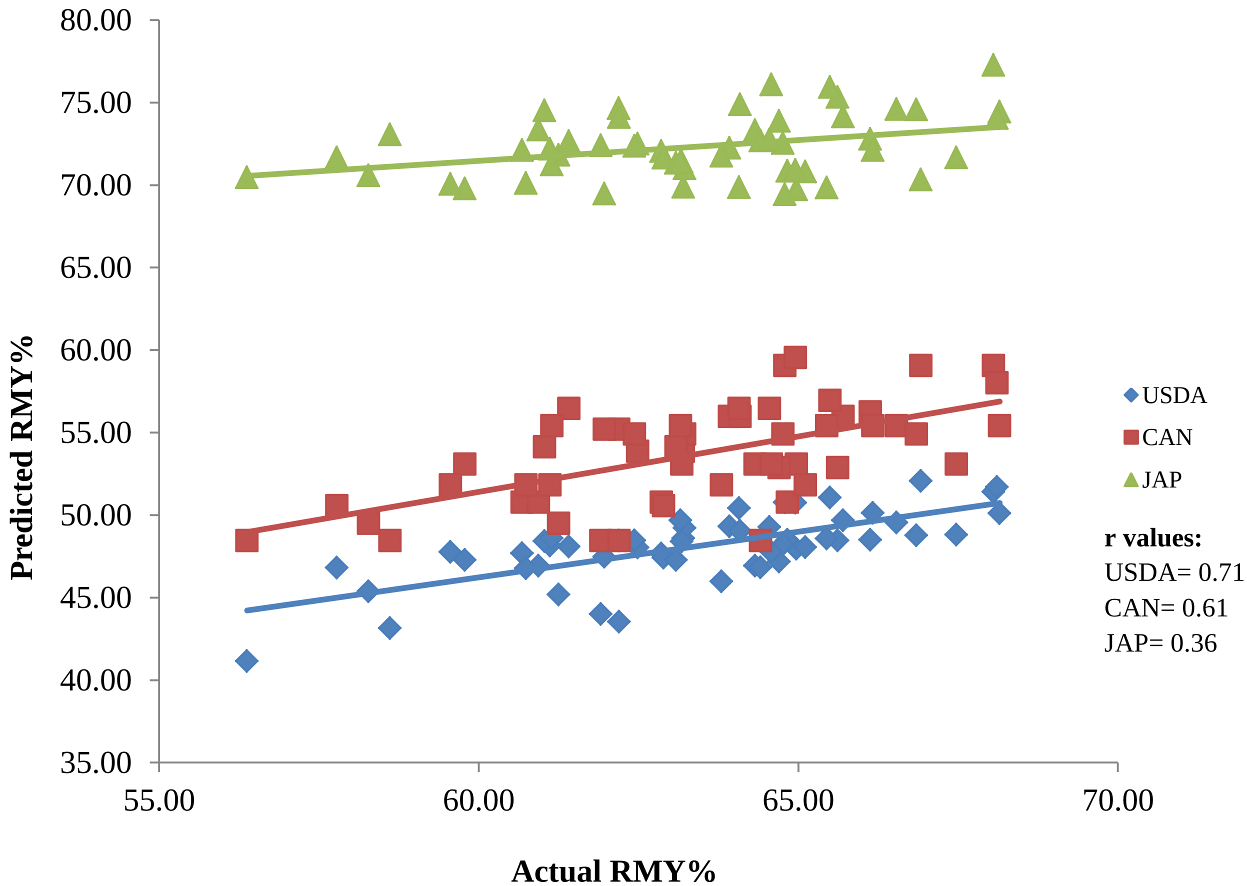

Figure 1. Association of actual red meat yield percentage with USDA (BCTRLRC), Canadian estimated yield (CAN) and Japanese yield estimation (JAP).

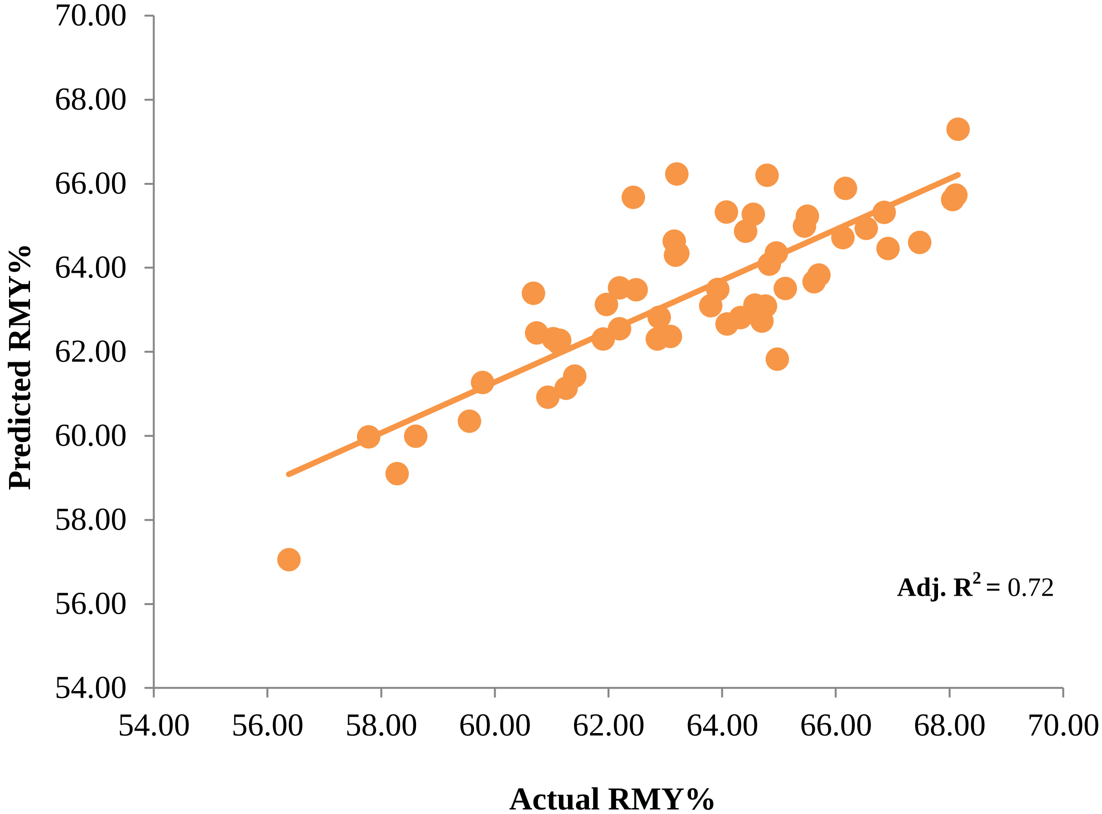

Figure 2. Association of actual red meat yield percentage with BIA measurements.