# LIVE AND CARCASS PRODUCTION TRAITS FOR PROGENY OF PUREBRED SIRES IN COMPARISON WITH THE CLONE OF A USDA PRIME YIELD GRADE ONE CARCASS

by

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## ABSTRACT

A two-part study was conducted to determine the sire success of "Alpha", a bull born in 2012 through somatic cell nuclear transfer from a carcass that graded USDA Prime Yield Grade 1 (P1). The first part of the study used a terminal sire system to compare Alpha progeny with progeny of three purebred (Angus, Charolais, Simmental) reference sires, selected for outstanding terminal sire production traits. Live production traits included: weaning weight, morbidity, mortality, and days on feed; carcass traits included: liver and lung abnormalities, individual quality and yield grade parameters, and total carcass value and value per cwt. A completely randomized experimental design structure was used. Data were analyzed using a mixed model with sire as the fixed effect and harvest date, sex, and pen as random effects. Next to Charolais-sired cattle, Alpha-sired heifers and steers had the largest ($P < 0.01$) longissimus muscle area and lowest yield grade. Economically, Alpha-sired steers were worth the greatest ($P < 0.01$) value per cwt, and Alpha-sired heifers were numerically worth the greatest value per cwt. The progeny produced from this terminal sire study were used in the second part of the study to determine the proficiency and value in sorting cattle into end-weight marketing groups upon feedyard arrival. Heifers and steers were sorted five-ways per sex (10 pens total) using a proprietary cattle classification and sorting system, combining feedlot arrival weight (kg), hip height (cm), and hip length (cm) into an equation. From there, the database projected appropriate number of days on feed by estimating incoming empty body fat, adjusted finished body weight, dry matter intake, and average daily gain. Five-way sort pens differed in targeted harvest date and days on feed. A completely randomized experimental design structure was used. Data were analyzed using a mixed model with sort pen as the fixed effect, and linear and quadratic contrasts were generated to asses trends by sort pen. In general, live traits that differed ($P < 0.01$) for

heifers followed a curvilinear trend when sorted by pen including: feedlot arrival weight, adjusted finished body weight, incoming empty body fat(%), and average daily gain. Live traits that differed ($P < 0.01$) for steers followed a linear trend of significance when sorted by pen including: feedlot arrival weight, adjusted finished body weight, incoming and outgoing empty body fat(%), and estimated dry matter intake. Heifer and steer carcass traits differed by pen for hot carcass weight ($P < 0.01$) and total carcass value ($P < 0.01$), suggesting the sort system was successful in sorting cattle upon feedyard arrival to improve uniformity, ensure the likelihood of achieving target empty body fat, and maximizing dollar value of individual animals. Many differences were observed in these data for carcass traits when analyzed by sire with limited differences observed when analyzed by pen, suggesting the sorting system was effective in grouping cattle upon feedyard arrival into uniform end-market harvest groups.

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## DEDICATION

This master's thesis is dedicated to my family:

To Mom,

To Dad,

To Samantha,

To Grandma Doreen,

To Grandpa Mike,

There are no words to express how thankful I am for the infinite love and support I have received from each of you. I want to thank you for instilling a passion and love for the cattle industry in me and for encouraging me to follow my dreams. I love each of you and am thankful for all that you have done for me.

**APPROVAL**

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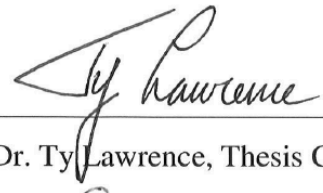

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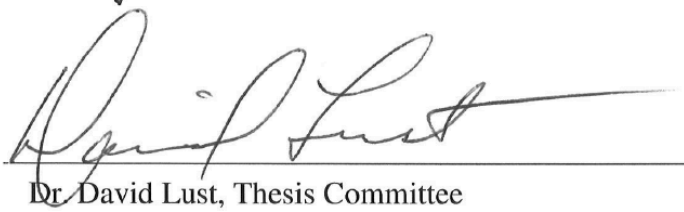

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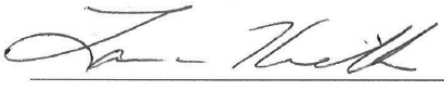

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# CHAPTER 1

# INTRODUCTION

Beef producers continuously search for production ventures that will improve the economic value of their herd. Herd improvement can result from both environmental and genetic influencers. One technology used in genetic improvement is somatic cell nuclear transfer (SCNT), commonly termed “cloning”. The cloned individual will be an identical genetic copy of the animal from which the DNA was originally derived (Gabor and Gjerris, 2006). Having the ability to salvage and replicate genetic material is especially beneficial for genetic outcomes that are rarely found within populations but are highly desired by the producer. The combination of a USDA Prime Quality Grade and a USDA Yield Grade 1 (P1) represents a rare antagonistic outcome, observed in only 0.07% of the U.S. beef population (Boykin et al., 2017) that combines two premium carcass outcomes of economic value for cattle producers.

Sorting cattle into uniform harvest groups by projecting appropriate end-point “doneness” is an additional venture that cattle feeders can implement to improve the value of their operation. Understanding and feeding to a target body composition on an individual basis allows for maximal profitability per animal, monitoring individual feed cost of gain, while maintaining consistency in meat quality (Guiroy et al., 2002). Currently, the great variation in size and maturity of feeder cattle in the United States may hinder maximization of economic value of each individual animal. In order to combat this, many feedyards have implemented the Cattle Classification and Sorting

System (CCSS), which improves uniformity and pen utilization, aiming to return a greater profit to cattle feeders (PCC, 2018).

# CHAPTER 2

# REVIEW OF THE LITERATURE

## 2.1. Cloning

### 2.1.1. Asexual Reproduction

The process of cloning, creating an identical copy or "twin" separated by time of birth, has been a hot topic of public discussion since the 1990s (Vajta and Gjerris, 2006). Although many believe cloning is a scientifically and technologically driven procedure, cloning, in fact, can occur naturally in the environment (Vajta and Gjerris, 2006). For many plant species across the world, cloning in the form of asexual reproduction is common (Vajta and Gjerris, 2006). For example, the above ground stems of strawberry plants have the ability to produce new plants, which are identical copies of the parent organism (Vajta and Gjerris, 2006). Asexual reproduction also has the ability to occur in animal species: jellyfish use a process called budding, worms use fragmentation, and parthenogenesis is commonly used by fish, lizards, and insects (Vajta and Gjerris, 2006). When it comes to livestock, asexual reproduction is non-existent, as natural reproduction for these animals combines genes of two individuals to create an offspring.

### 2.1.2. Embryo Splitting

Before the introduction of somatic cell nuclear transfer (SCNT) as a method of cloning, embryo splitting was used, where the blastomeres of a 2-cell embryo were separated and grown in water (Vajta and Gjerris, 2006). The first cloning procedure that made use of embryo splitting was carried out in 1891 on a sea urchin (Driesch, 1891) and

was later performed on a salamander in 1902 (Vajta and Gjerris, 2006). Embryo splitting at the 4-cell and morula stage have been performed in many livestock species including: porcine, bovine, and ovine (Illmensee and Levanduski, 2010). Stein-Stefani and Holtz (1994) reported successful 4-cell embryo splitting in swine, where splitting of the four-cell stage was easily accomplished, successful in production of identical twins, with a greater survival rate than splitting at the morulae stage (Stein-Stefani and Holtz, 1994). In cattle specifically, embryos split into blastomeres at the 4-cell stage have reported the ability to develop multiple monozygotic healthy calves (Johnson et al., 1995).

Approximately 50 years after the introduction of embryo splitting, Briggs and King (1952) performed SCNT using frogs, in which they removed the nuclei of the recipient eggs, and infused the empty egg with a donor nucleus. Mammalian cloning via nuclear-transfer methods first began in the mid-to-late 1970s with nuclear transplantation of a rabbit egg (Bromhall, 1975). The birth of two sheep, Megan and Morag, in 1995 marked the beginning of mammal production through somatic cell nuclear transfer (SCNT), followed by the Roslin Institute's ever famous "Dolly" in 1996, who became a public icon for cloning (Suk et al., 2007).

### 2.1.3. Somatic Cell Nuclear Transfer

The procedure of SCNT involves extracting a non-reproductive cell from an existing organism and inserting that nucleus into an oocyte (immature egg) in which the original nucleus is no longer present (Fig. 2.1) (Vajta and Gjerris, 2006). The oocyte is currently the only known environment where full reprogramming of the nuclei is known to occur, which makes it an incredibly important piece to the technology of SCNT (Galli

et al., 2012). Once filled with DNA from the donor animal, the oocyte (contained in a media) has an electrical current (electrofusion) passed through to fuse the inner nuclear membrane with the outer membrane of the donor cell (TransOva, 2018). This begins the process of replication, where the dividing cells form a zygote, followed by an embryo (Vajta and Gjerris, 2006).

The embryo is then implanted into a surrogate recipient dam, where it will develop into a fetus and be carried to full-term (Vajta and Gjerris, 2006) over a normal gestation period (TransOva, 2018). The individual produced at birth will be an identical genetic copy of the animal in which the DNA was originally derived (Vajta and Gjerris, 2006), essentially making it an identical twin separated in by time only. The entire SCNT procedure (Fig. 2.2) can be summed into three main steps: the oocyte becoming enucleated, the injection of the nuclei from the donor animal, and the charging of the newly constructed embryo, which is then transplanted into a new dam (Vajta and Gjerris, 2006).

The insertion procedure of the somatic cells (nuclei) is to inject them underneath the zona pellucida, which is a protein layer surrounding the plasma membrane of a cell, while inducing an electric impulse to cause the fusion of the cell membrane between the enucleated (empty) oocyte and the somatic cell (Vajta and Gjerris, 2006). Alternative procedures of the insertion are in practice, however, the aforementioned procedure is the most common across SCNT literature.

During standard SCNT procedures, the oocyte is deprived of the original maternal nuclear DNA, and the oocytes' mitochondrial DNA (mtDNA) is required to interact with a foreign nucleus (Hiendleder, 2007). The mitochondria is a maternally inherited

organelle responsible for energy in the cell, and during normal fertilization, sperm mitochondria are destroyed and maternal mtDNA is transferred to the offspring (Do et al., 2012). As a result of the SCNT procedure, most embryos, fetuses, and offspring produced carry mtDNA from both the recipient oocyte and somatic cells (Hiendleder, 2007). This termed "heteroplasmy" in the SCNT clone, which refers to having mitochondrial genomes of two different origins (Do et al., 2012).

Approximately 20 years have elapsed since Wilmut et al. (1997) introduced their work on the cloning of animals to the rest of the scientific world. Since then, most domestic mammals have been cloned, including: mice, rats, rabbits, and ferrets, which are generally referred to as laboratory animals, in addition to many production animals including: cattle, goats, pigs, horses, and deer (Galli et al., 2012). The goal of cloning was originally to multiply superior genotypes of individuals with high genetic value for livestock species and as a method to rescue endangered species of wildlife (Galli et al., 2012). However, a recent alteration in this trend has occurred, where the focus of cloning through the use of SCNT has shifted because of its ability to produce important biological models for basic research and a wealth of opportunities for biomedical studies (Galli et al., 2012).

One of the main limitations for the widespread commercial implementation of SCNT is referred to as the "cloning syndrome", which is characterized by large offspring syndrome (LOS), developmental abnormalities, and the high incidence of postnatal mortality (Ortegon et al., 2007). Kato et al. (2000) reported clones derived from adult cells had an increased abortion rate during the later stages of pregnancy and calves born from these cells had greater abnormalities. In addition, individuals produced from cloning

tend to be larger at birth than their counterparts, with abnormally large organs, that may lead to respiratory complications (Wells et al., 2004). High incidences of stillbirth, neonatal death, and fatal diseases have all factored into the high frequency of calf loss during SCNT (Watanabe and Nagai, 2009). As a means to counter LOS at time of parturition, hormone treatment and/or caesarean section have been implemented (Kubota et al., 2000). Assisted birthing procedures, such as caesarean section, have been used in the vast majority of bovine SCNT literature (Watanabe and Nagai, 2011), suggesting dystocia and birthing complications.

Rideout et al. (2001) reported animals produced from clones have a higher rate of developmental mortality and post-natal abnormalities. This phenomenon has been linked back to telomere length of clones and their offspring, where a great variation of results has been reported. A telomere is the end of a eukaryotic chromosome, with a specific sequence of proteins that stabilizes the end of the chromosome during replication (Xu and Yang, 2003). Scientists propose the telomere to be a "mitotic clock", where length of the telomere correlates with the number of cell divisions, and therefore, the molecular age of the cell (Olovnikov, 1973). In other words, as an animal ages chronologically, their telomere length should naturally shorten, as telomere length is an indicator of senescence (Jeon et al., 2005).

Shiels et al. (1999), reported shortened telomere lengths of Dolly the sheep when compared to control animals of the same age. Dolly's telomere length was reported to be comparable to that of the mammary tissue of the six-year-old donor (Shiels et al., 1999), and researchers attributed this finding to the production of clones being without germ line involvement (Xu and Yang, 2003). In contrast to the findings of Shiels et al. (1999),

elongation of telomere length has been observed in cloned cattle (Betts et al., 2001) and evidence of telomere rebuilding has been observed in cloned pigs (Jiang et al., 2004). Further deviating from the above research reports on telomere lengths and its correlation to cloned animals, Tian et al. (2000) reported telomere lengths of cloned cattle were no different from those of the controls. Thus, the literature reports highly variable telomere length for cloned animals and should not be a basis for negative speculation against SCNT as a means for reproduction.

A great deal of controversy has arisen over the expected lifespan of cloned animals, after Ogonuki et al. (2002) reported that the lifespan of mice cloned from somatic cells was shorter than that of sex-matched controls. However, premature aging may not be the primary cause of death (Fulka Jr. et al., 2004) as many of the cloned mice died from pathologies such as pneumonia (Ogonuki et al., 2002). The common assumption surrounding early death in clones is not because they are biologically old, but because of the abnormalities they accumulate in expression of different genes (Fulka Jr. et al., 2004). However, these abnormalities are not present in the offspring of clones, which suggests that the germline has the ability to correct epigenetic errors (Betts et al., 2005). When Dolly the sheep died at the age of six, due to a lung virus that killed other sheep in her barn, her short lifespan was labelled as an outcome of cloning (Zhang, 2017). The other four sisters that were created from the same cell line as Dolly outlived her by a number of years, suggesting premature aging may be greatly exaggerated in cloned animals (Zhang, 2017).

Efficiency is key when it comes to the use of animal cloning within agriculture, as the cost must be reduced to be economically viable for producers (Wells et al., 2004).

The commercial beef industry currently does not have incentive to invest into the cloning of livestock, as the efficiency of artificial insemination is more cost effective for producers (Suk et al., 2007). The approximate cost to commercially produce cloned cattle is estimated at $15,000 to $20,000 per animal, which has been a limiting factor for cattle breeders and their utilization of SCNT as a reproductive technology (Hasler, 2014). This being said, as the efficiency of cloning through SCNT increases, and the associated costs decline, cloning may potentially become more economically attractive for commercial beef producers (Suk et al., 2007).

### 2.1.4. ViaGen

ViaGen, a company known as "America's most trusted animal cloning company" (ViaGen, 2018), is one of only two large-scale cloning companies in North America. The other being Cyagra (Hasler, 2014). ViaGen was founded in Austin, TX in 2002 (Hasler, 2014), and with over 15 years of experience, has successfully cloned seven different animal species (ViaGen, 2018). These species include: cattle, swine, horse, sheep, deer, dogs, and cats (ViaGen, 2018). ViaGen strives to advance the science behind animal reproduction and genetic preservation, producing an identical twin to a superior animal, and was the first commercial animal cloning company to clone swine (ViaGen, 2018). What makes ViaGen unique is that they are a cloning team with industry experience currently with a commercial cloning focus in the areas of cattle, pigs, and horses, in addition to a successful companion animals platform that started in 2016 (ViaGen, 2018). ViaGen (2018) believes cloning livestock gives producers the ability to leverage the value of their best genetics and most profitable animals.

In 2012, Trans Ova Genetics purchased ViaGen, and two years after, a synthetic biology company, Intrexon, purchased the duo (ViaGen, 2018). Over the last 15 years, ViaGen has preserved thousands of cell lines from multiple non-primate mammals, including rare and endangered species (ViaGen, 2018) and is likely to expand on this in future years to come.

### 2.1.5. Regulations

Cloning for agricultural purposes, livestock cloning specifically, has been actively used by many countries in addition to the United States including: Argentina, Brazil, Canada, Chile, China, France, Germany, Japan, South Korea, and the United Kingdom (FDA, 2018).

In 2001, the U.S. Food and Drug Administration (FDA) began a risk assessment with regards to public concern of cloned animals (voluntary moratorium, tech providers, 2003 FDA executive summary), and in 2008, released a multi-page Final Risk Assessment, titled "Use of Animal Clones and Clone Progeny for Human Food and Animal Feed". The regulatory findings concluded meat from the offspring of clones was as safe as meat from non-cloned animals (FDA, 2018), which paralleled the findings from the National Academy (Tian et al., 2005). The release of these findings removed the last U.S. regulatory barrier for the marketing of milk and meat from cloned cattle, pigs, and goats (Hasler, 2014). In addition to the approval of the sale of milk and meat for public consumption from cloned livestock and their offspring, food products from cloned animals are not required by law to be labeled, in an effort to avoid bias of consumers' consumption of these products (Center for Food Safety, 2018).

In contrast with the United States decision to allow cloned products to enter the food chain, the Agriculture Committee of the European Parliament banned the use of animal cloning for food and halted imports to the European Union (E.U.) of cloned animals, their offspring, and products derived from cloned animal sources (Center for Food Safety, 2018). It is likely that as SCNT becomes more affordable and popular for global livestock producers that many regulations, such as the one placed on cloned livestock by the E.U., may be revisited and potentially removed.

## 2.2. Beef Herd Improvement Technologies

### 2.2.1. Seedstock, cow/calf, production of market animals

The beef seedstock industry refers to cattle that are used for breeding purposes, typically registered with a breed association, where their pedigrees are documented to assist in the estimation of their value as a parent (The Beef Site, 2009). The beef industry looks toward seedstock operations as the genetic suppliers of the industry, where genetic improvement is of great importance, and marketable units are purebred or registered bulls, cows, heifers, semen, and embryos (The Beef Site, 2009). The seedstock industry differs from the commercial industry, in that most commercial cattle are often crossbred, not registered, and are less frequently offered up as a replacement animal for breeding purposes (The Beef Site, 2009). Commercial cattle production offers the benefit of heterosis (hybrid vigor), efficiency, and occasionally marketability (Hammack, 2007). The seedstock industry is directly tied to the commercial and cow/calf industry, as the decision of the producer during selection of breeding stock affects the marketability of their calves (The Beef Site, 2009).

In an overview of genetic strategies in beef cattle, Hammack (2007) discussed the influence of production conditions and markets on cow/calf beef production systems and their genetic strategies. Genetic strategies for a beef cow herd should be based on climate, forage conditions, available labor and management skill, and market timing. Hammack (2007) stressed that pre-weaning and post-weaning performance of calves is important to both ends of the production system, and producers need to be aware of how their management may be impacting their market value.

Seidel (1981) suggested ways in which producers can use genetic strategies to improve the value of their herd. Although cattle are not seasonal breeders, producers manage their herds to reproduce seasonally, a means to align forage growth and calving, aiming for cows to calve prior to the time of the year when the cost of forage is lowest. Cattle have a low reproductive rate, usually calving one calf per year, and have a long interval (~5-6 years) between generations, causing genetic progress within a herd to be limited. Because of this, it is estimated that cattle breeders who work within the same herd for 40 years, will only see an average of six or seven generations within their cattle. Not only are herds limited by a slow reproductive rate, increase in herd count is limited by economic status of the producer. In response to their naturally slow reproductive rate, the cattle industry has made drastic advancements in reproductive technology to offset this slow progression of genetics such as terminal sire systems, embryo transfer and freezing, and artificial insemination.

Cattle that are raised for market purposes have a contrasting life course to those whom are born for genetic seedstock purposes. For many cow/calf operations, the calf crop that is not used for replacement will enter into cattle feeding systems. Cattle feeders

typically purchase calves anywhere from 600-900 pounds (ACFA, 2018), depending on whether the calves are delivered directly from their birth operation or if they were cycled through a backgrounder feeder program.

Post-arrival of cattle into the finisher yard, cattle feeders focus on a high energy ration of forage and grains with days in production ranging from 60-220 days (ACFA, 2018) aiming for a desired market weight of 1,100 to 1,400 pounds (Comerford et al., 2013). The greatest volume of cattle feeding operations in the United States are located in the Great Plains, from Colorado and Nebraska down to Texas (Comerford et al., 2013). There is high-risk associated with cattle feeding, as the beef industry is very cyclical, and cattle prices are heavily influenced by limited feed sources during drought associated with a high cost of feed (Comerford et al., 2013). The market favors higher-grading, uniformly finished cattle over lower-grading, less uniform cattle (Comerford et al., 2013). Profitability in the cattle feeding industry is all about efficiency in both cattle feed intake, and genetic manipulation for efficiency improvement (Trenkle and Willham, 1977).

### 2.2.2. Breed Development

Domestic cattle breeds all link back to one ancestor, the auroch (*Bos prigeminius bojanus*), a large and strong animal, hunted for its meat (Clutton-Brock, 1999). Skeletal remains of this now extinct *Bos* species, show morphological similarities to our domesticated cattle of today (Chroszcz et al., 2011). The National Association of Animal Breeders has 113 breed codes for semen identification, with the origins of these breeds from multiple countries (Hammack, 2009). In their discussion on breeds, Wallace and Ritchie (2006) described the majority of breeds have been developed by the combination of varying cattle strains that are within a similar region and have general type similarities.

Beef-type cattle breeds in North America can be classified into “British”, “Continental”, and “American” breed types (Wallace and Ritchie, 2006). Breeds associated with British type include: Shorthorn, Galloway, Hereford, Angus, and Devon, while breeds associated with the term Continental or Exotic include: Charolais, Simmental, Limousin, Gelbvieh, Maine-Anjou, Salers, Chianina, and the double-muscled breeds, which refers to cattle in a muscular hypertrophic state (Piedmontese and Belgian Blue, to name a few)(Wallace and Ritchie, 2006). The “American” breed type reflects beef breeds that were created in the U.S., that combine 3/8 to 1/2 *Bos indicus* (Brahman) genetics with *Bos taurus* genetics, producing a cross that is better adapted for hot climates (Hammack, 2014). The “American” breeds include: Beefmaster, Braford, Simbrah, Santa Gertrudis, Brangus, Barzona, and Brahmousin (Hammack, 2014).

Hammack (2009) discussed the origin, reproduction systems and genetic strategies of breed creation. Selection for some cattle populations over others began even earlier than the domestication of cattle, from both natural selection and human influenced selection. Shortly following, livestock owners started selecting herds based on production advantages such as milk, meat, and labor purposes. In the late 1700s, human-directed selection had begun linebreeding systems, where highly favored individuals were retained in the herd and used for production, which was later termed “pedigree breeds”. The introduction of a British type breed, Shorthorn cattle, were first seen in 1783 in the United States with Herefords entering the country in 1817. Purebred cattle were idealized originally with upgrading systems to improve the purity of a breed. Upgrading makes use of successive top-crosses of purebed sires on other breeds to improve the breed purity of the progeny, requiring a minimum of three top-cross, or 7/8 blood, to achieve progeny

that are deemed “pure” enough by the registry. Upgrading is the quickest and cheapest system of generating a large population size of purebreds and was used as the primary method of development in the 1960s and 70s.

Hammack (2009) also presented the benefits of crossbreeding systems in the cattle industry and the variation amongst these breeding systems that we commonly see today. In the last 50 years, the industry has realized the value in heterosis produced from the combination of favorable breeds. Prior to this realization, cattle breeders were focused on the purity of their herd from a uniformity standpoint. Now heavily used in production in North America, crossbreeding systems allow producers the ability to make breed combinations that are better suited for specific conditions such as climate type. Breeds are combined in several ways for a multitude of purposes, using a variety of breeding schemes and systems. The first of these schemes, pool breeds, are formed by combining two or more existing breeds, sometimes with the use of upgrading to create a superior genetic pool. The second, formula breeds, use the combination of two or more existing breeds to formulate specific breed percentages, where the exact breed percentage is reported on the individual’s pedigree. The third, composite breeds, are formed from crossing two or more established breed lines in specific percentages, and then intermating the crosses to maintain breed percentages. Composite breeds are vital in maintenance of heterosis in future generations of a cattle population, without an additional crossing requirement, and are more of a crossbreeding system than a new breed creation. The fourth, a true crossbred system, is the hybrid combination that is not used to form a breed or composite. Crossbreds can be used for breeding purposes in continuous crossbreeding systems, with the addition of outside genetic influence to avoid inbreeding.

### 2.2.3. Development of Expected Progeny Differences

Expected progeny differences (EPDs) are a mathematical index that estimates the genetic worth of an animal as a parent (Greiner, 2009). Greatly used in the bovine industry since 1993 (Kriese-Anderson and Dolezal, 1999), EPDs are also important for other livestock species including swine, sheep, and horses. Most major beef breed associations report EPD data for producers as a tool to help the breeder select between two animals giving them the ability to compare one animal to another (Richards, 2016). When comparing two animals of the same breed, EPDs are used to predict differences in expected performance between their future offspring (Greiner, 2009). Although EPDs were not originally designed to compare two animals of different breeds, it can be done successfully using adjustment values for the EPD measurements (Richards, 2016). The U.S. Meat Animal Research Center is responsible for producing the adjustment factor tables to assist in calculating EPDs across breeds (Richards, 2016), which has been valuable for many crossbreeding commercial cattle systems to date.

An individual animal's EPD is calculated from a number of variables, using complex statistical equations, with information including performance data, ancestral data, data from the individual's siblings (collateral relatives), and their progeny (Greiner, 2009). The calculation of EPD does not stop at individual animal, as genetic merit of mates are brought into the equation, along with environmental effects (Greiner, 2009). Environmental effects may include, but are not limited to, nutrition, climate, and geographical location—all of which can be measured between herds (Greiner, 2009). The use of artificial insemination has allowed for multiple herds across varying environments to have similar genetic lines, as semen from the same bull can be used on several cows

without that bull ever physically being part of the herd (Greiner, 2009). Common sires as a production tool have created genetic links between herds and serve as the foundation for across herd EPD calculation (Greiner, 2009).

Production, maternal, and carcass traits are highlighted by EPDs, and are reported in the same units of measurement as the trait under examination (Richards, 2016). Production traits include traits that come to mind when growth is in consideration including birth weight, weaning weight, and yearling weight (Richards, 2016). Weight is an indicator of growth, and weaning and yearling weight are genetic proof of the growth that will be passed from parent to offspring (Greiner, 2009). Because feeder cattle are sold by the pound, cattle with genetics for rapid early growth are valuable for cow-calf producers (Greiner, 2009). Once at the feedyard, yearling weight EPDs are valuable indicators for growth rate of cattle destined for slaughter (Greiner, 2009).

Maternal traits include calving ease, reported as deviations in percentage of unassisted births (Greiner, 2009), and maternal milk EPDs (Richards, 2016). Milk EPDs are reported different from birth and growth EPDs, as they reflect the animal's daughters milking ability, otherwise known as that individual's grandprogeny (Greiner, 2009). Cattle breeders of whom are looking to select bulls based on milk EPDs commonly do so with replacement in mind, planning to retain the bull's female offspring back into the herd (Greiner, 2009).

Carcass trait EPDs have gained popularity with breeders over the last decade, as more emphasis has been placed on the end product (Greiner, 2009). However, they are not available for all breeds (Greiner, 2009). All carcass trait EPDs are expressed as a constant slaughter age endpoint, at approximately 480 days of age (Greiner, 2009).

Carcass EPDs are calculated from two sources, which are both effectively used for selection: 1) steer and heifer progeny at the slaughter house, and 2) yearling bull and heifer progeny who have undergone an ultrasound scan (Greiner, 2009). Calculated carcass trait EPDs include: carcass weight (kg); percentage of intramuscular fat (marbling), which relates to USDA quality grade; ribeye area ($cm^2$), which is an objective assessment of muscling; fat thickness (inches), which is a primary factor in determination of USDA yield grade; and percent retail product, which is a predictor of differences in yields of closely trimmed muscle (Greiner, 2009).

It is suggested producers choose three or four traits they want to select for and ensure they find an animal within the top 25% of those traits within its breed (Richards, 2016). In order for EPD selection of livestock to work as a successful breeding and genetic tool, producers need to keep in mind the environment and any other limitations that might interfere with their program. For example, a producer whom is selecting for bulls with a high maternal milk EPD should consider the economics of available feed resources and the environment that will effect the success of their herd (Greiner, 2009). It is important to note the average EPD for a trait within a breed is not zero (Greiner, 2009). Genetic trend, defined as the improvement of genetics due to selection over a time period, is the reason why the average of a breed is not zero (Greiner, 2009). Selection of any one of the named traits above impacts the genetics of the breed causing an increase in the average for that trait within the breed (Greiner, 2009). Genetic evaluation is not static, with changes due to the constant selection and evolution for specific trait types (Spangler, 2018). Expected progeny differences are currently the most powerful tool to make genetic change in beef cattle (Greiner, 2009), if a producer is not impressed with the

progeny output in their herd, they can select for specific traits that will improve upon the weaknesses.

The development and worldwide use of EPDs has given beef producers a great opportunity to improve the genetics of their herd. Sire selection has proven to have a major impact on the genetic progress of a herd (Greiner, 2009), which should encourage producers to pay close attention when purchasing herd bulls. During the animal evaluation process the combination of EPDs and phenotypic conformation for soundness of structure and reproduction provides the greatest potential for determining the success of an animal as a parent (Greiner, 2009).

### 2.2.4. Terminal Sire System

There are two basic breeding programs currently used in beef cattle production—continuous and terminal breeding systems (Hammack, 2007). The greatest difference between these two breeding programs is whether or not heifers born into the program are retained for breeding purposes (Hammack, 2007). In continuous breeding programs, heifers born into the herd each year are retained for future breeding whereas in terminal breeding systems, no replacement heifers are retained (Hammack, 2007). A wealth of research has been completed surrounding the genetic variation within beef cattle breeds (Cundiff et al., 1986) and it is important to note that in terminal systems the genetic variance of a heifer's performance as a brood cow is not selected for (Hammack, 2007). Terminal sire systems provide complementarity, and the success of progeny are based on the genetic success of the sire (Cundiff et al., 1986). Therefore, replacement females in terminal sire systems are purchased or produced from an outside herd and should be selected for environmental adaptability and maternal characteristics (Hammack, 2007).

Regardless of the breeding program used, sires are the most crucial element for genetic selection, as the annual parentage of the sire is much greater than the dam, with one bull naturally siring 20 to 25 calves per year and increasing with artificial insemination (Hammack, 2007).

Terminal sire systems have shown to be successful in improving varying traits of carcass composition. Marshall (1994) completed a comprehensive review of over 30 beef sire breeds developing a comparison for carcass characteristics including: carcass weight (kg), fat depth (mm), marbling score, longissimus muscle area ($cm^2$), kidney fat (%) and estimated cutability (%). Amongst this data, Charolais ranked first amid the sires for carcass weight and were shown to have the least external fat depth, with a low rank for marbling (Marshall, 1994). Black Angus sires ranked highest for both marbling and thickness of fat cover (Marshall, 1994). Simmentals and Charolais ranked high for estimated cutability, which correlates to their ranking for fat depth and marbling (Marshall, 1994). In general, Charolais cattle are known for their muscle abilities, and Angus cattle are known for their ability to marble (Marshall, 1994), with the Simmental breed fitting between the two on the spectrum. From an economic standpoint for terminal systems, producers should select for carcass traits that have the greatest dollar value per century weight at the packer.

### 2.2.5. Artificial Insemination

Artificial insemination (AI) has been a staple technology for reproduction and genetic improvement of livestock species in recent years and has played an important role in insect and plant reproduction for many centuries (Foote, 2002). The years prior to the 1980s were vital in terms of AI development, making AI technology one of the most

impressive reproductive procedures for male management, semen collection, insemination methods, and preservation (Foote, 2002). The dairy industry has arguably benefited the greatest from the use of AI technology, as their entire genetic line has been impacted by the improved opportunity to alter breeding lines (Foote, 2002). The technology of AI would not be where it is today without the early work of Leeuwenhoek in 1678, and his first view of sperm cells, which he originally termed "animalcules" (Foote, 2002). It wasn't until 1784 that the first successful insemination was performed on a canine species (Spallanzani, 1784), sparking use of AI about 100 years later in other species, including rabbits and horses (Foote, 2002). A well-known Russian researcher, Milovanov, was the first to use AI in cattle in 1964, in addition to designing beneficial advancements for AI technology including the artificial vagina (Foote, 2002). Artificial insemination caught the attention of the Western world in 1933, which led to exponential growth in AI technology in the United States by 1940 (Foote, 2002). The developments in AI technology over the years have opened the door for advanced research on sire selection, semen collection, testicular evaluation, and fertility. In the cattle world, one of the major drivers for the use of AI technology is the opportunity to genetically select bulls for milk production (Foote, 2002). Transmitting superior genetics for milk production is of great importance to the dairy industry, specifically, and ensures that elite bulls are made available to the average producer.

The use of AI in beef cattle has been a growing trend over the last few decades, as beef cattle greatly outnumber dairy cattle in the United States (NCBA, 2016), and producers are keen on herd improvement through genetic selection. The number of beef producers using AI is considerably less than dairy producers because the production

management of beef cows is often on extensive ranges, making it less convenient for AI (Foote, 1981). Crossbreeding programs benefit from AI because it does not require the producer to maintain several different breeds of live bulls within their herd (Foote, 2002). Selection of sires in breeding programs is of great importance, as nearly all genetic progress comes from sire selection (Seidel, 1981). Selection of dams delivers only a 10 to 15% increase in genetic progress, which makes having a good artificial insemination program so important (Seidel, 1981).

Research and development of AI has progressed quickly over the last few decades and AI is now a common reproductive technology for the dairy, swine, horse, beef, and poultry species (Foote, 2002). The use of genomic evaluation in cattle has become a common trend recently, producers using AI as a tool for sire genomic selection (Hasler, 2014). According to Hasler (2014), genomic screening of bull calves, in particular, has caused the reduction in live animal purchase by bull studs. For beef cattle in the U.S., genomic information is greatest for the Angus, Hereford, and Simmental breeds (Hasler, 2014). The advancements in understanding of AI and knowledge gained has developed the successive reproductive strategies that have followed including embryo transfer, embryo freezing, and cloning.

### 2.2.6. Embryo Transfer

The first documented transfer of mammalian embryos was completed in 1890 by Walter Heape using a needle spearing technique for handling rabbit embryos, transferring them directly from donor to recipient with no intermediary step (Hasler, 2014). With only one reported embryo transfer (ET), again in a rabbit, between the years of 1890 and 1920, it wasn't until December of 1950 that Willet et al. (1951) at the University of Wisconsin

were successful in birthing a calf produced from ET. The technology and understanding of the surgical removal and transfer of embryos was developed primarily from the late 1940s into the 1960s (Hasler, 2014).

Embryo transfer was first made practical for use in cattle, followed by other livestock species, and has grown and developed commercially since the 1950s worldwide (Hasler, 2014). Technological development had a great impact on the early growth of the ET industry, in addition to the Canadian government making importation of cattle breeds (Simmental, Limousin, Charolais) from Europe legal (Betteridge, 2003). These cattle breeds were not able to be imported directly into the U.S. from Europe, but upon arrival in Canada, could be hauled to the U.S. (Betteridge, 2003). Because of this transfer from Canada to the U.S., there was a rapid increase in the number of Simmental cattle that were born in the U.S. using ET between the years of 1973 and 1975, with ET playing a huge role in the establishment of Simmental cattle in North America (Hasler, 2014). Unfortunately, in 2003 Canada's exportation of exotic cattle breeds to the U.S. and other nations came to a sudden halt as Canada confirmed its first native case of bovine spongiform encephalopathy (Hasler, 2014). The number of Canadian beef donors used for flush dropped dramatically in the years after 2003 and have never fully recovered (Hasler, 2014).

In 1976, ET research was ignited with studies on nonsurgical embryo recovery (Drost et al., 1976; Elsden et al., 1976; Rowe et al., 1976;), leading to rapid increase of commercial ET operations in Australia, North America, and Great Britain (Hasler, 2014). Researchers at the time referred to the non-surgical procedure of ET as the

"transcervical" method, which gained popularity, as it removed the need for surgery and allowed for practicality in the field (Betteridge, 2003).

Commercially, ET is viable, as it improves the reproductive rates of valuable cows (the donor), which are highly sought after by use of a less valuable recipient cow (Seidel, 1981). The bovine ET procedure commonly begins with superovulation of the donor female (Hasler, 2014), where the use of gonadotropins stimulates numerous ovulations rather than the normal single ovulation (Seidel, 1981). The addition of prostaglandin F2α as a synchronization method for estrus in the donor and recipient females was a major advancement for ovulation (Betteridge, 2003). For more than 35 years, nonsurgical flushing methods by use of silicone catheters in multiple length and sizes has been the common method of embryo recovery (Hasler, 2014).

The 1980s were a time of rapid progress for the ET industry, as the breakthrough in embryo micromanipulation and the successful results from *in vitro* fertilization, completely transformed the practice and were used frequently in cattle (Betteridge, 2003). Embryo splitting was a development from this phase of rapid progress, with commercial kits for splitting entering the market almost immediately (Betteridge, 2003). Although embryo splitting on its own did not catch on, most likely for economic reasons, it was a gateway for improved embryo cryopreservation and sexing (Betteridge, 2003). Since the 1980s, ET has been used extensively as a reproductive technology for purebred and commercial livestock herds. In addition, ET has been viewed as a useful technology for conservation of endangered species, with the birth of a Gaur (India wild cow) from a recipient Holstein cow and a Grant's zebra from a quarter horse (Betteridge, 2003). The

cost associated with ET has become more economically affordable over the last 35 years, with practitioner fees greatly reduced (Hasler, 2014).

### 2.2.7. *In Vitro* Fertilization

The 1970s saw moderate progress in the research field of *in vitro* fertilization (IVF), in particular, maturing livestock follicular oocytes and fertilizing them in vitro (Betteridge, 2003). Research was ongoing throughout this decade, aiming to demonstrate that follicular oocytes from one livestock species could be fertilized in the oviduct of another livestock species (Betteridge, 2003). In bovine, the procedure involves the retrieval of an oocyte from a donor cow, and is then transferred to an inseminated cow for fertilization (Seidel, 1981). When IVF first began, the success rate was low, and many of the oocytes had abnormalities (Seidel, 1981). Toward the end of the 1970s, it was validated by Newcomb and associates that oocytes, matured in vitro, could go through the fertilization process in the oviduct of a cow, to produce a live calf (Betteridge, 2003). Since then, IVF has been used as a generic phrase that includes the procedures of in vitro maturation (IVM) and in vitro culture (IVC), which are conducted in this order to produce embryos *in vitro* (Hasler, 2014). Applications of IVF over the years have included research and reproductive advancements to combat infertility barriers, as a quality control measure for semen, and as a means to recover ovaries from cull females at packing houses for use in IVF (Seidel, 1981; Hasler, 2014).

The cattle industry had its first accomplishment with IVF in 1977, where semen was capacitated in the oviduct (or uterus) of a cow who was in estrus (Hasler, 1998). The first IVF calf named Virgil (Betteridge, 2003), born in 1981, was a product of the University of Pennsylvania's School of Veterinary Medicine, and was the result of a

successful transfer of a 4-cell embryo into the oviduct of a recipient cow (Brackett et al., 1982). The birth of the first calves produced solely from IVM, IVF, and IVC occurred in 1987 (Hasler, 2014). The original use of IVF in cattle was for research purposes only, using oocytes from females that had been superovulated (Hasler, 1998). The improvement of IVM techniques permitted the use of procured ovaries from the slaughterhouse as a study aid for fertilization and culture methods (Hasler, 1998). Therefore, IVM was required in order for IVF to be efficiently studied (Hasler, 1998).

Transvaginal 'ovum pick up' (OPU) is the most commonly used method for follicular oocyte collection (Betteridge, 2003), and was developed in 1988 as a method that used ultrasound-guided aspiration (Hasler 2014). The success of OPU depends on multiple factors including donor age and breed differences (Galli et al., 2001). The age of the oocyte donor ranges from prepubertal to mature cows, with calves only two to three months in age acting as donors (Galli et al., 2001). From the perspective of many cattle breeding companies, young heifer calves are ideal donors, as they accelerate the process of genetic improvement by reducing the time between generations (Galli et al., 2001), However, the age of the donor impacts the number of viable embryos, with mature cows having the greatest number of good embryos relative to percent cleaved (Galli et al., 2001). Breed type also impacts OPU success rate as different breeds have differing numbers of follicles present on the ovaries (Qi et al., 2013). *Bos indicus* breeds of cattle tend to have more follicular waves and a greater number of small follicles in comparison to *Bos taurus* breeds (Qi et al., 2013). The *B. indicus* breed named Nelore has the largest number of ovarian follicles, and on average, has 18 to 25 naturally recovered oocytes per OPU session (Qi et al., 2013).

Inadequate sperm numbers during insemination of the mature oocyte originally formed a barrier for IVF procedures in cattle, resulting in lowered IVF success rate (Hasler, 1998). As a method to identify and combat the likelihood of a failed oocyte fertilization, the fertility of bulls has been determined using the cleavage rates of inseminated oocytes as an index (Hasler, 1998). An immature oocyte has the ability to produce a varying number of embryos through IVF (Hasler, 1998), improving the opportunity for reproduction of that certain genetic line. When OPU and IVF technology are combined, the average donor cow is capable of producing over 50 calves per year (Qui et al., 2013).

### 2.2.8. Embryo Freezing

A few decades after the discovery of ET, one of the most exciting and far-reaching advances of the embryo-based reproductive industries occurred. Whittingham et al. (1972) successfully froze, thawed, and transferred mouse embryos, which produced live young. A year later, Wilmut and Rowson (1973) produced the first bovine offspring from a frozen, and then thawed, blastocyst. The process of embryo freezing is termed 'cryopreservation', and embryos selected for this procedure are chosen based on their stage of maturity (Hasler, 2014).

Although embryo freezing was a breakthrough in terms of opportunity to market and sell livestock genetics internationally, the trend did not catch on immediately. The reason for this; low procedural survival for younger embryos during transfer (Betteridge, 2003). Practical application in the field for embryo freezing followed later in the same decade, when researchers from Cambridge University encouraged a shift to transcervical recovery and usage of a late morulae, which had increased tolerance to freezing and

thawing overall, improving survival rate (Betteridge, 2003). In both the United States and Canada, the percentage of frozen embryos has risen steadily, and is consistently higher for beef embryos over dairy (Hasler, 2014).

With the success of embryo freezing, Gardner and Edward proposed the technique of sexing embryos during transfer, using sex chromatin analysis, which was then modified to use chromosomes for sexing instead (Betteridge, 2003). Christmas day, 1975, was monumental in terms of bovine embryo sexing, with the birth of the first sexed calf (Betteridge, 2003).

### 2.2.9. Gene Alterations- CRISPR Cas-9

Clustered regularly interspaced short palindromic repeats (CRISPR), a gene alteration technology, was first discovered in the early 1990s, and has become one of the most popular tools for gene editing as it is precise, inexpensive, and easy to use (Tangermann, 2018). The power in altering DNA makes CRISPR an exciting revolutionary technique and is expected to be used in correcting the genetic errors and eliminating microbes that cause disease, resurrection of extinct species, healthier food alternatives, and eradication of dangerous pests (Tangermann, 2018).

When it comes to livestock species, CRISPR allows for faster paced genome editing than other technologies, and the production of animals with more extensive genetic modifications (Shrock and Guell, 2017). The CRISPR-Cas9 technology gives scientists the ability to change an organism's DNA, by allowing for genetic material to be added, removed, or altered at specific locations in the genome (GHR, 2018). There are approximately 20 nucleotide single guide RNA in CRISPR-Cas9, that undergo base-pairing with a target DNA sequence, which is far less complex than many of the similar

gene altering techniques previously used (Shrock and Guell, 2017). The CRISPR-Cas9 system is a tool that allows researchers to inactivate or modify genes by creating sequence-specific double-strand breaks (Shrock and Guell, 2017). Genome editing technologies have already been used in disease related gene function in cattle, where disease-related gene edited cattle have already been produced (Yum et al., 2018), for example, tuberculosis-resistant cattle (Wu et al., 2015). Research using CRISPR-Cas9 has also focused on prion diseases in cattle, where a prior protein mutation enabled the production of prion-deleted cattle, and has allowed for greater understanding of the function of the prion (Yum et al., 2018).

Genome editing technology has allowed for improvement of genetic traits in bovines specifically, such as the increase in muscle from the myostatin gene mutation (Yum et al., 2018). In addition, dehorning has been identified at the genome level, where transgenic cattle receive dehorning genes from cattle that are born naturally without horns (Carlson et al., 2016). These advances will benefit the cattle industry in the future, from both a productivity standpoint and on the animal welfare front (Yum et al., 2018). However, the United States FDA has not approved livestock produced from genome editing technology to enter into the food chain (Yum et al., 2018), and although CRISPR technology has gained a great amount of attention in the last 20 years, there are still technological and ethical hurdles that have kept CRISPR from becoming a common practice (Tangermann, 2018).

## 2.3. Beef Grading

### 2.3.1. USDA Quality Grading

Quality grade (QG) is based primarily on intramuscular fat content (marbling) and is used to sort carcasses into groups that are more homogenous in palatability (Allen, 2004). Quality grade is an important outcome of beef production, as it influences consumer's acceptance of beef, and impacts purchasing (Neely et al., 1998). In addition to marbling, QG is also influenced by maturity of the carcass, which is an estimate of physiological age of the animal (Allen, 2004). Prior to 2017, USDA used the degree of ossification of cartilage of the sacral, lumbar, and thoracic vertebrae and color and texture of the ribeye area as an indicator for maturity (Hale et al., 2013), where maturity was divided into a grade system from A to E, with A representing young carcasses, and E representing old, mature carcasses (Allen, 2004). Effective as of 18 December 2017, the USDA maturity scoring system now evaluates dentition as an indicator of age, and is monitored by the Food Safety and Inspection Service (FSIS) (USDA, 2017). Carcasses determined to be less than 30 months of age (MOA) are classified as A maturity, and final QG (with exception of dark cutters), is determined by degree of marbling (USDA, 2017). In the scenario where a carcass exhibits D or E maturity, maturity overrides dentition score (USDA, 2017). Any carcasses under 30 MOA that show advanced skeletal maturity are not eligible to grade Prime, Choice, Select, or Standard, and therefore, these grades are restricted to young cattle (USDA, 2017).

Once the carcass has been ribbed between the $12^{th}$ and $13^{th}$ rib, a grader, either human or camera (Allen, 2004), assesses the ribeye for amount of marbling present, and places a grade of either Prime, Choice, Select, or Standard for the carcass quality (Allen,

2004). Each of the four quality grading classes are broken down into three marbling score subclasses, and into 100 subunits, usually reported within tenths of each other (USDA, 2017). Prime, the QG with the greatest degree of marbling, is divided into abundant, moderately abundant, and slightly abundant, Choice QG includes moderate, modest, and small (Hale et al., 2013). Select QG has marbling of slight, and a Standard QG, which has the least marbling, is divided into traces and practically devoid (Hale et al., 2013).

Cattle that are over 30 MOA, are graded using the traditional method, receiving a grade of either Commercial, Utility, Cutter, or Canner for the carcass quality (AMS, 2018). Cattle that qualify for a minimum of the Commercial grade will differ in cutability in comparison to younger cattle grades, due to a wide variance of muscling and degree of fatness combinations (AMS, 2018). Cattle that qualify for the Commercial grade have the greatest degree of fat cover over the back, ribs and loin, and have firm muscling, compared to Canner grade cattle, which are inferior in fat and muscling (AMS, 2018).

### 2.3.2. USDA Yield Grading

Yield grade (YG) is an estimate of the percent of boneless, closely trimmed retail cuts that a carcass will yield (Allen, 2004). These retail cuts are derived from large primals of the animal, including the round, loin, rib and chuck (Hale et al., 2013). Yield grade is numbered from one to five, with a YG 1 having the greatest expected yield and a YG 5 having the lowest expected yield of meat (Hale et al., 2013). Each individual carcass is assigned a YG calculated from the YG equation, a formula that includes the measure of fat depth over the *longissimus dorsi* (ribeye), kidney, pelvic, and heart (KPH) fat as a total percentage of carcass weight, hot carcass weight, and ribeye area, measured using a dot-grid to determine area (Allen, 2004). Fat depth of the *longissimus dorsi* is

measured at 3/4 of the length of the muscle, between the 12th and 13th rib of the animal, and can be adjusted by the meat grader if the fat cover throughout the carcass is not homogenous (Allen, 2004).

### 2.3.3. International Standards for Quality & Yield Grading

Standards and regulations that determine the quality and yield of a beef carcass vary worldwide. The grading regulations for countries that have a predominant beef slaughter industry will be included in this review. Regulated grading systems are vital in ensuring that quality product is produced for consumers and to provide a common language for the trade of carcasses (Allen, 2004). One of the world's largest beef producing countries, the United States, is often used as a guideline in the development of other grading systems internationally.

In 1927, the first federal system of beef grading was introduced into the United States (Allen, 2004). Since then, the industry has gone through many changes and advancements in both knowledge and technology regarding how beef carcasses are analyzed (Allen, 2004). Grading services are voluntarily provided by the USDA and are graded on a quality and yield basis (USDA, 2017).

Australia, well-known for beef export and production, currently lacks a nationally accepted grading system for beef carcasses (Allen, 2004). Instead, Australia has two systems in place, an initiative from Meat and Livestock Australia (MLA) called Meat Standards Australia (MSA) (Allen, 2004) and a program partially owned by MLA called AUS-MEAT, that combines both AUS-MEAT and AUS-QUAL (Ausmeat, 2018). The carcass variables that are included in the meat grading system for MLA include: carcass weight, sex, tropical breed content, hanging method (either *Achilles* hung or

tenderstretch), ossification (to determine carcass maturity), marbling (using both MSA and AUS-MEAT measurements), rib fat (minimum of 3mm required), pH and temperature (MLA, 2016).

Meat and Livestock Australia developed the MSA program, aiming to ensure the production of quality product from the meat industry and guaranteeing that the consumer has a positive eating experience every time they purchase a specific cut of meat (MLA, 2016). This led MLA to create a branded beef product, labelled "MSA certified beef" that differentiates between three levels of eating quality (MSA, 2018). The MSA eating quality grades are MSA three star (MSA Graded), four star (Premium), and five star (Supreme), from least to best eating quality respectively (MSA, 2018). On the label for MSA graded beef, the eating quality grade is paired with cooking method and aging period, whereby a single packaged meat product can have a varying "star" rating based on cookery and aging (MSA, 2018). For example, on the packaging of an MSA graded striploin, a consumer may find two separate star grades, where a three-star eating quality was assigned when the product was cooked as a roast and aged for five days, but a four-star eating quality was assigned when the same product was aged for 28 days (MSA, 2018). The four main eating quality traits: tenderness, juiciness, flavor and overall liking, have been researched thoroughly in the development of MSA as a means to understand the individual and combined effects of these four traits and their impact on the star eating quality standard (MLA, 2016).

The development of a camera grading system called VIASCAN by MLA was another initiative to advance the Australian meat industry (Allen, 2004). The camera grading instrument uses video image analysis (VIA) to predict the amount of boneless,

closely trimmed product for sale from a carcass (Jones et al., 1995). Images of each carcass are captured by a colored video camera and saved in a computer system where color and dimensional measurements are related to important production traits, which then predicts carcass yield (Condon, 2017). Cannell et al. (1999) studied the accuracy of VIASCAN on its own and in combination with the USDA YG factors for carcass cutability. Results from this study reported that VIASCAN predicted fabrication yields more accurately than other online yield grade systems of the time, and when combined with USDA YG, was able to predict carcass cutability more accurately (Cannell et al., 1999). Since its debut in the late 1990s, the programming of VIASCAN has been altered, and is currently used by one of New Zealand's top lamb processors (Condon, 2017).

The formation of AUS-MEAT Limited in 1998 was part of a restructure initiative in Australia's red meat industry that operates as a joint venture between MLA and the Australian Meat Processor Corporation (Ausmeat, 2018). AUS-MEAT is responsible for setting standards for exportable meat and represents the partnership between government and industry (Ausmeat, 2018). There are three cornerstones that AUS-MEAT focuses to provide including: integrity in products and systems within the food supply chain; industry support, to ensure the Australian industry follows local and international growing and production regulations; and standards, which protect the reputation of the food industry in Australia (Ausmeat, 2018). The objectives of AUS-MEAT are management of red meat trade descriptions and national accreditation standards to ensure processors' quality is sufficient (Ausmeat, 2018). Trade descriptions are referred to as "AUS-MEAT language" and provide a standard way of describing meat products for retailers and customers to identify and order meat (Ausmeat, 2018). Currently, AUS-

MEAT is Australia and New Zealand's leading agribusiness for training, auditing, and certification (Ausmeat, 2018). Services provided by AUS-MEAT include: training and certification in livestock, meat, co-products (hides and rendering), horticulture, ethics (animal welfare), poultry and eggs (Ausmeat, 2018).

In April 2018, the most recent edition of the "Handbook of Australian Beef Processing" was released, highlighting the AUS-MEAT language and grading system (Ausmeat, 2018). The AUS-MEAT marbling system is measured from zero (least marbling) to nine (most marbling), rib fat measurement measures thickness of subcutaneous fat at the specified rib, and eye muscle area is the surface area of the *M. longissimus dorsi* at the ribbing site which varies from the $10^{th}$ to $14^{th}$ rib (Ausmeat, 2018). In addition to these measurements, meat color, maturity (ossification), and fat color are all included in the carcass evaluation process (Ausmeat, 2018).

In 1988, the Japan Meat Grading Association (JMGA) developed a grading system that established a set of guidelines called the "Beef Carcass Grading Standard", which evaluate the yield and quality of meat (JMGA, 2000). The yield score is divided into three grades, A through C, and is an estimate of percentage of yield of a carcass using a multiple regression equation (JMGA, 2000). The left side of the carcass is used for all measurements in the equation, and much like the United States grading system, the carcass is ribbed, however, instead of between the $12^{th}$ and $13^{th}$ rib, it is ribbed between the $6^{th}$ and $7^{th}$ (Allen, 2004). Using the $6^{th}$ and $7^{th}$ rib as a measurement source, the ribeye area, rib thickness (intermuscular fat), and subcutaneous fat thickness are used to estimate yield (JMGA, 2000).

The meat quality score is determined by 1) beef marbling, 2) meat color and brightness, 3) firmness and texture of meat, and 4) color and luster of the fat, and using this criteria, is classified into five grades, No. 1 to No. 5 (JMGA, 2000). The Japanese meat quality grading system evaluates beef marbling using the Beef Marbling Standard over three muscles (*longissimus thoracis,* dorsal *semispinalis dorsi*, *semispinalis capitis*) on the 6$^{th}$ and 7$^{th}$ rib cross-section (Allen, 2004). Meat color and brightness is evaluated using the Beef Color Standard, which has seven standards, with one being the lightest colored meat, and seven being the darkest colored meat (JMGA, 2000).

The Canadian standards for carcass grading are reported in full by the Beef Cattle Research Council (2016), and follow a system developed by the Government of Canada, run by a private, non-profit corporation named the Canadian Beef Grading Agency. Five characteristics make up the QG in Canada, including maturity (age), sex (pronounced masculinity), conformation (muscling), fat (color and texture), and meat (color, texture, and marbling). The highest marbled animals receive a grade of 'Canada Prime', which requires the carcass to have at minimum, slightly abundant level of marbling, following the USDA marbling card system. The 'A Grades' (A, AA, AAA) represent increasing levels of marbling from Canada A to AAA respectively, equivalent to USDA Standard, Select, and Choice, with the 'B' grades similar in youthfulness, but that fail to meet at least one of the other four characteristic categories. For carcasses that fail to meet the characteristic requirement for youthfulness, they are labelled as a 'D' grade, with a grade 'E' representing mature bulls and youthful bulls that have a pronounced level of masculinity.

The Canadian yield grade system is divided into three levels of estimated yield percentage, with greatest estimated yield as Canada 1 (59% or more) and least estimated yield as Canada 3 (53% or less) (BCRC, 2016). Overall carcass yield is predicted using measurements of fat depth and ribeye area length and width (BCRC, 2016). The Canadian Food Inspection Agency approved the e+v grading instrument, that captures and analyses the ribeye area between the 12$^{th}$ and 13$^{th}$ rib on both sides of the carcass, as a means to reduce the variability associated with human grading (BCRC, 2016). There are similarities and differences between each of the grading systems discussed above, but all have one focus in mind, to produce and sort quality product for the consumer.

## 2.4. Determining Tenderness

### 2.4.1. Tenderness Theories

The juiciness, tenderness, and flavor of a food product refers to the overall palatability of that product (Miller, 2004). In meat specifically, palatability refers to how meat tastes, and relates to the consumer eating experience (Miller, 2004). During mastication, juices are released from the meat product, and the amount of these juices identified by the consumer is referred to as overall juiciness (Miller, 2004). Tenderness is defined by how easily meat breaks down during the chewing process (Miller, 2004), and is influenced by four general characteristics: 1) postmortem proteolysis, 2) connective tissue quantity and quality, 3) contractile state and 4) intramuscular fat percentage (Belew et al., 2003). Intramuscular fat percentage, termed “marbling”, is of greatest interest in this discussion. Previous literature has reported contrasting values in terms of variation in tenderness that is accounted for by marbling. Jerimiah et al. (2003) reported marbling

accounts for 12-14% of the total variation in tenderness, whereas Blumer (1963) reported only a 5% influence.

The relationship between tenderness and intramuscular fat content was hypothesized by Smith and Carpenter (1974) to have four possible explanations: bulk density (bite effect), the lubrication effect, the insurance theory, and the strain theory. The bulk density effect hypothesizes that as marbling increases, the overall density of the bite of meat decreases, to the extent that meat with a high proportion of marbling is of greater tenderness. The lubrication effect focuses on the consumer perception of juiciness and tenderness of intramuscular fat during mastication, stimulating the salivary glands. This effect hypothesizes that meat with a greater degree of marbling is associated with increased tenderness and juiciness due to the lubrication of the mouth. The insurance theory focuses on the ability of the intramuscular fat to serve as buffer for any negative effects on the meat from cooking. The fat (marbling), is said to insulate the meat against the effects of extremely high temperatures. The strain theory emphasizes the effect of fat content on connective tissue durability, with an inverse relationship between strength of tissue and fat deposition.

### 2.4.2. Warner-Bratzler Shear Force Analysis

The idea of using shearing as an objective measure for meat tenderness was developed by Warner in the early 1920s and was later refined by Bratzler for certain specifications (Wheeler et al., 1997). These specifications included the refinement of blade shape, where a triangular shaped blade had the least variation between samples, and a circular blade had the greatest variation (Bratzler, 1932). Bratzler (1932) also analyzed the thickness of blade, reporting that thin blades (0.04 inches) had less variation than

thick (0.22 inches), in addition, he made implications on the material of the cutting edge of the blade, and ways in which the procedure could be altered for future use.

Coining the procedure the "Warner-Bratzler Shear Force Analysis" (WBSF), consistent sample collection and preparation are critical for obtaining accurate tenderness values (Wheeler et al., 1994). One steak collected from the *longissimus lumborum* between the 12$^{th}$ rib and the 5$^{th}$ lumbar vertebrae of the carcass, should be cut to one inch thick, and should be trimmed free of fat and bone (TAMU, 2018). Following removal from the carcass, the steak should undergo vacuum packing, followed by an age period of 14 days (0 to 3°C) postmortem prior to freezing (-20°C) for analysis at a later date (AMSA, 2015). When ready for tenderness analysis, steaks should be thawed to an internal temperature of 2 to 5°C, usually taking 24 to 36 hours to reach this internal temperature (AMSA, 2015). Once completely thawed, steak samples should have thermocouples inserted into the geometric center for temperature measurement, cooked to an internal temperature of 40°C before flipping over, to finish cooking to an internal temperature of 71°C (AMSA, 2015). After allowing steaks to cool down, to measure for drip loss, steaks should be cooled overnight at 2 to 5°C before the coring process. A minimum of six cores should be obtained from each steak parallel with the long axis of the muscle fibers (AMSA, 2015). Using the Warner-Bratzler shear force machine, each core should be sheared close to the center of the sample, to avoid hardening that occurs toward the outside of the meat sample (AMSA, 2015). The machine should be set to have a crosshead speed of 200 to 250 mm/min, measuring the kg of pressure to slice through the core sample, and once completed, the average of the cores should be used to determine tenderness of the original steak (AMSA, 2015)

In 2011, the USDA developed a tenderness certification using WBSF standards, with two certification levels, “Certified Tender” and “Certified Very Tender” (ASTM, 2011). The WBSF value was set at 43.25 N (4.4 kg) and lower and 38.25 N (3.9 kg) and lower for each level respectively (ASTM, 2011). Research conducted by Miller et al. (2001) reported that 99% of consumers were satisfied with the tenderness of their steak when it held a WBSF shear value of 33.34 N (3.4 kg) or less, which is reflected in the tenderness certification standards. Analysis by WBSF provides a numerical measurement of meat tenderness, and to date, has been the most widely used instrumental measure of its kind (Wheeler et al., 1997).

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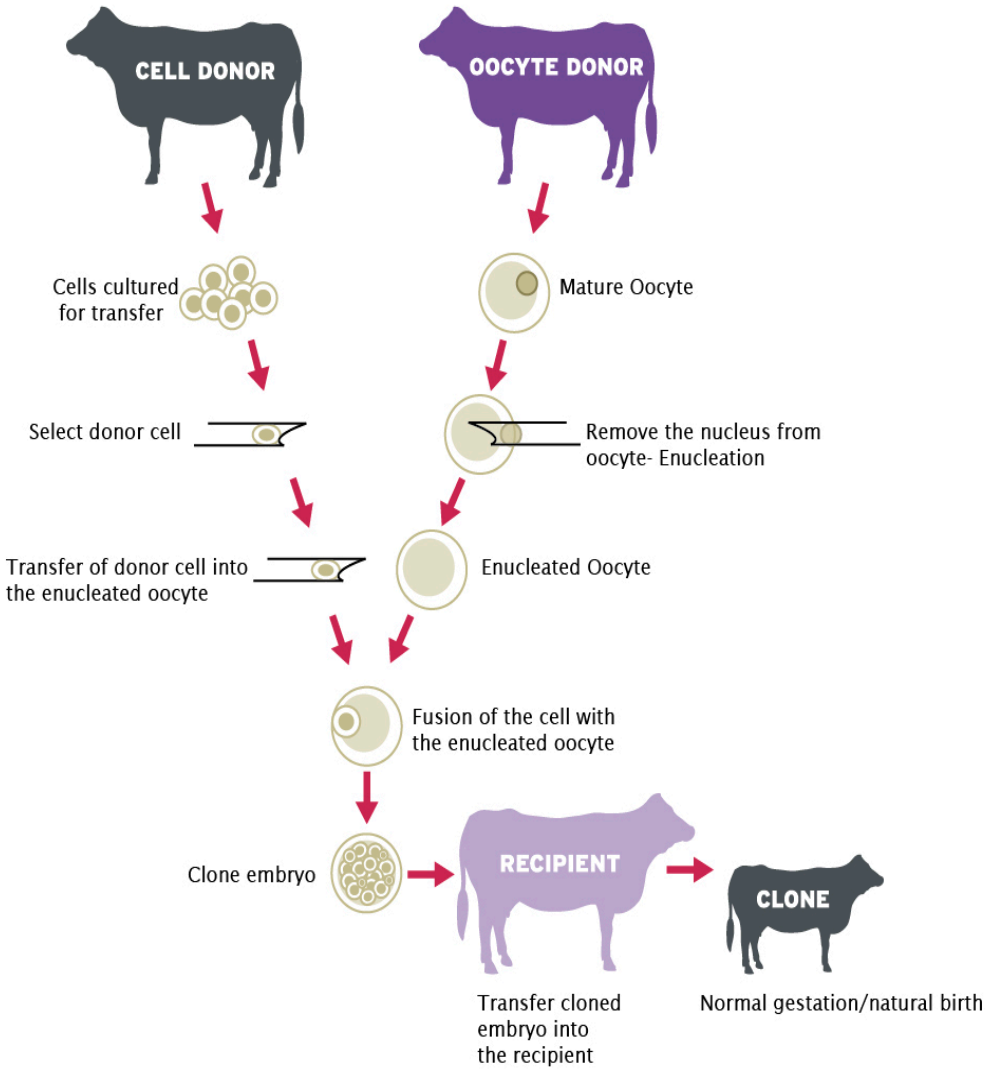


Fig. 2.1. Process of oocyte enucleation in somatic cell nuclear transfer (ViaGen, 2012).

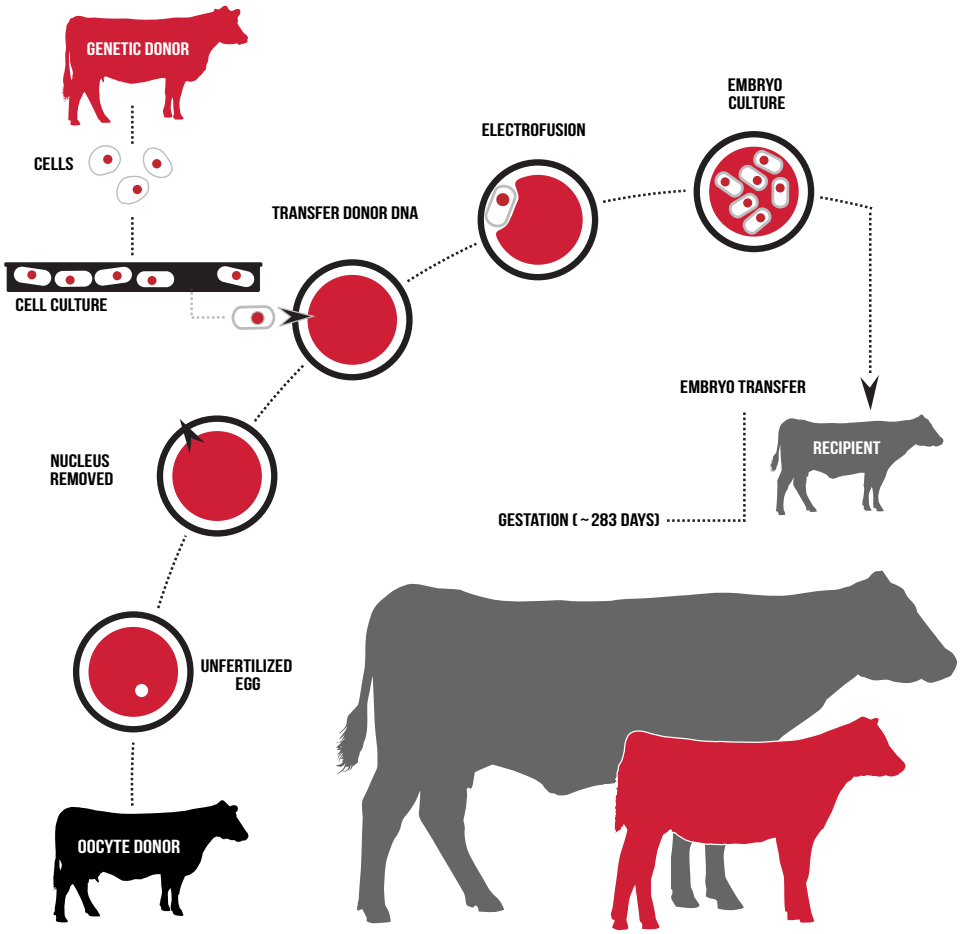


Fig. 2.2. Somatic cell nuclear transfer cloning process (TransOva, 2018).

# CHAPTER 3

# LIVE AND CARCASS PRODUCTION TRAITS FOR PROGENY OF PUREBRED SIRES IN COMPARISON WITH THE CLONE OF A USDA PRIME YIELD GRADE ONE CARCASS

## 3.1. Abstract

Cloning is a technology by which genetic material can be salvaged and replicated for future herd improvement. Carcasses that grade USDA Prime – Yield Grade 1 (P1), represent a rare and antagonistic outcome and are a goal for terminal sire selection. A terminal sire progeny test generated outcomes for a crossbred bull (14% Zebu, 86% Angus; Alpha), born in 2012 through somatic cell nuclear transfer from a carcass that graded P1. Alpha progeny (steers and heifers) were compared against progeny of three purebred (Angus; Charolais; Simmental) reference sires. Live production traits included weaning weight, morbidity, mortality, and days on feed; carcass traits included abscessed liver frequency and lung health, individual quality and yield grade parameters, and total carcass value and value per cwt. A completely randomized experimental design structure was used; data were analyzed using a mixed model with sire as the fixed effect and harvest date, sex, and pen as random effects. For live cattle traits, Alpha progeny were the lightest ($P = 0.03$) in weaning weight (kg), tended ($P = 0.08$) to have the lowest frequency of morbidity, and Alpha-sired heifers tended ($P = 0.07$) to have the heaviest weight (kg) at feedlot arrival. For carcass traits: Alpha-sired heifers and steers had the largest ($P < 0.01$) Longissimus muscle area next to the Charolais sire, Alpha-sired steers

had the lowest ($P$ <0.01) measure of fat thickness next to the Charolais sire, and Alpha-sired heifers and steers had the lowest ($P$ <0.01) yield grade next to the Charolais sire. Carcass value per cwt differed ($P$ < 0.01) for steers; Alpha-sired steers were worth the greatest value per cwt, and numerically, Alpha-sired heifers were worth the greatest value per cwt. These data indicate Alpha progeny performed comparably to high performing reference sires from multiple breeds for terminal sire production traits.

## 3.2. Introduction

Beef producers continuously search for production ventures that will improve the economic value of their herd. Herd improvement can result from both environmental and genetic influencers. One technology used in genetic improvement is somatic cell nuclear transfer (SCNT), commonly termed “cloning”. The cloned individual will be an identical genetic copy of the animal from which the DNA was originally derived (Gabor and Gjerris, 2006). Having the ability to salvage and replicate genetic material is especially beneficial for genetic outcomes that are rarely found within populations but are highly desired by the producer. The combination of a USDA Prime Quality Grade and a USDA Yield Grade 1 (P1) represents a rare antagonistic outcome, observed in only 0.07% of the U.S. beef population (Boykin et al., 2017) that combines two premium carcass outcomes of economic value for cattle producers.

The objective of this study was to compare the live and carcass production traits of progeny from four bulls in a terminal sire system. A terminal sire system is a basic breeding program in which no replacement heifers are retained for breeding purposes (Hammack, 2007), and the success of the progeny are based greatly on the genetic success of the sire (Cundiff et al., 1986). Sire selection is one of the most crucial

elements for genetic selection, as the annual parentage of the sire is between 20 to 25 calves through natural breeding, and increasing with implementation of reproductive technologies (Hammack, 2007). Progeny of three purebred sires (Angus, Charolais, Simmental), all of which are referenced for carcass characteristics within their breeds, were compared with progeny of a crossbred bull (14% Zebu, 86% Angus; Alpha) born in 2012 through SCNT, from a carcass that graded P1, to determine his genetic success as a sire.

### 3.3. Materials and Methods

All experimental procedures followed the guidelines described in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, Savoy, IL). The cloning procedure which created Alpha was completed under Institutional Animal Care and Use Committee (IACUC) 03-11-14. The progeny produced in this study were generated from semen given to Cactus Feeders (owner of dams) to be used for artificial insemination. Live cattle in this study were under direct care and supervision of Cactus Feeders. We received all live animal data from Cactus Feeders, thus, there was no requirement for an IACUC to be used for this study.

#### 3.3.1. Cloned sire procedure

The bull used in this study, "Alpha", was a product of somatic cell nuclear transfer (SCNT) performed with a tissue sample from a steer carcass that graded USDA Prime and Yield Grade 1 at the harvest facility in which he was discovered in 2012. The carcass from which Alpha was cloned was chosen based on genetic attributes that are of value in the USA beef population, including: longissimus muscle area of 102.6 $cm^2$, subcutaneous fat thickness of 1.1 cm, 354.7 kg hot carcass weight, calculated yield grade

of 1.98, and USDA marbling score of slightly abundant 70 (Slab$^{70}$, USDA Prime). In addition, DNA from Alpha was sent to Pfizer (Groton, CT) for genotypic analysis using GeneStar testing, reporting that Alpha was an ultrablack, with a genetic makeup of Angus crossed with Brangus x Black Angus. Alpha's genetic breed percentage was 86% Angus and 14% Zebu, determined using BreedSure genetic testing (ViaGen, 2018). Pfizer compared Alpha's genotype against all other cattle in their database, ranking Alpha in the 6, 8, 10, and 30 percentiles for tenderness, palatability, feed efficiency, and marbling, respectively. ViaGen LLC, a commercial livestock and pet cloning company, performed the enucleation and SCNT transfer procedure. The embryo was placed into a recipient cow, who carried out gestation at the Nance Ranch (Canyon, TX). Alpha was born in July 2012, and first milk was administered through a calf bottle. Alpha was raised and cared for at the West Texas A&M University Nance Ranch (Canyon, TX).

3.3.2. Randomization and artificial insemination

British x Continental beef cows (n = 1269) were artificially inseminated (AI) after synchronization, with semen collected from one of three selected purebred sires of the Charolais, Simmental, and Black Angus breeds, or from Alpha. Dams were AI'd on 3 and 4 December 2015, after timed AI synchronization. Ten straws of semen collected on each of the 4 sires were thawed at a time, and inserted into dams at random as they came through the processing shoot. In total, 312 straws of the crossbred sire, 300 straws of the Angus, 299 straws of the Simmental, and 358 straws of Charolais were delivered to the dams by 4 trained AI technicians.

The Full French Charolais sire, registered in the American International Charolais Association as Anjou Pure Power 184Y FFM837595, ranked in the 4$^{th}$ percentile of his

breed for ribeye area (REA) and in the 15th percentile for carcass weight (AICA, 2018). The Simmental sire, reported by ABS Global (2018) as Dikemans Sure Bet 29SM0390, ranked in the 4th percentile of his breed for marbling, and Black Angus sire, Rito Revenue 5M2 29AN1688, ranked in the top 1% of his breed for marbling.

Cleanup bulls (SimAngus breed) were turned out four days after AI to ensure females were bred. Of the 1269 dams that were exposed to semen, 869 live calves were born. Of the live calves born Alpha, Angus, Charolais, and Simmental sired 104, 134, 157, and 124 calves, respectively. Resulting in 350 calves that were sired by a cleanup bull (n = 314) or did not have sufficient DNA collected to link their parentage data (n = 36). During time of gestation, dams received a limit-fed standard diet composition and a supplement containing wheat middlings (53.57%), distillers grains with solubles (24.21%), and calcium carbonate (17.29%), in addition to nutrients and supplements vital for fetal health.

3.3.3. Calf identification and weaning

Progeny from these crosses (n = 876) were born in fall 2016, at Syracuse Feedyard, a confined cow/calf operation located in Syracuse, KS. Calves were tagged at birth with birthdate, and DNA samples of each calf were taken at intermediate processing and matched with an EID tag and individual visual ear tag. Sire semen was sent to Quantum Genetix, a livestock genetics lab in Saskatoon, AB, CAN, to produce a DNA sequence of each sire for offspring by sire analysis.

At birth, Syracuse Feedyard personnel evaluated calves on overall health, and dams on maternal ability. Calves born to unfit dams or in poor health condition (n=69), were transported to a dairy calf ranch located in Syracuse, KS, where they received

focused and elevated care to improve upon health. Of the calves raised at Fullmer, Alpha and the Simmental sired the least number of calves (2 calves per sire), the Angus sired 3 calves, and the Charolais sired 11 calves.

Calves in adequate health condition (n = 807) remained at Syracuse Feedyard, were weaned the 23 and 24 of January 2017 (Avg WW= 213.6 kg +- 5 kg), and were administered Ultrabac 7 (Zoetis Inc., Kalamazoo, MI), Pyramid 5 (Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO), Synanthic (Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO), Dectomax (Zoetis Inc., Kalamazoo, MI), and Cylence (Bayer HealthCare LLC, Shawnee Mission, KS). Post-weaning, calves were fed a baseline grow ration as a backgrounder diet, and health of the individuals was monitored daily by Syracuse Feedyard personnel.

On 1 May 2017, a snowstorm struck Syracuse, KS causing fatality (n = 114) in weaned calves located at the Syracuse Feedyard, removing these individuals from the study. Calves from the calf ranch were transferred to Syracuse Feedyard once health status was achieved, and were weighed using a platform scale upon arrival in mid May 2017. Weights from these calves are absent from weaning weight data.

3.3.4. Processing and sorting upon feedyard arrival

On 13 June 2017, calves (n = 754) were sorted by sex for shipping to Ulysses, KS, the following day. Upon arrival at Ulysses Feedyard, the heifers (n = 370) and steers (n = 373) were sorted five-ways per sex (totaling 10 pens) based on a combined frame score and weight measurement sorting system (Garrison, 2005). The sorting system grouped cattle by weight and frame; steers grouped into pen 490 (254.2 kg +- 32.8 kg), 491 (273.5 kg +- 16.7 kg), 492 (294.6 kg +- 18.1 kg), 493 (308.4 kg +- 21.2 kg), and 494

(335.8 kg +- 19.3 kg); heifers grouped into pen 495 (220.7 kg +- 21.6 kg), 496 (257.0 kg +- 13.8 kg), 497 (266.7 kg +- 19.0 kg), 498 (286.0 kg +- 24.0 kg), and 499 (307.7 kg +- 29.6 kg).

During five-way sorting, steers were implanted (based on arrival weight) with either Revalor-XS (40mg of estradiol + 200mg of trenbolone acetate; Intervet Inc., Millsboro, DE) (Pen 490, 491, 492), or Revalor-IS (16mg of estradiol + 80mg of trenbolone acetate; Intervet Inc., Millsboro, DE) (Pen 493, 494) to promote growth. Heifers were implanted (based on arrival weight) with either Revalor-200 (20mg of estradiol + 200mg of trenbolone acetate; Intervet Inc., Millsboro, DE) (Pen 495, 496, 497), or Revalor-IH (8mg of estradiol + 80mg trenbolone acetate; Intervet Inc., Millsboro, DE) (Pen 498, 499). Heifers were rectally palpated with an electric probe to verify possibility of pregnancy. For heifers (n = 3) in which palpation indicated pregnancy, lutalyse and dexamethasone were administered to stimulate abortion. Males identified as intact bulls (n = 11) were removed from the study.

A single round of re-implant was administered to eight of the ten pens of cattle starting 24 August 2017, administering Revalor-XS to steers from Pen 490, and 491. Heifers from Pen 496 through 499 and steers from Pen 492 were administered Revalor-200 and Revalor-XS, respectively, on 30 August 2017. On 25 September, heifers from Pen 495 were administered Revalor-200.

Morbidity was documented throughout life for each individual animal, based on the feedyard doctor tag. During arrival sort in Ulysses, the Syracuse doctor tag was removed and documented for each calf. Doctoring was documented at Ulysses Feedyard by a doctor tag, in addition to a print out of each animal and the time they spent in the

yard hospital. Morbidity was unable to be tracked to individual calf, as the individual ear tag was not reported on the doctor sheet print out.

The diet composition was equivalent across all weight groups, with a starter ration followed by a finisher ration at Ulysses Feedyard. Feed records were maintained electronically, with delivered amounts recorded at each feeding, and documented in a computerized system. Days on feed varied for the 10 pens of cattle, as breed and genetics naturally influence the target finish weight.

Performance Cattle Company's frame score and weight measurement system (Garrison, 2005), was utilized to group cattle into end weight groupings to increase uniformity at time of projected slaughter weight by measuring body weight, hip length, and hip height.

3.3.5. Slaughter and grading procedure

Cattle were harvested within their five-way (steers and heifers separate) sort pens (10 total) over 7 harvest dates. The first group harvested, heifer pen 499, was slaughtered 7 December 2017, followed by heifer pen 498 and steer pen 494 on 18 December 2017, heifer pen 497 on 2 January 2018, heifer pen 496 and steer pen 493 on 8 January 2018, steer pen 492 on 15 January 2018, heifer pen 495 and steer pen 491 on 29 January 2018, and the final group, steer pen 490, was slaughtered 26 February 2018. Cattle were harvested at Tyson Fresh Meats slaughter facility in Holcomb, KS approximately 83 km from the study feedyard.

At slaughter, individual animal identification was recorded, and individual EID tags were scanned using a handheld Allflex RFID stick reader (Allflex ISO RFID Stick Reader, RS340-60, France). Carcass data on individual animals were tracked throughout

the harvest floor by placing a shroud pin with a WTAMU sequence number tag into the brisket of the carcass. Two trained employees of the Beef Carcass Research Center (Canyon, TX) recorded frequency of liver abscess and evaluated lung health using a lung scoring system reported by Tennant et al. (2014). Frequencies of lungs scored as a one, two, three, M and E were reported. A lung score of one, two and three, was assigned to carcasses that had 5-15% consolidation of tissue, 15-50% consolidation of tissue or pleural adhesion, and greater than 50% consolidation of tissue, pleural adhesion, or greater than 50% of lung missing, respectively (Tennant et al., 2014). An M was recorded for lungs that had minor fibrin tag formation of lung tissue, and an E was recorded for lungs with extensive fibrin tag formation of lung tissue.

Hot carcass weight (kg) was recorded from the plant packer identification tag and referenced back to the plant print out. Carcasses were chilled 28 hours post-mortem and were graded at the commercial packing plant using the VBG2000 grading camera (VBG2000, E + V Technology, Oranienbury, Germany). In 2006, VBG2000 technology met the USDA requirement to determine official USDA marbling score, longissimus muscle area, and fat thickness (Woerner and Belk, 2008). In September 2009, after a research and adjustment period of the instrument, VBG2000 camera grading was approved for use in commercial packing facilities, and since then, several companies have utilized the technology (Mafi et al., 2014).

The camera administered a numerical value for marbling score for individual carcass, based on the USDA (2016) standards for grades of carcass beef (100 = Practically devoid$^{00}$; 200 = Traces$^{00}$; 300 = Slight$^{00}$; 400 = Small$^{00}$; 500 = Modest$^{00}$; 600 = Moderate$^{00}$; 700 = Slightly Abundant$^{00}$; 800 = Moderately Abundant$^{00}$; 900 =

Abundant$^{00}$). Fat thickness (cm), measured opposite of the longissimus muscle at the cut surface between the 12$^{th}$ and 13$^{th}$ rib, was measured by the plant camera grading system. In addition, longissimus muscle area (cm$^2$) was measured using camera technology. Yield grade (YG) was calculated utilizing hot carcass weight, longissimus muscle area and fat thickness measured from the plant camera data, with a constant value of 2.5% for kidney, pelvic, and heart fat estimation.

Total carcass value and carcass value per century weight (cwt) were calculated using a carcass base price of $192.42/cwt (AMSa, 2018), and carcass value pricing (Table 3.6) representative of the 2017 calendar year (AMSb, 2018). Table 3.7. was developed using the industry simple averages for the 2017 calendar year for hot carcass weight (kg) variations, Quality and Yield Grade distributions (AMSb, 2018).

3.3.6. Warner-Bratzler Shear-Force Analysis

Using the PROC POWER function (SAS, 2000), it was determined that from each pen of cattle, three commodity Choice carcasses per sire were selected, for a total of 12 carcasses per pen to follow through fabrication and collect a IMPS 180 strip loin for Warner-Bratzler shear force analysis. Due to these selection criteria, the number of loins collected from each pen per sire was not always equal.

The strip loins were aged for 14 days and then frozen at the West Texas A&M University Meat Lab (Canyon, TX). Strip loins were cut into one-inch thick steaks, with the second steak from the end used for WBSF. Individual steaks were re-frozen, and remained frozen until 11 October 2018, when they were thawed for WBSF analysis. On 12 October 2018, WBSF was completed according to the AMSA (2015) guidelines.

3.3.7. Experimental design & statistical analysis

A completely randomized experimental design structure was used, where individual animal was the experimental unit. Interval data were analyzed using the MIXED procedure of SAS (2000). The model included the fixed effect of sire, and the random effects of pen. For frequency outcomes, the PROC GLIMMIX procedure of SAS (2000) was used and separated by sex. The model included the individual quality grades and yield grades. The LSMEANS procedure was applied for multiple comparison among sire breed group means and separated when significant ($P < .05$) using the PDIFF option. Differences were considered significant at a $P$ value of $\leq 0.05$ and trends at a $P$ value of $\leq 0.10$.

**3.4. Results and discussion**

3.4.1. Gestation length

There was no difference ($P = 0.44$) in average gestation length between sires (Table 3.1), and all sire averages were comparable to the expected number of days in gestation for *Bos taurus* dams, which is approximately 283 days (Livesay and Bee, 1945). The mean gestation length of all calves with documented birthdate (n = 510) from the four sires used in this study was 284 d, with dam gestation length ranging from 260 to 327 days. A multitude of environmental factors can affect the length of gestation. Nogalski and Piwczynski (2012) reported that cow age is the greatest influencer on gestation length, in which gestation length increases as cow's age increases. Higher temperatures in the summer have been reported to shorten length of gestation (McClintock et al., 2003), in addition, gestation length is also altered by sex of fetus and weight of the growing fetus (Nogalski and Piwczynski, 2012). Nutrient availability also

plays an important role in the gestation period for beef cattle (Meyer et al., 2010), in which late gestation (months 6 to 9 of gestation) is the most critical period for ensuring adequate nutrients are available for the cow (Zhu et al., 2004). Because the dams were on a restricted diet during pregnancy, nutrient availability may have been a factor in increased gestation length that was reported in this study.

3.4.2. Weaning weight

Weaning weight of the calves (Table 3.1) indicated variation among sire groups. At time of weaning, a difference ($P = 0.03$) in weight (kg) was detected, with offspring sired by Alpha lower in weight than offspring from the other three sires. Calves ranged from 91 days of age to 158 days of age at weaning, averaging 133 days of age at time of weaning. Paterson (2015) reported that at weaning, calves are usually around seven months of age (~200 days), however, the ideal wean age should depend on the body condition of the cow to maintain future reproductive rates and reduce feed requirements. Because this study is unique in structure, calving in a feedlot setting with restricted feed availability, calves were weaned earlier than industry average to accommodate the low body condition scores of the dams.

There were no differences in weaning weight of calves sired by the Charolais, Angus, or Simmental bull. This outcome contrasts with Peacock et al. (1978) and Nadarajah et al. (1984) who reported the weaning weights of calves sired by a Charolais bull were heavier than that of Angus-sired calves. One explanation for the non-differing weaning weights observed in this study, is the precision of Angus producers in selecting for traits, such as weaning weight, from an extensive database of expected progeny differences (EPDs), which predict the genetic worth of the parent (Speer, 2011). In order

to develop an accurate breed EPD database, breeders must register their cattle; and the Angus breed outnumbers all other U.S. breeds significantly in number of cattle registered (Speer, 2011). Therefore, success of EPDs have allowed the Angus breed to improve their genetics at an exponentially fast rate, by way of precise and specific genetic selection (Speer, 2011).

Alpha's breed is a combination of *Bos taurus* (86% Angus) and *Bos indicus* (14% Zebu) genetics (BreedSure, ViaGen, 2018). It has been reported that the birth weight of *Bos indicus* calves are lighter (IMS, 2001), which in turn, would produce calves of lower weight at time of weaning. The *Bos indicus* influence on progeny sired by Alpha may be the cause for lower weaning weight.

3.4.3. Morbidity and mortality frequencies

Calf morbidity (Table 3.1) tended ($P = 0.08$) to be lower for offspring sired by Alpha compared to the other three sires. Based on the carcass composition of Alpha, USDA Prime Yield Grade one, it may be hypothesized that cattle with these rare genetic makeups have not succumbed to viral or bacterial illness at any period in their lifetime. Decrease in appetite and reduction in feed consumption is generated from sickness-related depression, and the energy needed to fight the illness reduces that available for muscle and fat production, ultimately affecting marbling and carcass weight (Robson, 2007). Morbidity is important for both the cattle feeder and beef processor, where promoting good health in calves may improve profits, resulting in an animal with a higher carcass value (Robson, 2007). Galyean (2006) reported that as calves received an increasing number of medical treatments, their value reduced when compared with non-treated calves. Calves treated one, two, and three or more times, returned $40.62, $58.35,

and $291.93 less than non-treated calves, respectively (Galyean, 2006). Stovall et al. (2000) reported a sickness carryover effect in quality grade in heifers. In addition, quality grade further reduced as treatment number increased (Stovall et al., 2000). Therefore, healthier cattle, with lower morbidity rates, have higher quality grades at slaughter than cattle that experienced sickness.

There was no difference ($P = 0.33$) in frequency of calf mortality (Table 3.1) across the four sires. Numerically, Charolais-sired calves had the greatest (17.3%) frequency of reported deaths, in agreeance with the findings of Amer et al. (1992), who reported that Charolais cattle had the lowest calf survival rate compared to Angus and Simmental cattle. It is important to note that calf mortality rates reported are inflated due to the 1 May 2017 storm.

3.4.4. Feedlot arrival weight

Upon arrival at Ulysses feedyard, cattle were weighed and sorted during processing. Feedlot arrival weight tended to differ ($P = 0.07$) between sires for heifers (Table 3.2); Alpha-sired heifers averaged the greatest weight numerically, and Angus sired heifers averaged the lightest weight. Feedlot arrival weight differed ($P < 0.01$) between sires for steers (Table 3.3); Angus-sired steers were lighter than steers from all other sires. At weaning, Alpha-sired calves averaged the lightest weight, but surpassed Angus-sired calves in live weight 142 days after weaning (feedlot arrival, 15 June 2017). Weaning is a great stressor in calves, and can cause lowered feed intake, resulting in reduced body weight (Parish, 2008).

3.4.5. Days on feed and days of age at harvest

Days on feed was calculated from date of feedlot arrival to date of harvest. The number of days on feed differed ($P < 0.01$) for heifers between sires (Table 3.2). Alpha- and Charolais-sired heifers were on feed for the longest length of time, differing from Simmental-sired heifers, whom differed from Angus-sired heifers, which spent the shortest length of days on feed. For steers, the number of days on feed differed ($P < 0.01$) between sires (Table 3.3), where Alpha-sired steers were on feed for the greatest number of days, which differed from the other three sires. Number of days on feed was determined using Performance Cattle Company's proprietary sorting system, which predicted slaughter dates for individual cattle based on feedlot arrival weight, hip height, and hip length (Garrison, 2005). Frame size is a good predictor for required number of days on feed, in which breeds such as Charolais and Simmental generally have larger frame size, are later maturing, and therefore, finish at heavier weights (Gaden, 2003). British breeds, such as Angus, are earlier maturing, and therefore, finish at lighter live weights, generally requiring fewer days on feed, which would explain why Angus cattle spent the shortest number of days on feed.

Days of age at harvest was calculated from birthdate to date of harvest. Harvest age differed ($P < 0.01$) for heifers between sires (Table 3.2). Charolais- and Alpha-sired heifers were the oldest in age at harvest, and Angus-sired heifers were the youngest. Age of steers at time of harvest differed ($P = 0.02$) between sires (Table 3.3); Alpha-sired steers were the oldest and differed from all other sires.

3.4.6. Hot carcass weight

Least squares means (Table 3.2) for heifer hot carcass weight (HCW) indicated no difference ($P = 0.82$) between sires. In contrast, least squares means (Table 3.3) for steer HCW (kg) indicated a difference ($P = 0.05$); steers sired by the Charolais and Simmental bulls were heavier than steers sired by Alpha. There was no difference in HCW of steers sired by the Charolais, Simmental, and Angus bulls, which disagrees with the findings of Chambaz et al. (2003), who reported Charolais sired steers were heavier than Simmental-sired steers, and Angus-sired steers had the lightest HCW of the three breeds.

Although Alpha sired steers had the lowest numerical average for HCW (413.8 kg), the average was greater than the HCW of the steer from which Alpha was cloned (354.7 kg). Alpha's breed consisted of 14% *Bos indicus*, which could influence his lighter HCW, as reported by Crouse et al. (1989), *Bos indicus* crossbred groups were lighter in weight than *Bos taurus* crossbred groups.

3.4.7. Liver and lung health

The frequency of heifers with abscessed livers (Table 3.2) did not differ between sires ($P = 0.83$), nor did frequency of steers with abscessed livers (Table 3.3) between sires ($P = 0.56$). As reported by Amachawadi and Nagaraja (2016), liver abscess incidence generally ranges from 10 to 20% and is highly variable. Numerically, average frequency of liver abscess ranged from approximately 5 to 10% and 8 to 17% for heifers and steers, respectively. It has been hypothesized that a greater incidence of liver abscess is likely caused by increased days on feed (Amachawadi and Nagaraja, 2016). Days on feed varied between heifer and steer groups, with heifers averaging 194 days on feed, and steers averaging 213 days on feed, in addition, steers likely had a greater intake of feed

than heifers. The increased number of days on feed and increased intake may be the cause for a higher range of abscess frequency observed in steers.

Lung health did not differ between sire groups for heifers (Table 3.2) or steers (Table 3.3). Tennant et al. (2014) reported that lung lesion scores had an economic impact on HCW differences, where steers with greater than 50% consolidation of tissue had significantly reduced HCW when compared to other lung health scores. Numerically, the frequency of lungs that scored a three ranged from 1.9 to 2.7% in heifers and was never reported in steers, which is a positive outcome in terms of economic value of the cattle in this study.

3.4.8. USDA yield grade and marbling score

Calculated YG differed ($P < 0.01$) for heifers (Table 3.2); Angus-sired heifers had the highest calculated YG, and Charolais-sired heifers had the lowest calculated YG, with Alpha- and Simmental-sired heifers being the intermediate. Calculated YG differed ($P < 0.01$) for steers (Table 3.3); Angus sired steers had the highest calculated YG, and Charolais sired steers had the lowest calculated YG. Again, Alpha- and Simmental-sired steers were intermediates.

Frequency of heifers stamped YG 1 (Table 3.4) differed ($P < 0.01$) between sires, with the Charolais having the greatest percentage of YG 1 heifer carcasses. This data in agreeance with that reported by Sexten et al. (2012), who observed that Charolais-sired cattle have reduced YG, which correlates with the findings of Marshall (1994) who reported that Charolais cattle rank high for estimated cutability.

Frequency of heifers stamped YG 2 differed ($P < 0.01$) between sires; heifers sired by Alpha and the Simmental had the greatest frequency of YG 2 carcasses, and

Angus-sired heifers, although not different than Charolais-sired heifers, had the lowest numerical frequency of YG 2. There was a difference ($P < 0.01$) between sires for heifers stamped YG 3, Angus-sired heifers were the greatest numerical frequency of YG 3 but did not differ statistically from Alpha-sired heifers. Although no difference ($P = 0.66$) was reported for YG 4 heifers between sires, this was likely a statistical Type II error, as Angus-sired heifers were the only group to receive a YG 4 stamp. There were no stamped YG 5 heifer carcasses in this study.

Steers stamped YG 1 (Table 3.5) tended ($P = 0.06$) to differ between sires, where 20% of Charolais-sired steers were stamped YG 1. Frequency of steers stamped YG 2 differed ($P < 0.01$) between sires; Charolais- and Alpha-sired steers had the greatest frequency of stamped YG 2, and Angus-sired steers had the least. There was a difference ($P = 0.02$) in frequency of YG 3 steer carcasses; Charolais-sired steers had the lowest frequency and differed from the other three sires. Stamped YG 4 steer carcasses differed ($P < 0.01$) between sires, where ~47% of Angus-sired steers graded YG 4, which differed from the other three sires.

Marbling score differed ($P < 0.01$) between sires for heifer (Table 3.2) and steer carcasses (Table 3.3). For both heifers and steers, offspring of the Angus sire had the greatest degree of marbling, and Charolais sired offspring had the least. There was no difference in marbling score between Alpha and Simmental sired steers and heifers.

USDA stamped carcass QG frequency of Prime, Certified Angus Beef (CAB), Choice, and Select (Tables 3.4, 3.5) were reported. Proportion of stamped Prime QG did not differ between sires for heifer ($P = 0.25$) or steer ($P = 0.19$) carcasses. However, it is important to note that 19% of Angus-sired heifers and ~23% of Angus sired-steers graded

Prime. This was expected, as Sexten et al. (2012) reported that Angus-sired cattle have a greater degree of intramuscular fat content (marbling).

Certified Angus Beef is a brand name in which subprimals and retail cuts are marketed. In order to qualify for CAB, cattle must appear to be Angus-influenced with a predominantly solid black coat, in addition to passing the 10 carcass quality standards (CAB, 2018). The standards include: modest or greater marbling, medium or fine marbling texture, "A" maturity (slaughtered younger than 30 mon), 10- to 16-square-inch ribeye area, 1,050 lb HCW (or less), less than 1-inch fat thickness, superior muscling (no dairy features), practically free of capillary ruptures (no blood splash), no dark cutters, and no neck hump exceeding 2 inches (CAB, 2018).

The proportion of heifers that qualified for CAB differed ($P < 0.01$) between sires, where Charolais-sired heifers were lower than heifers sired by the other three bulls. It is interesting to note that the proportion of Simmental-sired heifers that qualified for CAB was numerically greater than the proportion of Angus-sired heifers. For Angus-sired heifers and steers, backfat thickness greater than 1-inch was the most frequent carcass attribute that restricted carcasses from being eligible to qualify for CAB. Although no difference ($P = 0.85$) was detected for the proportion of steers that qualified for CAB marketing between sires, this is likely a Type II error, resulting from the inability of the statistical program to detect differences when one or more treatments had a zero-frequency occurrence. There were no Charolais steers that qualified for CAB marketing, in comparison with 35, 36, and 43% of steers for Simmental, Alpha, and Angus sired steers, respectively (Table 3.5). Charolais cattle have a mutation in the *SILV* gene, called a dilution, where two copies of the dilution gene produce a white coat color,

and one copy produces a gray or pale-red coat color (Wiener et al. 2007), reducing the likelihood that a Charolais will have a coat color that qualifies for CAB.

Frequency of grading Choice for heifers sired by the Charolais was greater ($P < 0.01$) than heifers sired by the Simmental, Alpha, and Angus. This differed from what was detected in the steers, where Charolais, Alpha, and Simmental sired steers differed ($P = 0.02$) from Angus sired steers in proportion of stamped Choice. Proportion of stamped Select QG tended to differ between sires for heifers ($P = 0.06$) and differed between sires for steers ($P = 0.01$). Charolais-sired steers were more frequently Select than steers sired by other bulls. The outcomes for QG were expected, as Sexten et al. (2012) reported that when compared to Angus sired cattle, Charolais sired cattle had a lower degree of marbling. The antagonistic relationship that was detected between the high marbling scores in Angus-sired calves with reduced cutability, and the improved cutability in Charolais-sired calves with reduced marbling score, was previously noted by Cundiff (1992).

3.4.9. *Longissimus* muscle area

*Longissimus* muscle area ($cm^2$), also referred to as LM area, was calculated by the camera grading system. Least squares means for heifer (Table 3.2) LM area indicated a difference ($P < 0.01$) between sires; Charolais-sired heifers had the largest LM area. Alpha- and Simmental-sired heifers did not differ in LM area, and Angus-sired heifers had the smallest LM area, not differing from Simmental-sired heifers. Least squares means for steer (Table 3.3) LM area indicated a difference ($P < 0.01$) between sires, where Charolais-sired steers had the largest LM area, Alpha- and Simmental-sired steers did not differ, and Angus-sired steers had the smallest LM area. These results agree with

that of Sexten et al. (2012) who reported that Charolais-sired steers had a larger longissimus muscle area than Angus-sired steers and Marshall (1994), who reported that of the Continental breeds, Charolais cattle ranked highest for LM area.

3.4.10. Fat thickness

Least squares means for the measure of subcutaneous fat on heifer (Table 3.2) and steer (Table 3.3) carcasses indicated a difference ($P < 0.01$) between sires; Angus-sired heifers and steers had the greatest measure of backfat thickness, and Charolais-sired heifers and steers had lowest measure of fat. Alpha- and Simmental-sired calves were nearly equal in subcutaneous fat and differed from Angus- and Charolais-sired calves. Sexten et al. (2012) reported that calves sired by a Charolais had less 12$^{th}$ rib fat compared to Angus-sired calves. In addition, Amer et al. (1992) reported that when compared to the Simmental and Angus breeds, Charolais cattle had the least fat depth. Therefore, fat thickness of the Charolais-sired cattle in this study was the most economically desirable, because as fat thickness increases, yield grade increases, and reduces desirability, as external fat is often considered a waste product (Drake, 2004). However, a minimal fat thickness (~3mm) is desired by the packer, as it keeps the meat from snap chilling and protects the meat from drying out (Drake, 2004).

3.4.11. Empty body fat (%)

Empty body fat (EBF) is a measure computed from carcasses metrics collected during harvest, including 12$^{th}$ rib subcutaneous fat thickness, HCW, USDA stamped quality grade, and longissimus muscle area (LM Area) (Guiroy et al., 2002). For heifer carcasses (Table 3.2), EBF percentage differed ($P < 0.01$) between sires, where Angus-sired heifers had the greatest percent EBF, Simmental- and Alpha-sired heifers did not

differ in EBF percentage, and Charolais-sired heifers had the lowest percent EBF. Steer carcasses (Table 3.3) differed ($P < 0.01$) between sires; Angus-sired steers had the greatest percentage of EBF, Alpha- and Simmental-sired steers did not differ in percent EBF, and Charolais-sired steers had the lowest percentage EBF. The outcome for both heifers and steers agreed with Guiroy et al. (2001), who reported that percentage EBF increased with increased marbling. In this study, Angus-sired steers and heifers had the greatest marbling score, which would explain why Angus-sired cattle had the greatest percent EBF. In addition, Charolais-sired heifers and steers had the lowest marbling scores, which corresponded with having the lowest EBF percentage. The EBF measurement is utilized by cattle feeders for "doneness" of animals, where cattle reaching approximately 28.6% EBF should grade USDA Choice (Guiroy et al., 2001). Smaller framed animals reach optimum body composition at lighter weights, and larger framed animals at heavier weights (Guiroy et al., 2002). This creates limitations from both ends of the spectrum, where smaller framed cattle have limited amount of edible meat, which reduces profitability, and larger framed cattle face the possibility of being discounted for larger and heavier carcass (Guiroy et al., 2002).

3.4.12. Total carcass value and carcass value per cwt

Total carcass value did not differ between sires for heifer carcasses (Table 3.2), dissimilar to steer carcasses (Table 3.3) which were different ($P = 0.04$) between sires. Charolais-sired steers were worth the greatest total value and did not differ from Simmental- and Angus-sired steers for total carcass value, Alpha-sired steers were worth the least and differed from all other breeds. Carcass value per cwt did not differ between sires for heifers, and numerically, Alpha-sired heifers were worth the greatest value per

cwt. In contrast, carcass value per cwt differed ($P < 0.01$) for steers, with Alpha-sired steers worth the greatest value per cwt. Total carcass value is reflective of HCW, and because Alpha-sired calves had the lightest HCW, we expect the total value of the carcass to be worth less.

3.4.13. Warner-Bratzler Shear Force Analysis results

The least squares means for Warner-Bratzler Shear Force (WBSF) analysis did not differ between sires for heifers or steers (Table 3.7), suggesting that all breeds were nearly equivalent for shear force. Mean shear force value (kg) was numerically greatest for Angus-sired heifers, and least for Charolais-sired heifers. In contrast, the mean shear force value for steers was numerically greatest for Charolais-sired steers, and least for Simmental-sired steers. An increased mean shear force value is reflective of reduced meat tenderness. ASTM (2011) developed a tenderness standard for WBSF, with shear values of 4.4kg "Certified Tender", and shear values of 3.9kg "Certified Very Tender". Mean shear values reported from these data were less than 3.9kg, classifying both heifers and steers from all sires as "Certified Very Tender". The WBSF values reported in this study are acceptable for tenderness, where unacceptable tenderness shear values have been reported as greater than 3.86 kg by Wulf et al. (1996) and greater than 4.54 kg by Tatum et al. (1999).The results from our data, where no difference was observed in tenderness between sires, may be due in part to the high quality of carcass genetics of the sires used in this study. Dikeman et al. (2005) described a great variation in tenderness within a breed type, suggesting that tenderness is a trait that can be selected for within a breed, which may be the reason why the four sires used in this study did not differ in WBSF values.

### 3.5. Conclusions

These data investigated the live and carcass production traits of heifers and steers in a terminal sire study. These findings suggest that a crossbred cloned bull, Alpha, who was selected for his carcass attributes, produces offspring that have desirable and comparable carcass traits when compared to offspring of high-performing carcass reference sires in the beef industry. These reference sires were included in this study because they are popular terminal sires, that are competitive within their breeds for varying carcass outcomes.

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**Table 3.1.** Calf metrics for all sire groups during duration of study at Syracuse Feedyard, Syracuse, KS.

| Outcome | Alpha | Rito Revenue | Pure Power | Sure Bet | SEM | *P* value |
|---|---|---|---|---|---|---|
| n | 104 | 134 | 157 | 124 | - | - |
| Mean gestation, d | 285 | 285 | 283 | 284 | 0.7 | 0.44 |
| Male, % | 51.9 | 48.5 | 45.9 | 55.6 | - | - |
| Female, % | 48.1 | 51.5 | 54.1 | 44.4 | - | - |
| Weaning weight, kg | 135.4[b] | 141.8[a] | 143.5[a] | 145.8[a] | 3.4 | 0.03 |
| Morbidity, % | 13.4 | 29.1 | 37.8 | 22.9 | - | 0.08 |
| Mortality, % | 10.4 | 13.6 | 17.3 | 8.6 | - | 0.33 |

**Table 3.2.** Heifer carcass metrics reported for all sires in study.

| Outcome | Alpha | Rito Revenue | Pure Power | Sure Bet | SEM | *P* value |
|---|---|---|---|---|---|---|
| n | 41 | 58 | 74 | 50 | - | - |
| Feedlot arrival weight, kg | 270.8 | 259.9 | 269.9 | 269.0 | 15.5 | 0.07 |
| Days on feed | 201[a] | 185[c] | 199[a] | 192[b] | 2.1 | <0.01 |
| Days of age at harvest | 473[ab] | 463[c] | 476[a] | 467[bc] | 2.3 | <0.01 |
| Abscessed liver, % | 4.8 | 6.9 | 9.5 | 7.7 | - | 0.83 |
| Lung score[1], % | | | | | | |
| 1 | 5.3 | 6.9 | 5.4 | 11.5 | - | 0.59 |
| 2 | 7.9 | 8.6 | 5.4 | 5.8 | - | 0.88 |
| 3 | 0 | 0 | 2.7 | 1.9 | - | 0.99 |
| M | 23.7 | 34.5 | 21.6 | 25.0 | - | 0.42 |
| E | 13.2 | 20.7 | 13.5 | 17.3 | - | 0.68 |
| Hot carcass weight, kg | 368.5 | 369.0 | 373.1 | 370.4 | 6.9 | 0.82 |
| Fat, cm | 1.5[b] | 1.8[a] | 1.1[c] | 1.5[b] | 0.1 | <0.01 |
| Longissimus muscle area, $cm^2$ | 95.2[b] | 90.2[c] | 99.9[a] | 93.3[bc] | 1.5 | <0.01 |
| Calculated yield grade | 2.82[b] | 3.44[a] | 2.22[c] | 2.99[b] | 0.1 | <0.01 |
| Marbling score[2] | 509[b] | 587[a] | 446[c] | 492[b] | 11.6 | <0.01 |
| Empty body fat[3], % | 30.4[b] | 33.2[a] | 27.8[c] | 30.7[b] | 0.3 | <0.01 |
| Total carcass value | 1562.90 | 1565.71 | 1583.00 | 1571.66 | 29.7 | 0.81 |
| Carcass value per cwt | 192.66 | 192.55 | 192.47 | 192.61 | 0.1 | 0.47 |

[1]Lung health: 1 = consolidation of lung lobes involving 5-15% of lung tissue; 2 = consolidation of lung lobes involving 15-50% of lung tissue; 3 = consolidation of lung lobes involving greater than 50% of lung tissue; M = minor fibrin tag formation on lung tissue; E = extensive fibrin tag formation on lung tissue.

[2]Marbling score: 400 = small[00], minimum required for U.S. Low Choice; 500 = modest[00], minimum required for U.S. Premium Choice.

[3]17.76207 + (4.68142 x 12[th] rib fat, cm) + (0.01945 x HCW, kg) + (0.81855 X quality grade; 4 = Select, 5 = Choice-, 6 = Choice, 7 = Choice+, 8 = Prime) – (0.06754 x longissimus muscle area, $cm^2$); Guiroy et al. (2002).

**Table 3.3.** Steer carcass metrics reported for all sires in study.

| Outcome | Alpha | Rito Revenue | Pure Power | Sure Bet | SEM | *P* value |
|---|---|---|---|---|---|---|
| n | 42 | 50 | 50 | 59 | - | - |
| Feedlot arrival weight, kg | 293.6[a] | 284.3[b] | 296.9[a] | 297.4[a] | 14.6 | <0.01 |
| Days on feed | 226[a] | 207[b] | 210[b] | 212[b] | 3.0 | <0.01 |
| Days of age at harvest | 495[a] | 482[b] | 486[b] | 484[b] | 2.9 | 0.02 |
| Abscessed liver, % | 16.7 | 10.2 | 8.0 | 8.8 | - | 0.56 |
| Lung Score[1], % | | | | | | |
| 1 | 11.9 | 4.1 | 2.0 | 8.8 | - | 0.31 |
| 2 | 7.1 | 10.2 | 4.0 | 0 | - | 0.72 |
| 3 | 0 | 0 | 0 | 0 | - | 1.00 |
| M | 16.7 | 32.7 | 18.0 | 21.1 | - | 0.27 |
| E | 16.7 | 6.1 | 14.0 | 15.8 | - | 0.45 |
| Hot carcass weight, kg | 413.8[b] | 420.6[ab] | 431.3[a] | 426.2[a] | 7.6 | 0.05 |
| Fat, cm | 1.5[b] | 2.0[a] | 1.1[c] | 1.6[b] | 0.08 | <0.01 |
| Longissimus muscle area, $cm^2$ | 96.8[b] | 90.7[c] | 102.6[a] | 96.2[b] | 1.1 | <0.01 |
| Calculated yield grade | 3.16[b] | 4.05[a] | 2.59[c] | 3.40[b] | 0.1 | <0.01 |
| Marbling score[2] | 504[b] | 586[a] | 420[c] | 489[b] | 14.1 | <0.01 |
| Empty body fat[3], % | 31.4[b] | 35.0[a] | 28.5[c] | 32.0[b] | 0.5 | <0.01 |
| Total carcass value | 1757.91[b] | 1787.41[ab] | 1831.42[a] | 1816.22[a] | 31.8 | 0.04 |
| Carcass value per cwt | 192.47[a] | 191.92[b] | 191.82[b] | 192.10[b] | 0.1 | <0.01 |

[1]Lung health: 1 = consolidation of lung lobes involving 5-15% of lung tissue; 2 = consolidation of lung lobes involving 15-50% of lung tissue; 3 = consolidation of lung lobes involving greater than 50% of lung tissue; M = minor fibrin tag formation on lung tissue; E = extensive fibrin tag formation on lung tissue.

[2]Marbling score: 400 = small[00], minimum required for U.S. Low Choice; 500 = modest[00], minimum required for U.S. Premium Choice.

[3]17.76207 + (4.68142 x 12[th] rib fat, cm) + (0.01945 x HCW, kg) + (0.81855 X quality grade; 4 = Select, 5 = Choice-, 6 = Choice, 7 = Choice+, 8 = Prime) – (0.06754 x longissimus muscle area, $cm^2$); Guiroy et al. (2002).

**Table 3.4.** USDA stamped carcass yield grade and quality grade of finishing heifers.

| Outcome | Alpha | Rito Revenue | Pure Power | Sure Bet | *P* value |
|---|---|---|---|---|---|
| n | 41 | 58 | 74 | 50 | - |
| Quality grade, % | | | | | |
| Prime | 2.4 | 19.0 | 0 | 0 | 0.25 |
| CAB[1] | 42.9[a] | 43.1[a] | 1.4[b] | 48.1[a] | <0.01 |
| Choice | 47.6[b] | 31.0[b] | 79.7[a] | 50.0[b] | <0.01 |
| Select | 7.1 | 6.9 | 18.9 | 1.9 | 0.06 |
| Yield grade, % | | | | | |
| 1 | 2.4[b] | 1.7[b] | 47.3[a] | 7.7[b] | <0.01 |
| 2 | 71.4[a] | 31.0[c] | 47.3[bc] | 57.7[ab] | <0.01 |
| 3 | 26.2[ab] | 46.6[a] | 5.4[c] | 23.1[b] | <0.01 |
| 4 | 0 | 20.7 | 0 | 0 | 0.66 |
| 5 | 0 | 0 | 0 | 0 | 1.0 |

[1]CAB: Certified Angus Beef; brand in which subprimals and retail cuts are marketed; carcasses meeting 10 quality standards.

**Table 3.5.** USDA stamped carcass yield grade and quality grade of finishing steers.

| Outcome | Alpha | Rito Revenue | Pure Power | Sure Bet | *P* value |
|---|---|---|---|---|---|
| n | 42 | 50 | 50 | 59 | - |
| Quality grade, % | | | | | |
| Prime | 2.4 | 22.5 | 0 | 0 | 0.19 |
| CAB[1] | 35.7 | 42.9 | 0 | 35.1 | 0.85 |
| Choice | 59.5[a] | 32.7[b] | 70.0[a] | 54.4[a] | 0.02 |
| Select | 2.4[b] | 2.0[b] | 28.0[a] | 10.5[b] | 0.01 |
| Yield grade, % | | | | | |
| 1 | 2.4 | 0 | 20.0 | 3.5 | 0.06 |
| 2 | 35.7[ab] | 2.0[c] | 56.0[a] | 29.8[b] | <0.01 |
| 3 | 57.1[a] | 44.9[a] | 22.0[b] | 54.4[a] | 0.02 |
| 4 | 4.8[b] | 46.9[a] | 0[b] | 12.3[b] | <0.01 |
| 5 | 0 | 6.1 | 0 | 0 | 1.00 |

[1]CAB: Certified Angus Beef; brand in which subprimals and retail cuts are marketed; carcasses meeting 10 quality standards.

**Table 3.6.** Carcass value grid based on average price for 2017 (AMSb, 2018).

| 2017 Carcass Base Price (AMSa, 2018) | Hot Carcass Weight, kg | Quality Grade | Yield Grade |
|---|---|---|---|
| | 181-227 (-28.58) | | 1.0-1.9 (+3.69) |
| | 227-250 (-20.54) | | 2.0-2.5 (+2.00) |
| | 250-272 (-8.00) | Prime (+13.12) | 2.6-3.0 (+1.62) |
| **192.42/cwt** | **273-408 (0.00)** | **Choice (0.00)** | **3.1-3.9 (0.00)** |
| | 409-454 (-1.28) | Select (-11.44) | 4.0-4.9 (-11.61) |
| | 454-476 (-7.29) | Standard (-28.68) | 5.0/up (-16.89) |
| | >476 (-23.70) | | |

**Table 3.7.** Warner-Bratzler Shear Force Analysis collected from loin samples of heifer and steers carcasses.

| Outcome | Alpha | Rito Revenue | Pure Power | Sure Bet | SEM | *P* value |
|---|---|---|---|---|---|---|
| *Heifer* | | | | | | |
| n | 15 | 9 | 15 | 14 | - | - |
| Mean shear, kg | 3.24 | 3.56 | 2.97 | 3.18 | 0.2 | 0.14 |
| Tender, % | 86.7 | 66.7 | 100 | 100 | - | - |
| Very Tender, % | 86.7 | 66.7 | 93.3 | 100 | - | - |
| *Steer* | | | | | | |
| n | 15 | 9 | 15 | 12 | - | - |
| Mean shear, kg | 3.07 | 3.21 | 3.27 | 2.85 | 0.2 | 0.20 |
| Tender, % | 100 | 100 | 93.3 | 100 | | |
| Very Tender, % | 100 | 100 | 86.7 | 100 | | |

# CHAPTER 4

# PROJECTING LIVE CATTLE SLAUGHTER VALUE BASED ON PERFORMANCE CATTLE COMPANY'S CATTLE CLASSIFICATION AND SORTING SYSTEM

## 4.1. Abstract

An experiment was conducted to determine the proficiency and value in sorting cattle upon feedyard arrival into end-weight marketing groups with improved uniformity. Commercial beef heifers ($n$ = 211) and steers ($n$ = 184) were sorted five-ways per sex (10 pens total) using a proprietary cattle classification and sorting system, which is based on an equation including feedlot arrival weight (kg), hip height (cm) and hip length (cm). The sorting system was equipped with a database to document live traits that included arrival weight, hip measurements, and frame score. From there, the database projected appropriate number of days on feed by estimating incoming empty body fat, adjusted finished body weight, dry matter intake, and average daily gain. Five-way sort pens differed in targeted harvest date and days on feed. Cattle were harvested at a commercial processing facility and graded after a 30-hr chill period. Carcass traits included liver and lung abnormalities, hot carcass weight, individual quality and yield grade parameters, and total carcass value. A completely randomized experimental design structure was used; data were analyzed using a mixed model with sort pen as the fixed effect, and harvest date as a random effect. Linear and quadratic contrasts were generated to asses trends by sort pen. In general, live traits that differed ($P < 0.01$) for heifers followed a curvilinear trend when sorted by pen; including feedlot arrival weight, adjusted finished body

weight, incoming empty body fat (%), and average daily gain. Live traits that differed ($P < 0.01$) for steers followed a linear trend of significance when sorted by pen including: feedlot arrival weight, adjusted finished body weight, incoming and outgoing empty body fat (%), and estimated dry matter intake. Heifer and steer carcass traits differed by pen for hot carcass weight ($P < 0.01$) and total carcass value ($P < 0.01$), suggesting that the sort system was successful in sorting cattle upon feedyard arrival to improve uniformity, ensure the likelihood of achieving target empty body fat, and maximizing dollar value of individual animals.

**4.2. Introduction**

A movement toward value-based marketing in the beef industry has driven the importance of individual animal value (Cross and Whittaker, 1992) and the implementation of individual animal management systems (Guiroy et al., 2002). Understanding and feeding to a target body composition on an individual basis allows for maximal profitability per animal and monitoring individual feed cost of gain, while maintaining consistency in meat quality (Guiroy et al., 2002). This requires all animals to be harvested at their individual target body composition, which can be a difficult task, as there is great variation in mature size between cattle; smaller framed animals reaching optimum body composition at lower body weights than larger framed cattle (Guiroy et al., 2002). In order to address this, Guiroy et al. (2001) developed an equation to predict percentage of empty body fat (EBF), which estimates a close-out feed allocation based on carcass composition data, and accounts for differences that affect individual animal requirements (i.e. breed type, body size, stage and rate of growth). Guiroy et al. (2001) reported that as marbling increased in an animal, the percentage of EBF increased and

cattle approximating 28.6% EBF were estimated to grade USDA Choice, allowing cattle nutritionists to utilize EBF as a tool to predict "doneness". Currently, the great variation in size and maturity of feeder cattle in the United States may hinder maximization of economic value of each individual animal. In order to combat this, many feedyards have implemented the Cattle Classification and Sorting System (CCSS), which improves uniformity and pen utilization, aiming to return a greater profit to cattle feeders (PCC, 2018). The CCSS calculates both incoming EBF and outgoing EBF, which may assist cattle feeders in projecting harvest dates based on individual animal body composition and their likelihood to avoid discounts for carcass size and grading characteristics.

## 4.3. Materials and Methods

All experimental procedures followed the guidelines described in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, Savoy, IL). Institutional Animal Care and Use Committee approval was not required for this study because all live cattle data were obtained from the Performance Cattle Company, LLC (Amarillo, TX) database and Cactus Feeders.

### 4.3.1. Cattle sorting

On 14 June 2017, a collective group of steers and heifers (n=754) arrived at Ulysses Feedyard, KS. Heifers (n = 370) and steers (n = 373) were sorted by sex into five pens each (10 pens total), using the Cattle Classification and Sorting System (CCSS, Performance Cattle Company, LLC., Amarillo, TX). The CCSS is utilized by cattle feeders to sort cattle into groups and balance cattle to maximize pen capacity during feedyard arrival sorting. The sorting system uses quantitative information such as body weight and hip measurements to make projections on each individual animal, improving

pen uniformity and size consistency, and allows the feeder to manage cattle on a pen basis rather than individual basis (PCC, 2018). During initial processing at the feedyard, cattle were individually weighed and external dimensions, including hip height (cm), which was measured from the base of the chute to top of midline perpendicular to the hook bone (*tuber coxae*), and hip length (cm), which measured distance from hooks (*tuber coxae*) to pins (*tuber ischiadicum*). From the culmination of these three criteria, an optimum target finish weight was projected, sorting the steers into five-way groups, and the heifers into five-way groups based on the number of days to reach their target finish weight. Steers were grouped to pens 490 (254.2 kg ± 32.8 kg), 491 (273.5 kg ± 16.7 kg), 492 (294.6 kg ± 18.1 kg), 493 (308.4 kg ± 21.2 kg), and 494 (335.8 kg ± 19.3 kg); heifers were grouped to pens 495 (220.7 kg ± 21.6 kg), 496 (257.0 kg ± 13.8 kg), 497 (266.7 kg ± 19.0 kg), 498 (286.0 kg ± 24.0 kg), and 499 (307.7 kg ± 29.6 kg). Individual animals were tagged with a representative lot tag of the pen in which they had been sorted, and cattle remained in these pens until harvest. Although 754 head were sorted upon initial feedyard arrival, data was only maintained throughout the study on heifers (n = 211) and steers (n = 184) with known sires.

4.3.2. Pen measurements and harvest date projections

Frame score of individual animal was measured using the approved equation by the Beef Improvement Federation (BIF, 2018). For males that are 5 to 21 months of age, frame score is calculated as: 0.4878 (ht) - 0.0289 (days of age) + .00001947 (days of age)$^3$ + 0.0000334 (ht) (days of age) -11.548. For females that are 5 to 21 months of age, frame score is calculated as: 0.4723 (ht) - 0.0239 (days of age) + 0.0000146 (days of age)$^3$ + 0.0000759 (ht) (days of age) -11.7086 (BIF, 2018). In the frame score equation ht refers

to hip height, determined on the topline of the animal directly over the hips or hooks (*tubar coxae*), measured with a measuring stick (Hammack and Gill, 2009).

Over the course of the feeding period at Ulysses Feedyard, KS, the CCSS digital database tracked dry matter intake (kg) per pen to estimate individual gain to feed ratio (kg) and average daily gain (kg). Dry matter intake (DMI), as reported by the NRC (2000), is the level of ration intake required by a cattle that contains the energy concentration recommended on an individual basis. With these calculations, the database was able to compute individual animal feed cost of gain per hundred weight. Harvest dates for each pen of cattle were projected by CCSS, aiming to optimize pen value by proposing marketing dates that consider cattle prices, premiums and discounts, and differential feeding costs to return the greatest net value of the pen (PCC, 2018).

Estimated incoming empty body fat and projected outgoing empty body fat were calculated using the equation reported by Guiroy et al., (2002): 17.76207 + (4.68142 x $12^{th}$ rib fat, cm) + (0.01945 x HCW, kg) + (0.81855 X quality grade; 4 = Select, 5 = Choice-, 6 = Choice, 7 = Choice+, 8 = Prime) – (0.06754 x longissimus muscle area, $cm^2$). Projected adjusted finished body weight (kg) was calculated using the equation reported by Guiroy et al., (2002): (EBW + [(28 – EBF) x 14.26])/0.891.

4.3.3. Harvest by pen

Cattle were harvested at the Tyson Fresh Meats slaughter facility in Holcomb, KS approximately 83 km from the study feedyard. At slaughter, individual animal identification was recorded in addition to sort pen identification. The majority of the cattle were harvested within their appropriate harvest pens, with the exception of four head throughout the seven slaughter dates that had been misplaced from assigned pen

throughout the feeding period. Carcass data on individual animals were tracked throughout the harvest floor by placing a shroud pin with a WTAMU sequence number tag into the brisket of the carcass. Two trained employees of the Beef Carcass Research Center (Canyon, TX) recorded frequency of liver abscess and evaluated lung health, reporting frequency of normal lungs, free of consolidation and fibrin tags.

Individual packer identification tags were recorded, which included hot carcass weight (kg). Prior to grading, carcasses were chilled 30 hours post-mortem. The plant camera grading technology (VBG2000, E + V Technology, Oranienburg, Germany) determined individual animal longissimus muscle area ($cm^2$), calculated USDA yield grade, fat thickness (cm) measured at the cut surface between the $12^{th}$ and $13^{th}$ rib, and assessed a numerical value for marbling score (100 = Practically devoid$^{00}$; 200 = Traces$^{00}$; 300 = Slight$^{00}$; 400 = Small$^{00}$; 500 = Modest$^{00}$; 600 = Moderate$^{00}$; 700 = Slightly Abundant$^{00}$; 800 = Moderately Abundant$^{00}$; 900 = Abundant$^{00}$).

Using a carcass base price of $192.42/cwt, which was the average carcass base value for 2017 (AMSa, 2018), and carcass value pricing for the 2017 calendar year (Table 3.6), total carcass value and carcass value per century weight (cwt) were calculated.

4.3.4. Experimental design & statistical analysis

A completely randomized experimental design structure was used, where individual animal was the experimental unit. Interval data were analyzed using the MIXED procedure of SAS (2000). The model included the fixed effect of pen, and the random effect of sire. The IML procedure was used to calculate linear and quadratic contrast coefficients to assess the effect of sort pen (days on feed). The LSMEANS

procedure was applied for multiple comparison among pen means and separated when significant ($P < .05$) using the PDIFF option. A difference was significant at $P$ value $\leq$ 0.05 and a trend at $P$ value $\leq$0.10.

**4.4. Results and Discussion**

Pen population counts differed between Tables 4.1 and 4.3 and Tables 4.2 and 4.4 because individual EID had been lost from some cattle upon arrival at Ulysses Feedyard. Performance Cattle Company's database calculates and projects measurements per individual animal based on individual EID tag.

4.4.1. Feedlot arrival weight, hip height, hip length

During initial processing, cattle were weighed, and hip height and length were measured as determinants for sorting. Feedlot arrival weight differed ($P < 0.01$) between pens for heifers (Table 4.1) and steers (Table 4.2), with a curvilinear (quadratic, $P < 0.01$) contrast effect for both. This was expected, because the cattle were sorted to pens with weight as one of the three criteria for sort. As determined by the sort system, cattle heaviest in weight upon arrival for both heifers and steers were grouped into pens with the earliest projected harvest date (heifers, pen 499, and steers, pen 494).

Hip height (cm) differed ($P < 0.01$) between pen for heifers (Table 4.1) and steers (Table 4.2). A quadratic ($P < 0.01$) effect was observed in heifers; heifers sorted to pens for earlier projected harvest (fewer days on feed) were taller in hip than heifers sorted to the later projected harvest pens. The curvilinear shape observed was due to the increase in hip height of heifers sorted to pen 498, which was greater than the hip height of heifers sorted into pen 499. Hip height of steers decreased linearly ($P < 0.01$) as number of days on feed increased.

Hip length (cm) did not differ between pens for heifers ($P = 0.20$) or steers ($P = 0.11$). One reason for this was that upon arrival to the feedyard cattle were under 12 months of age, and most hip length differentiation is observed in mature cattle (Hammack and Gill, 2009).

4.4.2. Empty body fat and adjusted finished body weight

Empty body fat (EBF) as a percentage of empty body weight (EBW), was calculated using the equation reported by Guiroy et al. (2002). For both EBF percentage incoming and outgoing, there was a difference ($P < 0.01$) between pens observed for heifers (Table 4.1) and steers (Table 4.2). For heifers, EBF incoming percentage of BW decreased curvilinearly (quadratic, $P < 0.01$) as days on feed increased, whereas EBF outgoing decreased linearly ($P < 0.01$) as days on feed increased. For steers, EBF incoming and outgoing as a percentage of BW decreased curvilinearly (quadratic, $P < 0.01$) as days on feed increased. As cattle feeders aim to reach USDA Choice quality grade the corresponding EBF percentage of BW is approximately 28.6% (Guiroy et al., 2001). In addition, cattle with notably less marbling, marketed as USDA Standard and Select were reported by Guiroy et al. (2001) with EBF percentage of BW at 21.1% and 26.2%, respectively. Following this pattern, cattle with notably improved levels of marbling, marketed as USDA Prime had approximately 31.9 to 32.5% EBF percentage of BW (Guiroy et al., 2001). Therefore, cattle in this study with numerical EBF outgoing values greater than 28.6% should be harvested at an earlier date to avoid excess subcutaneous fat thickness compared to cattle with lower EBF values. Excess subcutaneous fat thickness enhances the opportunity that the carcass will be discounted at harvest, which negatively impacts profitability.

Projected adjusted finished body weight (AFBW, kg) was calculated using the equation reported by Guiroy et al. (2002). For both heifers (Table 4.1) and steers (Table 4.2), AFBW differed between pens ($P < 0.01$). As days on feed increased for pen, there was a curvilinear (quadratic, $P < 0.01$) decrease in AFBW for heifers and a linear ($P < 0.01$) decrease in AFBW for steers. A shorter number of days on feed meant an earlier harvest date, cattle who were heavier for AFBW values reached endpoint finish with shorter days on feed. Since AFBW is shrunk body weight adjusted to 28% EBF, the linear relationship between number of days on feed (based on pen sort) and decrease in end weight was expected.

4.4.3. Frame score

Animal hip height was measured, and frame score was derived according to the Beef Improvement Federation (2018) equation, which assess frame score in a range from 1 to 11. A frame score of 1-3: mature early, grow slowly, and fatten at light weights; 4-5: moderate maturity and growth; 6-7: late maturing, fast growth, fatten at heavy weights; 8-11: very late maturing, extreme frame, difficult to fatten (Andrews, 2015; BIF, 2018). Based on the variability in frame score and body composition between pens, projected harvest dates varied.

Frame score differed ($P < 0.01$) between pens for both heifers (Table 4.1) and steers (Table 4.2). For heifers, a curvilinear (quadratic, $P < 0.01$) relationship was observed between frame score and number of days on feed. Steers were linear ($P < 0.01$) in relation of frame score and days on feed, steers that were the largest in frame were harvested first and steers that were the smallest in frame, were harvested last. These data oppose Andrews (2015), who reported that cattle smaller in frame score (1-3), mature

earlier, fatten at lighter weights, and therefore, would be harvested earlier. The sort and frame score output observed in this study did not meet the expectation that cattle smaller in frame score mature before animals larger in frame score. An explanation is that the sorting system used for this study placed a greater emphasis on weight for sort than hip height measure (which influences frame score). Therefore, frame score may be best used as a predictor for future weights at slaughter rather than as a measure of body size (Hammack and Gill, 2009). An additional explanation would be that frame score may also be associated with muscling, breed differences, and individual genotypes (Andrews, 2015), which may have caused the quadratic output observed in the heifers.

4.4.4. Feed conversion efficiency

Estimated dry matter intake (DMI, kg/d) differed ($P < 0.01$) between pens for both heifers (Table 4.1) and steers (4.2); as DMI decreased, number of days on feed increased linearly ($P < 0.01$) for heifers, and curvilinearly (quadratic, $P < 0.01$) for steers. Factors that influence DMI include size, body condition, stage and level of production, quality and availability of feed (Wieland, 2002). Average daily gain (ADG, kg/d) also differed ($P < 0.01$) between pens for both heifers (Table 4.1) and steers (Table 4.2). As number of days on feed increased, ADG decreased curvilinearly (quadratic, $P < 0.01$) for heifers and linearly ($P < 0.01$) for steers. Cattle sorted into pens that were harvested after fewer days on feed had heavier ($P < 0.01$) hot carcass weights (HCW, kg) at time of slaughter (Tables 4.3, 4.4). These data suggest that animals heavier in weight at feedlot arrival, have a greater DMI (kg) per day, and an increased average daily gain, resulting in a heavier HCW at time of slaughter.

The gain to feed ratio (kg) compares ADG (kg) of individual animals with amount DMI (kg/d) delivered to bunk. Gain to feed ratio differed between pens ($P < 0.01$) for both heifers (Table 4.1) and steers (Table 4.2). Days on feed tended to be linear ($P = 0.07$) in nature for heifers, and curvilinear (quadratic, $P < 0.01$) for steers, suggesting that the gain to feed ratio is not well predicted by number of days on feed, and is more related to individual animal. Gain to feed ratio, also referred to as feed conversion ratio by Shike (2013), proposes that a lower numerical value is more desirable, indicating that the animal required fewer kg of feed per kg of gain. Feed conversion ratio is correlated to growth rate (Shike, 2013), and growth rate is linked to sire growth potential (Short et al., 1999). One explanation for the quadratic nature of this data is that genetics, specifically sire genetics, may influence gain to feed ratio. Since sire was not a basis for sorting the cattle in this study, there was no pattern observed.

4.4.5. Economics

Feed cost of gain reported as dollars per century weight (cwt) differed ($P < 0.01$) for heifers (Table 4.1) and steers (Table 4.2) as number of days on feed differed. For heifers, feed cost of gain per cwt decreased curvilinearly (quadratic, $P < 0.01$) as number of days on feed increased. For steers, feed cost of gain per cwt decreased linearly ($P < 0.01$) as number of days on feed increased. Based on the observed results of dry matter intake and average daily gain (Tables 4.1, 4.2) in addition to hot carcass weight (Tables 4.3, 4.4), it can be concluded that cattle harvested at an earlier slaughter date had greater dry matter intake and ADG, which produced a heavier carcass. Therefore, greater DMI increases the cost of feed per day, and increases the cost of gain for cattle harvested on shorter days on feed.

Although feed cost of gain was greater for cattle slaughtered in the earlier harvested pens (499 & 494), improved total carcass value for these pens which was likely due to heavier HCW, accounted for the extra cost associated with increased feed. Total carcass value differed ($P < 0.01$) for both heifers (Table 4.3) and steers (Table 4.4); heifers following a curvilinear (quadratic, $P = 0.02$) trend, and steers following a linear ($P < 0.01$) trend. Therefore, cattle spending the fewest days on feed, sorted into the earliest harvested pens, were worth the greatest total value. Number of days on feed did not influence heifer carcass value per cwt ($P = 0.27$) but did increase carcass value per cwt ($P = 0.04$) of steers fed for a greater number of days prior to harvest.

4.4.6. Carcass traits

Subcutaneous fat thickness (cm) did not differ ($P = 0.42$) between pens for heifers (Table 4.3) slaughtered on differing days on feed, however, fat thickness decreased linearly ($P < 0.01$) between steer pens as days on feed increased (Table 4.4). Fat thickness is one of the greatest determinants of USDA Yield Grade, generally as fat thickness increases, yield grade becomes less desirable (Drake, 2004). These data disagree with that of Short et al. (1999), who reported that numerical yield grade increases with more days on feed. One reason for the discrepancy to literature in our results, may be linked back to sire, where sire-growth potential can influence yield grade (Short et al., 1999).

Marbling score did not differ ($P = 0.36$) between heifers as a factor of numbers of days on feed; numerically, heifers that spent the greatest length of time on feed prior to slaughter had the highest marbling score (Table 4.3). For steers (Table 4.4), marbling score differed ($P = 0.03$) between pens, where steers harvested after a longer period of

time on feed (pen 491) had increased marbling scores compared to steers with the shortest number of days on feed prior to slaughter (pen 494). These data agree with that of Drake (2004), who reported that marbling tends to increase with more days on feed, because as cattle are fed longer, they increasingly deposit intramuscular fat.

Heifer USDA stamped QG ($P = 0.12$) and YG ($P = 0.21$; Table 4.5) did not differ in frequency of grades between pens. The heifer pen harvested at the fewest number of days on feed had the greatest frequency of Certified Angus Beef, and overall, Choice QG and YG 2 was observed most frequently for all pens of heifers.

Steer USDA stamped QG ($P = 0.54$) and YG ($P = 0.24$; Table 4.6) did not differ in frequency of grades between pens. Choice QG and YG 3 was observed most frequently for all pens of steers. These data comparable with the frequency QG and YG distribution of U.S. feeder cattle in 2016 (Boykin et al., 2016). The 2016 National Beef Quality Audit reported that Choice QG and YG 3 was the most frequently observed combination, followed by Choice YG 2 (Boykin et al., 2016).

Warner-Bratzler Shear Force (Table 4.7) analysis indicated no difference in shear force measures between pens for heifers ($P = 0.79$) or steers ($P = 0.10$). These findings suggesting that number of days on feed did not influence meat tenderness, as an increased mean shear force value is reflective of reduced meat tenderness.

**4.5. Conclusions**

Implementing the Cattle Classification and Sorting System upon initial feedyard arrival aimed to reduce the number of cattle being discounted for under-weight or over-weight carcasses, by sorting cattle on an individual basis for appropriate end-point target. This resulted in improved uniformity of cattle marketed for harvest. In addition, the

sorting system was effective in ensuring cattle reach an empty body fat percentage greater than 28.6 % at harvest.

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**Table 4.1**. Heifer projections and metrics derived from Performance Cattle Company's (PCC, 2018) Cattle Classification and Sorting System.

| | Pen | | | | | | *P* value | | |
|---|---|---|---|---|---|---|---|---|---|
| Outcome | 499 | 498 | 497 | 496 | 495 | SEM | Pen | L[1] | Q[2] |
| n | 65 | 43 | 44 | 36 | 23 | - | - | - | - |
| Feedlot arrival weight, kg | 309.7[a] | 290.2[b] | 268.2[c] | 256.0[d] | 218.1[e] | 3.2 | <0.01 | <0.01 | <0.01 |
| Hip height, cm | 112.5[b] | 115.1[a] | 113.0[b] | 113.0[b] | 108.7[c] | 1.0 | <0.01 | <0.01 | <0.01 |
| Hip length, cm | 34.0 | 36.1 | 35.6 | 34.8 | 33.8 | 0.9 | 0.20 | - | - |
| Estimated empty body fat incoming[3], % | 16.6[a] | 15.8[b] | 14.9[c] | 14.3[d] | 12.8[e] | 0.1 | <0.01 | <0.01 | <0.01 |
| Projected empty body fat outgoing[3], % | 31.1[a] | 30.2[b] | 30.1[b] | 30.9[a] | 29.7[b] | 0.2 | <0.01 | <0.01 | 0.49 |
| Projected adjusted finished body weight[4], kg | 548.3[a] | 544.7[ab] | 540.8[ab] | 529.1[b] | 497.3[c] | 7.6 | <0.01 | <0.01 | <0.01 |
| Frame score[5] | 3.9[b] | 4.5[a] | 4.1[b] | 4.1[ab] | 3.2[c] | 0.2 | <0.01 | <0.01 | <0.01 |
| Projected dry matter intake, kg | 10.0[a] | 9.1[c] | 9.3[b] | 8.9[c] | 8.3[d] | 0.1 | <0.01 | <0.01 | 0.76 |
| Projected gain to 1 kg of feed, kg | 0.36[b] | 0.36[b] | 0.37[c] | 0.35[a] | 0.37[c] | 0.0 | <0.01 | 0.07 | 0.13 |
| Projected average daily gain, kg | 1.55[a] | 1.54[a] | 1.51[ab] | 1.46[b] | 1.34[c] | 0.0 | <0.01 | <0.01 | <0.01 |
| Projected feed cost of gain per cwt, $ | 74.08[a] | 67.44[b] | 69.09[b] | 67.61[b] | 68.05[b] | 1.3 | <0.01 | <0.01 | 0.01 |
| Days on feed | 176 | 187 | 202 | 208 | 229 | - | - | - | - |

[1]L: linear effect of increased number of days on feed.
[2]Q: quadratic effect of increased number of days on feed.
[3]17.76207 + (4.68142 x 12$^{th}$ rib fat, cm) + (0.01945 x HCW, kg) + (0.81855 X quality grade; 4 = Select, 5 = Choice-, 6 = Choice, 7 = Choice+, 8 = Prime) – (0.06754 x longissimus muscle area, cm$^2$); Guiroy et al. (2002).
[4](EBW + [(28 – EBF) x 14.26])/0.891; Guiroy et al. (2001).
[5]Frame score: measure of animal's hip height (cm); Andrews (2015).

**Table 4.2.** Steer projections and metrics derived from Performance Cattle Company's (PCC, 2018) Cattle Classification and Sorting System.

| | Pen | | | | | | *P* value | | |
|---|---|---|---|---|---|---|---|---|---|
| Outcome | 494 | 493 | 492 | 491 | 490 | SEM | Pen | L[1] | Q[2] |
| n | 49 | 43 | 42 | 31 | 19 | - | - | - | - |
| Feedlot arrival weight, kg | 336.4[a] | 310.0[b] | 293.9[c] | 273.7[d] | 241.7[e] | 4.1 | <0.01 | <0.01 | <0.01 |
| Hip height, cm | 118.7[a] | 117.1[ab] | 117.0[ab] | 115.3[bc] | 113.2[c] | 1.3 | <0.01 | <0.01 | 0.20 |
| Hip length, cm | 37.2 | 35.2 | 34.4 | 34.6 | 37.0 | 1.0 | 0.11 | - | - |
| Estimated empty body fat incoming[3], % | 17.7[a] | 16.6[b] | 16.0[c] | 15.1[d] | 13.8[e] | 0.2 | <0.01 | <0.01 | <0.01 |
| Projected empty body fat outgoing[3], % | 32.5[b] | 32.1[c] | 29.5[d] | 33.7[a] | 28.5[e] | 0.3 | <0.01 | <0.01 | <0.01 |
| Projected adjusted finished body weight[4], kg | 626.7[a] | 623.6[a] | 601.2[b] | 596.9[b] | 579.0[b] | 10.4 | <0.01 | <0.01 | 0.26 |
| Frame score[5] | 5.2[a] | 4.9[ab] | 4.9[ab] | 4.6[bc] | 4.1[c] | 0.3 | <0.01 | <0.01 | 0.15 |
| Projected dry matter intake, kg | 25.0[a] | 22.7[b] | 20.6[d] | 21.4[c] | 17.7[e] | 0.1 | <0.01 | <0.01 | <0.01 |
| Projected gain to 1 kg of feed, kg | 0.37[b] | 0.36[b] | 0.38[c] | 0.34[a] | 0.37[b] | 0.0 | <0.01 | 0.04 | <0.01 |
| Projected average daily gain, kg | 1.79[a] | 1.72[a] | 1.61[b] | 1.58[b] | 1.46[c] | 0.0 | <0.01 | <0.01 | 0.22 |
| Projected feed cost of gain per cwt, $ | 73.09[a] | 68.47[b] | 65.77[c] | 68.97[b] | 61.22[d] | 1.3 | <0.01 | <0.01 | 0.31 |
| Days on feed | 187 | 208 | 215 | 229 | 257 | - | - | - | - |

[1]L: linear effect of increased number of days on feed.

[2]Q: quadratic effect of increased number of days on feed.

[3]17.76207 + (4.68142 x 12[th] rib fat, cm) + (0.01945 x HCW, kg) + (0.81855 X quality grade; 4 = Select, 5 = Choice-, 6 = Choice, 7 = Choice+, 8 = Prime) – (0.06754 x longissimus muscle area, $cm^2$); Guiroy et al. (2002).

[4](EBW + [(28 – EBF) x 14.26])/0.891; Guiroy et al. (2001).

[5]Frame score: measure of animal's hip height (cm); Andrews (2015).

**Table 4.3.** Heifer carcass metrics reported for heifer sort pens.

| | Pen | | | | | | *P* value | | |
|---|---|---|---|---|---|---|---|---|---|
| Outcome | 499 | 498 | 497 | 496 | 495 | SEM | Pen | L[1] | Q[2] |
| n | 67 | 50 | 46 | 36 | 24 | - | - | - | - |
| Abscessed liver, % | 7.5 | 8.0 | 4.4 | 7.7 | 12.5 | - | 0.83 | - | - |
| Normal lung, % | 34.3 | 47.8 | 32.6 | 48.7 | 41.7 | - | 0.40 | - | - |
| Hot carcass weight, kg | 382.0[a] | 378.3[ab] | 375.5[ab] | 367.0[b] | 347.0[c] | 4.2 | <0.01 | <0.01 | 0.01 |
| Fat, cm | 1.5 | 1.5 | 1.5 | 1.4 | 1.4 | 0.2 | 0.42 | - | - |
| Longissimus muscle area, $cm^2$ | 94.9 | 97.3 | 96.8 | 94.8 | 88.4 | 0.7 | 0.52 | - | - |
| EBF, %[3] | 30.9 | 30.6 | 30.3 | 30.2 | 30.1 | 1.1 | 0.59 | - | - |
| Calculated yield grade | 2.95 | 2.84 | 2.82 | 2.85 | 2.78 | 0.3 | 0.78 | - | - |
| Marbling score[4] | 514 | 503 | 492 | 505 | 535 | 31.4 | 0.36 | - | - |
| Total carcass value | 1624.51[a] | 1604.56[ab] | 1594.55[b] | 1554.48[b] | 1474.35[c] | 17.7 | <0.01 | <0.01 | 0.02 |
| Carcass value per cwt | 192.61 | 192.41 | 192.50 | 192.67 | 192.67 | 0.1 | 0.27 | - | - |

[1]L: linear effect of increased number of days on feed.

[2]Q: quadratic effect of increased number of days on feed.

[3]17.76207 + (4.68142 x $12^{th}$ rib fat, cm) + (0.01945 x HCW, kg) + (0.81855 X quality grade; 4 = Select, 5 = Choice-, 6 = Choice, 7 = Choice+, 8 = Prime) – (0.06754 x longissimus muscle area, $cm^2$); Guiroy et al. (2002).

[4]Marbling score: 400 = $small^{00}$, minimum required for U.S. Low Choice; 500 = $modest^{00}$, minimum required for U.S. Premium Choice.

**Table 4.4.** Steer carcass metrics reported for steer sort pens.

| | Pen | | | | | | *P* value | | |
|---|---|---|---|---|---|---|---|---|---|
| Outcome | 494 | 493 | 492 | 491 | 490 | SEM | Pen | L[1] | Q[2] |
| n | 54 | 45 | 43 | 33 | 26 | - | - | - | - |
| Abscessed liver, % | 11.8 | 4.4 | 9.52 | 11.8 | 19.2 | - | 0.48 | - | - |
| Normal lung, % | 41.2 | 57.8 | 38.1 | 35.3 | 42.3 | - | 0.32 | - | - |
| Hot carcass weight, kg | 440.7[a] | 438.4[a] | 420.5[b] | 417.3[b] | 406.3[b] | 5.7 | <0.01 | <0.01 | 0.32 |
| Fat, cm | 1.7[a] | 1.7[a] | 1.5[b] | 1.5[b] | 1.4[b] | 0.2 | <0.01 | <0.01 | 0.30 |
| Longissimus muscle area, $cm^2$ | 97.4 | 97.9 | 96.6 | 97.3 | 93.1 | 2.7 | 0.08 | - | - |
| EBF, %[3] | 32.4[a] | 32.6[a] | 31.2[b] | 31.7[ab] | 30.8[b] | 1.3 | <0.01 | <0.01 | 0.41 |
| Calculated yield grade | 3.50 | 3.45 | 2.92 | 3.46 | 3.16 | 0.4 | 0.61 | - | - |
| Marbling score[4] | 480[b] | 500[ab] | 487[b] | 537[a] | 502[ab] | 36.3 | 0.03 | 0.10 | 0.35 |
| Total carcass value | 1868.46[a] | 1855.08[a] | 1783.04[b] | 1767.03[bc] | 1712.03[c] | 23.7 | <0.01 | <0.01 | 0.24 |
| Carcass value per cwt | 191.98[b] | 191.87[b] | 192.02[b] | 192.42[a] | 192.12[ab] | 0.2 | 0.04 | 0.15 | 0.96 |

[1]L: linear effect of increased number of days on feed.

[2]Q: quadratic effect of increased number of days on feed.

[3]17.76207 + (4.68142 x 12$^{th}$ rib fat, cm) + (0.01945 x HCW, kg) + (0.81855 X quality grade; 4 = Select, 5 = Choice-, 6 = Choice, 7 = Choice+, 8 = Prime) – (0.06754 x longissimus muscle area, $cm^2$); Guiroy et al. (2002).

[4]Marbling score: 400 = small$^{00}$, minimum required for U.S. Low Choice; 500 = modest$^{00}$, minimum required for U.S. Premium Choice.

**Table 4.5.** USDA stamped carcass yield grade and quality grade of finishing heifers.

| Outcome | 499 | 498 | 497 | 496 | 495 | *P* value |
|---|---|---|---|---|---|---|
| n | 67 | 50 | 46 | 36 | 24 | - |
| Quality grade, % | | | | | | |
| Prime | 9.0 | 2.0 | 4.4 | 5.1 | 4.2 | 0.62 |
| CAB[1] | 43.3 | 30.0 | 23.9 | 18.0 | 29.2 | 0.12 |
| Choice | 44.8 | 54.0 | 54.4 | 69.2 | 58.3 | 0.25 |
| Select | 3.0 | 14.0 | 17.4 | 7.7 | 8.3 | 0.21 |
| Yield grade, % | | | | | | |
| 1 | 10.5 | 22.0 | 21.7 | 20.5 | 20.8 | 0.48 |
| 2 | 46.3 | 40.0 | 52.2 | 61.5 | 58.3 | 0.32 |
| 3 | 26.9 | 30.0 | 21.7 | 15.4 | 20.8 | 0.56 |
| 4 | 16.4 | 8.0 | 4.3 | 2.6 | 0 | 0.21 |
| 5 | 0 | 0 | 0 | 0 | 0 | 1.0 |

[1]CAB: Certified Angus Beef; brand in which subprimals and retail cuts are marketed; carcasses meeting 10 quality standards.

**Table 4.6.** USDA stamped carcass yield grade and quality grade of finishing steers.

| Outcome | 494 | 493 | 492 | 491 | 490 | *P* value |
|---|---|---|---|---|---|---|
| n | 54 | 45 | 43 | 33 | 26 | - |
| Quality grade, % | | | | | | |
| Prime | 9.8 | 2.2 | 4.8 | 11.8 | 0 | 0.54 |
| CAB[1] | 23.5 | 33.3 | 23.8 | 32.4 | 30.8 | 0.76 |
| Choice | 56.9 | 57.8 | 52.4 | 47.1 | 53.9 | 0.89 |
| Select | 9.8 | 6.7 | 16.7 | 8.8 | 15.4 | 0.60 |
| Yield grade, % | | | | | | |
| 1 | 2.0 | 4.4 | 7.1 | 11.8 | 11.5 | 0.44 |
| 2 | 31.4 | 17.8 | 42.9 | 32.4 | 30.8 | 0.24 |
| 3 | 45.1 | 53.3 | 31.0 | 41.2 | 53.9 | 0.29 |
| 4 | 17.7 | 22.2 | 16.7 | 14.7 | 3.9 | 0.49 |
| 5 | 3.9 | 2.2 | 0 | 0 | 0 | 0.99 |

[1]CAB: Certified Angus Beef; brand in which subprimals and retail cuts are marketed; carcasses meeting 10 quality standards.

**Table 4.7.** Warner-Bratzler Shear Force Analysis collected from loin samples of heifer and steers carcasses.

| Outcome | | | | | | SEM | *P* value |
|---|---|---|---|---|---|---|---|
| *Heifer* | | | | | | | |
| Pen | 499 | 498 | 497 | 496 | 495 | | |
| n | 12 | 12 | 11 | 10 | 8 | - | - |
| Mean shear, kg | 3.16 | 3.40 | 3.21 | 3.12 | 3.11 | 0.2 | 0.79 |
| Tender, % | 100 | 83.3 | 90.9 | 100 | 100 | - | - |
| Very Tender, % | 91.7 | 75.0 | 90.9 | 100 | 87.5 | - | - |
| *Steer* | | | | | | | |
| Pen | 494 | 493 | 492 | 491 | 490 | | |
| n | 11 | 13 | 12 | 7 | 8 | - | - |
| Mean shear, kg | 3.10 | 3.28 | 3.07 | 3.34 | 2.69 | 0.2 | 0.10 |
| Tender, % | 100 | 92.3 | 100 | 100 | 100 | - | - |
| Very Tender, % | 100 | 92.3 | 100 | 100 | 100 | - | - |