LIVE AND CARCASS PRODUCTION TRAITS FOR PROGENY OF AN F1 USDA PRIME – YIELD GRADE 1 CARCASS CLONE SIRE IN COMPARISON WITH PROGENY OF POPULAR REFERENCE SIRES

by

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ABSTRACT

The cloning of beef carcasses that grade USDA Prime – Yield Grade 1 (P1) has produced a sire that ranked well against high performing bulls from multiple breeds. An F1 (P1 x P1) sire would ideally outperform its high performing parents. A terminal sire study was conducted comparing progeny of an F1 (P1 x P1) sire (AxG1) against progeny (heifers and steers) of four high performing sires of varying breeds {P1 (Alpha); Angus; Simmental; Angus x Simmental}. Production traits included morbidity and mortality frequencies, weaning weight, feedlot arrival weight, and days on feed; carcass traits included frequency of abscessed liver and lung health, quality and yield grade (YG) parameters, total carcass value, and carcass value per cwt. A completely randomized experimental design was used; data was analyzed using a mixed model with a fixed effect of sire and random effects of harvest date, sex, and pen. AxG1 sired heifers had the highest ($P < 0.01$) marbling score, the highest ($P < 0.01$) carcass value per cwt, and numerically had the lowest calculated yield grade and highest frequency of YG one carcasses. Steers sired by AxG1 had the least ($P = 0.05$) backfat thickness, lowest ($P < 0.01$) calculated yield grade, highest ($P < 0.01$) marbling score, highest ($P < 0.01$) frequency of USDA Prime carcasses, the highest ($P < 0.03$) total carcass value, and highest ($P < 0.01$) carcass value per cwt respectfully. Collectively, AxG1 steers and heifers exhibited the least 12th rib fat thickness and lowest USDA YG in addition to the largest longissimus muscle area, highest marbling score, and greatest frequency of

USDA Prime. These data suggest that AxG1 outperformed other high performing industry reference terminal sires in carcass quality and yield grade outcomes.

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DEDICATION

This thesis is dedicated to my grandparents, parents, and brother. Thank you for instilling a love of agriculture into me at a young age and for pushing me to follow my dreams. None of this would have been possible with you.

APPROVAL

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CHAPTER 1

INTRODUCTION

With the shift to a value-based marketing system, commercial cattle producers make breeding and management decisions based upon what will maximize profitability for their operation and commercial beef cattle production is generally most profitable when crossbreeding systems are utilized (Gregory and Cundiff, 1980; MacNeil, 2005). Crossbreeding with the assistance of current reproductive technologies including artificial insemination, *in vitro* fertilization, embryo transfer, and cloning can advance breed genetics much faster than natural breeding techniques. The carcass grading outcome USDA Prime and USDA Yield Grade 1 (P1) is a rare and antagonistic outcome (Boykin et al., 2017) that is highly coveted by commercial cattle producers. Cloning of P1 carcasses and subsequent crossbreeding of sires and dams produced progeny that performed highly in the terminal marketing system. The purpose of this project was to test progeny of an F1 sire (P1 x P1) in comparison against progeny of popular reference sires to determine his genetic success in the terminal commercial cattle marketing system.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1. Beef Reproductive Technologies

New reproductive technologies are a commonly practiced feature of the commercial beef industry used to improve the reproductive potential of cattle (Nicholas 1996). Both *in vitro* and *in vivo* technologies including artificial insemination (AI), estrus synchronization (ES), embryo transfer (ET), in vitro fertilization (IVF), and cloning are being used more commonly in seedstock operations, replacing conventional reproductive techniques (Choudhary et al., 2016). Through utilization of advanced reproductive biotechnologies, an increase in genetic merit of progeny has resulted from an increased intensity of selection from producers (Nicholas, 1996).

2.1.1. Artificial Insemination

Artificial insemination (AI) is an *in vivo* procedure involving the introduction of sperm into the female reproductive tract with intentions of achieving pregnancy through means alternative to sexual intercourse. As the first application of genetic engineering in the livestock industry, AI is considered one of the most powerful tools producers have at their disposal for genetic improvement (Smith et al., 2018). The application of AI technology has shown to increase reproductive efficiency by maximizing the utilization

of sperm produced by the bull, thus, allowing producers to increase the progeny of a selected sire by many hundred-fold (VanDemark, 1961).

In the late 1600's Leeuwenhoek and his associate Hamm became the first researchers to see sperm, which they named "animalcules" (Foote, 2002). Over a century following the discovery of sperm the first account of AI in practice was recorded by the Italian priest and researcher Lazzaro Spallanzani whom artificially bred a female canine and successfully brought to term 3 offspring (Spallanzani, 1784). Modern AI research began in the late 1800's with Walter Heape, a researcher from Trinity College Cambridge. Heape's research focused on the AI of rabbits, canine, and horses whilst observing seasonal effects on reproductive success (Heape, 1897). In 1899 Russian researcher Ivanoff led the first studies directed toward developing practical techniques for AI in domesticated farm animals, poultry, dogs, and rabbits (Ombelet and Robays, 2015). Ivanoff (1922) discussed the efficiency of reproduction and how AI enabled producers to breed 10 times more females with a single male than by natural mating. Major advancements in AI technology continued into the early 1900's including the development of the artificial vagina and the technique of collecting semen from bulls via rectal massage (Smith et al., 2018).

The dairy cattle industry quickly realized that AI technology could be an important asset to assist producers in herd management and improvement; this led to the organization of the first AI cooperative for dairy cattle in Denmark in 1936 (Foote, 2005). Similar cooperatives were formed across the northeastern United States in 1938 to begin assisting dairymen in implementing AI into their operations (Foote, 2005). Once AI cooperatives were established it was quickly determined that there was a need for

research to be conducted to advance the current techniques for management of bulls, collection and preservation of semen, and protocols for insemination (Smith et al., 2018). Studies evaluating semen quality, extenders, and freezing in addition to bull sexual behavior, sire genetic power, and intensity of semen collection were extensively conducted between the 1940's and the 1960's by dairy cattle researchers (Foote, 2002).

According to the most recent cattle inventory (USDA NASS, 2019) there are nearly 3.4 times more beef cows than dairy cows, however, AI is utilized on 7.6% of US beef cattle operations (USDA NAHMS, 2009) while around 72.5% of all dairy cattle in the United States are a result of AI (APHIS, 2009). The handling of semen and insemination of beef and dairy cattle is very similar, thus this large spread can be closely associated with the differing management of dairy versus beef cattle (Foote, 2002). Dairy cattle are managed in a way that is much more conducive to AI, whereas, beef cattle are regularly reared on larger ranges that can make gathering and estrus detection associated with AI much less cost-effective for producers versus natural breeding (Foote, 2002). Due to these difficulties, some producers are employing timed AI programs that enable cows' estrus to be synchronized, fundamentally removing the guesswork of estrus detection in the pasture (Sa Filho et al., 2013). Timed AI is also a useful reproductive tool that beef cattle producers can utilize if they follow a defined breeding season (Sa Filho et al., 2013). By defining a specific breeding season, producers can time calving to a period that is most convenient for their specific management strategies and with the addition of AI producers can utilize genetically superior bulls without the hassle of keeping live sires on their operation (Sa Filho et al., 2013). Additionally, popularity of AI within

crossbreeding programs has grown due to producers' ability to breed cattle without having to maintain bulls of varying breeds on their operation (Foote, 2002).

Commercialization of AI paved the way for a wide variety of research on reproductive technologies throughout much of the 20th century including ET, ES, and cloning. Artificial insemination has current applications in sheep, goats, swine, poultry, horses, dogs, rabbits, mice, foxes, as well as several zoo animals, endangered species and in humans (Foote, 1999).

2.1.2. Estrus Synchronization

Synchronization of estrus is a management technique that manipulates or induces an estrous cycle in livestock with intentions of bringing a considerable percentage of females into estrus at similar times for the purpose of timed breeding (Odde, 1990). Popularity of ES in beef cattle production stems from the growing breeder utilization of AI and the discovered importance of developing of an ES system to maximize efficiency of herd reproduction (Odde, 1990). The fundamental methods of ES can be broken up into three overarching categories: prostaglandin, progesterone, or gonadotropin releasing hormone (GnRH) based systems (Islam, 2011).

The isolation and synthesis of estrogen (Allen and Doisy, 1923) and progesterone (Corner and Allen, 1929) kickstarted a whirlwind of research aimed at controlling the estrus cycle of sheep and cattle. Herd ES with progestogens operate by retaining high levels of progesterone in the female reproductive system; synchronization occurs between 2 to 5 days after the removal of exogenous progestin (Islam, 2011). Early studies administering progesterone in feed, through injection, or released intravaginally had great success in synchronizing the herd, however, low levels of fertility were reported (Beal,

1998). Research conducted concurrently determined that estradiol was luteolytic in bovine when administered early in the estrous cycle, thus, it was determined that combination treatments of progesterone and estradiol were the most effective in herd synchronization (Beal, 1998). This combination method is the basis for the commercial progesterone products SYNCRO-MATE B (Sanofi Animal Health Inc.), EAZI-BREED CIDR (Zoetis), and PRID DELTA (Ceva Animal Health). Another regularly used method of progesterone administration is through feeding melengestrol acetate (MGA) with simultaneous injections of prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$).

In the early 1970's it was determined that $PGF_{2\alpha}$ induced luteolysis and could effectively synchronize estrus (Beal, 1998). Prostaglandin $F_{2\alpha}$ has been reported to be an effective ES tool in cows when administered between days 8 and 17 of the estrous cycle (Islam, 2011); however, a number of studies note that effective ES can be obtained when $PGF_{2\alpha}$ is administered between days 5 and 21 of the estrous cycle (Beal, 1998). Both one and two dose ES systems have been studied with $PGF_{2\alpha}$ with the most success stemming from the two-dose system using a 10-12 day interval (Islam, 2011). Some popular $PGF_{2\alpha}$ and analogue products currently on the market are Lutalyse (Zoetis), Estrumate (Merck Animal Health), Synchsure (Boehringer Ingelheim), and estroPLAN (Parnell).

The third and most recently developed ES system utilizes GnRH in combination with $PGF_{2\alpha}$, a progestogen, or both. Gonadotropin Releasing Hormone administered during a cow's estrous cycle will cause regression or ovulation of a dominant growing follicle and a new wave of follicular growth begins (Islam, 2011). There are four major ES programs that use GnRH in conjunction with $PGF_{2\alpha}$: Ovsynch, CO-Synch, Hybrid

Synch, and Select Synch. A few GnRH based ES systems also use progesterone products, like MGA or CIDR, to further enhance the success rate of estrus in cows (Islam, 2011).

Estrus synchronization in its current state with combination treatments of $PGF_{2\alpha}$, progesterone, or GnRH aim at regressing existing follicles and developing a new wave of follicles in synchronization so timed breeding can become possible (Beal, 1998). With the ability to control estrus and subsequently AI cattle, these two technologies have been deemed as the most important and widely applicable technologies in bovine reproductive management (Patterson et al., 2003).

2.1.3. Embryo Transfer

Embryo transfer is a reproductive technology in which an embryo is placed into the uterus of a female with the intent of successfully initiating a pregnancy. Cambridge researcher Walter Heape reported the first successful ET when he removed two fertilized ova from an Angora doe rabbit and subsequently transferred the ova into the fallopian tube of a Belgian hare doe rabbit who was fertilized by a Belgian hare buck (Heape, 1890). The doe gave birth to 6 kits, 4 Belgian hare and 2 Angora young, with Heape noting that they Belgian showed no resemblance to the Angora young and vice versa (Heape, 1890). Willett et al. (1951) reported the first successful ET in cattle with the ovum donor being a Shorthorn x Holstein cross yearling heifer who went through an ES program and was subsequently inseminated with purebred Holstein semen. Five days following AI the heifer was slaughtered, the reproductive tract was removed, fertilized ova were flushed from the tract, and a surgical procedure was performed to insert the ova into the uterus of a Holstein heifer (Willett et al., 1951). Two hundred and seventy-eight

days later a heifer calf was born, and it was determined that the calf developed from the transplanted ova (Willett et al., 1951).

Following the success of Willett, advances in superovulation and ET led to great commercial success of the technologies in the United States in the 1970's (Seidel, 1981). Early interest in commercial ET in cattle came from the high costs of purchasing imported cattle breeds from Europe (Hasler, 2003). Adoption of nonsurgical ovum recovery and transfer techniques in the late 1970's led to ET becoming an on-farm procedure and the number of calves birthed by this technology increased over 100% from 1979 to 1980 (Hasler, 1992). During the 1980's the ET industry saw rapid growth due to the development of embryo cryopreservation methods, thus, the technology was no longer dependent on timely availability of donor cows (Hasler, 2003). During the 1980's there were no significant improvements to the ET system, however, technicians began to improve their skills over this time and to this day many practitioners have 30 or more years of experience in the field (Hasler, 2003). Embryo transfer is a technology that has grown rapidly over the past 40 years and has great potential for genetic improvement from superior female lines, and with the production of embryos from companies including TransOva and Hoofstock Genetics valuable maternal genetics can be utilized.

2.1.4. IVF

In vitro fertilization is another reproductive technology that is allowing breeders the ability to advance their genetic profile without succumbing to the struggles of natural breeding. Utilization of IVF in cattle has created a way to overcome infertility problems, assess performance of male and female gametes, extend the value of high quality semen, and allow for females with superior genetics to have more progeny than would be

possible through natural breeding techniques (Brackett, 1983). The IVF procedure involves the recovery of oocytes from females, fertilization in vitro with sperm, embryo culture in a media, and transfer of fertilized ova into a donor female that will carry the pregnancy to term.

Early studies, ranging from the late 1870's to the early 1950's, attempting to fertilize mammalian eggs *in vitro* claimed many successes in small animals like rabbits; however, with modern knowledge of embryology many of these claims can be refuted (Bavister, 2002). Leading up to 1954 no studies had reported sperm penetration into eggs *in vitro*, together with pronuclei and second polar body formation, which brings into question the validity of many early successful IVF proclamations (Bavister, 2002). Studies by Austin (1951) and Chang (1951) both determined that even when spermatozoa rapidly reached the oviducts there was a significant delay before the actual penetration of the egg occurred. It was determined that in some mammalian species spermatozoa must reside in the female reproductive tract for a period of time and acquire the capacity to penetrate eggs; thus, Austin (1951) conceived the term 'capacitation' to describe the changes sperm goes through during this period. The failure of most attempts to achieve IVF prior to 1951 were most likely due to the need for the sperm used to undergo capacitation (Bavister, 2002). Chang (1959), in a groundbreaking study conducted in rabbits, successfully transferred IVF eggs into a donor female and brought to term live young that resembled their parent's coat color. The first report of a live bovine offspring as a result of IVF techniques was in Pennsylvania in 1981 (Brackett et al.,1982).

In cattle, *in vitro* techniques including fertilization, maturation, and culture of eggs have provided a great source of embryos for other genetic technologies including

ET, transgenesis and cloning while also allowing research to be done surrounding patterns of gene expression, development of embryos, genetic disorders, and also being a model for human embryogenesis studies (Choudhary et al., 2016). Optimization of genetic selection and crossbreeding programs, improvement of pregnancy rates in low fertility herds, and rate of selection for quantitative traits can be greatly improved by utilizing embryos produced through IVF (Hansen, 2006).

2.2. Cloning

2.2.1. Cloning in Nature

Asexual reproduction is a form of reproduction in which offspring arise from a single organism without sexual intercourse; no external genetic material is shared with the newly created organisms. In studying plant biology, it is very common to encounter cloning by asexual reproduction as a form of multiplication achieved through two different forms: vegetative reproduction and agamospermy (Silvertown, 2008).

In most animal phyla asexual reproduction is a naturally occurring phenomenon; an oscillation between sexual and asexual reproduction is common in select invertebrate taxa (Vrijenhoek, 1998). Forms of asexual reproduction include budding and fragmentation in invertebrates and parthenogenesis, gynogenesis, and hybridogenesis in vertebrate species (Vrijenhoek, 1998; Vajta and Gjerris, 2006). Parthenogenesis is a clonal form of inheritance where a single female can establish a population with all offspring (female only) being genotypically identical to the mother (Vrijenhoek, 1998). If parthenogenic populations are to advance genetically there must be a male sexual interaction or mutation must occur at some point in the population (Vrijenhoek, 1998). Gynogenesis requires fertilization from male sperm to initiate cleavage of eggs but no

genetic material is transferred to the offspring or future generations (Vrijenhoek, 1998). Hybridogenesis also requires fertilization from sperm, however, paternal genes are transferred to the offspring, but only maternal genes continue generation to generation (Vrijenhoek, 1998).

The only similar occurrence to natural cloning in mammals is the occurrence of genetically identical individuals or monozygotic twins (Vajta and Gjerris, 2006). However, monozygotic twins are not produced by result of asexual reproduction and the two organisms share all genetic data; artificial clones would only share core DNA and mitochondrial DNA would differ (Vajta and Gjerris, 2006).

2.2.2. Embryo Splitting

Due to the totipotent nature of early embryonic cells it is possible to split blastomeres during their cleavage stage and create 2 or more embryos with identical genomes (Tang et al., 2012). The earliest reports of embryo splitting date back to the late 1800's when German biologist Hans Driesch separated blastomeres of a 2-cell embryo of a sea urchin which eventually led to the independent development of two sea urchins (Driesch, 1891). Around a decade later Hans Spemann (1902) validated the success of Driesch by splitting embryos of a vertebrate amphibian by tightening a baby hair around a 2-cell embryo until the cells split developing into 2 young. Modern embryo splitting in mammals was reported by Steen Willadsen (1979) on sheep embryos. Success of Willadsen's experiments in sheep were attributed to a technique where he added new blastomeres to an evacuated oocyte and then fixed the embryo in agar to seal the damaged zona pellucida and allow for development in the female reproductive tract (Willadsen, 1979). Willadsen also reported the successful birth of twin calves a few years

following his experiments in sheep (Willadsen et al. 1981). The successes of Willadsen sparked the enthusiasm of producers to perform embryo splitting for a more rapid multiplication of their valuable cattle (Vajta and Gjerris, 2006). One of the downfalls of embryo splitting is that physiologically an embryo can only be split 1 to 2 times with the ability to produce at most 2 to 4 identical offspring (Vajta and Gjerris, 2006). Peak commercial embryo splitting in cattle occurred in the late 1980's when producers realized the high cost did not justify the low efficiency and pregnancy rates of the procedure (Vajta and Gjerris, 2006).

2.2.3. Nuclear Transfer

Nuclear transfer is a process in which the karyoplast of a donor cell is transferred to a fertilized and enucleated recipient cell; then the restructured cell is activated, cultured and transferred into a donor for gestation. The result is a true clone of the donor that has identical genomic DNA and would only differ in mitochondrial DNA. Robert Briggs and Thomas King (1952) reported the first successful nuclear transfer in their experiment conducted with amphibians. The pair transplanted nuclei of advanced stage blastula cells into enucleated eggs from a Northern Leopard Frog and subsequently observed cleavage and development of a normal embryo (Briggs and King, 1952). A study from Hoppe and Illmensee (1982) claimed to successfully clone a mouse through nuclear transfer; the study has since been refuted by many laboratories due to the inability to successfully clone through the methods used by the pair (Di Berardino, 2001). Years later, Willadsen (1986) had a vital breakthrough and uncontestably cloned the first mammal in his lab. Willadsen (1986) combined whole blastomeres from 8 and 16-cell embryos of sheep with enucleated eggs; leading to a successful birth and thus paving the way to clone other

mammalian species. Just a year later, following the success of Willadsen, Prather et al. (1987) reported the first births of cattle through nuclear transfer. Cibelli et al. (1998) reported the birth of the first transgenic bovine calves resulting from nuclear transfer of fetal fibroblasts. Because the calves born were transgenic, there were implications that NT could be a potential method to advance animal breeding and genetics (Cibelli et al., 1998).The ability to clone through nuclear transfer opened many doors into embryonic development and research and in the livestock industry there were implications that the technology could be used to preserve genetics of high performing animals (Vajta and Gjerris, 2006). Cloning at this time only utilized embryonic cells for transfers and it was determined that the more advanced a donor cell was the lower level of success that was achieved in transfers toward later stages of development (Vajta and Gjerris, 2006). Throughout the 1970's and 1980's many transfer experiments were conducted on different stage donor cells from amphibians; however, no adult frogs were cloned from the somatic cells of adult frogs (Di Berardino, 2001). Questions arose over the possibility of cloning adult somatic cells because of the ability to determine phenotype of the donor animal cells; an act at the time that was not possible to accomplish because cloning was limited to embryonic cells (Di Berardino, 2001).

2.2.4. Somatic Cell Nuclear Transfer

The scientific community was stunned in 1996 when the first viable offspring of a cloned animal from adult mammal somatic cells was reported in Edinburgh, UK at the Roslin Institute (Wilmut et al., 1997). Epithelial cells obtained from the mammary gland of a 6-year-old ewe went through somatic cell nuclear transfer (SCNT) techniques and produced a single viable offspring given the name "Dolly" (Wilmut et al., 1997). The

cloning of animals by SCNT is the process of transferring the nucleus of a somatic cell into an enucleated oocyte whose genomic DNA is removed (Rodriguez-Osorio et al. 2012). Following the nucleus transfer, the reconstructed embryo is artificially activated, cultured, and transferred to a host where the production of a live offspring can develop (Campbell et al., 2007); a process very similar to embryonic cell nuclear transfer. Since Dolly's arrival, over 20 mammalian species have been successfully cloned by SCNT techniques (Rodriguez-Osorio et al., 2012), with the most recent being 2 cynomolgus monkeys produced from fetal monkey fibroblasts (Liu et al., 2018).

Kato et al. (1998) documented the first successful birth of cattle resulting from SCNT. 8 identical calves were born via SCNT from cumulus and oviductal cells derived from an adult cow (Kato et al., 1998). Following the early reports of bovine SCNT, documented cases of cloning in beef jumped drastically and as of 2005, 83 labs reported successful cloning in bovine; accounting for over 50% of all mammalian cloning (Oback and Wells, 2007). The applications of cattle cloning are numerous including preservation of endangered breeds, reduction of genetic variability for research models, human cell-based therapies, many transgenic applications, and the multiplication of high quality or desired genetics (Wells, 2005).

Wells (2005) claimed that cloning could be useful in maximizing the benefits of composite breeds allowing for performance tested or superior sires to disseminate their genetics. This holds true and can be validated by the work of researchers from West Texas A&M University who cloned carcasses from USDA Prime – Yield Grade 1 (P1) animals that resulted in 2 bulls and 3 heifers. Subsequently, the mating of one of the crossbred bulls and the heifers resulted in F1 (P1 x P1) progeny. Additionally, a terminal

sire study was conducted to compare the P1 sire against purebred sires (Sperber et al., 2018). The study demonstrated that the P1 sire performed very well against the selection of reference sires (Sperber et al., 2018); thus, illustrating that cloning via SCNT is a useful technology to preserve high quality genetics.

2.2.5. Cloning Anomalies and Limitations

There are numerous studies that report normal behavior, growth rates, reproductive performance, and life spans of cloned animals as well as their offspring (Wells, 2005). However, there are a variety of different abnormalities that can occur throughout the entirety of the cloning process that should be addressed.

Nuclear transfer related anomalies that occur can be caused by a number of factors including inappropriate donor cell or recipient oocyte, failed synchrony between cell cycle phase of donor nucleus and recipient cytoplasm, incomplete programing of donor genome, and poor handling of oocytes, somatic cells, and embryos that causes damage to the cells (Vajta and Gjerris, 2006). Some anomalies that have been reported include low pregnancy rates with high percentage losses in early and late gestation, difficult parturition, early postnatal deaths, stillbirths, short lifespans and malformations (Wells, 2005; Vajta and Gjerris, 2006). Not unique to cloning, however used regularly to describe malformations and diseases associated with cloning and in vitro embryo manipulation, is large offspring syndrome (LOS) (Vajta and Gjerris, 2006). In several species LOS has been noted to cause placental abnormalities, fetal overgrowth, stillbirth, increased body temperature, malformations of urogenital tract, liver, and brain, in addition to immune dysfunction, which leads to bacterial and viral infections (Vajta and Gjerris, 2006). The syndrome of cloned offspring having an unforeseen death or

abnormal phenotypes appearing later in life continues to be a point of research associated with cloning (Wells, 2005).

Another anomaly to note is the reported differences in telomere length of cloned animals versus normally reproduced animals. Telomeres are repeating DNA sequences located at the ends of chromosomes; telomeric shortening occurs during cell replication and it is hypothesized that telomere length can be a form of determining the age of a cell (Vajta and Gjerris, 2006). Dolly, the first SCNT cloned sheep, had shorter telomeres than age matched sheep and it has been hypothesized that this syndrome could have led to the animal's declining health and premature death (Wells, 2005). However, other studies have had contradictory views and found that telomere lengths in clones have been normal or longer due to a process during early embryogenesis that restores telomere length (Wells, 2005). Thus, future studies surrounding SCNT could possibly investigate telomere length and the association with other abnormalities in some cloned animals.

Due to the commercialization of cloning, in 2001 the Food and Drug Administration (FDA) of the United States asked producers with cloned animals to keep them out of the food chain until an adequate assessment could be made on the safety of the animals for consumers. In 2008 the FDA released a document entitled "Animal Cloning: A Risk Assessment" that tackled the safety of consuming cloned animals; the final verdict of the paper was that cloned animals and their progeny are completely safe to enter the food supply (FDA, 2008). However, due to the high costs associated with cloning it is highly unlikely that cloned animals will enter the food supply.

2.2.6. Summary of Cloning and Reproductive Technologies

The combination of reproductive technologies including AI, ET, IVF, ES and cloning have allowed producers and researchers to evoke rapid genetic changes to produce future generations of superior livestock (Hernandez Gifford and Gifford, 2013). Visscher et al. (2000) reported that combining reproductive technologies in a breeding system is unlikely, however, a high potential for genetic change would be expected from a combination of techniques. Sperber et al. (2018) reported that through cloning valuable genetics were preserved from a beef carcass and the sire produced performed well in a terminal sire test against reference sires from multiple breeds. With the combined use of AI, ET, and cloning, WTAMU has proven that a combination system of reproductive technologies can preserve and advance generations of higher performing cattle.

2.3. Beef Grading

2.3.1. Quality Grading

Quality grades of beef are the characteristics of meat, which predict the palatability of the lean (USDA, 2017). Federal quality grading of beef carcasses was first proposed after an investigation by Mumford (1902) that highlighted the importance of classifying market ready cattle into a geographical classification and subsequently into a quality grade determined by their weight, quality, and conformation. This bulletin proposed the formal grading of carcasses that would allow feeders, packers, and meat purveyors to market and purchase dressed cattle in a standardized manner (Mumford, 1902). In 1914, the United States Department of Agriculture (USDA) appropriated funds to develop the Office of Markets and Rural Organization to establish a market reporting

service for the trade of meat and livestock (Kiehl and Rhodes, 1960). Grade specifications for dressed beef were formulated in 1916 by the USDA and in 1924 a bulletin was released that outlined the official federal grading standards of dressed beef (Davis and Whalin, 1924). Since the inauguration of dressed beef grading, the specifications of carcass grading have continually been updated to match market standards and to provide a single standard for steer, heifer and cow beef (USDA, 2017).

For steers and heifers, quality grading is broken up into 8 designations: Prime, Choice, Select, Standard, Commercial, Utility, Cutter, and Canner (USDA, 2017). The USDA utilizes 2 factors to determine beef grade: marbling and maturity (USDA, 2017). To prepare for grading, a beef carcass is split in half down the backbone and additionally cut between the 12^{th} and 13^{th} ribs to expose the ribeye (USDA, 2017). The quality of the lean is determined by evaluating the intramuscular fat (marbling) and firmness of the cut surface (USDA, 2017). Maturity of a carcass can be determined in several ways including dentition, ossification of bones and cartilage, and evaluation of the color and texture of the cut surface of the ribeye (USDA, 2017). The relationship of marbling, maturity, and quality for steers and heifers can observed in Figure 2.1.

2.3.2. Yield Grading

Yield grading of beef estimates the yield of boneless closely trimmed, retail cuts expected to be derived from the major wholesale cuts of a carcass (USDA, 2017). The first proposed system of yield determination in cattle was presented at the 1952 Reciprocal Meat Conference and took measurements including length of body, length of hind leg, circumference of round, depth of body, length and width of ribeye, area of ribeye and thickness of fat over ribeye in three areas (AMSA, 1952). In 1960 at the

American Society of Animal Production conference, Murphey et al. (1960) reported a yield study of 162 beef carcasses representative of the era. This study led to the development of a multiple-linear regression equation using 12th rib fat depth, percentage kidney-pelvic-heat fat (KPH), hot carcass weight (HCW), and ribeye area (REA) to predict the percent boneless closely trimmed round, loin, rib and chuck (BCTRLRC; Murphy et al., 1960). Another equation, the calculated yield grade, was developed as a 1 through 10 index (Murphy et al., 1960) and later changed to a 1 through 5 index that utilize the same carcass metrics to estimate percentage BCTRLRC (Lawrence, 2016). Yield grade is determined by the following equation: Yield Grade = 2.50 + (2.50*adjusted fat thickness, inches) + (0.20*percent KPH) + (0.0038*HCW, pounds) – (0.32*REA, square inches) (USDA, 2017). Twelfth rib subcutaneous fat depth is most closely related (r = -0.53 to -0.66) to boneless lean yield followed by percentage KPH, ribeye area, and hot carcass weight (Lawrence, 2016). Federal yield grading was officially put into effect on June 1, 1965.

Following the development of the yield grade equation, a multitude of studies (Abraham et al, 1980; Farrow et al, 2009; Lawrence et al., 2010) have evaluated the effectiveness of the carcass variables to determine actual cutability of beef carcasses. At the inception of yield estimation, the market was predominately smaller-framed earlier-maturing Hereford cattle; presently, the cattle population is a multifarious genetic mass of medium and large framed cattle. Lawrence et al. (2010) reported that the yield grade equation is a poor estimator (adjusted R^2 of 0.31 to 0.38) of red meat yield in beef cattle and Farrow et al. (2009) noted that the prediction of saleable meat yield of beef carcasses can be improved by updating the equation via modifications to current measures and the

addition of new measures. Though the cattle population has evolved, the yield grade equation has seen no revisions since its 1965 initiation though numerous studies have shown its inability to accurately predict red meat yield.

2.3.3. Instrument Grading

Since the start of grading in the early 1900's, USDA graders have evaluated beef carcasses subjectively. However, grading application has been highly variable due to the human error associated with subjective assessment and it has been reported that error for yield grades specifically is high (Cross et al., 1983). In 1978 the United States General Accounting Office (USGAO) released a report recommending the United States Department of Agriculture (USDA) increase research, improve grading standards and program management, and resolve questions about the adequacy and accuracy of current beef grading standards (USGAO, 1978). Following the USGAO report, the USDA collaborated with the National Aeronautics and Space Administration and the Jet Propulsion Laboratory to begin development of an instrument to assist in beef quality and yield determination (Cross et al., 1983). A consensus was reached that video imaging analysis had the greatest potential for successful grading and a contract was reached between the USDA and Kansas State University to begin development of such an instrument called a video image analyzer (VIA; Cross et al., 1983). Throughout the late 1980's, 90's, and early 2000's many studies were conducted to test the effectiveness of the VIA technology in beef yield and quality grading (Woerner and Belk, 2008). Two VIA technologies, Computer Vision System (CVS; RMS Research Management Systems, USA, Inc., Fort Collins, CO) and VBG2000 (E+V Technology, Oranienburg, Germany) have been approved for assessment of official USDA yield grade

characteristics (ribeye area and fat thickness) and marbling score (Woerner and Belk, 2008). The USDA has identified graders as the primary source of divergence in grading and with the implementation of instrument grading have began a process of improving accuracy, precision, and repeatability of carcass grading (Woerner and Belk, 2008). Millions of dollars have been devoted to the research of instrument grading of beef cattle and they have been advantageous to producers, packers, and consumers in establishing and improving a true value-based marketing system for beef (Woerner and Belk, 2008).

2.3.4. Certified Angus Beef

Certified Angus Beef (CAB) is a USDA-certified brand that was established in 1978 as a result of Fred Johnson (Angus rancher), C.K. Allen (American Angus Association Chief), and Mick Colvin's (CAB executive) sustained battle with the USDA and Congress (Minnick, 2010). The group obtained a USDA certification known as Schedule G-1, CAB, which has grown to be the largest individual Angus marketing certification, accounting for over 44% of all cattle certified "Angus" (Siebert and Jones, 2013). Certified Angus Beef is a brand owned and maintained by the American Angus Association (AAA) and is a voluntary marketing program driven by participants desire to receive a premium from the beef they are producing (Siebert and Jones, 2013).

For beef carcasses to qualify for CAB they must meet a set of live animal and carcass specifications. The live animal and carcass specifications are listed in Figure 2. These specifications are the foundation of CAB and allow the brand to provide a consistent, high-quality consumer eating experience while also promoting the Angus cattle breed (Bass, 2016). Bass (2016) detailed each CAB specification scientifically showing how beef qualifying for the brand is more palatable than and other branded beef

programs. Claborn et al. (2011) conducted an in-home consumer trial testing the acceptance of CAB steaks versus USDA Choice and Select steaks. Consumers reported that CAB steaks were juicier ($P > 0.05$) than USDA Choice and Select steaks and trained sensory panelist rated CAB steaks higher ($P > 0.05$) in all palatability traits except flavor intensity (Claborn et al., 2011).

CAB has proven for over 4 decades that consumers are willing to pay for a product proven to be of a higher quality and has proven to be the most successful of the 51 USDA certified beef programs.

2.4. Beef Production

2.4.1. Beef Production System

Beef cattle production is one of the largest sectors of United States agriculture and has a rich history dating to early European settlers transporting cattle to the newly discovered East coast colonies. The current beef cattle industry is segmented, being composed of cow-calf producers, backgrounders, feeders, packers, and retailers (Koch et al., 1986); all serving a vital purpose of moving cattle from pasture to plate.

Cow-calf production refers to an operation that maintains beef cows with the purpose of producing calves (Herring, 2014). This segment can be further divided into seedstock and commercial producers. Seedstock producers typically focus on rearing herds with the intention of producing specific breed genetics that will be introduced into commercial crossbred operations for herd improvement (USDA, 2012). It is estimated that seedstock producers constitute around 9.5% of the US cattle herd, however, these small producers are the primary source of genetic improvement (USDA NAHMS, 2009). Commercial cattle operations aim to produce calves fit for the feedlot industry and are

then destined to produce beef (USDA, 2012). Approximately 76% of all operations produce strictly commercial cattle and 14% of all cattle operations are both seedstock and commercial producers (USDA NAHMS, 2009).

Following weaning from the cow-calf phase of production, young and lighter weight calves regularly go through a "stocker" or "backgrounding" phase. Backgrounding operations generally operate by managing young cattle during a period of growth and development on forage-based diets to help reduce feed costs and prepare cattle for feedlot transition (USDA, 2012). In stocker operations improved forages such as small grains or cool season forages are utilized by producers to reduce cost of weight gain for cattle destined for confined feeding (Herring, 2014). Additional benefits of backgrounding cattle include acclimating cattle to eating from a bunk, drinking from a trough, and receiving vaccinations before being comingled in feedlots.

Cattle are then placed into feedlots where they are fed grains such as corn, barley, and sorghum in a confinement setting (Herring, 2014). They are fed to add muscle and fat until a weight appropriate for slaughter (USDA, 2012). Typically, cattle arrive at feedlot and begin on a starter ration that is approximately 40-45% grain with a substantial amount of roughage; a transition onto a grower ration (50-65% grain) and a finisher ration (70-85%) will occur later in life approaching time of slaughter (Herring, 2014). Cattle can be marketed in a variety of ways to feedlots; feedyards may purchase cattle from a sale barn, directly from a cow-calf or stocker operation, or producers may retain ownership throughout the finishing process (USDA, 2012). In 2018, the average cost of gain for cattle on feed ranged from $74.85 to $79.75 per cwt and the average net return ranged from $8 to $145 per head (Langemeier, 2018). At the conclusion of the feeding

period, typically when cattle reach a weight between 1100 to 1500 lbs, cattle are marketed to beef processors.

Beef processors purchase cattle from feedlots and transform the animals into meat products and by-products. Large beef processors can harvest and process between 4000 and 6000 cattle per day. In modern facilities, animals are slaughtered, cooled, graded, and fabricated (degree varies between facilities) before being sold to retailers around the nation (Herring, 2014). Following fabrication into boxed beef, beef is shipped to further processing plants or to retailers for sale to the public.

2.4.2. Fed Beef Marketing

Once fed cattle reach a desired weight, cattle owners have several different alternatives for pricing and marketing: live weight pricing, dressed weight pricing, and grid pricing (The Cattle Site, 2009).

Live weight pricing is accomplished on a pen level; price is established on average weight and perceived quality of a pen of cattle rather than individual animals receiving values (The Cattle Site, 2009). For certain pens of cattle there is potential loss of revenue because projected carcass quality is not always reflected; high-quality animals are often discounted and low-quality cattle can receive premiums (The Cattle Site, 2009).

Dressed weight pricing, or “in the beef”, value of animals is based on the HCW at slaughter (The Beef Site, 2009). “In the beef” pricing does not require buyers to estimate the dressing percentage of animals, however, quality and yield grade estimates are still required. As with live weight pricing, dressed weight pricing does not reward higher quality carcasses; below average and low-quality animals receive the same price per hundred weight as high-quality animals (The Beef Site, 2009).

Value-based marketing, or grid pricing, markets cattle individually based on carcass characteristics. A base price is determined using either the USDA's weighted regional carcass price, the plants previous weeks average, or from the cash dressed price (The Beef Site, 2009). After the base price is determined carcass premiums and discounts are assigned to individual carcasses; adjustments include quality grade, yield grade, HCW, meat color, carcass maturity, breed, carcass defects, and eligibility for specific marketing programs (The Beef Site, 2009). The base price is for carcasses that grade USDA Choice – yield grade 3; the most valuable carcasses would grade Prime Yield Grade 1 and the lowest value carcasses would be Standard Yield Grade 5 (The Beef Site, 2009). Other discounts and premiums would be applied to carcasses in addition to the grading grid; these adjustments differ between processing facilities and regions of the country.

2.4.3. EPDs and Genetic Improvement

Expected progeny differences (EPDs) are selection indices that provide breeders and commercial cattle producers estimates of the genetic value of an animal as a parent (Greiner, 2009). The use of EPDs is specifically useful when comparing individuals within the same breed to help predict differences in performance of their future offspring (Greiner, 2009). There are EPDs calculated for birth, growth, maternal and carcass traits which help both breeders and commercial cattle producers make the most educated selection of sires and dams for their specific herd needs.

The technology for genetic selection indices has been around since the early 1940's when Hazel (1943) developed early EPDs for the Iowa State College swine herd. In 1968 the Beef Improvement Federation (BIF) was established to standardize programs

and methodologies and to create greater awareness, acceptance and usage of beef cattle performance concepts (BIF, 2018). In 1970 the BIF released the first edition of the Guidelines For Uniform Beef Improvement Programs which was an educational tool designed to help improve techniques and methods of evaluating sires and dams to drive breed improvement (Willham, 1979; BIF, 2018). The BIF advocated for the usage of EPDs in their guidelines so that producers could make herd genetic decisions with proven data and keep more precise herd reports. Beef breed associations began to conduct sire evaluation programs throughout the 1970's that helped build databases of sire performance and enhance EPDs with the data collected (Willham, 1979). The use of EPDs to advance breed genetics is especially important when crossbreeding for the commercial cattle herd to take advantage of breed complementarity and capitalize on heterosis in reproductive traits (Willham, 1979). The seedstock sector arguably exists to provide germplasm to commercial cattle producers; the selection for single EPD traits by breeders could lead to genetic antagonisms among traits and subsequently compromise commercial beef improvement by decreasing production or fitness of progeny. (MacNeil, 2005). Commercial cattle herds are most economically efficient when capturing heterosis and breed complementarity from multiple breeds so that terminal progeny exhibit improved growth and carcass characteristics (MacNeil, 2005).

More recently, the addition of genomic data to EPDs, Genomic Enhanced EPDs (GE-EPDs), has allowed breeders to add accuracy to traditional summary indices. Genomic testing is generally available through breed associations that have partnered with companies providing genotyping services including Zoetis, Neogen/GeneSeek, and Quantum Genetix. To provide genotyping data, companies utilize arrays to test for single

nucleotide polymorphisms (SNPs) in the genome. A variety of tests are offered ranging from high-density chips that typically have between 50,000 and 150,000 SNPs to lower density chips with less than 50,000 SNPs. One of the main advantages of including geenomic information in EPDs is the improved accuracy of young animals that have little other information on which to base genetic merit (Van Eenennaam, 2011). Improved accuracy is quite helpful with young bulls, however, with well-proven sires with high accuracy EPDs, little change is likely to occur with genomic addition to an EPD (Van Eenennaam, 2011). Additionally, 12 breed associations have collaborated to create International Genetics Solutions (IGS), a multibreed database enabling EPDs to be calculated between breeds on a common base (Van Eenennaam, 2011).

Since 1969 the U.S. Meat Animal Research Center has been conducting the Germplasm Evaluation Program (GEP) designed to characterize cattle breeds that represent diverse biological types and traits of economic importance in beef production (Wheeler et al., 2006). Since its inception, the program has completed 8 lifetime cycles comparing a wide variety of crossbred cattle that are adapted to differing climates; collected data includes preweaning traits, postweaning growth and carcass traits, feed efficiency, and reproduction and maternal performance (Wheeler et al., 2006). Furthermore, from the data collected throughout the GEP, across breed EPD (AB-EPD) tables and adjustment factors have been created (Kuehn, 2012). The AB-EPDs for the 18 breeds represented in the tables could be useful for terminal crossbreeding producers to help identify bulls in different breeds with high potential for growth and favorable carcass characteristics (Kuehn, 2012).

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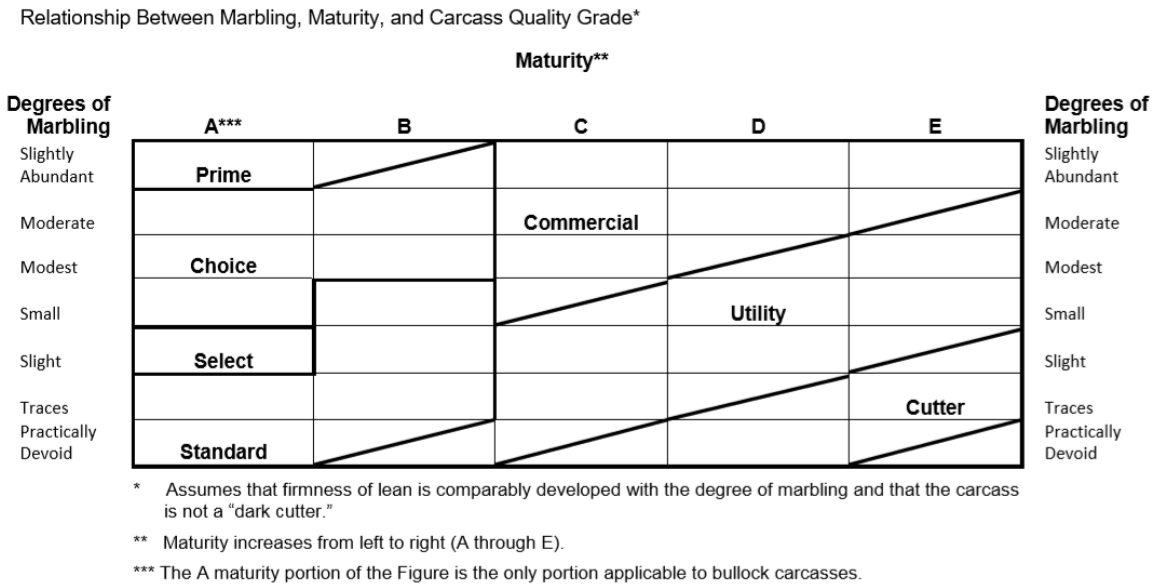

Figure 2.1. Relationship of marbling, maturity, and carcass quality grade (USDA, 2017).

Table 2.1 Certified Angus Beef Program: G-1 Specification[1]

Requirements
a. Phenotypic or genotypic requirements of the American Angus Association's (AAA) Live Animal Specification
b. Classed as Steer or Heifer carcasses only
c. U.S. Prime or Choice and have a minimum marbling score of Modest 0
d. Less than 30 months of age with lean color, texture, and firmness, meeting the requirements for A maturity in the U.S. grade it qualifies for
e. Medium or fine marbling texture
f. Ribeye Area (REA) of 10.0 to 16.0 square inches
g. Hot Carcass Weight (HCW) of 1,050 pounds or less
h. Fat Thickness (FT) less than 1.0 inch
i. Moderately thick or thicker muscling and tend to be at least moderately wide and thick in relation to length
j. No hump exceeding 2 inches in height
k. Practically free (not detracting from visual quality) of capillary rupture in the ribeye muscle
l. Free of "dark cutting" characteristics

[1]Table adapted from USDA AMS G-1 Specifications

CHAPTER 3

LIVE AND CARCASS PRODUCTION TRAITS FOR PROGENY OF AN F1 USDA PRIME – YIELD GRADE 1 CARCASS CLONE SIRE IN COMPARISON WITH PROGENY OF POPULAR REFERENCE SIRES

3.1. Abstract

The cloning of beef carcasses that grade USDA Prime – Yield Grade 1 (P1) has produced a sire that ranked well against high performing bulls from multiple breeds. An F1 (P1 x P1) sire would ideally outperform its high performing parents. A terminal sire study was conducted comparing progeny of an F1 (P1 x P1) sire (AxG1) against progeny (heifers and steers) of four high performing sires of varying breeds {P1 (Alpha); Angus; Simmental; Angus x Simmental}. Production traits included morbidity and mortality frequencies, weaning weight, feedlot arrival weight, and days on feed; carcass traits included frequency of abscessed liver and lung health, quality and yield grade (YG) parameters, total carcass value, and carcass value per cwt. A completely randomized experimental design was used; data was analyzed using a mixed model with a fixed effect of sire and random effects of harvest date, sex, and pen. AxG1 sired heifers had the highest ($P < 0.01$) marbling score, the highest ($P < 0.01$) carcass value per cwt, and numerically had the lowest calculated yield grade and highest frequency of YG one carcasses. Steers sired by AxG1 had the least ($P = 0.05$) backfat thickness, lowest ($P <$

0.01) calculated yield grade, highest ($P < 0.01$) marbling score, highest ($P < 0.01$) frequency of USDA Prime carcasses, the highest ($P < 0.03$) total carcass value, and highest ($P < 0.01$) carcass value per cwt respectfully. Collectively, AxG1 steers and heifers exhibited the least 12th rib fat thickness and lowest USDA YG in addition to the largest longissimus muscle area, highest marbling score, and greatest frequency of USDA Prime. These data suggest that AxG1 outperformed other high performing industry reference terminal sires in carcass quality and yield grade outcomes.

3.2. Introduction

With the shift to a value-based marketing system, commercial cattle producers make breeding and management decisions based upon what will maximize profitability for their operation. Commercial beef cattle production is generally most profitable when crossbreeding systems are utilized to capture heterosis and breed differences in future generations (Gregory and Cundiff, 1980; MacNeil, 2005).

The cloning project coined “PrimeOne”, has allowed our team at West Texas A&M University to salvage rare and desirable genetics that producers in the commercial cattle industry seek. In 2012 the “PrimeOne” project resulted in a bull (14% Zebu, 86% Angus; Alpha) and three identical heifers (Gammas) produced via SCNT from carcasses that graded USDA Prime – Yield Grade 1; a rare and antagonistic outcome observed in only 0.07% of the US beef population and highly sought after by beef producers (Boykin et al., 2017). In a terminal sire study, live and carcass production traits for Alpha progeny were compared to progeny of purebred Angus, Charolais, and Simmental reference sires (Sperber et al., 2018). For all outcomes that differed ($P < 0.05$), Alpha progeny ranked

either first or second; suggesting that Alpha progeny performed comparably against other high performing reference sires for terminal production traits (Sperber et al., 2018).

The subsequent breeding of Alpha to Gamma cows produced progeny (AxG_{1-13}) in 2015 via ET. An F1 sire (AxG1) would ideally outperform its high performing carcass quality and yield grade parents (Alpha and Gamma). Due to Alpha's progeny's performance in a terminal sire study (Sperber et al., 2018), our hypothesis was that AxG1 would be a higher performing terminal sire with progeny exhibiting live and carcass traits highly desired by commercial cattle producers. A terminal sire study was conducted to compare progeny of four sires (purebred Angus, purebred Simmental, Angus x Simmental and Alpha) selected for their carcass and production traits to progeny of AxG1 to determine his success in the terminal sire system.

3.3. Materials and Methods

The cloning procedure that created Alpha and the Gammas was completed under Institutional Animal Care and Use Committee (IACUC) 03-11-14. The progeny produced in this study were conceived from semen provided to Cactus Feeders (Amarillo, TX) to be used for artificial insemination. All live cattle in the current study were under the direct care and supervision of Cactus Feeders and all live cattle data was collected by their employees. 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).

3.3.1. F1 sire procedure

The sire that is the focus of this study, "AxG1", is the progeny of two USDA Prime and Yield Grade 1 carcass clones. The cloning process that resulted in the sire

"Alpha" and the dams "Gammas" was described by Sperber (2018). Alpha semen was utilized to inseminate Gamma cow oocytes via AI and fertilized ova were transferred into recipient cows at the WTAMU Nance Ranch (Canyon, TX) via ET. The breeding resulted in nine bull and four heifer AxG progeny born in April 2015; seven males were castrated and two males remained intact (AxG1 and AxG2). We hypothesized that AxG steers would exhibit desirable live and carcass performance traits as calves until harvest. The AxG steers were placed into the WTAMU Feedlot (Canyon, TX) and fed until desired quality grade was reached for harvest. At harvest in May 2016 at the WTAMU Meat Lab (Canyon, TX), AxG steers exhibited an average USDA marbling score of Moderate 30 (Md^{30}, USDA High Choice), average longissimus muscle area of 96.9 square centimeters, and an average calculated USDA Yield Grade of 2.1. All listed AxG steer carcass metrics were highly desirable by beef producers, indicating that AxG steers performed well against industry standards. With such valuable paternal and maternal genetics, the hypothesis that AxG1 could be a high performing terminal sire arose.

3.3.2. Randomization and AI

British x Continental beef cows (n = 991) were artificially inseminated (AI) following estrus synchronization between 28 and 30 November 2016. Cows were AI'd with semen from one of five sires: Alpha, AxG1, a purebred black Angus (Rampage), a purebred Simmental (Sure Bet), and an Angus x Simmental (Protégé). Straws of semen for each sire were thawed 10 at a time and dams were inseminated as they entered the chute randomly. On the last day of AI semen for Rampage became unavailable and semen from Protégé was substituted. Total semen straw counts for each sire were: 257-AxG1, 241-Alpha, 245-Sure Bet, 171-Rampage, and 77-Protégé.

Rampage, the Angus sire reported by ABS Global (De Forest, WI) as Quaker Hill Rampage 0A36 29AN1891, was the Angus breeds' top sire for registrations in 2018, the breed leader for $Beef, $Feedlot, and $Weaning and is the top 1% of the Angus breed for REA and FAT. Sure Bet, the Simmental sire reported by ABS Global (De Forest, WI) as Dikemans Sure Bet 29SM0390, has a .95 Accuracy rating and is ranked in the breeds top 10% for marbling. Protégé, the Angus x Simmental sire reported by ABS Global (De Forest, WI) as TSN Protégé Z896, is in the top 1% of its breed for weaning weight and HCW.

Dams were exposed to cleanup bulls (SimAngus) four days following AI to ensure they were bred. Out of the 991 dams that were exposed to semen and live sires, 739 live calves were born. Calf count for each sire was: AxG1 (n = 105), Alpha (n = 87), Rampage (n = 77), Surebet (n = 97), and Protégé (n = 55), cover bulls (n = 307). The remaining calves (n = 11) did not have sufficient DNA to allow for parentage testing.

3.3.3. Calf identification and weaning

Calves in this study (n = 739) were born in fall 2017 at Syracuse Feedyard (Cactus Feeders; Amarillo, TX), a confined cow-calf operation located in Syracuse, KS. Gestation and parturition occurred in feedyard pens. At birth calves received a visual tag that identified their birth date, Inforce 3 (Zoetis Inc., Kalamazoo, MI), and Calf Guard (Zoetis Inc., Kalamazoo, MI); bull calves were castrated with elastic band and administered tetanus vaccination. Calves that were treated for illness received an additional ear tag that identified the date and treatment. Health data for calves receiving treatment was also recorded in the feedyards' database system for later reporting.

At birth, Syracuse Feedyard employees evaluated dam maternal abilities and calf health. Calves born in poor health or to dams unfit to rear a calf (n = 30) were transported to Fullmer dairy calf ranch located in Syracuse, KS, where they received enhanced care. Of the calves raised at Fullmer, the Sure Bet and Protege each sired 1 calf, AxG1 sired 3 calves, Alpha sired 5 calves, Rampage sired 6 calves; and 14 calves were sired by cover bulls.

Intermediate processing of calves (n = 709) occurred on 17, 18, 19, 26, and 27 November 2017. Calves received Bovi-Shield GOLD 5 (Zoetis Inc., Kalamazoo, MI) and Ultrabac 7 (Zoetis Inc., Kalamazoo, MI), an additional visual identification tag, and an electronic identification tag. Tissue biopsy punches were taken for each calf and semen from each sire was sent to Quantum Genetix (Saskatoon, AB, CAN) for parentage testing.

On 5, 7, and 8 March 2018 calves in Syracuse Feedyard were weaned and calves from Fullmer were reintroduced into the feedyard population. During weaning processing calves were implanted with Revalor-G (40 mg trenbolone acetate + 8 mg estradiol; Intervet Inc., Millsboro, DE), administered CyLence Pour-On Insecticide (Bayer Health Care LLC, Shawnee Mission, KS), Synanthic (Boehringer Ingelheim Vetmedica Inc., St. Joseph, MO), Dectomax (Zoetis Inc., Kalamazoo, MI), Presponse SQ (Boehringer Ingelheim Vetmedica Inc., St. Joseph, MO), and Ultrabac 7 (Zoetis Inc., Kalamazoo, MI); weaning weights were recorded.

3.3.4. Feedyard arrival and processing

On 21 June 2018 calves (n = 652) were sorted by sex and shipped from Syracuse Feedyard to Ulysses Feedyard (Cactus Feeders; Amarillo, TX) in Ulysses, KS. Upon

arrival at Ulysses, steers (n = 363) were sorted five ways and heifers (n = 289) were sorted 4 ways for a total of 9 finishing pens.

Sorting was achieved by utilizing a combined frame and weight measuring system (CCSS) from Performance Cattle Company (Amarillo, TX). The CCSS system is designed to classify cattle via algorithms utilizing frame dimensions and weight collected during arrival or intermediate processing. The system allows feedyards to select the number of sort pens desired and uniformly classifies cattle into pens while also estimating harvest date.

During arrival sorting, steers were implanted (based on arrival weight) with either Revalor-IS (80 mg trenbolone acetate + 16 mg estradiol; Intervet Inc., Millsboro, DE) (Pens 159, 160, and 161), or Revalor-XS (200 mg trenbolone acetate + 40 mg estradiol; Intervet Inc., Millsboro, DE) (Pens 162 and 163). Heifers were implanted with either Revalor-IH (80 mg trenbolone acetate + 8 mg estradiol; Intervet Inc., Millsboro, DE) (Pens 164 and 165) or Revalor-200 (200 mg trenbolone acetate + 20 mg estradiol; Intervet Inc., Millsboro, DE) (Pens 166 and 167). All cattle were treated with Bovishield 3 (Zoetis Inc., Kalamazoo, MI), Dectomax (Zoetis Inc., Kalamazoo, MI), Synanthic (Boehringer Ingelheim Vetmedica Inc., St. Joseph, MO), and Nasalgen IP (Merck Inc., Summit, NJ). Heifers were rectally palpated via ultrasound to test for pregnancy. For heifers (n = 2) which were determined pregnant, Lutalyse (Zoetis Inc., Kalamazoo, MI) and dexamethasone injections were administered to initiate abortion. Males identified as bulls (n = 7) were castrated via emasculator.

For cattle in pens 159, 160, 161, 164, and 165 a terminal implant was not administered at initial processing and required a re-implant. On 05 September 2018 pens

159, 160, and 161 were implanted with Revalor XS (200 mg trenbolone acetate + 40 mg estradiol; Intervet Inc., Millsboro, DE) and administered Bovishield 3 (Zoetis Inc., Kalamazoo, MI). On 07 November 2018 heifers in pen 164 were implanted with Revalor-200 (200 mg trenbolone acetate + 20 mg estradiol; Intervet Inc., Millsboro, DE) and administered Bovishield 3 (Zoetis Inc., Kalamazoo, MI). On 12 November 2018 heifers in pen 165 were implanted with Revalor-200 (200 mg trenbolone acetate + 40 mg estradiol; Intervet Inc., Millsboro, DE) and administered Bovishield 3 (Zoetis Inc., Kalamazoo, MI).

At arrival processing at Ulysses Feedyard, Syracuse Feedyard calf tags and hospital tags were removed, and health data was reported for all animals. Each animal received a lot tag with individual identification. Morbidity and mortality for animals was recorded via the lot tag's individual identification number and reported in the feedyard's health data system.

The diet that all cattle received was equivalent and included flaked corn, corn stalks, wet distiller's grain, liquid fat, urea, mineral package, and micro ingredients. Feed delivered was recorded daily and maintained electronically in the feedyard operating system. Days on feed varied between groups due to sex and individual growth characteristics.

3.3.5. Slaughter and grading procedures

Steers and heifers were slaughtered in their five-way (steers) or four-way (heifers) arrival sort pens beginning with heifers in pen 167 being harvested on 12 November 2018. Steers from pen 163 and heifers from pen 166 were harvested on 26 November 2018. Heifers from pen 165 were harvested on 19 December 2019 and steers from pen

162 were harvested on 02 January 2019. Steers from pen 161 were harvested on 07 January 2019. Heifers from pen 164 and steers from pen 160 were harvested on 21 January 2019. Steers from pen 159 were the final lot to reach harvest on 20 February 2019. All cattle were marketed to Tyson Fresh Meats Inc. (Dakota Dunes, SD) and harvested at Tyson Fresh Meats Holcomb, KS beef slaughter facility approximately 90 km from Ulysses Feedyard.

All slaughter data was obtained by trained data collectors from West Texas A&M University Beef Carcass Research Center (BCRC) (Canyon, TX). Individual visual identification tags were recorded, electronic identification tags (EID) were recorded via Allflex RS420 Series Stick Reader (Allflex USA, DFW Airport, TX) and WTAMU ID tag was attached to carcasses via shroud pin. Liver and lung health outcomes were recorded. Lungs were visually evaluated and manually palpated to determine the presence and severity of lung lesions, interlobular adhesions, plural adhesions, missing lobes and interlobular fibrin tags. Lung scores were Normal (healthy lungs), Minor (presence of minor fibrin tags), Extensive (presence of extensive fibrin tags), 1 (0-15% consolidated lung tissue), 2 (15-50% consolidated lung tissue), 3 (>50% consolidated lung tissue) (Tennant et al., 2014). Livers were visually evaluated to determine health according to the scoring system reported by Brown and Lawrence (2010). Liver scores were Edible (no abnormalities), A- (1 or 2 small abscesses), A (1 or 2 large abscesses or multiple small abscesses), A+ (multiple large abscesses), A+AD (liver was adhered to diaphragm or gastrointestinal tract by abscess), A+OP (ruptured abscess on liver), A+AD/OP (ruptured abscess and adhered diaphragm or gastrointestinal); other abnormalities recorded were cirrhosis, distoma, and telangiectasis (Brown and Lawrence, 2010).

Following visceral evaluation, the packer identification tag number and HCW were recorded.

Following a 28 h chill carcasses were ribbed for USDA-AMS grading. Cattle were quality and yield graded via the VBG2000 camera (E+V Technology, Oranienburg, Germany). Kidney, pelvic, and heart fat percentage for camera calculated yield grade was determined via plant specific algorithm.

A PROC POWER test ($\alpha = 0.05$; $\beta = 0.90$) (SAS Institute, Carry, NC) was conducted to determine an appropriate number of strip loins per sire in each pen to collect. Three Certified Angus Beef (CAB), IMPS 180 strip loins were collected from each sire in each pen for Warner-Bratzler shear force (WBSF). All sires in the study were genetically homozygous black; thus, the decision to collect CAB carcasses was made to reflect the quality standards associated with the brand. Strip loins were collected following fabrication of carcasses and were vacuum-sealed. Loins were transported to the WTAMU meat lab (Canyon, TX). Due to the standards required for cattle to qualify for CAB and the distribution of sire progeny across pens, incomplete loin collections occurred in multiple sires and pens. Loin totals for sire and sex were: 12 AxG1 heifers, 12 Alpha heifers, 9 Rampage heifers, 10 Sure Bet heifers, 5 Protégé heifers, 15 AxG1 steers, 15 Alpha steers, 14 Rampage steers, 13 Sure Bet steers, and 6 Protégé steers.

3.3.6. Warner-Bratzler Shear Force Procedure

Collected loins were wet aged 14 days after harvest date at 3°C; on day 14 loins were frozen at -29°C for storage. On 25 and 26 July 2019 frozen loins were processed to produce steaks for WBSF. Frozen loins were cut into steaks 2.54-cm-thick and the cranial end steak was vacuum sealed and kept frozen at -29°C. On 23 and 24 September 2019

steaks were thawed at 5°C for 24 h. On 24 and 25 September 2019 steaks were cooked in a forced-air convection oven (Blodgett DFG-100-3, G.S. Blodgett Corporation, Essex Junction, VT) set at 177°C to an internal temperature of 71°C. Internal temperature was determined via Omega MDSSi8 meter (Omega Engineering Inc., Stamford, CT) and 0.001 gauge Omega Precision Fine Wire Thermocouples (Omega Engineering Inc., Stamford, CT). Cooked steaks were plastic wrapped and chilled for 24 h at 5°C. On 25 and 26 September 2019 six cores (1.27 cm diameter) were removed parallel to the muscle fibers of each steak. Cores were sheared (Instron 5944, Instron, Norwood, MA) with a WBSF shear blade attachment at 250 mm/min. Shear blade specifications are reported in the AMSA Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Meat (AMSA, 2016).

3.3.7. Statistical Analysis

A completely randomized experimental design was utilized; individual animal was considered the experimental unit. Syracuse Feedyard heifer and steer data were jointly analyzed. For Ulysses Feedyard data and carcass data heifers and steers were analyzed separately. Continuous and frequency data were analyzed using PROC MIXED and PROC GLIMMIX procedures of SAS 9.4 (SAS Institute Inc., Cary, NC) respecitively. Fixed effect of sire was utilized and random effects of Syracuse pen, Ulysses pen and harvest date were used. The Kenward-Roger's approximation for denominator degrees of freedom was used to correct unequal cell sizes. Additionally, days on feed (DOF), hot carcass weight (HCW), backfat thickness (FAT), and marbling score were utilized as covariates in separate models. Least square means were generated with the LSMEANS option of SAS and means were separated and denoted different ($P \leq$

0.05) using the pairwise comparison PDIFF option of SAS (SAS Institute Inc., Cary, NC). Significance was determined at ($P \leq 0.05$) and tendencies were observed at ($0.05 < P \leq 0.10$).

3.4. Results and Discussion

3.4.1. Gestation

Calves born from test sires in Syracuse Feedyard did not differ ($P = 0.13$) in gestation length (Table 3.1). The average gestation period length across all sires was 283 d, the general industry mean gestation length for beef cattle (Livesay and Bee, 1945). Cows bred to Alpha averaged 284 d gestation period and calves from the four other sires averaged a 282 d gestation period. Gestation length for AI sired calves born at Syracuse Feedyard ranged from 268 d to 328 d. Foote (1981) reported that gestation length exceeded 300 d at a frequency of 1.07%. Additionally, Sobek (2015) reported an extreme gestation length of 307 d in Simental and Montbeliard breeds of cattle. Although unusual, cattle (n = 7) in this study exceeded the 307 d gestation period reported by Sobek (2015). A variety of factors including dam breed, sire breed, age, parity number, body condition score and weight of dam, seasonal effects, sex of calf, and nutrition status of dam have all been reported to affect the gestation length of beef cattle (Andersen and Plum, 1965). Variety of dams utilized, a limit fed diet offered to dams throughout gestation, and differences in sires could have all affected the wide range observed in the gestation length.

3.4.2. Weaning weight

Differences in weaning weights (Table 3.1) were observed across sire groups. At weaning, a difference ($P < 0.01$) in weight (kg) was observed; Rampage sired calves were

heaviest (210.7 kg), followed by Sure Bet (205.8 kg), AxG1 (196.0 kg), Protégé (194.9 kg), and Alpha sired calves exhibiting the lowest average weaning weight (188.0 kg). Weights across all sires averaged 201 kg and ranged from 58 kg to 297 kg. Average days of age at weaning across all sires was 180 d and ranged from 136 d to 194 d. Rampage and Protégé's EPD's (ABS, 2019) report the sires to be in the top 1% of their respective breeds for weaning weight, thus higher weaning weights were not surprising outcomes for the pair.

In a profitable beef operation weaning of calves is accomplished to begin transitioning calves from reliance on their dams into stocker operations that will advance them through the beef production system. The average time of weaning for beef calves is around seven to eight months of age however, a variety of factors affect the time of weaning including dam body weight, body condition score, suckling status, and nutrition status. Syracuse feedyard brings extra dynamics to cow calf production due to dams being limit fed and all cattle being reared in confinement, thus the average age of weaning was lower than normal. Landaeta-Hernandez et al. (2013) reported that when fed in confinement, dams that were more dominant exhibited higher 90 d calf weight than dams that were subordinate. Dam body weight also followed the same trend as calf weight with dominant cattle obtaining a higher body weight than subordinate cattle (Landaeta-Hernandez et al., 2013). Additionally, dams that are fed a low energy ration pre and postpartum have been noted to have calves that exhibited lower weaning weights than dams fed a higher energy ration (Corah et al., 1975; Houghton et al., 1990). Due to the operations of Syracuse feedyard, either of the referenced reasons could have attributed to differing weaning weights across sires.

3.4.3. Calf morbidity

Calf morbidity differed ($P = 0.05$) between sires with AxG1 siring the highest percentage (24.8%) of treated calves (Table 3.1). Calves reared in confinement have been shown to have an increased frequency of morbidity for scours and bovine respiratory disease (BRD) than calves raised on pasture (Burson, 2017). Cattle raised in confinement are in much tighter enclosures where high levels of comingling are imminent; in conjunction with confined calves exhibiting a higher frequency of shedding bovine coronavirus and cryptosporidium (Burson, 2017), elevated calf morbidity was plausible. However, calves fed in confinement have exhibited elevated antibody titers to bovine viral diarrhea, bovine respiratory syncytial virus, infectious bovine rhinotracheitis, and parainfluenza 3; all viruses associated with BRD development (Burson, 2017). Thus, cattle fed in confinement may have a more enriched immune response than pasture fed cattle and could be more prepared for comingling during the marketing process or during feedlot arrival. Mortality data was unable to be obtained in full due to incomplete records and was excluded from data analysis.

3.4.4. Feedyard performance

Heifer feedlot arrival weight did not differ ($P = 0.75$) between sires (Table 3.2). Numerically, heifers sired by Rampage were heaviest (303.9 kg) and Alpha sired calves were lightest (297.2 kg). For steers, arrival weight did not differ between sires ($P = 0.79$). Rampage sired steers were heaviest (324.2 kg) while Protégé steers were lightest (317.9 kg) (Table 3.3).

Days on feed (DOF) was calculated as the number of days between feedlot arrival date and harvest date. For heifers, DOF differed ($P < 0.01$) between sires. Rampage

(159.9 d), Sure Bet (160.8 d) and Protégé (160.6 d) heifer progeny had the lowest DOF and AxG1 (174.5 d) and Alpha (174.5 d) progeny had the highest DOF (Table 3.2). Average DOF differed ($P < 0.01$) for sired steers (Table 3.3). As with the heifers, Rampage (188.4 d), Sure Bet (189.8 d) and Protégé (185.2 d) progeny's had the lowest DOF and AxG1 (199.7 d) and Alpha (206.3 d) progeny had the highest. Heifer DOF differed ($P < 0.01$) when FAT was used as a covariate (Table 3.12), did not differ ($P = 0.22$) in the marbling score covariate model (Table 3.13) and tended to differ ($P = 0.10$) when HCW was used as a covariate (Table 3.11). Steer DOF differed ($P < 0.02$) when HCW (Table 3.15) and FAT were used as covariates (Table 3.16) and tended to differ ($P = 0.06$) when marbling score was used as a covariate (Table 3.17).

Heifer harvest age differed ($P = 0.03$) between sires with Sure Bet (448.4 d), Rampage (449.2 d) and Protégé (449.5 d) having the youngest calves while Alpha (459.5 d) and AxG1 (461.8 d) had the oldest calves. Steer harvest age differed ($P < 0.01$) between sires with Protégé (472.7 d), Sure Bet (475.2 d) and Rampage (475.6 d) having the youngest calves while AxG1 (486.5 d) and Alpha (490.6 d) had the oldest calves. Harvest age of heifers differed ($P = 0.02$) when FAT (Table 3.12) was used as a covariate but did not differ ($P < 0.17$) when HCW (Table 3.11) or marbling score (Table 3.13) were covariates. Harvest age of steers did not differ ($P = 0.15$) when marbling score was used as a covariate (Table 3.17) but differed ($P < 0.02$) when HCW (Table 3.15) and FAT (Table 3.16) were covariates.

The utilization of the CCSS system from Performance Cattle Company (Garrison, 2005) sorted both heifers and steers based on body weight and animal body measurements into uniform harvest groups. It is likely that the greater DOF and older

harvest age for AxG1 and Alpha was due to a greater number of progeny from the pair that were sorted into later harvest groups by the CCSS system. Small framed cattle will reach a final harvest size earlier than cattle of a large frame size (Dolezal et al., 1993); early maturing cattle with smaller frame sizes would reach harvest at an earlier date and be on feed fewer days than larger framed cattle.

Morbidity did not differ ($P = 1.0$) between sires for steers (Table 3.9) and heifers (Table 3.8). Rampage, Alpha, and AxG1 had less than 2.5% morbidity and Sure Bet and Protégé had 0% morbidity for steer progeny. AxG1 sired heifers had 6.5% morbidity while no other sire progeny had reported morbidity. Mortality did not differ ($P = 1.0$) between sires for steers (Table 3.9) and heifers (Table 3.8). Sure Bet heifers had a 5.1% mortality rate while no other sired heifers had reported mortality. AxG1 steers had a 1.7% mortality rate while not other sired steers had reported mortality.

3.4.5. Liver and lung health

The frequency of heifers with presence of lung consolidation scores 1, 2, 3 and extensive fibrin tag did not differ ($P > 0.81$) between sires (Table 3.8). Minor fibrin tag formation tended to differ ($P = 0.09$) between sires for heifers. Protégé heifer progeny had the highest frequency of minor fibrin tags at 40%, a 16.5% increase from the next highest sire Rampage at 23.5%. AxG1 and Alpha heifer progeny exhibited the lowest frequencies of minor fibrin tags, with 10.9% and 8.8% respectively. There was no difference ($P > 0.64$) for frequencies of lung abnormalities in steers (Table 3.9). Tennant et al. (2014) reported that advanced lung lesion scores had negative economic effects mainly associated with reduced HCW at slaughter. Overall lung health for the study was positive with a low frequency of advanced lung lesions for steers and heifers.

No difference ($P = 0.68$) was observed for frequency of liver abscesses in heifers (Table 3.8). In heifers, Protégé progeny had the highest frequency of liver abscesses at 15% while Alpha calves had the lowest frequency at 2.9%. Liver abscesses in steers tended to differ ($P = 0.09$) across sires. Rampage sired steers had a 25.6% liver abscess rate and Sure Bet steers had a 14.8% liver abscess rate. Alpha, AxG1 and Protégé steers all had less than 7.3% liver abscess rate. Liver abscesses have been a major economic liability to producers and beef processors and were once ranked as the second highest concern of beef processors (Nagaraja and Chengappa, 1998). At slaughter, liver abscesses have been proven to reduce carcass gain and dressing percentage in addition to lowering feed intake versus cattle with normal livers (Brinks et al., 1990). The notably low occurrence of liver abscesses in Alpha sired calves (10.1 %) is a positive outcome for both producers and processors.

3.4.6. Hot carcass weight

Least square means (Table 3.2) for heifer HCW (kg) differed ($P < 0.01$) between sires. Rampage sired heifers had the highest HCW (372.8 kg) while Alpha heifers had the lowest (346.7 kg). Differences ($P < 0.01$) in HCW were observed when DOF (Table 3.10), FAT (Table 3.12), and marbling score (Table 3.13) were used as covariates. Additionally, least square means (Table 3.3) for steer HCW differed ($P < 0.01$) between sires. As with heifers, Rampage sired steers had the highest HCW (434.2 kg) and Alpha steers had the lowest (414.0 kg). Differences ($P < 0.01$) in HCW were observed when DOF (Table 3.14), FAT (Table 3.16), and marbling score (Table 3.17) were used as covariates. Hot carcass weight has been reported to account for 50-92% of the total

revenue of beef carcass marketed on value-based grids (Tatum et al., 2006). Thus, higher HCW are sought after by beef producers.

3.4.7. Fat thickness

Least square means (Table 3.2) for heifer FAT (cm) did not differ ($P = 0.67$) between sires. For heifers, when DOF (Table 3.10) and HCW (Table 3.11) were used as covariates, FAT did not differ ($P \geq 0.64$) between sires. However, when marbling score was the covariate (Table 3.13) FAT tended to differ ($P = 0.08$) with AxG1 and Alpha heifers exhibiting the least FAT (1.4 cm) and Rampage and Sure Bet heifers having the most FAT (1.6 cm). For steers, least square means (Table 3.3) differed ($P = 0.05$) between sires. AxG1 calves had the least backfat thickness (1.6 cm), differing from all other sires except for Sure Bet (1.7 cm). Steers of all other sires did not differ in backfat thickness (1.8 cm). When DOF (Table 3.14) and marbling score (Table 3.17) were used as covariates, FAT differed ($P \leq 0.05$) between sires while when HCW was the covariate (Table 3.15) FAT did not differ ($P = 0.11$). Backfat thickness is the yield grade component most closely related to cutability and is an important metric for calculating yield grade of beef carcasses (Lawrence, 2016). Fat thickness has been considered the most important variable in multiple regression equations designed to predict percentage of boneless steak and roast meat (Abraham et al., 1968).

3.4.8. *Longissimus* muscle area

Least square means of heifer (Table 3.2) LMA differed ($P = 0.05$) between sires. Sure Bet heifers (94.6 cm^2) had the largest average LMA followed by AxG1 heifers (93.8 cm^2). Heifer LMA differed ($P \leq 0.05$) when DOF (Table 3.10), HCW (Table 3.11), FAT (Table 3.12), and marbling score (Table 3.13) were used as covariates. For least square

means of steer (Table 3.3) LMA there was no difference ($P = 0.14$) between sires. However, AxG1 steers had the largest LMA (93.7 cm^2). Steer LMA did not differ ($P \geq 0.17$) when DOF (Table 3.14) or FAT (Table 3.16) were covariates. However, differences ($P \leq 0.04$) in LMA were observed when HCW (Table 3.15) and marbling score (Table 3.17) were covariates. AxG1 steers had the largest LMA (93.2 cm^2 – 95.2 cm^2) across all statistical models. Another important factor of the yield grade equation, LMA has a moderate positive correlation coefficient (0.47; $P < 0.01$) to cutability and can be a useful tool in creating cutability prediction equations (Crouse et al., 1975).

3.4.9. Calculated yield grade

Least square means for heifer (Table 3.2) calculated yield grade did not differ (P = 0.22) between sires. AxG1 heifers numerically had the lowest average yield grade of all heifer sires (YG 2.73) in the no covariate model. Calculated yield grade did not differ ($P \geq 0.22$) when DOF (Table 3.10) or HCW (Table 3.11) were covariates. However, differences ($P < 0.01$) in calculated yield grade were observed when FAT (Table 3.12) and marbling score (Table 3.13) were covariates. Notably, when marbling score was the covariate, AxG1 heifers had the lowest calculated yield grade (YG 2.55). Frequency of heifers stamped USDA Yield Grade (YG) 1, 3, 4, and 5 (Table 3.4) did not differ ($P > 0.25$). The frequency of heifers to grade YG 2 tended to differ ($P = 0.08$) between sires; Alpha heifers had the highest frequency and graded 73.6% YG 2 while Rampage heifers had the lowest frequency and graded 44.1% YG 2. Although there was no difference ($P > 0.25$) for frequency of heifers grading YG 1, 3, 4, and 5, it is noteworthy that AxG1 heifers graded 15.2% YG1 (over 2x next highest; Rampage 5.9% YG 1) and had 0% YG 4 carcasses. Notably, Alpha sired heifers exhibited the highest percentage of YG 1 and 2

carcass (76.5%). There were no YG 5 carcasses for any sires. Although backfat thickness for heifers was very similar across all sires, AxG1 heifers likely had a lowest average YG due to lighter HCW and larger LMA; thus, lowering carcass YG.

Least square means for steer (Table 3.3) calculated YG differed ($P < 0.01$) between sires. AxG1 steers had the lowest average yield grade (YG 3.49) and differed from Rampage (YG 3.80) and Protégé (YG 3.91) sired steers in the no covariate model. Calculated YG of steers tended to differ ($P = 0.10$) between sires when FAT was the covariate (Table 3.16) ,with AxG1 and Sure Bet having the lowest yield grade (YG 3.61). When DOF (Table 3.14), HCW (Table 3.15), and marbling score (Table 3.17) were covariates, calculated yield differed ($P \leq 0.02$) between sires with AXG1 steers exhibiting the lowest values (YG 3.37 – 3.51). Frequency of steers stamped YG 1-5 (Table 3.5) did not differ ($P > 0.13$) between sires. AxG1 steers numerically had the lowest frequency of YG 4 carcasses (16.0%) while also having the highest percentage of carcasses grading YG 1 and 2 (84%). There were no steers achieving YG 1 and Alpha and Rampage were the only sires to have steers grading YG 5 (2.2% and 2.6% respectfully). AxG1 steers likely exhibited lower average YG due to having large LMA, moderate HCW, and low FAT; thus, lowering carcass YG.

Lawrence et al. (2008) reported that there was a linear relationship established that requires a minimum LMA per unit of HCW in calculating the yield grade equation. As HCW increases, the required LMA also increases; a carcass with a lighter HCW would require a smaller LMA to meet this relationship. However, if a carcass with a lighter HCW has a larger LMA than required, the yield grade of the carcass will drop. This is likely the case for AxG1 sired progeny's carcasses. Although the HCW for AxG1

sired steers and heifers were numerically lighter throughout the study, a larger LMA associated with these carcasses was sufficient to help lower the YG.

3.4.10. Quality grading and marbling scores

The least square means for heifer marbling scores (Table 3.2, 3.10, 3.11, and 3.12) differed ($P < 0.01$) between sires across all statistical models. AxG1 sired heifers had the highest marbling score (574 - 588; Modest^{74} – Modest^{88}) and differed from all other sires in all statistical models. The frequency for heifer carcasses to be stamped USDA Prime, G-1 (Certified Angus Beef), Choice, and Select (Table 3.4) did not differ ($P > 0.16$) between sires. However, AxG1 heifers had the highest frequency of carcasses stamped USDA Prime and G-1 (10.8% and 60.9% respectfully). Notably, Alpha sired heifers had the second highest frequency of carcasses stamped USDA Prime and, G-1 (8.8% and 50.0% respectfully).

Least square means for steer marbling scores (Tables 3.3, 3.14, 3.15, and 3.16) differed ($P < 0.01$) between sires across all statistical models. AxG1 steers had the highest average marbling score (621 - 636; Moderate^{21} – Moderate^{36}) and differed from steers from all other sires in all statistical models. The frequency of steers (Table 3.5) to be stamped USDA G-1 and Select did not differ ($P > 0.68$) between sires. Frequency of sires grading USDA Choice tended to differ ($P = 0.07$) between sires; AxG1 steers had the lowest frequency of grading USDA Choice (17.9%) while Rampage steers had the highest frequency (46.2%). The frequency of steers grading USDA Prime differed ($P < 0.01$) between sires. AxG1 steers had the highest frequency (33.9%) of USDA Prime stamped carcasses, differing from all other sired steers. Alpha sired steers had the second

highest frequency (13.3%) of USDA Prime stamped carcasses, a very notable figure, however, overshadowed by AxG1 grading performance.

Boykin et al. (2017) reported that the mean marbling score for the National Beef Quality Audit (NBQA) – 2016 was 470 (Small[70]); though all sires in this study had numerically higher marbling scores than reported in the 2016 NBQA, AxG1 progeny had numerically over a 100 degree higher marbling score (610; Moderate[10]) than the audit average. Additionally, in the 2016 NBQA around 3.98% of carcasses graded USDA Prime (Boykin et al., 2017) while AxG1 progeny in this study graded 23.53% USDA Prime; close to six times the amount of USDA Prime carcasses from the audit. AxG1 progeny were also more likely to grade USDA Prime (23.53%) than USDA Low or Commodity Choice (21.57%).

3.4.11. Empty body fat (%)

Least square means of heifer calculated empty body fat (EBF; %) (Table 3.2) did not differ ($P = 0.83$) between sires. Heifer EBF did not differ ($P \geq 0.73$) when DOF (Table 3.10) or HCW (Table 3.11) were covariates yet tended to differ ($P = 0.07$) when FAT (Table 3.12) was the covariate. However, EBF differed ($P < 0.01$) in heifers when marbling score was the covariate (Table 3.13) with AxG1 having the lowest calculated EBF (29.7%). For least square means of steer EBF (Table 3.3) tended to differ ($P = 0.09$) between sires with Protégé steers exhibiting the highest numeric EBF (33.8%) while Sure Bet steers had the lowest (32.6%). Steer EBF did not differ ($P = 0.28$) when HCW was the covariate (Table 3.15) yet tended to differ ($P = 0.07$) when DOF was the covariate (Table 3.14). Additionally, steer EBF differed ($P < 0.01$) between sires when FAT (Table 3.16) and marbling score (Table 3.17) were covariates. Sure Bet steers had the lowest

EBF (32.9%) when FAT was the covariate and AxG1 had the lowest EBF (32.4%) when marbling score was the covariate. Guiroy et al., (2002) reported that as quality grade increases EBF generally increased as well; USDA Standard cattle would have numerically lower EBF than USDA Prime cattle. The USDA Prime and Yield Grade 1 carcass that Alpha was cloned from had an EBF of 30.1%, lower than the average reported for USDA Prime carcasses by Guiroy et al. (2002). AxG1 steers were the highest grading carcasses and had the second lowest EBF values. This can be attributed to AxG1 steer carcasses having the lowest backfat thickness and lower HCW's which would lower the carcasses EBF, even as carcasses graded higher.

3.4.12. Carcass value

Least square means for heifer carcass value per cwt (Tables 3.2, 3.10, 3.11, 3.12, 3.13) differed ($P < 0.01$) between sires across all statistical models. AxG1 heifers had the highest value per cwt ($195.35/cwt – $195.48/cwt) in the no covariate, DOF, HCW, and the FAT models. Alpha sired heifers had the highest carcass value per cwt ($194.52/cwt) in the marbling score covariate model. Additionally, total carcass value of heifers (Table 3.2, 3.10, 3.11, 3.12, 3.13) differed ($P \leq 0.05$) between sires across all statistical models. Rampage sired heifers had the highest total carcass value ($1566 - $1575) for the no covariate, DOF, FAT, and marbling score models due to Rampage heifers having the highest HCW. When HCW is held constant in the statistical model AxG1 heifers had the highest total carcass value ($1550) while Rampage heifers had the lowest value ($1518). In all statistical models except when HCW was a covariate, Rampage heifers had the highest total carcass value and the lowest value per cwt. The inverse is true for AxG1 and Alpha heifers. This inverse relationship is due to AxG1 and Alpha sired heifers having

numerically the lowest HCW's while Rampage heifers having the highest HCW; Rampage heifers had more pounds of carcass to sell even though their price per cwt was lower than AxG1 and Alpha heifers.

The least square means for steer carcass value per cwt (Tables 3.3, 3.14, 3.15, 3.16, and 3.17) differed ($P < 0.01$) between sires across all statistical models. AxG1 steers had the highest value per cwt ($192.11/cwt – $193.22/cwt) and differed from all other sires in all statistical models. No difference ($P = 0.22$) was observed for total carcass value between sires in the marbling score covariate model (Table 3.17). Total carcass value least square means differed ($P \leq 0.03$) between sires in the no covariate (Table 3.3), DOF (Table 3.14), HCW (Table 3.15), and FAT (Table 3.16) models. AxG1 steers had the highest total carcass value ($1772 - $1796) across all statistical models. Unlike the occurrence in heifers, AxG1 steers had moderate HCW; this in addition to higher average USDA quality grades and lower average USDA yield grades allowed AxG1 sired steers to have the highest carcass value per cwt and total carcass value across all statistical models.

3.4.13. Warner-Bratzler Shear Force

The Warner-Bratzler Shear Force (WBSF) method of mechanical tenderness testing was developed in the 1920's by K.F. Warner (1952) and refined in 1932 at Kansas State University as a master's degree thesis project for L.J. Bratzler (1932). Since its development WBSF has become possibly the most utilized form of mechanical tenderness testing for meat.

Least square means for heifer and steer average WBSF values (Table 3.7) did not differ ($P > 0.24$) between sires. ASTM International created a minimum tenderness

threshold value (MTTV) of 4.4 kg in WBSF testing to be considered “Certified Tender” beef. Additionally, the claim “Certified Very Tender” can be attained by reaching a MTTV of 3.9 kg in WBSF testing. Both steers and heifers of all sires had mean WBSF values under the “Certified Very Tender” threshold. Frequencies of both steers and heifers to be “Certified Tender” and “Certified Very Tender” did not differ ($P > 0.24$) between sires. Numerically, Protégé heifers had the lowest frequency of “Certified Tender” heifers (60.0%) while Sure Bet had the highest frequency (100%); Sure Bet is ranked in the top 1% of his breed for shearing value. Rampage sired steers numerically had the lowest frequency of steers to be “Certified Tender” at 92.9%; 100% of AxG1, Alpha, Sure Bet and Protégé steers were “Certified Tender.” Protégé heifers had the lowest frequency of heifers to be “Certified Very Tender” (21.9%) whereas Sure Bet heifers had the highest frequency (80.0%). For both sexes of all tested sires average mean tenderness values were below the 3.9 kg threshold of “Certified Very Tender”, indicating that tenderness values across the entire study were highly desirable.

3.5. Conclusion

The data from this project investigated the terminal sire traits for steers and heifers sired by an F1 USDA Prime – Yield Grade 1 carcass clone sire. Findings from this study suggest that the F1 bull, AxG1, outperformed his cloned sire, Alpha, and three other popular industry terminal sires of varying breeds in carcass quality and yield grade outcomes. The progeny of AxG1 exhibited carcass performance that would be highly desired by commercial cattle producers, validating that Ax1 is a high-performing terminal sire in the beef industry.

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Table 3.1. Gestation, calf performance, and health.

Outcome	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* -value
n	105	87	77	97	55	-	-
Mean Gestation, d	282	284	282	282	282	1.1	0.13
Female, %	43.8	41.4	44.2	43.3	47.3	-	-
Male, %	56.2	58.6	55.8	56.7	52.7	-	-
Weaning weight, kg	196.0^{bc}	188.0^{c}	210.7^{a}	205.8^{ab}	194.9^{bc}	6.3	<0.01
Morbidity, %	24.8^{a}	15.0^{ab}	10.8^{b}	9.2^{b}	17.9^{ab}	-	0.05

Table 3.2. Heifer feedlot and carcass performance.

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	46	36	34	42	26	-	-
Arrival weight, kg	298.2	297.2	303.9	300.6	300.0	20.6	0.75
Days on feed	174.5[a]	174.5[a]	159.9[b]	160.8[b]	160.6[b]	4.0	<0.01
Harvest age, d	461.8[a]	459.5[ab]	449.2[bc]	448.4[c]	449.5[bc]	4.0	0.03
Hot carcass weight, kg	352.9[bc]	346.7[c]	372.8[a]	362.5[ab]	361.3[ab]	6.2	<0.01
Backfat thickness, cm	1.5	1.4	1.5	1.5	1.4	0.1	0.70
Longissimus muscle area, (cm^2)	93.8[a]	91.8[ab]	93.0[a]	94.6[a]	89.1[b]	1.3	0.05
Calculated yield grade	2.73	2.77	3.02	2.86	3.04	0.1	0.22
Marbling score[1]	583[a]	539[b]	524[b]	521[b]	505[b]	25.3[b]	<0.01
Empty body fat[2]	30.7	30.3	31.0	30.6	30.5	0.5	0.83
Carcass value, cwt[3]	195.48[a]	194.72[ab]	191.09[c]	193.39[b]	191.25[bc]	0.8	<0.01
Total carcass value[3]	1521[bc]	1487[c]	1572a	1546[ab]	1525[abc]	25.3	0.02

[1]Marbling scores: 400=Small[00] (Minimum for USDA Choice), 500=Modest[00] (Minimum for USDA Premium Choice).
[2]Empty body fat (EBF) = 17.76207 + (4.68142 × FT) + (0.01945 × HCW) + (0.81855 × QG) − (0.06754 × LMA); FT = fat thickness, cm; HCW = hot carcass weight, km; QG = quality grade (Select = 4, Low Choice = 5, Average Choice = 6, High Choice = 7, Low Prime = 8); LMA = longissimus muscle area, sq cm (Guiroy et al., 2002).
[3]Carcass values calculated according to Table 3.6.

Table 3.3. Steer feedlot and carcass performance.

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	59	51	43	55	29	-	-
Arrival weight, kg	322.8	321.7	324.2	321.8	317.9	19.4	0.79
Days on feed	199.7^{a}	206.3^{a}	188.4^{b}	189.8^{b}	185.2^{b}	4.1	<0.01
Harvest age, d	486.5^{a}	490.6^{a}	475.6^{b}	475.2^{b}	472.7^{b}	3.9	<0.01
Hot carcass weight, kg	420.0^{bc}	414.0^{c}	434.2^{a}	415.2^{c}	430.3^{ab}	8.3	<0.01
Backfat thickness, cm	1.6^{b}	1.8^{a}	1.8^{a}	1.7^{ab}	1.8^{a}	0.08	0.05
Longissimus muscle area, (cm^2)	93.7	90.5	92.7	92.5	90.6	1.3	0.14
Calculated yield grade	3.49^{c}	3.71^{ab}	3.80^{a}	3.55^{bc}	3.91^{a}	0.1	<0.01
Marbling score[1]	630^{a}	576^{b}	562^{bc}	539^{c}	543^{bc}	22.3	<0.01
Empty body fat[2]	33.3	33.5	33.7	32.6	33.8	0.6	0.09
Carcass value, cwt[3]	193.22^{a}	189.85^{b}	184.52^{c}	190.01^{b}	182.85^{c}	2.2	<0.01
Total carcass value[3]	1788^{a}	1730^{b}	1764^{ab}	1739^{b}	1730^{b}	18.1	0.03

[1]Marbling scores: 400=Small^{00} (Minimum for USDA Choice), 500=Modest^{00} (Minimum for USDA Premium Choice).
[2]Empty body fat (EBF) = 17.76207 + (4.68142 × FT) + (0.01945 × HCW) + (0.81855 × QG) − (0.06754 × LMA); FT = fat thickness, cm; HCW = hot carcass weight, km; QG = quality grade (Select = 4, Low Choice = 5, Average Choice = 6, High Choice = 7, Low Prime = 8); LMA = longissimus muscle area, sq cm (Guiroy et al., 2002).
[3]Carcass values calculated according to Table 3.6.

Table 3.4. USDA quality and yield stamps of heifers.

Outcome	AxG1	Alpha	Rampage	Sure Bet	Protégé	*P* value
n	46	36	34	42	26	-
Carcass quality stamp, %						
Prime	10.8	8.8	2.9	0.0	5.0	0.76
Certified Angus Beef	60.9	50.0	35.3	48.7	30.0	0.16
Choice	26.1	41.2	47.1	51.3	55.0	0.16
Select	2.2	0.0	14.7	0.0	10.0	0.52
Yield Grade, %						
1	15.2	2.9	5.9	5.4	10.0	0.39
2	47.8	73.6	44.1	51.4	30.0	0.08
3	37.0	20.6	44.1	40.5	50.0	0.25
4	0.0	2.9	5.9	2.7	10.0	0.79
5	0.0	0.0	0.0	0.0	0.0	1.0

Table 3.5. USDA quality and yield stamps of steers.

Outcome	AxG1	Alpha	Rampage	Sure Bet	Protégé	*P* value
n	59	51	43	55	29	-
Carcass quality stamp, %						
Prime	33.9[a]	13.3[b]	5.1[b]	3.7[b]	4.0[b]	<0.01
Certified Angus Beef	48.2	57.8	48.7	57.4	44.0	0.68
Choice	17.9	28.9	46.2	37.0	44.0	0.07
Select	0	0	0	1.9	8.0	0.83
Yield Grade, %						
1	0	0	0	0	0	1.0
2	16.1	8.9	5.1	20.4	4.0	0.18
3	67.9	62.2	59.0	57.4	52.0	0.68
4	16.0	26.7	33.3	22.2	44.0	0.13
5	0	2.2	2.6	0	0	1.0

Table 3.6. Carcass value-based pricing grid for duration of project.[1] (AMSb, 2019)

Base carcass price[1] (AMSa, 2019)	Quality grade	Hot carcass weight, kg	Yield grade
		181-227 (-29.71)	1.0-2.0 (+3.75)
	Prime (+12.68)	227-250 (-21.34)	2.0-2.5 (+2.00)
	CAB (+3.74)	250-272 (-8.37)	2.5-3.0 (+1.63)
190.71/cwt	**Choice (0.00)**	**272-408 (0.00)**	**3.0-4.0 (0.00)**
	Select (-11.39)	408-454 (-1.68)	4.0-5.0 (-11.50)
	Standard (-29.06)	454-476 (-7.18)	>5.0 (-17.19)
		>476 (-23.70)	

[1]Project duration was considered calf conception date to last calf harvest date (November 2016 – February 2019).

Table 3.7. Warner-Bratzler shear force outcomes.

Outcome	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
Heifers							
n	12	12	9	10	5	-	-
Mean shear values, kg	3.8	3.5	3.6	3.2	3.4	0.2	0.24
Certified Tender[1], %	75.0	91.7	88.9	100.0	60.0	-	0.62
Certified Very Tender[1], %	58.3	66.7	66.7	80.0	21.9	-	0.87
Steers							
n	15	15	14	13	6	-	-
Mean shear values, kg	3.4	3.4	3.6	3.5	3.5	0.16	0.69
Certified Tender[1], %	100.0	100.0	92.9	100.0	100.0	-	1.00
Certified Very Tender[1], %	100.0	100.0	71.4	76.9	83.3	-	0.99

[1]Marketing claims certified by ASTM International and USDA AMS;
Certified Tender ≤ 4.4 kg and Certified Very Tender ≤ 3.9 kg.

Table 3.8. Heifer feedlot health outcomes.

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	46	36	34	42	26	-	-
Morbidity, %	6.5	0	0	0	0	-	1.0
Mortality, %	0	0	0	5.1	0	-	1.0
Liver abscesses, %	8.7	2.9	8.8	10.8	15.0	-	0.68
Lung abnormalities, %							
1	0	5.9	5.9	5.1	6.7	-	0.92
2	2.2	0	8.8	0	5.0	-	0.81
3	0	0	5.9	2.7	0	-	0.98
Minor	10.9	8.8	23.5	16.2	40.0	-	0.09
Extensive	8.7	14.7	11.8	0	15.0	-	0.92

Table 3.9. Steer feedlot health outcomes.

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	59	51	43	55	29	-	-
Morbidity, %	1.7	2.2	2.5	0	0	-	1.0
Mortality, %	1.7	0	0	0	0	-	1.0
Liver abscesses, %	7.0	7.3	25.6	14.8	4.0	-	0.09
Lung abnormalities, %							
1	1.7	0	0	1.9	0	-	1.0
2	3.5	8.9	5.1	9.3	12.0	-	0.64
3	1.8	4.4	5.1	3.7	0	-	0.93
Minor	1.8	0	7.7	0	8.0	-	0.74
Extensive	21.1	22.2	12.8	14.8	24.0	-	0.66

Table 3.10. Heifer feedlot and carcass performance: DOF covariate.

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	46	36	34	42	26	-	-
Hot carcass weight, kg	354.4^{bc}	348.1^{c}	373.9^{a}	363.6^{ab}	362.3^{ab}	5.9	<0.01
Backfat thickness, cm	1.4	1.4	1.5	1.5	1.4	0.1	0.64
Longissimus muscle area, (cm^2)	93.9^{a}	91.9^{ab}	92.9^{a}	94.5^{a}	89.1^{b}	1.3	0.05
Calculated yield grade	2.77	2.73	3.02	2.85	3.04	0.1	0.22
Marbling score[1]	574^{a}	529^{b}	517^{b}	513^{b}	496^{b}	15.5	<0.01
Empty body fat[2]	30.6	30.2	30.9	30.6	30.4	0.5	0.80
Carcass value, cwt[3]	195.35^{a}	194.59^{ab}	191.08^{c}	193.38^{b}	191.24^{c}	0.8	<0.01
Total carcass value[3]	1526^{bc}	1493^{c}	1575^{a}	1550^{ab}	1528^{abc}	24.8	0.03

[1]Marbling scores: 400=Small^{00} (Minimum for USDA Choice), 500=Modest^{00} (Minimum for USDA Premium Choice).
[2]Empty body fat (EBF) = 17.76207 + (4.68142 × FT) + (0.01945 × HCW) + (0.81855 × QG) − (0.06754 × LMA); FT = fat thickness, cm; HCW = hot carcass weight, km; QG = quality grade (Select = 4, Low Choice = 5, Average Choice = 6, High Choice = 7, Low Prime = 8); LMA = longissimus muscle area, sq cm (Guiroy et al., 2002).
[3]Carcass values calculated according to Table 3.6.

Table 3.11. Heifer feedlot and carcass performance: HCW covariate.

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	46	36	34	42	26	-	-
Days on feed	173.2	171.7	163.0	161.9	161.2	4.1	0.10
Harvest age, d	460.8	457.2	451.7	449.4	449.9	4.0	0.17
Backfat thickness, cm	1.5	1.5	1.5	1.5	1.4	0.1	0.87
Longissimus muscle area, (cm^2)	94.1	92.3	92.3	94.4	89.0	1.3	0.05
Calculated yield grade	2.81	2.92	2.86	2.81	3.01	0.1	0.67
Marbling score[1]	588[a]	549[b]	516[b]	520[b]	505[b]	26.6	<0.01
Empty body fat[2]	31.0	30.9	30.4	30.5	30.4	0.5	0.73
Carcass value, cwt[3]	195.38[a]	194.50[ab]	191.30[c]	193.41[b]	191.25[c]	0.8	<0.01
Total carcass value[3]	1550[a]	1542[ab]	1518[d]	1535[bc]	1518[cd]	6.1	<0.01

[1]Marbling scores: 400=Small[00] (Minimum for USDA Choice), 500=Modest[00] (Minimum for USDA Premium Choice).
[2]Empty body fat (EBF) = 17.76207 + (4.68142 × FT) + (0.01945 × HCW) + (0.81855 × QG) − (0.06754 × LMA); FT = fat thickness, cm; HCW = hot carcass weight, km; QG = quality grade (Select = 4, Low Choice = 5, Average Choice = 6, High Choice = 7, Low Prime = 8); LMA = longissimus muscle area, sq cm (Guiroy et al., 2002).
[3]Carcass values calculated according to Table 3.6.

Table 3.12. Heifer feedlot and carcass performance: FAT covariate.

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	46	36	34	42	26	-	-
Days on feed	174.6[a]	174.7[a]	159.7[b]	160.6[b]	160.8[b]	4.1	<0.01
Harvest age, d	462.0[a]	459.8[ab]	448.9[bc]	448.0[c]	449.9[abc]	4.0	0.02
Hot carcass weight, kg	353.7[bc]	347.5[c]	371.3[a]	361.0[ab]	361.8[ab]	5.9	<0.01
Longissimus muscle area, (cm^2)	93.6[ab]	91.5[bc]	93.4[ab]	95.0[a]	88.8[c]	1.2	<0.01
Calculated yield grade	2.78[c]	2.83[bc]	2.93[ab]	2.77[c]	3.08[a]	0.1	<0.01
Marbling score[1]	586[a]	542[b]	519[b]	516[b]	507[b]	23.2	<0.01
Empty body fat[2]	30.8	30.5	30.6	30.3	30.6	0.2	0.07
Carcass value, cwt[3]	195.46[a]	194.69[ab]	191.13[c]	193.43[b]	191.24[b]	0.8	<0.01
Total carcass value[3]	1524[ab]	1491[b]	1566[a]	1540[a]	1528[ab]	23.6	0.05

[1]Marbling scores: 400=Small[00] (Minimum for USDA Choice), 500=Modest[00] (Minimum for USDA Premium Choice).
[2]Empty body fat (EBF) = 17.76207 + (4.68142 × FT) + (0.01945 × HCW) + (0.81855 × QG) − (0.06754 × LMA); FT = fat thickness, cm; HCW = hot carcass weight, km; QG = quality grade (Select = 4, Low Choice = 5, Average Choice = 6, High Choice = 7, Low Prime = 8); LMA = longissimus muscle area, sq cm (Guiroy et al., 2002).
[3]Carcass values calculated according to Table 3.6.

Table 3.13. Heifer feedlot and carcass performance: Marbling score covariate.

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	46	36	34	42	26	-	-
Days on feed	169.1	173.9	162.4	163.9	165.2	3.8	0.22
Harvest age, d	455.9	458.8	452.2	451.7	454.6	3.7	0.63
Hot carcass weight, kg	349.7^{b}	346.3^{b}	373.1^{a}	363.2^{a}	362.8^{a}	6.9	<0.01
Backfat thickness, cm	1.4	1.4	1.6	1.6	1.5	0.1	0.08
Longissimus muscle area, (cm^2)	95.2^{a}	92.0^{b}	92.4^{ab}	94.3^{ab}	88.0^{c}	1.2	<0.01
Calculated yield grade	2.55^{c}	2.75^{bc}	3.06^{a}	2.89^{ab}	3.14^{a}	0.1	<0.01
Empty body fat[1]	29.7^{c}	30.1^{bc}	31.2^{a}	30.9^{ab}	31.1^{ab}	0.4	<0.01
Carcass value, cwt[3]	194.27^{a}	194.52^{a}	191.45^{c}	193.73^{ab}	192.05^{bc}	0.7	<0.01
Total carcass value[3]	1497^{b}	1484^{b}	1574^{a}	1550^{a}	1536^{ab}	29.6	<0.01

[1]Empty body fat (EBF) = 17.76207 + (4.68142 × FT) + (0.01945 × HCW) + (0.81855 × QG) − (0.06754 × LMA); FT = fat thickness, cm; HCW = hot carcass weight, km; QG = quality grade (Select = 4, Low Choice = 5, Average Choice = 6, High Choice = 7, Low Prime = 8); LMA = longissimus muscle area, sq cm (Guiroy et al., 2002).

[3]Carcass values calculated according to Table 3.6.

Table 3.14. Steer feedlot and carcass performance: DOF covariate.

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	59	51	43	55	29	-	-
Hot carcass weight, kg	422.1^{bc}	416.2^{c}	436.0^{a}	417.1^{c}	432.1^{ab}	8.3	<0.01
Backfat thickness, cm	1.6^{b}	1.8^{a}	1.8^{a}	1.7^{ab}	1.8^{a}	0.1	0.05
Longissimus muscle area, (cm^2)	94.0	91.1	93.1	92.7	90.7	1.1	0.17
Calculated yield grade	3.48^{c}	3.71^{ab}	3.80^{a}	3.54^{bc}	3.91^{a}	0.1	<0.01
Marbling score[1]	621^{a}	568^{b}	556^{b}	532^{b}	536^{b}	15.5	<0.01
Empty body fat[2]	33.2	33.4	33.7	32.6	33.8	0.6	0.09
Carcass value, cwt[3]	192.72^{a}	189.30^{b}	184.08^{c}	189.57^{b}	182.42^{c}	2.3	<0.01
Total carcass value[3]	1791^{a}	1734^{b}	1765^{ab}	1741^{b}	1731^{b}	18.1	0.03

[1]Marbling scores: 400=Small^{00} (Minimum for USDA Choice), 500=Modest^{00} (Minimum for USDA Premium Choice).
[2]Empty body fat (EBF) = 17.76207 + (4.68142 × FT) + (0.01945 × HCW) + (0.81855 × QG) − (0.06754 × LMA); FT = fat thickness, cm; HCW = hot carcass weight, km; QG = quality grade (Select = 4, Low Choice = 5, Average Choice = 6, High Choice = 7, Low Prime = 8); LMA = longissimus muscle area, sq cm (Guiroy et al., 2002).
[3]Carcass values calculated according to Table 3.6.

Table 3.15. Steer feedlot and carcass performance: HCW covariate.

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	59	51	43	55	29	-	-
Days on feed	199.0^{ab}	204.7^{a}	191.0^{b}	189.1^{b}	186.7^{b}	4.1	0.02
Harvest age, d	485.8^{ab}	489.3^{a}	477.6^{bc}	474.6^{c}	473.9^{c}	3.9	0.02
Backfat thickness, cm	1.7	1.8	1.8	1.7	1.8	0.1	0.11
Longissimus muscle area, (cm^2)	94.0^{a}	91.6^{ab}	91.5^{ab}	93.3^{a}	89.8^{b}	1.1	0.03
Calculated yield grade	3.51^{c}	3.77^{ab}	3.74^{ab}	3.60^{bc}	3.87^{a}	0.1	0.02
Marbling score[1]	631^{a}	579^{b}	559^{bc}	541^{c}	542^{bc}	23.0	<0.01
Empty body fat[2]	33.4	33.8	33.4	32.9	33.6	0.5	0.28
Carcass value, cwt[3]	192.68^{a}	188.44^{b}	185.95^{bc}	188.66^{b}	183.79^{c}	1.3	<0.01
Total carcass value[3]	1796^{a}	1757^{b}	1730^{bc}	1758^{b}	1709^{c}	12.9	<0.01

[1]Marbling scores: 400=Small^{00} (Minimum for USDA Choice), 500=Modest^{00} (Minimum for USDA Premium Choice).
[2]Empty body fat (EBF) = 17.76207 + (4.68142 × FT) + (0.01945 × HCW) + (0.81855 × QG) − (0.06754 × LMA); FT = fat thickness, cm; HCW = hot carcass weight, km; QG = quality grade (Select = 4, Low Choice = 5, Average Choice = 6, High Choice = 7, Low Prime = 8); LMA = longissimus muscle area, sq cm (Guiroy et al., 2002).
[3]Carcass values calculated according to Table 3.6.

Table 3.16. Steer feedlot and carcass performance: FAT covariate

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	59	51	43	55	29	-	-
Days on feed	200.1^{ab}	205.9^{a}	187.8^{bc}	190.2^{bc}	184.6^{c}	4.1	<0.01
Harvest age, d	486.6^{a}	490.4^{a}	475.2^{b}	475.5^{b}	472.3^{b}	3.9	<0.01
Hot carcass weight, kg	421.8^{abc}	413.0^{c}	433.0^{a}	416.3^{bc}	428.4^{ab}	7.4	<0.01
Longissimus muscle area, (cm^2)	93.2	90.8	93.0	92.2	91.0	1.4	0.33
Calculated yield grade	3.61	3.65	3.71	3.61	3.77	0.1	0.10
Marbling score[1]	636^{a}	573^{b}	557^{b}	542^{b}	536^{b}	21.3	<0.01
Empty body fat[2]	33.7^{a}	33.2^{bc}	33.3^{b}	32.9^{c}	33.2^{bc}	0.2	<0.01
Carcass value, cwt[3]	192.53^{a}	190.25^{ab}	184.99^{c}	189.57^{b}	183.63^{c}	1.9	<0.01
Total carcass value[3]	1789^{a}	1729^{b}	1763^{ab}	1740^{b}	1729^{b}	18.0	0.02

[1]Marbling scores: 400=Small^{00} (Minimum for USDA Choice), 500=Modest^{00} (Minimum for USDA Premium Choice).
[2]Empty body fat (EBF) = 17.76207 + (4.68142 × FT) + (0.01945 × HCW) + (0.81855 × QG) − (0.06754 × LMA); FT = fat thickness, cm; HCW = hot carcass weight, km; QG = quality grade (Select = 4, Low Choice = 5, Average Choice = 6, High Choice = 7, Low Prime = 8); LMA = longissimus muscle area, sq cm (Guiroy et al., 2002).
[3]Carcass values calculated according to Table 3.6.

Table 3.17. Steer feedlot and carcass performance: Marbling score covariate.

Outcomes	AxG1	Alpha	Rampage	Sure Bet	Protégé	SEM	*P* value
n	59	51	43	55	29	-	-
Days on feed	193.8	204.7	190.0	193.7	189.4	3.9	0.06
Harvest age, d	480.3	489.1	477.2	479.5	477.0	3.7	0.15
Hot carcass weight, kg	418.4^{bc}	413.8^{c}	434.3^{a}	415.9^{c}	430.9^{ab}	8.5	<0.01
Backfat thickness, cm	1.6^{b}	1.8^{a}	1.8^{a}	1.7^{ab}	1.8^{a}	0.1	<0.01
Longissimus muscle area, (cm^2)	94.5^{a}	90.7^{b}	92.7^{ab}	92.1^{ab}	90.2^{b}	1.3	0.04
Calculated yield grade	3.37^{c}	3.70^{ab}	3.81^{a}	3.60^{b}	3.95^{a}	0.1	<0.01
Empty body fat[1]	32.4^{c}	33.4^{ab}	33.8^{a}	33.1^{bc}	34.1^{a}	0.5	<0.01
Carcass value, cwt[3]	192.11^{a}	189.70^{a}	184.60^{b}	190.50^{a}	183.25^{b}	2.2	<0.01
Total carcass value[3]	1772	1728	1764	1746	1736	20.2	0.22

[1]Empty body fat (EBF) = 17.76207 + (4.68142 × FT) + (0.01945 × HCW) + (0.81855 × QG) − (0.06754 × LMA); FT = fat thickness, cm; HCW = hot carcass weight, km; QG = quality grade (Select = 4, Low Choice = 5, Average Choice = 6, High Choice = 7, Low Prime = 8); LMA = longissimus muscle area, sq cm (Guiroy et al., 2002).

[3]Carcass values calculated according to Table 3.6.