2021

Influence of Preharvest Management Strategies in Beef Cattle on Growth Performance, Carcass Characteristics, and Meat Quality

Erin Gubbels
South Dakota State University

INFLUENCE OF PREHARVEST MANAGEMENT STRATEGIES IN BEEF CATTLE ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND MEAT QUALITY

By

ERIN R. GUBBELS

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major Animal Science

South Dakota State University

2021

THESIS ACCEPTANCE PAGE

Erin R. Gubbels

This thesis is approved as a creditable and independent investigation by a candidate for the master's degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Amanda Blair
Advisor Date

Joseph P Cassady
Department Head Date

Nicole Lounsbery, PhD
Director, Graduate School Date

ACKNOWLEDGEMENTS

There are so many people who deserve a “thank you” and so much more for their help throughout my master’s program. I first want to thank my committee members. Thank you for devoting your time, help, and support during my time here. I greatly appreciate everything you have done for me, especially Dr. Amanda Blair. She has been an advisor, mentor, role model, and so much more for the past few years. Words can’t describe how thankful I am for everything she has done for me. Thank you for believing in me. Dr. Ken Olson, Dr. Keith Underwood, Dr. Judson (Kyle) Grubbs, and Dr. Zach Smith thank you for bearing with me the past few years and for everything you have taught me, as well as for the knowledge, encouragement, and laughs along the way. I am very grateful for you all. Dr. Lonnie (Billy) Wilburn, thank you for serving as my grad faculty representative. Your insight and input has been greatly appreciated.

Dr. Janna Block, Adele Harty, Robin Salverson and the crews at Cottonwood and Hettinger, thank you for your help for both of my projects and overseeing the calves during the backgrounding phase, as well as for your mentorship along the way. Dr. Cody Wright, Kevin VanderWal, Paul Schlobohm, and the crews at the CCERF and RNC, thank you for your help during the finishing phase and weigh days, and to Jason Griffin for helping with the feed samples. Thanks also to everyone at Darnall Feedlot for helping with the finishing phase of the weaning study. My projects could not have been done without all of you and I can’t thank you enough. Dr. Jerrad Legako and Dr. Andrea Krieg at Texas Tech University, thank you for assisting with the fatty acid analysis and lab techniques. A big thank you to Adam Rhody and the meat lab crew for your help with fabricating strip loins, getting stuff ready for judging practices and everything in between. It’s greatly appreciated!

Thanks to the SDSU faculty and staff for teaching me and making a person feel at home! To the 2020 SDSU meat judging team, thanks for a great year despite the COVID challenges and for helping me become a better instructor. Thank you to the graduate students here at SDSU and especially everyone who put in the many long hours in my sensory panel. It’s been great getting to know you all! A big thank you to the meat science grad students: Trevor DeHaan, Jessica Janssen, Clay Newton, Lydia Hite, Dr. Christina Bakker, Samantha Egolf, and Austin Egolf. I couldn’t have gotten through the last couple of years without your help and support. Danielle Abbe, thank you for your encouragement and for putting up your home for Jess and I when we were working at Texas Tech. A special thank you to everyone at Blair Brothers Angus for the support when I came back for my masters and during my time here the past couple years. Thanks for making me feel like part of the family. To Trevor DeHaan, you have been my rock and have always reminded me to believe in myself, helped me keep my nose to the grindstone, and so much more. Words can’t describe how thankful I am to have you in my life.

Lastly, I want to thank my family and friends for the continuous encouragement, support, and love you have provided me. I wouldn’t be where I am today without you. Above all, I want to thank God for the journey down this road and for being my go-to for all of the challenges and rewards in between.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

INFLUENCE OF PREHARVEST MANAGEMENT STRATEGIES IN BEEF CATTLE ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND MEAT QUALITY

ERIN R. GUBBELS

2021

The overall goal of this thesis project was to better understand the influence of preharvest management strategies at critical growth and development periods on beef performance and meat quality. This was accomplished through two primary objectives: 1) to investigate the effects of maternal prepartum dietary energy source during mid- and late-gestation on growth performance, carcass composition, and meat quality of offspring and 2) to compare the influence of two low stress weaning methods with conventional weaning on post-weaning performance and carcass characteristics of steers. For objective 1, Angus-based cows from two sources (n = 129 from South Dakota State University, Experiment 1 and n = 70 from North Dakota State University, Experiment 2) were stratified by body weight (BW) and age and placed into two treatment groups: Concentrate (fed a concentrate-based diet) or Forage (fed a forage-based diet) during mid- and late-gestation. In both Experiment 1 and 2, maternal prepartum dietary energy source during mid and late gestation did not significantly alter offspring performance, carcass merit or meat quality ($P > 0.10$). For objective 2, steer calves (n = 90) from a single source were stratified by BW and dam age into three groups: ABRUPT (calves isolated from dams on the day of weaning), FENCE (calves separated from dams via a fence for 7 days prior to completely weaning), and NOSE (nose-flap inserted and calves

remained with dams for 7 days prior to completely weaning). Weaning method influenced ($P < 0.10$) growth performance during and shortly after the weaning event but differences did not persist into the finishing period. Weaning methods did not influence ($P > 0.01$) haptoglobin concentrations or carcass measurements. Maternal dietary energy source and weaning method had limited impacts on long-term offspring performance and carcass merit. Collectively these results indicate cow/calf producers have flexibility in the dietary sources and weaning strategies they utilize.

CHAPTER I: Review of Literature

Erin R. Gubbels

Department of Animal Science

South Dakota State University, 57007

Introduction

The global population is projected to increase by 1.2 billion people by 2050 (FAO, 2009). This will require farmers and ranchers to continue to improve production practices in efforts to promote sustainability of the animal agriculture industry. In addition, the growing demand for high quality products stresses the production of more consistently flavorful, juicy, and tender beef products. Numerous strategies have been implemented in the beef industry to produce high quality products and promote overall production efficiency. However, most of the strategies currently utilized in the beef industry focus on the post-weaning phase of production. There are opportunities to influence composition, gain, and efficiency prior to weaning. Of special interest are management practices that have the potential to alter growth and development of tissues that influence performance and drive carcass value. Specifically, this review will focus on the factors and mechanisms that contribute to muscle and adipose tissue growth and development prior to weaning.

While there are numerous factors that can affect overall growth and performance of beef cattle, this review is divided into two distinct areas: 1) understanding the influence of fetal programming on offspring growth performance, carcass characteristics,

and meat quality and 2) evaluating the influence of weaning strategies on growth performance and carcass characteristics.

Fetal Development Timeline

Animal growth can be referred to as the increase in tissue mass through the production of new cells via hyperplasic growth and increase in size through hypertrophic growth (Wu et al., 2006). Hyperplasia refers to the increase in cell number, whereas hypertrophy refers to the increase in cell size. Growth of tissues during early fetal development is primarily accomplished through hyperplasia. Hypertrophic growth takes over as the animal matures and incorporation of satellite cells also contributes to postnatal growth. As outlined by Du et al., (2010a), the first two months of gestation is referred to as the embryonic stage, with the remainder of gestation being referred to as the fetal stage.

In beef cattle it is estimated that primary myogenesis begins just before the first month of gestation and continues until just before the fourth month of gestation (Du et al., 2010a). Secondary myogenesis begins just before the third month of gestation and continues until month seven or eight (Du et al., 2010a). From this point of gestation on, primary and secondary muscle fibers continue to grow via hypertrophy. Adipogenesis is initiated at approximately four months of gestation and continues postnatally given adequate energy in the diet (Du et al., 2013). Four major adipose tissue depots develop as a result of adipogenesis including visceral, subcutaneous, intermuscular, and intramuscular. Intramuscular fat, commonly known as marbling, is of key interest as a greater amount of marbling is associated with high quality beef products (Park et al., 2018). Intramuscular adipogenesis is proposed to begin in mid-gestation (Du et al.,

2010a) and undergoes more extensive development postnatally, between four to eight months of age, which generally overlaps the time of weaning (Du et al., 2013).

Myogenic, adipogenic, and fibrogenic cells develop from common progenitor cells known as pluripotent mesenchymal cells. They become further differentiated based on which cell lineage they become committed to. Myogenic progenitor cells further differentiate into myocytes and form muscle, adipogenic progenitor cells further differentiate into adipocytes and contribute to adipose tissue, and fibrogenic progenitor cells further differentiate into fibroblasts to form connective tissue proper. (Aberle et al., 2001)

Fibrogenesis

The connective tissue surrounding muscle (epimysium, perimysium, and endomysium) is primarily composed of collagen and provides the framework for muscle during fetal developmental through a process known as fibrogenesis (Bruce and Roy, 2019). Connective tissue proper is composed of ground substance and extracellular fibers such as collagen and elastin. The ground substance contains proteoglycans and precursors for collagen (tropocollagen) and elastin (tropoelastin) synthesis (Aberle et al., 2001). Collagen is the primary structural protein in muscle connective tissues and is the most abundant protein in the animal body. During fibrogenesis, tropocollagen is synthesized in fibroblasts and then secreted into the intracellular matrix to be assembled into collagen fibrils (Aberle et al., 2001). The endomysium surrounds individual muscle fibers, the perimysium surrounds muscle fiber bundles, and the epimysium surrounds the whole muscle (Aberle et al., 2001). During late gestation, the primordial perimysium and epimysium is formed in fetal skeletal muscle (Du et al., 2010b).

Postnatally, connective tissue is known to contribute to background toughness through the cross-linking of collagen (Lepetit et al., 2008). Collagen content and cross-linking are positively correlated, while collagen turnover and cross-linking are negatively correlated (Archile-Contreras et al., 2010). Further, the turnover of collagen can be accelerated by compensatory growth, causing extracellular remodeling and ultimately increasing tenderness (Archile-Contreras et al., 2011). Therefore, preventing excessive collagen accumulation is essential to decrease background toughness.

Adipocytes and fibroblasts are derived from the same progenitor cells, therefore adipogenesis and fibrogenesis can be considered competitive processes. Strategies that reduce fibrogenic differentiation could enhance adipogenic differentiation, resulting in increased marbling and improved tenderness. Further, it has been demonstrated that influences from the maternal environment early in development may shift myogenic cell differentiation to adipogenic cell differentiation indicating the potential to manipulate composition early in development (Du et al., 2010a).

Adipogenesis

Adipogenesis refers to the proliferation, differentiation, and conversion of undifferentiated cells into adipose tissue (Hausman et al., 2009). In ruminants, it is estimated that adipogenesis begins close to mid-gestation and continues throughout the remainder of the fetal phase, as well as postnatally (Bonnet et al., 2010). The process begins with mesenchymal stem cells that become committed to the adipogenic lineage following signaling from regulatory factors. These cells form adipoblasts, which are the early precursors to adipocytes. (Hausman and Richardson, 2004). In the presence of adequate blood flow, adipoblasts continue to grow in size and proliferate, accumulating

lipid droplets near the center of the cell. Adipoblasts continue to proliferate and begin to differentiate into preadipocytes. Preadipocytes continue to proliferate and then go through a withdraw from the cell cycle (Gregoire, 2001). Preadipocytes that have exited the cell cycle undergo DNA replication and double in number. Through the signaling of transcription factors, preadipocytes further differentiate into an adipocyte (Gregoire, 2001). Lipid droplets continue to accumulate in the developing adipocyte, which is considered to be in a multilocular stage (Gregoire, 2001). Accumulation of lipid droplets continues until they combine to form one large droplet, converting developing adipocytes from a multilocular to a unilocular stage (Gregoire, 2001). During this time, cytoplasm and other cell organelles are pushed off to one side as the cell continues to undergo hypertrophy and form a mature adipocyte (Hausman et al., 2009). Adipocytes are mature fat cells that accumulate lipids over time.

As mentioned, there are four major adipose tissue depots in livestock including visceral, subcutaneous, intermuscular, and intramuscular (Du et al., 2013). During fetal development, visceral fat is deposited first, followed by subcutaneous, intermuscular, and intramuscular fat deposition (Du et al., 2013). Early adipogenesis occurring during mid-gestation is primarily associated with the development of visceral adipocytes (Robelin, 1981). It is estimated that development of subcutaneous adipocytes occurs between the mid to late fetal stage to approximately 8 months of age (postnatal) (Hood and Allen, 1973). Development of intramuscular fat is estimated to occur from the late fetal-neonatal stage to approximately 250 days of age (postnatal). Research has shown that adipogenesis can be shifted to enhanced intramuscular fat accumulation during the period between approximately 130 and 250 days of age through the supplementation of nutrients or

feeding grain-based diets (Du et al., 2013). This timeframe coincides with the weaning event in most beef herds and is referred to as the “marbling window” (Du et al., 2013). It is considered an ideal time to manipulate marbling deposition.

High quality beef products are commonly associated with greater amounts of intramuscular fat content (Park et al., 2018). Carcasses with increased marbling content generally yield higher premiums for producers when cattle are harvested. Beef products with increased amounts of marbling typically produce improved ratings for tenderness, juiciness, and flavor when evaluated by sensory panels (Hunt et al., 2014), and are commonly associated with a better eating experience for consumers.

The accumulation of fatty acids is primarily responsible for increasing intramuscular fat content (Wood et al., 2008). The deposition of intramuscular fat is dependent on the balance between the uptake, synthesis, and degradation, of triglycerides. Intramuscular adipocytes consists of triglycerides, which primarily make up the neutral lipid fraction, and phospholipids, which make up the polar lipid fraction (Legako et al., 2015). The polar lipid fraction contains a large proportion of polyunsaturated fatty acids (PUFAs) (Mottram et al., 1998), whereas the neutral lipid fraction contains saturated fatty acids (SFAs). Steaks with higher amounts of PUFAs compared to SFAs (>0.45) and lower n-6:n-3 ratios (<4.0) have been shown to have greater nutritional value (Chail et al., 2017). An increased ratio of n-6:n-3 PUFA has been reported to be a risk factor for cancer, diabetes, and heart disease in humans, and a reduction of this ratio is suggested to prevent chronic diseases (Simopoulos, 2004). In addition to nutritional value, fatty acid composition has been shown to influence sensory attributes of meat (Wood et al., 2004; Legako et al., 2015; Chail et al., 2017). Meat

quality and sensory attributes can be influenced by adipose tissue firmness, lipid oxidation, and flavor profile. These factors are all subject to changes in the fatty acid profile of the product (Wood et al., 2004). The melting point of different fatty acids and composition of those fatty acids within the product influences adipose tissue firmness (Wood et al., 2004). The propensity for unsaturated fatty acids to undergo lipid oxidation can lead to off flavors and rancidity (Wood et al., 2004; Legako et al., 2015). In addition, unsaturated fatty acids contribute most to flavor development, whereas juiciness and tenderness are more affected by the total amount of fatty acids rather than the fatty acid profile (Wood et al., 2004).

Myogenesis

Although there are three types of muscle (skeletal, cardiac, and smooth) in the body, this review will focus on the formation of skeletal muscle as it is the primary muscle type associated with meat (Aberle et al., 2001). Pluripotent mesenchymal cells commit to a myogenic lineage following signaling from myogenic regulatory factors (MRFs). Skeletal muscle development of the limbs and trunk is derived from somites and develop from an anterior to posterior position (Biressi et al., 2007). The ventral sclerotome and dorsal dermomyotome quickly differentiate from somatic cells during limb bud formation (Biressi et al., 2007). From the dermomyotome, mononucleated muscle cells are formed after terminal differentiation of myogenic precursor cells (Biressi et al., 2007). These mononucleated muscle cells form the primary myotome (Biressi et al., 2007).

Myoblast differentiation occurs in continuous waves. Muscle development requires multiple waves of myoblast differentiation as only a small number of myogenic

precursor cells terminally differentiate during the embryonic stage (Biressi et al., 2007). Myogenic precursor cells migrate from the myotome starting with embryonic myoblast, then fetal myoblast, and finally satellite cells (Biressi et al., 2007). Since myoblasts are mononucleated cells, they have the ability to divide and adhere to surrounding myoblast to form multinucleated cells and continue this process to form multinucleated embryonic myotubes (Hossner, 2005). As the myotubes mature, the myofibrillar proteins actin and myosin are added. Nuclei are centrally located in the myotubes until adequate myofibrillar proteins are accumulated and force the nuclei to the periphery (Biressi et al., 2007). Collections of fused myotubes are referred to as muscle fibers or myofibers. Later, successive groups of myoblasts will migrate, align, and fuse to form secondary myotubes later during the fetal stage of myogenesis (Duprez, 2002). In this process, the primary muscle fibers are used as a template for the secondary myoblast to congregate around to form secondary muscle fibers (Duprez, 2002). Primary muscle fibers are typically formed within the first two months of gestation during the embryonic stage in cattle, while secondary muscle fiber formation continues throughout mid-gestation (Du et al., 2010a). During the fetal stage, secondary myogenesis initiates the increase in size of myofibers developed during primary myogenesis through hypertrophic growth (Aberle et al., 2001). Hyperplastic growth of muscle is estimated to end during late gestation in beef cattle, therefore they are born with nearly all their skeletal muscle fibers (Du et al., 2010a) indicting the prenatal period is a crucial time to develop and/or manipulate muscle tissue.

The net growth of postnatal muscle tissue is described as total protein synthesis minus total protein degradation (Du et al., 2010a). Protein synthesis is the process in which cells assemble amino acids intro proteins. The process of protein degradation or

breakdown into polypeptides and into amino acids by various proteases is known as proteolysis. Muscle growth occurs radially and longitudinally as newly synthesized proteins are systematically replaced through the process of protein turnover (Aberle et al., 2001), which is necessary for growth to occur.

Two types of fibers can be found in muscle: red (oxidative, slow, Type I and Type IIA) and white (glycolytic, fast, Type IIX(D) and Type IIB) (Aberle et al., 2001). Fibers are differentiated based on various characteristics including their contraction speed, myoglobin content, and lipid content (Aberle et al., 2001). Red fibers are generally referred to as slow twitch fibers whereas white fibers are fast twitch. Red fibers are generally smaller in diameter, have a greater amount of lipid associated with them, and are more fatigue-resistant (Aberle et al., 2001). Most muscles contain both types of fibers. However, red muscles are those with higher proportions of red muscle fibers and white muscles contain lower proportions of red muscle fibers. In cattle, it appears red muscle fibers originate from primary myotubes while white muscle fibers primarily originate from secondary myotubes (Robelin et al., 1993). Therefore, in addition to regulating the number of muscle fibers formed, the fetal period can also impact the composition of muscle fiber types (Zhu et al., 2004). A variety of factors can regulate the numbers of muscle fibers and myonuclei present (Owens et al., 1993). During gestation, maternal nutrition may influence fiber type distribution and ultimately impact offspring growth and physiology. Maternal nutrient restriction has been shown to shift muscle fiber type from type IIA (red) to more type IIX (white) in offspring from dams that experienced 50% of their nutrient requirements (Zhu et al., 2006). As red muscle fibers

have been suggested to be positively correlated with marbling and tenderness (Hwang et al., 2010), shifting muscle fiber type could have long-term implications on meat quality.

Fetal Programming

The concept of fetal programming, or developmental programming, in humans originated from epidemiological data with the "fetal origins" hypothesis. This theory linked poor maternal nutrition and low birth weights with increased incidences of cardiovascular, metabolic, and endocrine disease in adults (Godfrey and Barker, 2001). "Programming" defines a critical period of development where a stimulus or challenge is experienced that alters the trajectory of development with lasting effects (Godfrey and Barker, 2001). Growth and development of muscle and adipose tissue is heavily influenced by complex biological events that can be manipulated by genetics, maternal age, maternal nutrition, and a variety of environment factors experienced by the fetus during gestation (Wu et al., 2006). Altering development during gestation has been reported to have substantial long-lasting effects on the offspring (Funston, et al., 2012).

During gestation, the partitioning of nutrients to different body tissues depends on their metabolic rate, with tissues having a lower metabolic rate given less priority than tissues with higher metabolic rates (Redmer et al., 2004). Nutrients are carried in the blood stream and therefore partitioning of nutrients is also dependent on the rate of blood flow. In the maternal body, the brain and central nervous system are of highest priority, followed by the placenta and fetus, and finally bone, muscle, and fat given lowest priority (Redmer et al., 2004). However, partitioning of nutrients has been reported to differ between adult and adolescent dams, with a higher priority for nutrients given to growth of maternal tissues and fat deposition in heifers and young cows (Redmer et al., 2004).

Therefore, it is important to consider the effect of maternal age on fetal growth and development.

First-calf heifers and mature cows provided a high-energy diet compared to a low-energy diet during mid-gestation had increased body weight before parturition and increased calf birth weight (Corah et al., 1975). Multiparous cows that experienced a global nutrient restriction during mid- and late-gestation had calves with lighter birth weights compared to multiparous cows that did not experience a nutrient restriction (Greenwood and Cafe, 2007). Heifers experiencing the same level of restriction experienced more extreme reductions in calf birth weights compared to the mature cows (Greenwood and Cafe, 2007). Therefore, it appears mature females are more able to buffer the effects of a nutritional insult than younger females. The completion of maternal growth likely contributes to this differences, as mature dams do not have to partition nutrients to both their own growth as well as offspring growth, suggesting that maternal nutrition has a greater impact on fetal growth and development when dams are not mature.

Research shows that placental size is also a major factor influencing fetal growth. The placenta serves as a reservoir of nutrients for the fetus during gestation. Therefore, understanding factors that affect placental size during gestation is key for determining ultimate effects on growth and development (Redmer et al., 2004). Maternal nutrition is the key extrinsic factor that affects placental size (Redmer et al., 2004; Vonnahme et al., 2018). Vonnahme et al. (2018) suggested placental size can only be affected if nutrient restriction is experienced during the time at which placental growth is exponential. This rapid placental growth occurs during early embryonic growth in early gestation. A low

plane of nutrition in sheep during early- to late-gestation resulted in a reduction in placental mass (Anthony et al., 2003). However, it has been suggested that the bovine placenta is not as sensitive to nutritional alterations during gestation as the ovine placenta as it continues to grow throughout gestation (Vonnahme et al., 2018). During the final third of gestation (late gestation), the placenta experiences structural remodeling causing the placenta to decrease in mass due to tissue dehydration (Ott et al., 1997). Maternal overfeeding during this time has been shown to result in a higher degree of placental tissue dehydration by reducing the number of cells, not the overall cell size (Wallace, 2000). Restriction during late-gestation may or may not result in reductions of placental mass depending on maternal nutrient reserves (Anthony et al., 2003). This suggests developmental programming may alter growth depending on the level of restriction and gestational timing (Anthony et al., 2003).

The idea of implementing developmental programming in livestock was introduced by Wallace in 1948 who suggested that altered nutrition in late gestation decreases offspring performance (Vonnahme et al., 2018). Recent advances in fetal programming research have shown that altering maternal nutrition during the fetal stage can result in lasting effects on offspring productivity factors, including growth, feed intake, feed efficiency, muscle development, and meat quality (Funston et al., 2012). This can ultimately influence carcass merit and overall meat quality of the offspring by altering deposition of fat and number of muscle fibers (Wu et al., 2006). Since muscle fiber number and a majority of intramuscular adipocyte generation sites are determined before birth, the uterine environment plays a crucial role in determining compositional metrics such as muscle mass and marbling content later in life.

Recently, studies in the livestock industry have been directed towards understanding the impact of maternal nutrition on physiological measures of the offspring. As discussed, primary myogenesis establishes the base of muscle fibers for secondary fibers to develop on and around. However, in regard to nutrient partitioning, fetal skeletal muscle development has a lower priority compared to the development of the brain, heart, and liver and therefore has the potential to be easily influenced by maternal nutrient manipulation (Zhu et al., 2006). In early gestating sheep (28 days to 78 days), feeding 50% of the nutrient requirements as determined by NRC (1985) resulted in a reduction of the ratio of secondary to primary muscle fibers and the total number of secondary muscle fibers present (Zhu et al., 2004). In a similar study, a reduction of the ratio of secondary to primary muscle fibers up to approximately 20% was observed (Quigley et al., 2008). Zhu et al., (2006) reported lambs from ewes that experienced a 50% nutrient restriction in early gestation had a tendency to have reduced muscle fiber number and an increase in muscle fiber diameter when compared to lambs from non-restricted ewes. In the same study, the restricted lambs exhibited greater amounts (48%) of visceral fat, in addition to the downregulation of enzymes involved in energy metabolism. This downregulation would impair the ability to utilize glucose and fatty acids in skeletal muscle, leading to an overall decrease in fatty acid oxidation and increased obesity (Zhu et al., 2006). In a similar study, a significant decrease in birth weights and reduced muscle weights of the *vastus lateralis*, *longissimus muscle*, and *semitendinosus* was observed in offspring from ewes fed a diet restricted to 50% of nutrient requirements late in gestation (d 85 to 115), as opposed to receiving 50% of nutrient requirement restrictions during d 30 to 70, d 55 to 95, or no restrictions during

gestation (Fahey et al., 2005). In the same study, restricting the maternal diet to 50% of the nutrient requirement from d 30 to 70 of gestation altered muscle fiber number by decreasing the number of fast twitch (white) muscle fibers.

Myogenesis and adipogenesis appear to be more sensitive to maternal nutrient restriction experienced during mid- to late-gestation in the bovine fetus compared to the ovine fetus (Greenwood and Cafe, 2007). Further, bovine fetuses have been reported to experience alterations during organogenesis in early-gestation, leading to long-term health implications (Greenwood and Cafe, 2007). Du et al., (2010a) suggested early- to mid-gestation nutrient restriction decreases muscle fiber number and ultimately muscle mass in offspring. In early gestation (d 32 to 115), heifers receiving 55% of NRC requirements had calves with increased muscle fiber diameter and faster glucose clearance, but maternal treatment did not influence feed efficiency, weaning weights or carcass measurements (Long et al., 2010). In contrast, Gonzalez et al., (2013) suggested the size of muscle fibers and muscle progenitor cell numbers from heifers that were nutrient restricted in early gestation could be recovered through realimentation in late-gestation. This is accomplished through compensatory growth of the fetal muscle by the dam. It was also suggested the duration of nutrient restriction can determine the long-term consequences of the fetal muscle structure and if continued throughout mid-gestation, the number of connective tissue cells can increase and affect offspring meat quality (Gonzalez et al., 2013). The opportunity to influence tissues important to carcass yield and quality is a growing research interest.

In mid- to late-gestation of bovine fetal development, maternal nutrient restriction reduces hypertrophic growth of offspring muscle fibers and reduces adipogenesis,

ultimately leading to decreased marbling (Du et al., 2010a). In a study conducted by Underwood et al., (2010), dams allowed to graze improved pastures providing 6 to 11 % crude protein from mid- to late-gestation had offspring with increased weaning weights when compared to dams grazing native range providing 5.4 to 6.5 % crude protein. The progeny from dams grazing improved pastures also had improved average daily gains, greater total body weight gain, heavier body weights at slaughter, and heavier hot carcass weights. However, birth weights, yield grades, marbling scores, and kidney pelvic and heart fat percentage were similar between treatments. The progeny from dams grazing improved pastures also had greater fat thickness and adjusted fat thickness along with reduced moisture content of meat samples and tended to have a greater percentage of crude fat as evaluated by ether extract of the *longissimus* muscle. Moreover, the progeny from improved pastures also recorded reduced Warner-Bratzler shear force values indicating a more tender product. From this data, it is suggested that maternal plane of nutrition, specifically crude protein availability, can influence development of tissues important to carcass and meat quality.

Webb et al. (2019) investigated the effects of maternal metabolizable protein restriction during mid and late gestation on carcass composition and meat quality of offspring. Restriction of 80% of the dietary metabolizable protein requirement during mid-gestation followed by no restriction during late-gestation influenced meat tenderness as steaks from progeny that experienced restriction were less tender than progeny from dams that were not restricted during mid-gestation. In addition, protein restricted dams in mid-gestation had progeny that produced steaks with increased fatty acid content, while progeny from dams that were protein restricted in late-gestation had decreased fatty acid

content suggesting manipulation of maternal metabolizable protein can influence meat quality of progeny.

Mohrhauser et al. (2015) observed no differences in hot carcass weight, dressing percent, adjusted 12th rib backfat, percentage of kidney pelvic and heart fat, marbling score, or intramuscular fat content between offspring from dams in a positive energy status during mid-gestation compared with offspring from dams in a negative energy status. However, improved USDA Yield Grade and a tendency for larger ribeye area was reported in progeny from dams in a negative energy status. No differences were observed in carcass composition or meat quality analysis, with the exception of the percent soluble collagen within the muscle increasing over time as expected. Total collagen content was greater in offspring from dams in positive energy status compared to negative energy status; this contradicts other evidence reporting increased collagen in progeny from dams that have been nutrient restricted (Kablar et al., 2003; Bispham et al., 2005; Karunaratne et al., 2005). Moreover, tendencies for lower USDA yield grades and reduced backfat were observed for offspring from dams in a negative energy status Mohrhauser et al. (2015). These data provide an example of the influence altered maternal energy can have on carcass cutability and meat quality.

Volatile fatty acids (VFA) are the main products of the digestion of feed by bacteria in the rumen, provide a majority of the energy required by ruminants, and serve as substrates for synthesis of glucose and fat (Ferrell et al., 1982; Bell and Bauman, 1997). Major VFA produced by rumen microorganisms include acetate, propionate, and butyrate (Bell and Bauman, 1997). Various dietary energy sources ferment in the rumen to yield differing proportions of specific short- and long-chain fatty acids. Forage-based

diets result in VFA composition of approximately 65 to 70% acetate, 15 to 25% propionate, and 5 to 10% butyrate (Penner et al., 2009). Grain-based diets high in readily fermentable carbohydrate (starch) reduce acetate by 10 to 15% and increase propionate by 20 to 25% (Penner et al., 2009). Propionate is the only VFA that contributes directly to the net synthesis of glucose, which is a major energy substrate utilized by uterine and placental tissues for fetal growth (Ferrell et al., 1982). Typically, beef cattle are finished on high concentrate diets that result in fermentation of propionate and increased glucose production. Glucose plays an important role in intramuscular fat cell proliferation and growth that ultimately determines the amount of marbling in the carcass. Radunz et al. (2012) hypothesized that maternal diets high in starch would increase the ruminal production levels of propionate and lead to increased circulating blood glucose concentrations available to the developing fetus. However, no differences were detected in circulating levels of blood glucose between offspring from dams fed hay-based, corn-based, or dried corn distillers grains-based diets during late gestation. Radunz et al., (2010) reported that calves from dams fed the corn-based or dried corn distillers grains-based diets during late gestation had heavier birth weights than dams fed hay-based diets, as well has heavier weaning weights. Progeny ultrasound measurements recorded at 24 and 72 hr after birth and 84 d into the finishing period of backfat and longissimus muscle area did not differ between treatments, and when fed to a common backfat, treatments did not influence average daily gain, dry matter intake, feed efficiency, receiving body weight, final body weight, hot carcass weight, USDA Yield Grade, or ribeye area. However, dressing percent was higher in progeny from dams fed a high fiber diet. This indicates that a diet low in starch may yield a higher dressing carcass while also

increasing the amount of intramuscular fat when evaluated at a common backfat thickness. However, there is limited research investigating the effect of dietary energy source and the subsequent effects on offspring carcass characteristics and meat quality.

Based on these results, there may be differences in nutrient utilization and performance of offspring from cows fed forage or concentrate-based diets. The ability to manipulate subcutaneous fat while maintaining IMF fat content during gestation could provide producers with a key tool to maintain high quality carcasses, while not receiving discounts for fatter carcasses. This could improve sustainability of the beef industry, as well as allow producers to be more profitable. Further research related to maternal prepartum dietary energy and source is warranted to investigate the effects on progeny growth performance and carcass merit.

Weaning Management

One of the most strategic periods to influence growth and development of a beef animal is between four and eight months of age. This timeframe generally coincides with weaning in most beef cattle operations. Early weaning is generally considered at approximately 130 days after birth (~ 4 months of age) whereas traditional weaning occurs around 205 days after birth (~ 8 months of age) (Bohnert et al., 2006). This positions the weaning event at a key time during intramuscular adipogenesis development and advancing muscle growth, suggesting this management period could provide an opportunity to manipulate overall marbling and muscle growth (Du et al., 2013).

Early weaning is often utilized to reduce grazing pressure in extensively grazed systems, extend the grazing period for rangeland cows, increase cow body condition

scores (BCS), and improve reproductive efficiencies in cows (Arthington et al., 2005) (Bohnert et al., 2006). A study by Myers et al., (1999) concluded that early weaning increased average daily gain, decreased daily intake, improved feed efficiency, and improved USDA quality grades compared with traditionally weaned calves. In addition, early weaned calves were observed to have increased average daily gain and improved feed efficiency in the early backgrounding phase and improved overall feed efficiency compared with calves weaned during a more traditional time (Arthington et al., 2005). In a study by Short et al., (1996), no growth or carcass improvements were observed when calves were weaned early. However, delaying weaning to a more traditional time increased weaning weight but decreased dam weight and body condition score if the dams were not supplemented with protein (Short et al., 1996). Moreover, increased carcass weights and final weights were observed in calves weaned during a traditional time (Wolcott et al., 2010).

Time of weaning is heavily dependent on factors that are often out of a producer's control. Environmental conditions, labor availability, and feedstuff price and availability are just a few of the factors influencing weaning times and strategies. Weaning stress is another factor producers have to consider, which can result in behavioral, hormonal and immune function alterations (Lynch et al., 2012). Stress during this time has also been shown to negatively impact calf health and performance by making calves more susceptible to respiratory infections (Boland et al., 2008). Concentrations of acute phase proteins are suggested to be indicators of stress in weaned calves (Arthington et al. 2003). Acute phase proteins (such as haptoglobin) are stimulated as a defense mechanism in response to trauma, inflammation, or infection (Hughes et al. 2014). In the bovine,

haptoglobin is one of the most abundant acute phase proteins and binds to free hemoglobin to reduce inflammation and toxicities (Di Filippo et al., 2018). Research by Arthington et al. (2008), indicated calves weaned using low-stress methods tended to have reduced serum haptoglobin concentrations. However, further research is required to determine if haptoglobin concentration is a reliable method of assessing stress in beef calves.

Observation of animal behavior during weaning is also a key indicator of stress. Generally, most beef operations in the United States abruptly separate cows and calves during the weaning event (Haley et al., 2005). Low stress weaning strategies aim to divide the weaning process into two stages: 1) physical separation and 2) separation from milk as a nutritional source. It is suggested that two-stage methods decrease the degree of changes in behavior as opposed to simultaneous social and nutritional separation (Haley et al., 2005). Alternative weaning practices further aim to reduce stress by terminating calf suckling before the calves are fully separated from their dams (Boland et al., 2008). Fence-line weaning (Price et al., 2003) and inserting an anti-suckling device into the nose of the calf (Haley et al., 2005) are two alternative weaning methods utilized in the beef industry. Fence-line weaning involves separation of calves from their dams via a fence such that they remain in adjacent pens or pastures. Anti-suckling devices are inserted into a calf's nose to prevent nursing but allow contact between the calf and dams. Calves abruptly weaned are reported to spend more time walking around a backgrounding pen, standing, and vocalizing compared to calves weaned using alternative methods that spent more time eating, laying down, and ruminating (Haley et al., 2005). Similar behavior

patterns were reported in a study comparing alternative weaning methods to abrupt weaning by Price et al. (2003).

Studies have evaluated the influence of low-stress methods on calf physiology, performance, and health for a short period after the weaning process (Price et al., 2003; Haley et al., 2005; Boland et al., 2008; Campistol et al., 2010a). Calves weaned using low-stress methods had heavier body weights one-week post-weaning when compared to calves weaned using conventional methods (Campistol et al., 2010a). Haley et al. (2005) also reported greater average daily gains the week following weaning in calves weaned using an anti-suckling devices compared with calves weaning using abrupt separation. Improved weight gains and reduced behavioral stress was also evaluated with fenceline weaning (Price et al., 2003). However, fenceline weaning was observed to maintain growth performance while decreasing the amount of stress measured by blood metabolites, such as blood urea nitrogen, creatine kinase, glucose, and nonesterified fatty acid concentrations (Boland et al., 2008). While differences in behavior, blood metabolites, and performance have been evaluated at and shortly after the weaning event, there is limited information regarding the impact of low stress weaning methods on long-term feedlot performance and carcass characteristics of beef cattle.

Summary

There are multiple means by which muscle growth and adipose tissue deposition can be influenced throughout the early life of a beef animal to produce high quality products and promote production efficiency. Specifically, understanding the influence of maternal dietary energy source during mid and late gestation on offspring muscle growth and marbling deposition could offer producers an opportunity to optimize offspring

performance and carcass merit. Maternal dietary energy restriction, maternal energy status, and protein restriction during gestation can alter offspring growth and carcass composition. However, there is limited research on the effects of maternal dietary energy source provided during mid- and late gestation on offspring performance and carcass characteristics and therefore warrants further investigation. In addition, stress during the weaning event has been shown to impact short term post-weaning performance. Alternative weaning methods have been implemented in efforts to reduce the stress experienced during this time. Unfortunately, the effect these methods have during the late-finishing phase as well as on carcass characteristics has not been studied. Identifying management practices that optimize muscle growth and marbling deposition during these two production phases (prenatal and weaning) will allow for the production of more pounds of high-quality beef. Therefore, to better understand mechanisms influencing the quantity and quality of beef products, the objectives of this thesis are:

1. To investigate the effects of maternal prepartum dietary energy source (forage-based vs. concentrate-based) during mid- and late-gestation on growth performance, carcass composition, and meat quality of offspring.
2. To compare the influence of two low stress weaning methods with conventional weaning on long-term post-weaning performance and carcass characteristics of steers.

LITERATURE CITED

Aberle, E. D., Forrest, J. C., Gerrard, D. E., & Mills, E. W. (2001). *Principles of Meat Science* (Fourth ed.). Dubuque, IA: Kendall/ Hunt Publishing Company.

Anthony, R. V., Scheaffer, A. N., Wright, C. D., & Regnault, T. R. H. (2003). Ruminant models of prenatal growth restriction. *Reproduction*, 183-194.

Archile-Contreras, A. C., Cha, M. C., Mandell, I. B., Miller, S. P., & Purslow, P. P. (2011). Vitamins E and C May Increase Collagen Turnover by Intramuscular Fibroblasts. Potential for Improved Meat Quality. *Journal of Agricultural and Food Chemistry, 59*(2), 608-614. doi:10.1021/jf103696t

Archile-Contreras, A. C., Mandell, I. B., & Purslow, P. P. (2010). Disparity of dietary effects on collagen characteristics and toughness between two beef muscles. *Meat Science, 86*(2), 491-497. doi:10.1016/j.meatsci.2010.05.041

Arthington, J. D., Eicher, D., Kunkle, W. E., & Martin, F. G. (2003). Effect of transportation and commingling on the acute-phase protein response, growth, and feed intake of newly weaned beef calves. *Journal of Animal Science, 81*(5), 1120-1125.

Arthington, J. D., Qiu, X., Cooke, R. F., Vendramini, J. M. B., Araujo, D. B., Chase, C. C., & Coleman, S. W. (2008). Effects of preshipping management on measures of stress and performance of beef steers during feedlot receiving. *Journal of Animal Science, 86*(8), 2016-2023. doi:10.2527/jas.2008-0968

Arthington, J. D., Spears, J. W., & Miller, D. C. (2005). The effect of early weaning on feedlot performance and measures of stress in beef calves. *Journal of Animal Science, 83*(4), 933-939.

Bell, A. W., & Bauman, D. E. (1997). Adaptations of Glucose Metabolism During Pregnancy and Lactation. *Journal of Mammary Gland Biology and Neoplasia, 2*(3), 265-278. doi:10.1023/a:1026336505343

Biressi, S., Molinaro, M., & Cossu, G. (2007). Cellular heterogeneity during vertebrate skeletal muscle development. *Developmental Biology, 308*(2), 281-293. doi:10.1016/j.ydbio.2007.06.006

Bispham, J., Gardner, D. S., Gnanalingham, M. G., Stephenson, T., Symonds, M. E., & Budge, H. (2005). Maternal nutritional programming of fetal adipose tissue development: Differential effects on messenger ribonucleic acid abundance for uncoupling proteins and peroxisome proliferator-activated and prolactin receptors. *Endocrinology, 146*(9), 3943-3949. doi:10.1210/en.2005-0246

Bohnert, D. W., Ganskopp, D. C., Johnson, D. D., Falck, S. J., Merrill, M. L., & Clark, A. A. (2006). Effects of early weaning on cow performance, grazing behavior, and winter feed costs in the intermountain west. *Journal of Animal Science, 84,* 146-146.

Boland, H. T., Scaglia, G., Swecker, W. S., & Burke, N. C. (2008). Effects of alternate weaning methods on behavior, blood metabolites, and performance of beef calves. *The Professional Animal Scientist, 24*, 539-551.

Bonnet, M., Cassar-Malek, I., Chilliard, Y., & Picard, B. (2010). Ontogenesis of muscle and adipose tissues and their interactions in ruminants and other species. *Animal, 4*(7), 1093-1109. doi:10.1017/s1751731110000601

Bruce, H. L., & Roy, B. C. (2019). Meat Science And Muscle Biology Symposium: Biological Influencers Of Meat Palatability: Production factors affecting the contribution of collagen to beef toughness. *Journal of Animal Science, 97*(5), 2270-2278. doi:10.1093/jas/skz097

Campistol, C., Kattesh, H. G., Waller, J. C., Rawls, E. L., Arthington, J. D., Engle, T. E., & Carroll, J. A. (2010a). Effects of two-stage and total vs. fenceline weaning on the physiology and performance of beef calves. *Journal of Dairy Science, 93*, 107-107.

Chail, A., Legako, J. F., Pitcher, L. R., Ward, R. E., Martini, S., & MacAdam, J. W. (2017). Consumer sensory evaluation and chemical composition of beef gluteus medius and triceps brachii steaks from cattle finished on forage or concentrate diets. *Journal of Animal Science, 95*(4), 1553-1564. doi:10.2527/jas.2016.1150

Corah, L. R., Dunn, T. G., & Kaltenbach, C. C. (1975). Influence of prepartum nutrition on the
reproductive performance of beef females and the performance of their progeny. In.

Di Filippo, P. A., Lannes, S. T., Meireles, M. A. D., Nogueira, A. F. S., Ribeiro, L. M. F., Graca, F. A. S., & Gloria, L. S. (2018). Acute phase proteins in serum and

cerebrospinal fluid in healthy cattle: possible use for assessment of neurological diseases. *Pesquisa Veterinaria Brasileira, 38*(4), 779-784. doi:10.1590/1678-5150-pvb-5093

Du, M., Huang, Y., Das, A. K., Yang, Q., Duarte, M. S., Dodson, M. V., & Zhu, M. J. (2013). Meat Science And Muscle Biology Symposium: Manipulating mesenchymal progenitor cell differentiation to optimize performance and carcass value of beef cattle. *Journal of Animal Science, 91*(3), 1419-1427. doi:10.2527/jas.2012-5670

Du, M., Tong, J., Zhao, J., Underwood, K. R., Zhu, M., Ford, S. P., & Nathanielsz, P. W. (2010a). Fetal programming of skeletal muscle development in ruminant animals. *Journal of Animal Science, 88,* E51-E60. doi:10.2527/jas.2009-2311

Du, M., Yan, X., Tong, J. F., Zhao, J. X., & Zhu, M. J. (2010b). Maternal Obesity, Inflammation, and Fetal Skeletal Muscle Development. *Biology of Reproduction, 82*(1), 4-12. doi:10.1095/biolreprod.109.077099

Duprez, D. (2002). Signals regulating muscle formation in the limb during embryonic development. *International Journal of Developmental Biology, 46*(7), 915-925.

Fahey, A. J., Brameld, J. M., Parr, T., & Buttery, P. J. (2005). The effect of maternal undernutrition before muscle differentiation on the muscle fiber development of the newborn lamb. *Journal of Animal Science, 83*(11), 2564-2571.

FAO. (2009). Food and Agriculture Organization of the United Nations (FAO). *How to feed the world 2050.*

Ferrell, C. L., Prior, R. L., Christenson, R. K., & Ford, S. P. (1982). Blood flow and nutrient uptake of the bovine uterus and fetus. In (pp. 30-31). Roman L. Hruska U.S. Meat Animal Research Center Report.

Funston, R. N., Summers, A. F., & Roberts, A. J. (2012). Alpharma Beef Cattle Nutrition Symposium: Implications of nutritional management for beef cow-calf systems. *Journal of Animal Science, 90*(7), 2301-2307. doi:10.2527/jas.2011-4568

Godfrey, K. M., & Barker, D. J. (2001). Fetal programming and adult health. In (Vol. 4, pp. 611-624).

Gonzalez, J. M., Camacho, L. E., Ebarb, S. M., Swanson, K. C., Vonnahme, K. A., Stelzleni, A. M., & Johnson, S. E. (2013). Realimentation of nutrient restricted pregnant beef cows supports compensatory fetal muscle growth. *Journal of Animal Science, 91*(10), 4797-4806. doi:10.2527/jas.2013-6704

Greenwood, P. L., and L. M. Cafe. 2007. Prenatal and pre-weaning growth and nutrition of cattle: Longterm consequences for beef production. Animal 1(9):1283-1296. (Article) doi: 10.1017/s175173110700050x

Gregoire, F. M. (2001). Adipocyte differentiation: From fibroblast to endocrine cell. *Experimental Biology and Medicine, 226*(11), 997-1002.

Haley, D. B., Bailey, D. W., & Stookey, J. M. (2005). The effects of weaning beef calves in two stages on their behavior and growth rate. *Journal of Animal Science, 83*(9), 2205-2214.

Hausman, G. J., M. V. Dodson, K. Ajuwon, M. Azain, K. M. Barnes, L. L. Guan, Z. Jiang, S. P. Poulos, R. D. Sainz, S. Smith, M. Spurlock, J. Novakofski, M. E. Fernyhough, and W. G. Bergen. 2009. Board-Invited Review: The biology and regulation of preadipocytes and adipocytes in meat animals. Journal of Animal Science 87(4):1218-1246. (Review) doi: 10.2527/jas.2008-1427

Hausman, G. J., & Richardson, R. L. (2004). Adipose tissue angiogenesis. *Journal of Animal Science, 82*(3), 925-934.

Hood, R. L., & Allen, C. E. (1973). Cellularity of bovine adipose-tissue. *Journal of Lipid Research, 14*(6), 605-610.

Hossner, K. L. (2005). Hormonal Regulation of Farm Animal Growth. *Hormonal Regulation of Farm Animal Growth*, 1-223. doi:10.1079/9780851990804.0000

Hughes, H. D., Carroll, J. A., Sanchez, N. C. B., & Richeson, J. T. (2014). Natural variations in the stress and acute phase responses of cattle. *Innate Immunity, 20*(8), 888-896. doi:10.1177/1753425913508993

Hunt, M. R., A. J. Garmyn, T. G. O'Quinn, C. H. Corbin, J. F. Legako, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2014. Consumer assessment of beef palatability

from four beef muscles from USDA Choice and Select graded carcasses. Meat Science 98(1):1-8. (Article) doi: 10.1016/j.meatsci.2014.04.004

Hwang, Y. H., Kim, G. D., Jeong, J. Y., Hur, S. J., & Joo, S. T. (2010). The relationship between muscle fiber characteristics and meat quality traits of highly marbled Hanwoo (Korean native cattle) steers. *Meat Science, 86*(2), 456-461. doi:10.1016/j.meatsci.2010.05.034

Kablar, B., Krastel, K., Tajbakhsh, S., & Rudnicki, M. A. (2003). Myf5 and MyoD activation define independent myogenic compartments during embryonic development. *Developmental Biology, 258*(2), 307-318. doi:10.1016/s0012-1606(03)00139-8

Karunaratne, J. F., Ashton, C. J., & Stickland, N. C. (2005). Fetal programming of fat and collagen in porcine skeletal muscles. *Journal of Anatomy, 207*(6), 763-768. doi:10.1111/j.1469-7580.2005.00494.x

Legako, J. F., Dinh, T. T. N., Miller, M. F., & Brooks, J. C. (2015). Effects of USDA beef quality grade and cooking on fatty acid composition of neutral and polar lipid fractions. *Meat Science, 100*, 246-255. doi:10.1016/j.meatsci.2014.10.013

Lepetit, J. (2008). Collagen contribution to meat toughness: Theoretical aspects. *Meat Science, 80*(4), 960-967. doi:10.1016/j.meatsci.2008.06.016

Long, N. M., Prado-Cooper, M. J., Krehbiel, C. R., DeSilva, U., & Wettemann, R. P. (2010). Effects of nutrient restriction of bovine dams during early gestation on

postnatal growth, carcass and organ characteristics, and gene expression in adipose tissue and muscle. *Journal of Animal Science, 88*(10), 3251-3261. doi:10.2527/jas.2009-2512

Lynch, E. M., M. McGee, S. Doyle, and B. Earley. 2012. Effect of pre-weaning concentrate supplementation on peripheral distribution of leukocytes, functional activity of neutrophils, acute phase protein and behavioural responses of abruptly weaned and housed beef calves. Bmc Veterinary Research 8:11. (Article) doi: 10.1186/1746-6148-8-1

Mohrhauser, D. A., Taylor, A. R., Underwood, K. R., Pritchard, R. H., Wertz-Lutz, A. E., & Blair, A. D. (2015). The influence of maternal energy status during midgestation on beef offspring carcass characteristics and meat quality. *Journal of Animal Science, 93*(2), 786-793. doi:10.2527/jas.2014-8567

Mottram, D. S. (1998). Flavour formation in meat and meat products: a review. *Food Chemistry, 62*(4), 415-424. doi:10.1016/s0308-8146(98)00076-4

Myers, S. E., Faulkner, D. B., Ireland, F. A., Berger, L. L., & Parrett, D. F. (1999). Production systems comparing early weaning to normal weaning with or without creep feeding for beef steers. *Journal of Animal Science, 77*(2), 300-310.

Ott, T. L., Wiley, A. A., & Bartol, F. F. (1997). Effects of stage of gestation and uterine ligation on ovine placentome development and glycosaminoglycans. *Journal of Animal Science, 75*(4), 1053-1062.

Owens, F. N., Dubeski, P., & Hanson, C. F. (1993). Factors that alter the growth and development of ruminants. *Journal of Animal Science, 71*(11), 3138-3150. doi:10.2527/1993.71113138x

Park, S. J., S. H. Beak, D. J. S. Jung, S. Y. Kim, I. H. Jeong, M. Y. Piao, H. J. Kang, D. M. Fassah, S. W. Na, S. P. Yoo, and M. Baik. 2018. Genetic, management, and nutritional factors affecting intramuscular fat deposition in beef cattle - A review. Asian Australas. J. Anim. Sci. 31(7):1043-1061.(Review) doi: 10.5713/ajas.18.0310

Penner, G. B., Taniguchi, M., Guan, L. L., Beauchemin, K. A., & Oba, M. (2009). Effect of dietary forage to concentrate ratio on volatile fatty acid absorption and the expression of genes related to volatile fatty acid absorption and metabolism in ruminal tissue. *Journal of Dairy Science, 92*(6), 2767-2781. doi:10.3168/jds.2008-1716

Price, E. O., Harris, J. E., Borgwardt, R. E., Sween, M. L., & Connor, J. M. (2003). Fenceline contact of beef calves with their dams at weaning reduces the negative effects of separation on behavior and growth rate. *Journal of Animal Science, 81*(1), 116-121.

Quigley, S. P., D. O. Kleemann, S. K. Walker, P. A. Speck, S. R. Rudiger, G. S. Nattrass, M. J. DeBlasio, and J. A. Owens. 2008. Effect of variable long-term maternal feed allowance on the development of the ovine placenta and fetus. Placenta 29(6):539-548. (Article) doi: 10.1016/j.placenta.2008.02.014

Radunz, A. E., Fluharty, F. L., Day, M. L., Zerby, H. N., & Loerch, S. C. (2010). Prepartum dietary energy source fed to beef cows: I. Effects on pre- and postpartum cow performance. *Journal of Animal Science, 88*(8), 2717-2728. doi:10.2527/jas.2009-2744

Radunz, A. E., Fluharty, F. L., Relling, A. E., Felix, T. L., Shoup, L. M., Zerby, H. N., & Loerch, S. C. (2012). Prepartum dietary energy source fed to beef cows: II. Effects on progeny postnatal growth, glucose tolerance, and carcass composition. *Journal of Animal Science, 90*(13), 4962-4974. doi:10.2527/jas.2012-5098

Redmer, D. A., Wallace, J. M., & Reynolds, L. P. (2004). Effect of nutrient intake during pregnancy on fetal and placental growth and vascular development. *Domestic Animal Endocrinology, 27*(3), 199-217. doi:10.1016/j.domaniend.2004.06.006

Robelin, J. (1981). Cellularity of bovine adipose tissues - developmental-changes from 15-percent to 65-percent mature weight. *Journal of Lipid Research, 22*(3), 452-457.

Robelin, J., Picard, B., Listrat, A., Jurie, C., Barboiron, C., Pons, F., & Geay, Y. (1993). Myosin expression in semitendinosus muscle during fetal development of cattle - immunocytochemical and electrophoretic analyses. *Reproduction Nutrition Development, 33*(1), 25-41. doi:10.1051/rnd:19930103

Short, R. E., Grings, E. E., MacNeil, M. D., Heitschmidt, R. K., Haferkamp, M. R., & Adams, D. C. (1996). Effects of time of weaning, supplement, and sire breed of calf during the fall grazing period on cow and calf performance. *Journal of Animal Science, 74*(7), 1701-1710.

Simopoulos, A. P. (2004). Omega-6/omega-3 essential fatty acid ratio and chronic diseases. *Food Reviews International, 20*(1), 77-90. doi:10.1081/fri-120028831

Underwood, K. R., J. F. Tong, P. L. Price, A. J. Roberts, E. E. Grings, B. W. Hess, W. J. Means, and M. Du. 2010. Nutrition during mid to late gestation affects growth, adipose tissue deposition, and tenderness in cross-bred beef steers. Meat Science 86(3):588-593. (Article) doi: 10.1016/j.meatsci.2010.04.008

Vonnahme, K. A., Tanner, A. R., & Hildago, M. A. V. (2018). Effect of maternal diet on placental development, uteroplacental blood flow, and offspring development in beef cattle. *Animal Reproduction, 15*, 912-922. doi:10.21451/1984-3143-ar2018-0050

Wallace, J. M. (2000). Nutrient partitioning during pregnancy: adverse gestational outcome in overnourished adolescent dams. *Proceedings of the Nutrition Society, 59*(1), 107-117. doi:10.1017/s0029665100000136

Webb, M. J., J. J. Block, R. N. Funston, K. R. Underwood, J. F. Legako, A. A. Harty, R. R. Salverson, K. C. Olson, and A. D. Blair. 2019. Influence of maternal protein restriction in primiparous heifers during mid and/or late-gestation on meat

quality and fatty acid profile of progeny. Meat Science 152:31-37. (Article) doi: 10.1016/j.meatsci.2019.02.006

Wolcott, M. L., Graser, H. U., & Johnston, D. J. (2010). Effects of early weaning on growth, feed efficiency and carcass traits in Shorthorn cattle. *Animal Production Science, 50*(4), 315-321. doi:10.1071/an09153

Wood, J. D., Enser, M., Fisher, A. V., Nute, G. R., Sheard, P. R., Richardson, R. I., Whittington, F. M. (2008). Fat deposition, fatty acid composition and meat quality: A review. *Meat Science, 78*(4), 343-358. doi:10.1016/j.meatsci.2007.07.019

Wood, J. D., R. I. Richardson, G. R. Nute, A. V. Fisher, M. M. Campo, E. Kasapidou, P. R. Sheard, and M. Enser. 2004. Effects of fatty acids on meat quality: a review. Meat Science 66(1):21-32. (Article; Proceedings Paper) doi: 10.1016/s0309-1740(03)00022-6

Wu, G., Bazer, F. W., Wallace, J. M., & Spencer, T. E. (2006). Board-Invited Review: Intrauterine growth retardation: Implications for the animal sciences. *Journal of Animal Science, 84*(9), 2316-2337. doi:10.2527/jas.2006-156

Zhu, M. J., Ford, S. P., Means, W. J., Hess, B. W., Nathanielsz, P. W., & Du, M. (2006). Maternal nutrient restrcition affects properties of skeletal muscle. In (Vol. 575, pp. 241-250). J Physiol.

Zhu, M. J., Ford, S. P., Nathanielsz, P. W., & Du, M. (2004). Effect of maternal nutrient restriction in sheep on the development of fetal skeletal muscle. *Biology of Reproduction, 71*(6), 1968-1973. doi:10.1095/biolreprod.104.034561

CHAPTER II : Comparison of Winter Cow Feeding Strategies on Fetal Development, Offspring Performance, and Meat Quality

Erin R. Gubbels

Department of Animal Science

South Dakota State University, 57007

ABSTRACT

The objective of this research was to investigate the effects of maternal prepartum dietary energy source (forage-based vs. concentrate-based) during mid and late gestation on growth performance, carcass composition, and meat quality of offspring. Angus-based cows from 2 sources [n = 129 from South Dakota State University (SDSU) and n = 70 from North Dakota State University (NDSU)] were stratified by body weight (BW) and age and placed into two treatment groups at a drylot facility in north central South Dakota: Concentrate (dams fed a concentrate-based diet: 56.6% corn grain, 24.1% wheat straw, 13.3% modified distiller's grain w/ solubles, 4.6% suspension supplement, and 1.4% limestone) or Forage (dams fed a forage-based diet: 71.9% wheat straw, 21.8% grass/ alfalfa hay, 3.7% corn silage, and 2.6% suspension supplement). Treatment diets were provided during mid- and late-gestation and cows returned to respective source herds to calve. A subset of 96 calves (n = 24 heifers/treatment, n = 24 steers/treatment) from the SDSU cows and 40 calves (n = 10 heifers/treatment, n = 10 steers/treatment) from the NDSU cows closest to the mean weaning weight of each herd were shipped to the SDSU Cottonwood Field Station for the backgrounding period. At the conclusion of the backgrounding phase, all calves were transported approximately 526 km to

Brookings, SD for the finishing phase of the study. Calves from SDSU (Experiment 1) were finished at the SDSU Cow-Calf Education and Research Facility and calves from NDSU (Experiment 2) were finished at the SDSU Ruminant Nutrition Center. Calf BW and average daily gains (ADG) were calculated. Ultrasound ribeye area, fat thickness, and intramuscular fat at the 10 to 12th rib sections were assessed during backgrounding and finishing to evaluate composition and project marketing dates. Carcass measurements were recorded at the time of harvest and included hot carcass weight, 12th rib backfat, REA, USDA Yield Grade and Quality Grade, marbling score, and objective color measurements. A striploin was collected from each carcass and portioned into 2.54 cm steaks. Four steaks were assigned to age for 3, 7, 14 or 21 d for Warner-Bratzler Shear Force (WBSF) analysis. A steak was collected for analysis of crude fat, and an additional steak was collected and aged 14 d for a trained sensory panel evaluation. A final steak was collected for Fatty Acid Methyl Ether Synthesis (FAMEs), evaluated only in Exp. 1. In Exp. 1, maternal dietary treatment did not influence ($P > 0.05$) offspring BW, or DMI. In Period 1 (d 0-23) of the finishing phase, offspring from dams fed a forage-based diet tended ($P = 0.08$) to have an improved ADG compared to offspring from dams fed a concentrate-based diet, however no differences ($P > 0.05$) in ADG were detected between treatment groups in subsequent periods. In period 2 (d 23-51), steers from both treatments had similar ($P > 0.05$) G:F, and had improved ($P < 0.05$) G:F compared to both forage and concentrate heifers, however forage heifers had improved ($P < 0.05$) G:F compared to concentrate heifers. Additionally in period 2 (d 23-51), steers from the concentrate treatment had greater ($P < 0.05$) ADG compared with steers from the forage treatment, while ADG of heifers did not differ ($P > 0.05$). In period 3 (d 51-78), steers from the

forage fed dams had greater ($P < 0.05$) ADG than steers from the concentrate treatment and heifers from either treatment, which were similar ($P > 0.05$). In the final period (d 106 until their respective harvest date), steers from both treatments had similar ($P > 0.05$) ADG, and had similar ($P > 0.05$) ADG compared to both forage and concentrate heifers, however forage heifers had improved ($P < 0.05$) ADG compared to concentrate heifers. Heifers from the concentrate treatment tended to have increased ($P = 0.07$) muscle depth measured via ultrasound during the backgrounding phase compared with heifers from the forage treatment, while muscle depth of steers did not differ ($P > 0.05$) between treatments. Offspring from the forage treatment tended to have increased ($P = 0.06$) 12^{th} rib backfat (BF) than the offspring from the concentrate treatment and tended to have higher ($P = 0.08$) yield grades at harvest. Offspring from the concentrate treatment had higher ($P < 0.05$) a* and b* values than the forage treatment. The concentrations (mg/g raw wet tissue) of arachidonic, nervonic, and docosapentaenoic acids were increased in offspring from the concentrate fed dams ($P < 0.05$). In Experiment 2, offspring from the forage treatment had increased ($P < 0.05$) BF measured via ultrasound during the finishing phase compared to the concentrate treatment. Maternal prepartum dietary energy source during mid and late gestation did not significantly ($P > 0.05$) alter offspring carcass merit or meat quality. However, offspring from the concentrate treatment also had increased ($P < 0.05$) juiciness and tended ($P = 0.08$) to have increased tenderness ratings compared to offspring from the forage treatment. Results from this study suggest that the variation in winter cow diets applied in this study during mid- and late-gestation has limited influence on progeny performance. Provided that nutrient

requirements are met, it appears that utilizing alternative diets for the beef cow herd does not significantly influence beef product quality.

INTRODUCTION

Recent advances in fetal programming research have shown that altering maternal nutrition during the fetal stage can result in altered postnatal effects on offspring productivity measures, including growth, feed intake, feed efficiency, muscle development, and meat quality (Funston et al., 2012). Within the first two months of conception in the ruminant, development of adipocytes and fibroblasts occur along with development of skeletal muscle cells, all of which are primarily derived from mesenchymal stem cells (Du et al., 2010). Development of marbling, or intramuscular fat, is of great economic importance to the beef industry. Adipogenesis is initiated around the fourth month of gestation, partially overlapping with the second wave of myogenesis. Du et al. (2010) suggested this stage of development represents a major opportunity for maternal nutrition to positively or negatively affect stem cell differentiation. Since the number of mesenchymal stem cells decrease as cattle mature, strategies to increase marbling during early life could be more effective than later in life after weaning. After 250 d of age, marbling is primarily enhanced only through the growth of preexisting adipocytes and nutritional influences have little impact on adipocyte development (Du et al., 2010). Smith and Crouse (1984) reported that different regulatory processes control fatty acid synthesis in intramuscular and subcutaneous adipose tissue, indicating that it may be possible to increase marbling without proportional increases in backfat that could negatively impact yield grade. Thus, the fetal stage may be of key importance to overall carcass quality of offspring.

Volatile fatty acids (VFA) are the main products of the digestion of feed by bacteria in the rumen, provide a majority of the energy required by ruminants, and serve as substrates for synthesis of glucose and fat (Ferrell et al., 1982; Bell and Bauman, 1997). Major VFA's produced by rumen microorganisms include acetate, propionate, and butyrate (Bell and Bauman, 1997). Various dietary energy sources ferment in the rumen to yield differing proportions of specific short- and long-chain fatty acids. Forage-based diets result in VFA composition of approximately 65 to 70% acetate, 15 to 25% propionate, and 5 to 10% butyrate (Penner et al., 2009). Grain-based diets high in readily fermentable carbohydrate (starch) reduce acetate by 10 to 15% and increase propionate by 20 to 25% (Penner et al., 2009). Propionate is the only VFA that contributes directly to the net synthesis of glucose, which is a major energy substrate utilized by uterine and placental tissues for fetal growth (Ferrell et al., 1982). Typically, beef cattle are finished on high concentrate diets that result in fermentation of propionate and increased glucose production. Glucose plays an important role in intramuscular fat cell proliferation and growth that ultimately determines the amount of marbling in the carcass. Therefore, it seems plausible that diets based on nonstructural carbohydrates (starch) rather than structural carbohydrates (fiber) could influence fetal development and subsequent carcass composition. Previous literature has shown that providing first-calf heifers and mature cows with a high-energy diet 100 d prepartum increased body weight before parturition and calf birth weight (Corah et al., 1975). In that study, subsequent weaning weight was greater for calves from cows consuming the high-energy diet. However, Radunz et al. (2012) reported feeding corn to dams in late pregnancy resulted in offspring with reduced marbling scores, a tendency towards reduced intramuscular fat percentage, and more

carcasses grading USDA Select compared to those from hay-fed cows. Because fetal adipocyte differentiation and growth is initiated in mid-gestation, it is possible that different responses would be observed if maternal dietary treatments had been implemented earlier. Based on these results, there may be differences in nutrient utilization and performance of offspring from cows fed forage or concentrate-based diets. We hypothesized that variations in the proportion of volatile fatty acids produced in the rumen of the gestating cow during mid- and late- gestation would differentially influence fetal development and offspring carcass composition, leading to alterations of performance and meat quality of offspring.

MATERIALS AND METHODS

Cow Management

All animal care and experimental protocols were approved by the South Dakota State University (SDSU) Animal Care and Use Committee (approval number 18-081E). Mature, Angus-based, spring-calving cows from the SDSU Antelope Range and Livestock Research Station (n = 131) and the North Dakota State University (NDSU) Hettinger Research Extension Center (n = 70) were evaluated for pregnancy in the fall of 2017 and assigned to dietary treatments based on cow age and body condition score (BCS). Cattle remained in their respected research station groups due to differences in mature body weight, frame size, genetic background, and time of conception. Groups were randomly assigned to forage-based or limit-fed concentrate-based dietary treatments and allotted to four pens based on source and treatment [SDSU Forage (n = 64), SDSU Concentrate (n = 65), NDSU Forage (n = 35), NDSU Concentrate (n = 35)]. Dietary

composition for the treatment diets is provided in Table 2.1. Feed intake was controlled so that cows in both treatments consumed equal levels of protein and energy. Cows were provided the treatment diets beginning at approximately d 94 of gestation and continuing until approximately 30 d prior to calving. Both diets were formulated to maintain cow body condition. Body weights (BW) and body condition scores (BCS) from the beginning (d 0) and end (d 98) of the treatment period were used to monitor the influence of dietary energy source on cow performance. After a 2 week diet adaptation period to account for differences in gut fill (cows were provided treatment diets that vaired in digestibility and intake compared to the pre-treatment diet), average body weight of SDSU cows was 598 ± 49.4 kg and 666 ± 52.4 kg, and average body condition score was 5.2 ± 0.39 and 5.3 ± 0.31 for concentrate and forage treatments respectively, while average body weight of NDSU cows was 712 ± 77.3 kg and 747 ± 85.5 kg, and average body condition score was 6.2 ± 0.96 and 6.7 ± 0.78 for concentrate and forage treatments respectively. At the completion of the treatment period average body weight of SDSU cows was 639 ± 60.7 kg and 635 ± 57.4 kg, and average body condition score was 5.4 ± 0.57 and 5.1 ± 0.38 for concentrate and forage treatments respectively, while average body weight of NDSU cows was 703 ± 81.8 kg and 710 ± 85.9 kg, and average body condition score was 6.4 ± 0.75 and 6.7 ± 0.89 for concentrate and forage treatments respectively. At the end of the treatment period, cows were returned to native range pastures and managed as a common group through weaning.

Offspring Management

At approximately 60 days of age, all calves were vaccinated with a killed vaccine for clostridial diseases (Vision 7 Somnus with SPUR, Merck Animal Health, Madison,

NJ). At approximately 110 days of age, all calves were administered a modified-live vaccine for prevention of bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), bovine respiratory syncytial virus (BRSV) Types 1 and 2, and parainfluenza-3 (PI_3), Haemophilus somnus, and *Mannheimia haemolytica* (Pyramid 5+ Presponse SQ, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO). At weaning, all calves were administered an anthelmintic (Dectomax Pour-On Solution, Zoetis, Parsippany, NJ) and were provided boosters of the clostridial disease and respiratory disease vaccines. Also during this time, a subset of 96 calves (n = 24 heifers/treatment, n = 24 steers/treatment) from the SDSU cows and 40 calves (n = 10 heifers/treatment, n = 10 steers/treatment) from the NDSU cows closest to the mean weaning weight of each herd were shipped to the SDSU Cottonwood Field Station for the backgrounding period. Calves were fed a common receiving diet consisting of grass hay and dried distillers grains with solubles during an 75 or 83 d (Exp. 2 and Exp. 1, respectively) backgrounding period. On d 28 and 36 postweaning respectively, NDSU and SDSU calves were weighed to monitor performance and ultrasounded to determine backfat thickness (BF), muscle depth (longissimus dorsi), and intramuscular fat (IMF) measured at the 12th and 13th rib. At the conclusion of the backgrounding phase, all calves were transported approximately 526 km to Brookings, SD for the finishing phase of the study. Upon arrival, calves were administered a booster to vaccinate against clostridia perfringens type A (Clostridium Perfringens Type A Toxoid; Elanco, Greenfield, IN). The SDSU calves were finished in an Insentec monitoring system (Insentec, Marknesse, the Netherlands) at the SDSU Cow-Calf Education and Research facility (CCERF) to monitor individual feed intake. Steers and heifers were separated into two pens. The NDSU calves were stratified by sex and

initial body weight into group pens (4 pens/treatment with 5 head/pen) and finished at the SDSU Ruminant Nutrition Center (RNC). Because the calves from each source location were finished in different systems, the SDSU calves will be referred to as Experiment 1 and the NDSU calves as Experiment 2. Finishing diets for each group of cattle are provided in Table 2.2. Diet ingredients were sampled weekly and averaged to determine the dry matter (AOAC method no. 935.29), crude protein (AOAC method no. 990.03), neutral detergent fiber (Ankom Technology Method 6), acid detergent fiber (Ankom Technology Method 5), ash (AOAC method no. 942.05), crude fat (AOAC method no. 2003.06), and tabular value of energy content of diets while on test. Cattle were weighed at 28 d intervals during the finishing period to monitor performance (hereafter referred to as Period 1, Period 2, etc.). Following a step-up period, calves were administered an initial growth promoting implant on d 23 of the finishing period containing 100 mg trenbolone acetate (TBA) and 14 mg estradiol benzoate (EB) (Synovex-Choice, Zoetis Inc., Parsippany, NJ). Cattle were re-implanted with 100 mg TBA and 14 mg EB (Synovex-Choice, Zoetis Inc., Parsippany, NJ) and a second ultrasound was conducted on d 80 of the finishing period. Ultrasound measures collected during the backgrounding period and finishing period were compared to determine changes in composition. The second ultrasound was also used to predict harvest date. The harvest target was determined when the predicted BF was approximately 1.27 cm, resulting in three harvest dates at d 131, d 145, and d 180 of the finishing period. Cattle were weighed the morning of slaughter to determine final live bodyweight and shipped 235 km to a commercial packing facility.

Carcass Evaluation and Sample Collection

All cattle were tracked individually through the harvest process. Following carcass chilling (approximately 24 hours), hot carcass weight (HCW), ribeye area (REA), 12th rib BF, USDA Yield Grade (YG), marbling score, carcass maturity, USDA Quality Grade (QG), and objective color measurements (L*, a*, and b*) were recorded for each individual carcass using a handheld Minolta colorimeter (Model CR-310, Minolta Corp., Ramsey, NJ; 50 mm diameter measuring space, D65 illuminant). A strip loin (IMPS #180) was collected from each carcass and transported to the SDSU Meat Science Laboratory and portioned into 2.54-cm steaks. Four steaks were aged for either 3, 7, 14, or 21 days for evaluation of Warner-Bratzler shear force (WBSF). Additional steaks were utilized to determine fatty acid profile using Fatty Acid Methyl Ether (FAME) synthesis, crude fat percentage using ether extraction, and consumer palatability of 14 d aged samples using a trained sensory panel.

Warner-Bratzler Shear Force

Steaks designated for WBSF determination were thawed for 24 hours at 4°C then cooked on an electric clamshell grill (George Foreman, Model GRP1060B, Middleton, WI) to an internal temperature of 71ºC. A thermometer (Model 35140, Cooper-Atkins Corporation, Middlefield, CT) was used to record the peak internal temperature. Cooked steaks were cooled at 4°C for 24 hr before removing 6 cores (1.27 cm diameter) parallel to the muscle fiber orientation (AMSA, 2015). A single, peak shear force measurement was obtained for each core using a texture analyzer (Shimadzu Scientific Instruments Inc., Lenexa, KS, Model EZ-SX) with a Warner-Bratzler attachment. Measurements of the peak shear force value were averaged to obtain a single WBSF value per steak.

Ether Extract

At 3 d postmortem, the anterior face of each striploin was removed during fabrication and frozen at -20ºC and later used to determine percent crude fat using the ether extract method outlined by Mohrhauser et al. (2015). Steaks were thawed slightly and all exterior fat, epimysial connective tissue, and additional muscles were removed from the longissimus muscle. Samples were minced, immersed in liquid nitrogen, and powdered for 15 seconds using a Waring commercial blender (Waring Products Division, Model 51BL32, Lancaster, PA). Homogenized samples were weighed in duplicate 5-gram samples into dried aluminum tins, covered with dried filter papers, and dried in an oven at 100ºC for 24 hr. Dried samples were then placed into a desiccator and were reweighed after cooling. Samples were extracted using petroleum ether in a side-arm Soxhlet extractor (Thermo Fischer Scientific, Rockville, MD) for 60 hr followed by drying at room temperature and subsequent drying in an oven at 100°C for 4 hr (Ether Extract; AOAC, 2007). Dried extracted samples were placed into a desiccator for 1 hr and were cooled and then reweighed. Crude fat was calculated by subtracting the pre-extraction weight from the post-extraction sample weight and expressed as a percentage of the pre-extraction sample weight.

Fatty Acid Composition

A sub-sample of 30 steaks per treatment were selected that were closest to the mean marbling score from Experiment 1 (30 per treatment from the SDSU offspring) to evaluate composition of individual fatty acids using direct FAME synthesis. Steaks were thawed slightly and external fat, epimysial connective tissue, and additional muscles were

trimmed from the longissimus muscle. Samples were minced, immersed in liquid nitrogen, and powdered for 15 seconds using a Waring commercial blender (Waring Products Division, Model 51BL32, Landcaster, PA). Duplicate 1 g samples were weighed and processed to generate FAMEs according to procedures of O'Fallon et al. (2007).

Trained Sensory Panel

An eight-member trained sensory panel evaluated samples according to standards set by AMSA (2015). Strip loin samples were evaluated for juiciness (1 = extremely dry; 18 = extremely juicy), tenderness (1 = extremely tough; 18 = extremely tender), and beef flavor (1= extremely bland; 18 = extremely intense) on an anchored unmarked line scale. Steaks were cooked on an electric clamshell grill (George Foreman, Model GRP1060B, Middleton, WI) to an internal temperature of 71ºC. After cooking, steaks were rested for five minutes and then cut into 2.5 x 1 x 1-cm samples. Two cubes were placed into a prelabeled plastic cup, covered with a plastic lid in order to retain heat and moisture, and held in a warming oven (Metro HM2000, Wilkes-Barre, PA) at 60ºC until served. Ten samples were evaluated in each session, one session per d, for a total of 10 sessions. Samples evaluations were alternated by treatment to reduce first and last order bias. Samples were served to panelists in a randomized fashion, in private booths, under red lights to limit observation of visual differences and evaluated for each trait on an anchored unmarked line scale.

Statistical Analyses

Response variables were analyzed using generalized linear mixed model procedures (SAS GLIMMIX, SAS Inst. Inc., Cary, NC). The intrauterine environment was considered the experimental unit for Experiment 1 and for ultrasound measurements, carcass characteristics, and meat quality data for Experiment 2. Pen was considered the experimental unit for growth performance data for Experiment 2. Experiment 1 was analyzed as a completely randomized design and Experiment 2 was analyzed as a randomized complete block design to determine the effects of treatment, calf sex and their interaction. For WBSF, aging period was added to the model as a repeated measure and peak cooking temperature was included as a covariate. Separation of least squares means was conducted using protected LSD with an alpha level of 0.05. Treatment by sex interactions were evaluated and reported if significant.

RESULTS

Growth Performance

Experiment 1: Animal performance and growth data for Experiment 1 is reported in Table 2.3. Maternal dietary treatment did not influence ($P > 0.05$) offspring BW, or DMI. A tendency ($P = 0.07$) for a treatment × sex interaction was detected for G:F in Period 2. Steers from both treatments had similar G:F, and had improved G:F compared to both forage and concentrate heifers, however forage heifers had improved G:F compared to concentrate heifers (Figure 2.4). A tendency ($P = 0.05$) for a treatment × sex interaction was detected for ADG in Period 2. Steers from the concentrate treatment had greater ($P < 0.04$) ADG compared with steers from the forage treatment, while ADG of heifers did not differ ($P > 0.05$; Figure 2.1). A tendency ($P = 0.07$) for a treatment × sex

interaction was also detected for ADG in period 3. Steers from the forage fed dams had greater ($P < 0.04$) ADG than steers from the concentrate treatment and heifers from either treatment, which were similar ($P > 0.05$, Figure 2.2). A tendency ($P = 0.07$) for a treatment × sex interaction was observed for ADG in the final period. Steers from both treatments had similar ADG, and had similar ADG compared to both forage and concentrate heifers, however forage heifers had improved ADG compared to concentrate heifers (Figure 2.3). In Period 1 (d 0-23) of the finishing phase, offspring from dams fed a forage-based diet tended ($P = 0.08$) to have an improved ADG compared to offspring from dams fed a concentrate-based diet, however no differences ($P > 0.05$) in ADG were detected between treatment groups in subsequent periods. As expected, steers had greater ($P < 0.05$) BW compared to heifers at all time periods and had an increased ($P < 0.05$) initial ADG compared to heifers. However, heifers had an increased ($P \leq 0.05$) ADG in period 1 and 4. Steers tended to have increased ($P = 0.051$) ADG at Period 1 (d 0-23) and had increased ($P < 0.05$) ADG at Period 4 (d 78-106) compared to heifers. Heifers had greater ($P < 0.05$) DMI during Period 1, however, DMI did not differ ($P > 0.05$) between steers and heifers for the remainder of the finishing period. Steers had improved ($P < 0.05$) G:F during Period 3, while heifers had improved ($P < 0.05$) G:F during Period 4. It is likely that differences in G:F were driven by differences in ADG rather than DMI.

Experiment 2: Performance and growth data for Experiment 2 is reported in Table 2.7. Maternal treatment did not influence ($P > 0.05$) offspring growth performance in Experiment 2. As expected, steers had heavier ($P < 0.05$) body weights from Periods 1 through 3 of the finishing phase, however, heifer and steer body weight were similar at weaning, as well as during the backgrounding phase, Period 4 of the finishing phase and

at the final weight. In this experiment, ADG, DMI, and G:F did not differ between sexes ($P > 0.05$).

Ultrasound Measurements

Experiment 1: Ultrasound measurements for Exp. 1 are reported in Table 2.4. Maternal treatment did not influence ($P > 0.05$) offspring BF, IMF percentage or muscle depth during the finishing phase. A treatment × sex interaction ($P = 0.028$) was detected for muscle depth during the backgrounding phase (Table 5; Figure 2.5). Heifers from the concentrate treatment tended to have increased ($P = 0.07$) muscle depth compared with heifers from the forage treatment, while muscle depth of steers did not differ ($P > 0.05$) between treatments. Heifers had increased ($P < 0.05$) BF compared to steers at the initial ultrasound during the backgrounding phase.

Experiment 2: Ultrasound measurements for Exp. 2 are reported in table 2.8. Maternal treatment did not influence ($P > 0.05$) offspring muscle depth or IMF percentage. Offspring from the forage treatment tended ($P = 0.09$) to have increased BF during the finishing phase, as well as tended ($P = 0.07$) to gain more BF from the initial to the final ultrasound compared to the concentrate treatment. Steers had increased ($P < 0.05$) muscle depth at both ultrasound periods and tended ($P = 0.08$) to have decreased BF compared to heifers.

Carcass Characteristics

Experiment 1: Carcass measurements for Exp. 1 are reported in Table 2.5. Maternal treatment did not influence ($P > 0.05$) offspring HCW, REA, marbling score, L* values or the proportion of carcasses in each USDA Quality and Yield Grade

category. Offspring from the forage treatment tended to have decreased (P = 0.06) 12th rib fat thickness and tended to have lower (P = 0.08) USDA Yield Grades compared to offspring from the concentrate treatment. Offspring from the concentrate treatment had increased (P < 0.05) a* and b* values compared to the forage treatment. As expected, steers had heavier (P < 0.05) HCW and larger (P < 0.05) REA than heifers. Heifers had increased (P < 0.05) BF and marbling scores, as well as increased (P < 0.05) a* and b* values and tended (P = 0.07) to have higher USDA Yield Grades.

Experiment 2: Carcass measurements for Exp. 2 are reported in Table 2.9. Maternal treatment did not influence (P > 0.05) any carcass traits evaluated in Exp. 2. Similar to Exp. 1 Steers had heavier (P < 0.05) HCW, larger (P < 0.05) REA, decreased (P < 0.05) BF and marbling scores, and lower (P < 0.05) USDA Yield Grades compared to heifers.

Meat Quality Characteristics

Experiment 1: Meat quality characteristics for Exp. 1 are reported in table 2.6. Maternal treatment did not influence (P > 0.05) crude fat percentage, moisture content, WBSF, or sensory characteristics of steaks from offspring. Heifers had decreased (P < 0.05) moisture and increased crude fat content compared to steers. As expected, WBSF improved (P < 0.05) each aging period (4.75 ± 0.152 kg, 3.79 ± 0.112 kg, 2.98 ± 0.088 kg, and 2.65 ± 0.064 kg for steaks aged 3, 7, 14, and 21 days, respectively).

Experiment 2: Meat quality characteristics for Exp. 2 are reported in table 2.10. Maternal treatment did not influence (P > 0.05) crude fat percentage, moisture content, WBSF, or flavor of steaks from offspring. However, offspring from the concentrate

treatment had increased ($P < 0.05$) juiciness, and tended to have increased ($P = 0.08$) tenderness compared to offspring from the forage treatment as evaluated by a trained sensory panel. Heifers had increased ($P < 0.05$) crude fat and decreased moisture content compared to steers, which is likely the result of heifers having greater amounts of marbling compared to the steers. As expected, WBSF improved ($P < 0.05$) from d 4 to 7, and from d 7 to 14, but d 14 did not differ from d 21 (WBSF values were 4.79 ± 0.156 kg, 3.74 ± 0.156 kg, 2.91 ± 0.156 kg, and 2.63 ± 0.157 kg for steaks aged 3, 7, 14, and 21 days, respectively).

Fatty Acid Composition

Fatty acid composition was only analyzed for Exp. 1 (Table 2.11 and 2.12). The concentration (mg/g wet raw tissue; Table 2.11) of arachidonic (C20:4n6), nervonic (C20:1n9), and docosapentaenoic (C22:5n3) acids were increased in samples from the concentrate treatment ($P < 0.05$); however, treatment did not influence ($P > 0.05$) concentration of other fatty acids. The concentration (mg/g) of capric (C10:0), myristic (C14:0), myristoleic (C14:1n5), palmitoleic (C16:1n7), and heptadecenoic (C17:1) acids were increased ($P < 0.05$) in samples from heifers compared with steers. Sex did not influence ($P > 0.05$) concentration of other fatty acids.

When analyzed as a percentage of total fatty acids (%, g/100 g total fatty aicds; Table 2.12), docosatrienoic (C22:3), nervonic (C24:1n9), and docosapentaenoic (C22:5n3) acids were increased ($P < 0.05$) in samples from the concentrate treatment compared with the forage treatment. Treatment did not influence ($P < 0.05$) the percentage of other fatty acids. The percentage of myristic (C14:0), palmitoleic (C16:1n7), and heptadecenoic (C17:1) acids were increased ($P < 0.05$) in samples from

heifers compared with steers, but the percentage of stearic (C18:0) acid was increased ($P < 0.05$) in samples from steers. Sex did not influence ($P > 0.05$) the percentage of other fatty acids.

DISCUSSION

The majority of fetal muscle and adipose tissue growth and development occurs during mid- and late-gestation (Du et al., 2010a). Alterations to fetal development imposed by maternal stressors, such as maternal nutrient restriction have been shown to have long term impacts on offspring growth and performance (Underwood et al., 2010; Mohrhauser et al., 2015; Webb et al., 2019). From a production perspective, management decisions made in response to drought, availability of feedstuffs, or cost of feedstuffs can alter the gestational environment potentially leading to changes in fetal development. In the present study, drought conditions in 2017 resulted in limited forage availability at the SDSU Antelope Range and Livestock Research Station and the NDSU Hettinger Research Extension Center. Therefore, a management decision was made to transport a portion of these cow herds to a drylot from November 2017 through February 2018 to take advantage of lower cost feedstuffs and preserve range conditions. Based on feed prices of 2017, dams in the concentrate-based treatment were fed a diet that cost approximately $0.90/ day and the forage-based treatment were fed a diet that cost approximately $1.07/ day. Others have evaluated dietary energy source during late gestation (Radunz et al., 2012), but to date literature concerning the effects of maternal dietary energy source (forage vs. concentrate) during mid- and late-gestation on offspring performance and meat quality traits is limited.

In agreement with the present study, Radunz et al., (2012) also reported that maternal energy source did not influence feedlot receiving BW, DMI, ADG, G:F, or final BW of offspring. Taylor et al. (2016) also reported that maternal energy status (positive or negative energy status) during mid-gestation did not influence offspring BW, ADG, DMI, or G:F during the finishing phase. However, studies investigating maternal protein supplementation in late gestation have reported differences in offspring performance. Larson et al., (2009) investigated the effects of dam winter grazing system and crude protein supplementation during late gestation. Offspring weaning BW, BW at feedlot entry, reimplant BW, ADG, and DMI were all increased if the dams were supplemented with protein during late gestation (Larson et al., 2009). Summers et al. (2015) compared dams provided a supplement with a high level of rumen undegradable protein (RUP) or a low level of RUP during late gestation with a non-supplemented control. Offspring from dams supplemented with a high level of RUP had increased BW at feedlot entry compared to progeny from non- supplemented dams. However, progeny from non-supplemented dams tended to have greater ADG and had greater DMI during the reimplant period as well as greater overall DMI (Summers et al., 2015). Differences in growth performance between studies is likely due to differences in nutrients evaluated (energy vs. protein), timing of maternal dietary treatments during gestation, and varying degrees of restriction or supplementation. However, these studies indicate that offspring performance is sensitive to changes in the maternal diet.

In Exp. 1, muscle depth of heifers from the concentrate treatment were similar to steers from both treatment groups but tended to have 9% greater muscle depth than heifers from the forage treatment at the initial ultrasound during the backgrounding

phase. As ultrasound measures were recorded shortly after the weaning event, the heifers from the forage treatment may have taken longer to adjust to the backgrounding environment, hindering their muscle growth. However, no differences were detected at the finishing period ultrasound, which could most likely be attributed to recovery of muscle growth via compensatory growth. In Exp. 2, backfat thickness tended to be decreased in offspring from the concentrate treatment by 15% during the finishing phase compared to the forage treatment. This contradicts findings in Exp. 1 where there were no differences in backfat measured via ultrasound. Differences between experiments may be due to differences in cow size and body condition between the two source groups or the different types of finishing systems utilized in Exp. 1 and Exp. 2. As expected, heifers were fatter (9% and 12% for Exp. 1 and 2 respectively), compared to steers. In Exp. 2, muscle depth of steers was greater than heifers (14% and 7% for backgrounding and finishing phases, respectively). Radunz et al., (2012) provided dams either hay-based, corn-based, or dried corn distillers grains-based diets during late gestation and evaluated carcass measures of progeny via ultrasound at 24 to 72 hr after birth and 84 d into the finishing phase. However, unlike the present study, no differences were reported in ultrasound measures of progeny carcass traits. Differences in diet composition, timing of dietary treatments during gestation and timing of ultrasound evaluation may explain the differences between the findings of Radunz et al. (2012) and the present study.

In Exp. 1 backfat thickness of offspring from forage fed dams tended to be decreased by 7% and USDA Yield Grades also tended to be 7% lower. However this finding was not observed in Exp. 2. Differences between the two experiments may be attributed to genetic and management differences between the source cow herds, as well

as the differences in offspring finishing systems. While no direct comparisons with the present study are available in the literature other research has demonstrated that offspring fat depots may be especially sensitive to alterations in the maternal diet. When fed to a common backfat endpoint, Radunz et al., (2012) reported that offspring from dams fed a fiber-based diet (hay) in late gestation had increased marbling scores and no carcasses that graded USDA Select compared to offspring from dams fed a starch-based diet (corn). Underwood et al., (2010) reported that fat thickness and adjusted 12th rib fat thickness was greater in offspring from dams grazing improved pasture that providing more crude protein than offspring form dams grazed on native range during mid gestation. Wilson et al., (2015) observed a tendency for progeny from dams provided a distillers grain supplement during late gestation to have decreased backfat thickness compared to progeny from dams that were not supplemented. Steers from dams supplemented protein during late gestation were reported to have increased marbling scores, as well as a greater proportion of carcasses grading USDA Choice or better compared to steers from dams not supplemented protein (Larson et al., 2009). Mohrhauser et al. (2015) reported a tendency for decreased backfat and lower USDA Yield Grades, with no influence on marbling score, in offspring from dams in a negative maternal energy status during mid-gestation compared to offspring from dams in a positive maternal energy status. Summers et al., (2015) also observed decreased 12th rib fat thickness with no differences in marbling score in progeny from dams that were supplemented a diet with low RUP in late gestation compared to progeny from dams not supplemented with RUP.

Heifers in both Exp. 1 and Exp. 2, heifers had increased BF (14% and 17% for Exp. 1 and 2, respectively) and YG (7% and 17% for Exp. 1 and 2, respectively)

compared to steers, but decreased HCW (9% and 8% for Exp. 1 and 2, respectively) and REA (8% and 11% for Exp. 1 and 2, respectively). Mohrhauser et al., (2015) also reported steers to have heavier HCW, reduced marbling scores, and larger ribeye areas. However, in contrast to the present study, steers were reported to have higher a* values and tended to have higher L* values compared to heifers (Mohrhauser et al., 2015). In addition, the marbling score of heifers was greater (9% and 15% for Exp. 1 and 2, respectively) compared to steers. This is consistent with other studies suggesting heifers have greater amounts of marbling when compared to steers and bulls (Park et al., 2018).

Because there were no differences in marbling scores between treatment groups the lack of difference in crude fat and moisture content is not unexpected. Other studies investigating alterations in maternal energy have evaluated WBSF and also reported no differences in this objective measure of tenderness (Radunz et al., 2012; Mohrhauser et al., 2015). However, studies investigating alterations in maternal protein levels reported steaks from offspring of dams with restricted protein intake during mid-gestation had increased WBSF values (less tender meat) compared to offspring of dams with adequate protein intake (Underwood et al., 2010; Webb et al., 2019). In Exp. 2, steaks from the offspring of dams in the concentrate treatment were rated 11% juicier and there was a tendency for a 7 % improvement in tenderness ratings by a trained sensory panel compared to steaks from the forage treatment. The difference in sensory ratings between treatments and between Experiments in this study is unclear. Other studies investigating the effects of maternal nutrition during gestation on sensory characteristics of steaks is lacking. As no differences were observed between treatments for WBSF, crude fat, moisture content, or marbling scores more research is necessary to understand the

influence of maternal dietary energy source on the sensory attributes of steaks from offspring. In both Exp. 1, and Exp. 2 heifers had increased crude fat (25% and 27% for Exp. 1 and 2, respectively) and decreased moisture content (2% for both Exp. 1 and 2) compared to steers, which is likely attributed to the heifers having greater amounts of marbling compared to the steers.

There is limited information on the effects of maternal diet on the fatty acid composition of meat from offspring. Webb et al. (2019) also reported that arachidonic acid was sensitive to changes in maternal diet. Offspring of dams provided adequate protein during mid-gestation produced offspring with increased concentrations of arachidonic acid compared with protein restricted dams. A study by Chail et al., (2017) evaluated the effects of finishing diet on fatty acid composition in the *gluteus medius* and *triceps brachii* and also observed increased concentration of arachidonic acid when cattle were fed a grain-based diet as compared to a forage-based diet. Results from the present study suggest that maternal diet can influence fatty acid composition of steaks from progeny and warrants further investigation.

IMPLICATIONS

Results from this study suggest that variation in winter cow diets during mid- and late-gestation has limited influence on progeny performance. Collectively, these data suggest a forage-based diet provided to cows during mid- and late-gestation differentially influences deposition of subcutaneous fat without compromising marbling score or tenderness. As dams in the present study were fed to meet nutrient requirements during mid- and late-gestation, mechanisms by which energy source in mid- to late-gestation can affect growth rate of progeny might be minimized when energy needs of the cow are met.

Provided that nutrient requirements are met, it appears that utilizing alternative diets for the beef cow herd does not significantly influence progeny performance and beef product quality. This provides flexibility for cow/calf producers to feed their gestating cows available energy sources during drought and/or variable growing conditions without concern for offspring performance or carcass traits. However, further investigation is required to analyze responses due to differences in glucose precursors due to differing VFA profiles.

LITERATURE CITED

American Meat Science Association (AMSA). 2015. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. AMSA, Champaign, IL.

Ankom. 2006. Ankom Technology Method 5. Acid Detergent Fiber in Feeds. Filter Bag Technique. Ankom Technology. Macedon, New York. This method is a modification of AOAC Official Method 973.18. Fiber (Acid Detergent) and Lignin (H2SO4) in Animal Feed. Official Methods of Analysis of AOAC International. 19th ed. Dr George W Latimer, Jr (ed). Gaithersburg, Maryland.

Ankom. 2006. Ankom Technology Method 6. Neutral Detergent Fiber in Feeds. Filter Bag Technique. Ankom Technology. Macedon, New York. This method is a modification of AOAC Official Method 2002.04. Amylase-Treated Neutal Detergent Fiber in Feeds. Using Refluxing in Beakers or Crucibles. Official Methods of Analysis of AOAC International. 19th ed. Dr George W Latimer, Jr (ed). Gaithersburg, Maryland.

AOAC. Official Methods of Analysis, 19th ed.; Association of Official Analytical Chemist: Arlington, VA, USA, 2012.

AOAC International. 2012. AOAC Official Method 2003.06. Crude Fat in Feeds, Cereal Grains, and Forages. Official Methods of Analysis of AOAC International. 19th

ed. Dr George W Latimer, Jr (ed). Gaithersburg, Maryland. Modified for extraction with petroleum ether.

AOAC International. 2012. AOAC Official Method 942.05. Ash of Animal Feed. Official Methods of Analysis of AOAC International. 19th ed. Dr George W Latimer, Jr (ed). Gaithersburg, Maryland.

AOAC International. 2012. AOAC Official Method 990.03. Protein (Crude) in Animal Feed. Combustion Method. Official Methods of Analysis of AOAC International. 19th ed. Dr George W Latimer, Jr (ed). Gaithersburg, Maryland.

Bell, A. W., and D. E. Bauman. 1997. Adaptations of Glucose Metabolism During Pregnancy and Lactation. Journal of Mammary Gland Biology and Neoplasia 2(3):265-278. (Article) doi: 10.1023/a:1026336505343

Chail, A., Legako, J. F., Pitcher, L. R., Ward, R. E., Martini, S., & MacAdam, J. W. (2017). Consumer sensory evaluation and chemical composition of beef gluteus medius and triceps brachii steaks from cattle finished on forage or concentrate diets. *Journal of Animal Science, 95*(4), 1553-1564. doi:10.2527/jas.2016.1150

Corah, L. R., Dunn, T. G., & Kaltenbach, C. C. (1975). Influence of prepartum nutrition on the reproductive performance of beef females and the performance of their progeny. In.

Du, M., Tong, J., Zhao, J., Underwood, K. R., Zhu, M., Ford, S. P., & Nathanielsz, P. W. (2010a). Fetal programming of skeletal muscle development in ruminant animals. *Journal of Animal Science, 88,* E51-E60. doi:10.2527/jas.2009-2311

Du, M., Yan, X., Tong, J. F., Zhao, J. X., & Zhu, M. J. (2010b). Maternal Obesity, Inflammation, and Fetal Skeletal Muscle Development. *Biology of Reproduction, 82*(1), 4-12. doi:10.1095/biolreprod.109.077099

Du, M., J. X. Zhao, X. Yan, Y. Huang, L. V. Nicodemus, W. Yue, R. J. McCormick, and M. J. Zhu. 2011. Fetal muscle development, mesenchymal multipotent cell differentiation, and associated signaling pathways. Journal of Animal Science 89(2):583-590. (Article) doi: 10.2527/jas.2010-3386

Ferrell, C. L., Prior, R. L., Christenson, R. K., & Ford, S. P. (1982). Blood flow and nutrient uptake of the bovine uterus and fetus. In (pp. 30-31). Roman L. Hruska U.S. Meat Animal Research Center Report.

Funston, R. N., Summers, A. F., & Roberts, A. J. (2012). Alpharma Beef Cattle Nutrition Symposium: Implications of nutritional management for beef cow-calf systems. *Journal of Animal Science, 90*(7), 2301-2307. doi:10.2527/jas.2011-4568

Larson, D. M., Martin, J. L., Adams, D. C., & Funston, R. N. (2009). Winter grazing system and supplementation during late gestation influence performance of beef cows and steer progeny. *Journal of Animal Science, 87*(3), 1147-1155. doi:10.2527/jas.2008-1323

Mohrhauser, D. A., A. R. Taylor, K. R. Underwood, R. H. Pritchard, A. E. Wertz-Lutz, and A. D. Blair. 2015. The influence of maternal energy status during midgestation on beef offspring carcass characteristics and meat quality. J Anim Sci 93(2):786-793. (Article) doi: 10.2527/jas.2014-8567

O'Fallon, J. V., Busboom, J. R., Nelson, M. L., & Gaskins, C. T. (2007). A direct method for fatty acid methyl ester synthesis: Application to wet meat tissues, oils, and feedstuffs. *Journal of Animal Science, 85*(6), 1511-1521. doi:10.2527/jas.2006-491

Park, S. J., S. H. Beak, D. J. S. Jung, S. Y. Kim, I. H. Jeong, M. Y. Piao, H. J. Kang, D. M. Fassah, S. W. Na, S. P. Yoo, and M. Baik. 2018. Genetic, management, and nutritional factors affecting intramuscular fat deposition in beef cattle - A review. Asian-Australasian Journal of Animal Sciences 31(7):1043-1061. (Review) doi: 10.5713/ajas.18.0310

Penner, G. B., Taniguchi, M., Guan, L. L., Beauchemin, K. A., & Oba, M. (2009). Effect of dietary forage to concentrate ratio on volatile fatty acid absorption and the expression of genes related to volatile fatty acid absorption and metabolism in ruminal tissue. *Journal of Dairy Science, 92*(6), 2767-2781. doi:10.3168/jds.2008-1716

Radunz, A. E., Fluharty, F. L., Relling, A. E., Felix, T. L., Shoup, L. M., Zerby, H. N., & Loerch, S. C. (2012). Prepartum dietary energy source fed to beef cows: II. Effects on progeny postnatal growth, glucose tolerance, and carcass

composition. *Journal of Animal Science, 90*(13), 4962-4974. doi:10.2527/jas.2012-5098

Smith, S. B., & Crouse, J. D. (1984). Relative Contributions Of Acetate, Lactate And Glucose To Lipogenesis In Bovine Intramuscular And Subcutaneous Adipose-Tissue. *Journal of Nutrition, 114*(4), 792-800.

Summers, A. F., Blair, A. D., & Funston, R. N. (2015). Impact of supplemental protein source offered to primiparous heifers during gestation on II. Progeny performance and carcass characteristics. *Journal of Animal Science, 93*(4), 1871-1880. doi:10.2527/jas.2014-8297

Taylor, A. R., D. A. Mohrhauser, R. H. Pritchard, K. R. Underwood, A. E. Wertz-Lutz, and A. D. Blair. 2016. The influence of maternal energy status during mid-gestation on growth, cattle performance, and the immune response in the resultant beef progeny1. The Professional Animal Scientist 32(4):389-399. doi: https://doi.org/10.15232/pas.2015-01469

Underwood, K. R., J. F. Tong, P. L. Price, A. J. Roberts, E. E. Grings, B. W. Hess, W. J. Means, and M. Du. 2010. Nutrition during mid to late gestation affects growth, adipose tissue deposition, and tenderness in cross-bred beef steers. Meat Science 86(3):588-593. (Article) doi: 10.1016/j.meatsci.2010.04.008

Webb, M. J., J. J. Block, R. N. Funston, K. R. Underwood, J. F. Legako, A. A. Harty, R. R. Salverson, K. C. Olson, and A. D. Blair. 2019. Influence of maternal protein

restriction in primiparous heifers during mid and/or late-gestation on meat quality and fatty acid profile of progeny. Meat Science 152:31-37. (Article) doi: 10.1016/j.meatsci.2019.02.006

Wilson, T. B., Schroeder, A. R., Ireland, F. A., Faulkner, D. B., & Shike, D. W. (2015). Effects of late gestation distillers grains supplementation on fall-calving beef cow performance and steer calf growth and carcass characteristics. *Journal of Animal Science, 93*(10), 4843-4851. doi:10.2527/jas.2015-9228

Table 2.1 Dietary components (dry matter basis) consumed by cows receiving a forage-based (FOR) or concentrate-based

Ingredient	CONC[1]	FOR[1]
Wheat Straw,%	24.1	71.9
Grass/ Alfalfa Hay, %	---	21.8
Corn Silage, %	---	3.7
Suspension Supplement[2], %	4.6	2.6
Corn Grain, %	56.6	---
Modified Distiller's Grain w/ Solubles, %	13.3	---
Limestone, %	1.4	---
	--- Diet Composition ---	
Dry Matter Intake, kg	6.4	10.73
Dry Matter Intake, % BW	0.98	1.65
Roughage Intake, % BW	0.30	1.58
Crude Protein, % of DM	12.02	7.55
TDN, % of DM	73.18	50.88
NEm (Mcal/kg)	1.67	0.99
NEg (Mcal/kg)	1.05	0.46

[1]Diets formulated based on NRC (2000) requirements

[2]Suspension supplement: 20% Crude Protein (≤ 20% Non-protein nitrogen), 3.55-4.55% Ca, 0.20% P, 0.30% Mg, 1% K, 528.63 ppm Mn, 12.65 ppm Co, 480 ppm Cu, 5.50 ppm Se, 1440 ppm Zn, 40000 IU/lb Vit. A, 11300 IU/lb Vit. D3, 75 IU/lb Vit. E, 400 g/ton monensin.

Table 2.2. Dietary components and nutrient composition consumed by offspring during the finishing phase.

	Experiment 1[1]	Experiment 2[1]
Ingredient	--- % DM basis ---	
Grass Hay	11.43	---
Earlage	12.33	---
Dry Rolled Corn	55.45	30.35
Dried Distiller Grains w/ Solubles[2]	20.10	17.48
High Moisture Corn	---	32.50
Oatlage	---	12.90
Pelleted melengestrol acetate supplement[3]	---	1.90
Suspension Supplement for Exp.1[3]	0.70	---
Suspension Supplementfor Exp. 2[4]	---	4.86
	--- Nutrient composition of diet ---	
DM %	72.00	70.37
CP %	14.61	14.35
ADF %	10.32	8.78
NDF %	20.74	19.47
Crude Fat %	3.74	4.34
Ash %	3.41	5.87
NEm (Mcal/kg)	2.05	2.07
NEg (Mcal/kg)	1.36	1.39

[1]Diets formulated based on NRC (2000) requirements for offspring fed at the Cow-Calf Education and Research Facility (Experiment 1) or Ruminant Nutrition Center (Experiment 2).
[2]In experiment 1, dried distillers grains w/ solubles fed to heifers included melengestrol acetate (MGA, Zoetis, Parsippany, NJ) at a rate sufficient to provide 0.50 mg·hd-1·d-1; steers received dried distillers grains w/ solubles without MGA.
[3]Soybean hull based: provided MGA at a rate sufficient to provide 0.50 mg·hd-1·d-1; steers received soybean hull only pelleted supplement.
[4]Suspension supplement: 30.8% protein (26.6% non-protein nitrogen), 8% Ca, 0.2% P, 0.4% Mg, 7.1% K, 15.6 ppm Co, 337.6 ppm Cu, 33.8 ppm I, 723.8 ppm, Mn, 3.2 ppm Se, 1107.8 ppm Zn, 4310 IU/lb Vit A, 1080 IU/lb Vit D3, 384.6 IU/lb Vit E, 512.3 g/ton monensin.
[5]Suspension supplement: 44.03% protein (38.97% non-protein nitrogen), 11.06% Ca, 0.39% P, 7.10% K, 0.22% Mg, 0.39% S, 1.42 ppm Co, 101.47 ppm Cu, 12.18 ppm I, 116.14 ppm Fe, 309.49 ppm Mn, 2.94 ppm Se, 674.78 ppm Zn, 20294.12 IU/lb Vit A, 202.94 IU/lb Vit E, 588.24 g/ton monensin, 1.29% fat, 11.13% TSI, 52.33% Ash.

Table 2.3. Growth performance for Experiment 1 progeny of cattle fed a prepartum dietary energy source consisting of limit-fed concentrate (CONC) or ad-libitum forage (FOR) diet during mid- and late-gestation.

	Treatment[1]			Sex			P – value[2]		
	CONC	FOR	SEM[3]	Heifers	Steers	SEM[3]	Trmt	Sex	T x S
Weaning BW, kg	281	227	3.7	272[a]	286[b]	3.7	0.475	0.009	0.951
				--- Backgrounding Phase ---					
Day 36									
BW, kg	280	280	3.2	274[a]	286[b]	3.2	0.830	0.012	0.748
ADG[4], kg	-0.04	0.09	0.067	0.06	-0.01	0.067	0.166	0.495	0.735
				--- Finishing Phase ---					
Initial (d 0)									
BW, kg	321	321	3.4	309[a]	333[b]	3.4	0.994	<0.001	0.909
ADG[4], kg	0.86	0.84	0.042	0.74[a]	0.96[b]	0.042	0.738	<0.001	0.743
Period 1 (d 0-23)									
BW, kg	354	357	3.7	346[a]	365[b]	3.7	0.544	<0.001	0.618
ADG[4], kg	1.46	1.60	0.055	1.60	1.45	0.055	0.079	0.051	0.246
DMI[5], kg	6.47	6.02	0.271	6.94[b]	5.56[a]	0.271	0.243	<0.001	0.743
G:F[6]	0.25	0.26	0.002	0.22	0.29	0.002	0.825	0.105	0.148
Period 2 (d 23-51)									
BW, kg	402	403	4.5	385[a]	421[b]	4.5	0.915	<0.001	0.255
ADG[4], kg	1.72	1.65	0.055	1.37[a]	2.00[b]	0.055	0.312	<0.001	0.054
DMI[5], kg	7.40	7.22	0.328	7.35	7.26	0.328	0.706	0.843	0.960
G:F[6]	0.21	0.21	0.004	0.17[b]	0.27[a]	0.004	0.566	<0.001	0.065
Period 3 (d 51-78)									
BW, kg	448	451	5.0	428[a]	471[b]	5.0	0.651	<0.001	0.629
ADG[4], kg	1.68	1.77	0.054	1.60[a]	1.84[b]	0.054	0.224	0.002	0.071
DMI[5], kg	8.47	8.36	0.378	8.39	8.48	0.374	0.881	0.852	0.973
G:F[6]	0.19	0.20	0.004	0.18[b]	0.21[a]	0.004	0.435	0.033	0.319
Period 4 (d 78-106)									
BW, kg	502	507	5.27	486[a]	524[b]	5.27	0.499	<0.001	0.612
ADG[4], kg	1.96	2.02	0.057	2.07[b]	1.91[a]	0.057	0.416	0.047	0.874

DMI[5], kg	11.13	11.07	0.275	10.81	11.39	0.275	0.866	0.143	0.880
G:F[6]	0.18	0.17	0.004	0.19[a]	0.16[b]	0.004	0.902	0.007	0.727
Final[7]									
BW, kg	579	590	6.95	555[a]	614[b]	6.86	0.241	<0.001	0.660
ADG[4], kg	1.43	1.49	0.046	1.43	1.47	0.046	0.416	0.764	0.067
DMI[5], kg	14.02	14.00	0.190	14.04	13.99	0.190	0.964	0.862	0.253
G:F[6]	0.10	0.10	0.003	0.10	0.10	0.003	0.263	0.505	0.307

[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.
[2] Probability of difference among least square means
[3] Standard error of the mean
[4] ADG calculated from end of previous period to end of current period.
[5] DMI: Dry matter intake
[6] F:G. Feed to gain ratio
[7] Final BW, ADG, DMI, and F:G calculated based on when each animal was harvested at either d 131, d 145, or d 180.
[ab]LSmeans lacking a common superscript differ ($P \leq 0.05$).

Table 2.4. Least square means for ultrasound measurements from Experiment 1 progeny of cattle fed a prepartum dietary energy source consisting of limit-fed concentrate (CONC) or ad-libitum forage (FOR) diet during mid- and late-gestation.

	Trmt[1]			Sex			P-value[3]		
	CONC	FOR	SEM[2]	Heifers	Steers	SEM[2]	Trmt	Sex	T x S
	--- Initial ultrasound during backgrounding phase ---								
Backfat, mm	3.94	3.82	0.124	4.06[b]	3.70[a]	0.124	0.503	0.046	0.502
Muscle Depth, mm	40.18	39.66	0.926	39.67	40.17	0.926	0.692	0.700	0.028
Intramuscular fat,%	5.07	4.98	0.1104	5.07	4.97	0.110	0.557	0.539	0.486
	--- Ultrasound during finishing phase ---								
Backfat, mm	6.69	6.52	0.249	6.69	6.52	0.249	0.663	0.622	0.265
Muscle Depth, mm	50.76	50.93	0.877	50.64	51.05	0.877	0.890	0.743	0.926
Intramuscular fat,%	4.25	4.28	0.065	4.31	4.22	0.064	0.711	0.339	0.172
	--- Change between ultrasound periods ---								
Backfat, mm	2.75	2.69	0.226	2.63	2.81	0.226	0.802	0.576	0.405
Muscle Depth, mm	10.58	11.31	1.276	10.97	10.91	1.276	0.684	0.974	0.127
Intramuscular fat,%	-0.82	-0.72	0.123	-0.76	-0.78	0.123	0.546	0.945	0.975

[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.
[2]Standard error of the mean
[3]Probability of difference among least square means
[ab]LSmeans lacking a common superscript differ ($P \leq 0.05$).

Table 2.5. Least squares means for maternal prepartum dietary energy source on Experiment 1 progeny carcass characteristics, meat quality and carcass value.

	Trmt[1]			Sex			P-value[2]		
	CONC	FOR	SEM[3]	Heifers	Steers	SEM[3]	Trmt	Sex	T x S
Hot carcass weight, kg	349	351	4.4	335[a]	366[b]	4.4	0.710	<0.001	0.299
Ribeye area, cm^2	85.8	87.7	1.23	83.2[a]	89.7[b]	1.35	0.271	0.006	0.889
12^{th} rib fat thickness,cm	1.22	1.14	0.041	1.27[b]	1.09[a]	0.046	0.060	0.002	0.304
USDA Yield grade	3.0	2.8	0.08	3.0	2.8	0.09	0.084	0.070	0.811
Marbling score[4]	537	539	13.9	563[b]	513[a]	15.7	0.909	0.013	0.699
L^{*}[5]	42.05	41.83	0.277	41.99	41.90	0.314	0.534	0.838	0.826
a^{*}[5]	25.27[b]	24.59[a]	0.138	25.25[b]	24.60[a]	0.156	<0.001	0.002	0.921
b^{*}[5]	10.45[b]	10.03[a]	0.093	10.46[b]	10.02[a]	0.105	<0.001	0.001	0.660
USDA Quality Grade[6]									
Prime, %	5.22	9.14	0.689	9.21	5.17	0.782	0.588	0.615	0.963
Upper 2/3 Choice, %	53.00	50.66	0.337	65.66	37.72	0.391	0.865	0.272	0.864
Low Choice, %	36.19	30.95	0.381	20.16	50.18	0.420	0.715	0.267	0.635
USDA Yield Grade[6]									
Yield Grade 2, %	57.55	61.62	0.339	50.95	67.69	0.381	0.761	0.384	0.556
Yield Grade 3, %	40.50	36.50	0.339	46.59	30.96	0.383	0.761	0.399	0.794

[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.

[2]Probability of difference among least square means

[3]Standard error of the mean

[4]Marbling score: 200=Traces[0], 300=Slight[0], 400=Small[0], 500=Modest[0]

[5]Recorded 3 d postmortem; L*: 0 = Black, 100 = White; a*: Negative values = green; Positive values = red; b*: Negative values = blue; Positive values = yellow

[6]Calculated proportions of USDA Quality and Yield Grade (data did not converge for a quality grade of USDA Select, or USDA Yield Grade less than a 2 or greater than a 3)

[ab]LSmeans lacking a common superscript differ ($P \leq 0.05$).

Table 2.6. Least square means for meat characteristics from Experiment 1 progeny of cattle fed a prepartum dietary energy source consisting of limit-fed concentrate (CONC) or ad-libitum forage (FOR) diet during mid- and late-gestation.

	Trmt[1]			Sex			P-value[2]		
	CONC	FOR	SEM[3]	Heifers	Steers	SEM[2]	Trmt	Sex	T x S
Crude Fat, %	6.31	6.24	0.339	7.17[b]	5.39[a]	0.384	0.865	<0.001	0.621
Moisture, %	71.48	71.50	0.264	70.69[a]	72.29[b]	0.299	0.945	<0.001	0.728
WBSF[4], kg	3.48	3.60	0.128	3.38	3.71	0.137	0.480	0.068	0.637
Tenderness[5]	12.43	12.85	0.285	12.87	12.41	0.318	0.263	0.284	0.833
Juiciness[5]	10.98	11.49	0.295	11.33	11.14	0.330	0.192	0.665	0.328
Flavor[5]	9.83	9.64	0.228	9.84	9.64	0.255	0.531	0.555	0.232

[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.

[2]Probability of difference among least square means

[3]Standard error of the mean

[4]Warner-Bratzler Shear Force

[5]Strip loin samples were evaluated for juiciness (1 = extremely dry; 18 = extremely juicy), tenderness (1 = extremely tough; 18 = extremely tender), and beef flavor (1= extremely bland; 18 = extremely intense).

[ab]LSmeans lacking a common superscript differ ($P \leq 0.05$).

Table 2.7. Growth performance for Experiment 2 progeny of cattle fed a prepartum dietary energy source consisting of limit-fed concentrate (CONC) or ad-libitum forage (FOR) diet during mid- and late-gestation.

	Treatment[1]			Sex			P – value[2]		
	CONC	FOR	SEM[3]	Heifers	Steers	SEM[3]	Trmt	Sex	T x S
Weaning BW, kg	271	271	8.5	264	279	8.5	0.992	0.278	0.879
				--- Backgrounding Phase ---					
Day 28									
BW, kg	295	299	9.5	287	307	9.5	0.781	0.199	0.943
ADG[4], kg	0.85	1.00	0.065	0.83	1.02	0.065	0.181	0.102	0.723
				--- Finishing Phase ---					
Initial (d 0)									
BW, kg	333	332	6.7	320[a]	345[b]	6.7	0.930	0.030	0.470
ADG[4], kg	0.79	0.69	0.045	0.70	0.79	0.045	0.188	0.216	0.267
Period 1 (d 0-23)									
BW, kg	364	362	7.09	350[a]	376[b]	7.09	0.860	0.040	0.450
ADG[4], kg	1.34	1.31	0.091	1.32	1.32	0.091	0.770	1.000	0.770
DMI[5], kg	7.14	7.14	0.076	7.08	7.21	0.076	1.000	0.180	0.180
G:F[6]	0.18	0.18	0.003	0.19	0.18	0.003	0.880	0.830	0.900
Period 2 (d 23-51)									
BW, kg	422	413	19.3	400[a]	435[b]	19.3	0.350	0.020	0.270
ADG[4], kg	2.09	1.81	0.210	1.80	2.11	0.210	0.240	0.190	0.410
DMI[5], kg	9.31	8.94	0.502	8.93	9.32	0.502	0.320	0.300	0.770
G:F[6]	0.22	0.20	0.003	0.20	0.22	0.003	0.500	0.290	0.580
Period 3 (d 51-78)									
BW, kg	466	462	10.5	442[a]	485[b]	10.5	0.720	0.030	0.610
ADG[4], kg	1.62	1.80	0.149	1.55	1.86	0.149	0.290	0.110	0.270
DMI[5], kg	9.47	9.29	0.283	9.09	9.67	0.283	0.570	0.130	0.700
G:F[6]	0.17	0.19	0.003	0.17	0.19	0.003	0.140	0.200	0.250
Period 4 (d 78-106)									
BW, kg	506	500	14.5	486	520	14.5	0.690	0.100	0.630

ADG[4], kg	1.44	1.36	0.165	1.54	1.25	0.165	0.660	0.160	0.730
DMI[5], kg	9.60	9.27	0.289	9.78	9.10	0.289	0.340	0.100	0.610
G:F[6]	0.15	0.14	0.002	0.16	0.14	0.002	0.870	0.180	0.850
Final[7]									
BW, kg	548	550	16.1	530	568	16.1	0.930	0.100	0.710
ADG[4], kg	1.67	1.99	0.158	1.75	1.90	0.158	0.140	0.410	0.810
DMI[5], kg	11.08	11.28	0.325	11.31	11.05	0.325	0.600	0.470	1.000
G:F[6]	0.15	0.17	0.002	0.15	0.17	0.002	0.170	0.290	0.830

[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid and late gestation.
[2] Probability of difference among least square means
[3] Standard error of the mean
[4] ADG calculated from end of previous period to end of current period.
[5] DMI: Dry matter intake
[6] F:G. Feed to gain ratio
[7] Final BW, ADG, DMI, and F:G calculated based on when animals were harvested on d 131.
[ab]LSmeans lacking a common superscript differ ($P \leq 0.05$).

Table 2.8. Least square means for ultrasound measurements from Experiment 2 progeny of cattle fed a prepartum dietary energy source consisting of limit-fed concentrate (CONC) or ad-libitum forage (FOR) diet during mid- and late-gestation.

	Trmt[1]			Sex			P-value[2]		
	CONC	FOR	SEM[3]	Heifers	Steers	SEM[3]	Trmt	Sex	T x S
	--- Initial ultrasound during backgrounding phase ---								
Backfat, mm.	4.68	4.83	0.010	5.07	4.45	0.010	0.667	0.082	0.884
Muscle Depth, mm	43.68	44.42	0.941	41.15[a]	46.95[b]	0.941	0.585	0.001	0.823
Intramuscular fat,%	4.28	4.20	0.138	4.32	4.16	0.138	0.677	0.407	0.560
	--- Ultrasound during finishing phase ---								
Backfat, mm	7.45	8.77	0.534	8.27	7.95	0.534	0.089	0.679	0.471
Muscle Depth, mm	51.35	51.88	0.966	49.92	53.32	0.966	0.698	0.018	0.399
Intramuscular fat,%	4.40	4.28	0.064	4.37	4.31	0.064	0.173	0.519	0.286
	--- Change between ultrasound periods ---								
Backfat, mm	2.77	3.93	0.448	3.20	3.50	0.448	0.073	0.638	0.435
Muscle Depth, mm	7.67	7.47	1.033	8.77	6.37	1.033	0.892	0.109	0.322
Intramuscular fat,%	0.12	0.08	0.133	0.05	0.15	0.133	0.816	0.580	0.265

[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.

[2] Probability of difference among least square means

[3]Standard error of the mean

[ab]LSmeans lacking a common superscript differ ($P \leq 0.05$).

Table 2.9. Least squares means for maternal prepartum dietary energy source on Experiment 2 progeny carcass characteristics, meat quality and carcass value

	Trmt[1]			Sex			P-value[2]		
	CONC	FOR	SEM[3]	Heifers	Steers	SEM[3]	Trmt	Sex	T x S
Hot carcass weight, kg	330	330	4.61	317[a]	342[b]	4.61	0.972	0.001	0.611
Ribeye area, cm^2	82.6	81.9	2.26	78.1[a]	86.5[b]	2.26	0.814	0.013	0.508
12^{th} rib fat thickness,cm	0.94	1.02	0.053	1.07[b]	0.89[a]	0.053	0.418	0.016	0.497
USDA Yield grade	2.7	2.8	0.130	3.0[b]	2.5[a]	0.130	0.452	0.013	0.957
Marbling score[4]	484	493	20.43	529[b]	448[a]	20.43	0.770	0.008	0.526
L^{*}[5]	42.27	42.26	0.366	42.30	42.22	0.366	0.989	0.885	0.282
a^{*}[6]	25.51	25.36	0.189	25.36	25.50	0.189	0.573	0.588	0.192
b^{*}[7]	10.56	10.54	0.148	10.55	10.55	0.148	0.911	0.994	0.224
USDA Quality Grade[8]									
Low Choice, %	56.70	34.83	0.525	30.00	62.02	0.510	0.425	0.309	0.425
Select, %	20.00	21.39	0.618	14.29	28.99	0.659	0.935	0.477	0.477
USDA Yield Grade[8]									
Yield Grade 2, %	66.67	44.50	0.506	39.56	71.01	0.510	0.413	0.308	0.939
Yield Grade 3, %	28.99	50.00	0.510	55.50	24.66	0.525	0.425	0.309	0.702

[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.
[2] Probability of difference among least square means
[3]Standard error of the mean
[4]Marbling score: 200=Traces[0], 300=Slight[0], 400=Small[0], 500=Modest[0]
[5]Recorded 3 d postmortem; L*: 0 = Black, 100 = White; a*: Negative values = green; Positive values = red; b*: Negative values = blue; Positive values = yellow
[6]Calculated proportions of USDA Quality and Yield Grade (data did not converge for a quality grade of USDA Select, or USDA Yield Grade less than a 2 or greater than a 3)
[ab]LSmeans lacking a common superscript differ ($P \leq 0.05$).

Table 2.10. Least square means for meat characteristics from Experiment 2 progeny of cattle fed a prepartum dietary energy source consisting of limit-fed concentrate (CONC) or ad-libitum forage (FOR) diet during mid- and late-gestation.

	Trmt[1]			Sex			P-value[2]		
	CONC	FOR	SEM[3]	Heifers	Steers	SEM[3]	Trmt	Sex	T x S
Crude Fat, %	5.20	5.54	0.360	6.21[b]	4.53[a]	0.360	0.513	0.002	0.767
Moisture, %	72.59	72.45	0.293	71.87[a]	73.18[b]	0.293	0.729	0.003	0.523
WBSF[4], kg	3.50	3.54	0.165	3.40	3.64	0.173	0.836	0.308	0.342
Tenderness[5]	12.59[b]	11.73	0.341	12.56	11.76	0.341	0.082	0.106	0.441
Juiciness[5]	10.70[b]	9.67[a]	0.304	10.16[a]	10.21[b]	0.304	0.022	0.921	0.201
Flavor[5]	9.20	8.82	0.332	9.09	8.93	0.332	0.415	0.729	0.166

[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.

[2] Probability of difference among least square means

[3] Standard error of the mean

[4]Warner-Bratzler Shear Force

[5]Strip loin samples were evaluated for juiciness (1 = extremely dry; 18 = extremely juicy), tenderness (1 = extremely tough; 18 = extremely tender), and beef flavor (1= extremely bland; 18 = extremely intense).

[ab]LSmeans lacking a common superscript differ ($P \leq 0.05$).

Table 2.11. Concentration of total lipid concentration in raw tissue (mg/g raw wet tissue) of lipid fatty acid categories (Saturated fatty acids, SFA; monounsaturated, MUFA; and polyunsaturated fatty acids, PUFA) from Experiment 1 progeny of dams fed a concentrate (CONC) or forage (FOR) diet during mid- and late-gestation.

	Trmt[1]			Sex			*P*-value[2]		
Fatty Acid	CONC	FOR	SEM[3]	Heifer	Steer	SEM[3]	Trmt	Sex	T x S
C10:0	0.03	0.03	0.003	**0.03[b]**	**0.02[a]**	0.003	0.710	**0.013**	0.290
C12:0	0.04	0.04	0.003	0.05	0.04	0.003	0.540	0.100	0.466
C14:0	2.15	2.06	0.154	**2.34[b]**	**1.87[a]**	0.172	0.663	**0.042**	0.348
C15:0	0.29	0.30	0.024	0.32	0.27	0.027	0.846	0.105	0.629
C16:0	19.37	19.43	1.410	20.58	18.23	1.572	0.974	0.264	0.477
C17:0	0.86	0.89	0.079	0.94	0.81	0.088	0.742	0.250	0.853
C18:0	10.33	10.73	0.788	10.45	10.61	0.879	0.697	0.896	0.495
C20:0	0.05	0.04	0.006	0.05	0.04	0.007	0.452	0.103	0.660
C14:1n5	0.57	0.50	0.042	**0.62[b]**	**0.46[a]**	0.047	0.204	**0.017**	0.402
C16:1n7	2.15	1.95	0.134	**2.35[b]**	**1.76[a]**	0.150	0.264	**0.005**	0.295
C16:1trans	0.24	0.25	0.014	0.25	0.24	0.016	0.723	0.698	0.566
C18:1n9	27.24	27.33	1.909	29.34	25.23	2.128	0.970	0.152	0.593
C18:1trans	2.58	2.41	0.203	2.47	2.52	0.226	0.517	0.853	0.467
C18:1n7	0.94	1.10	0.104	1.16	0.89	0.116	0.230	0.088	0.603
C18:2trans	0.004	0.003	0.0001	0.004	0.003	0.0006	0.628	0.596	0.245
C18:2n6	2.96	2.63	0.170	2.80	2.79	0.190	0.147	0.978	0.657
C18:3n6	0.02	0.02	0.001	0.01	0.02	0.001	0.766	0.201	0.806
C18:3n3	0.27	0.24	0.012	0.25	0.25	0.014	0.051	0.916	0.948
C20:2	0.06	0.05	0.004	0.06	0.05	0.005	0.638	0.240	0.921
C20:3n6	0.01	0.01	0.001	0.01	0.01	0.001	0.210	0.901	0.749
C20:4n6	**0.55[b]**	**0.46[a]**	0.025	0.493	0.524	0.028	**0.009**	0.405	0.547
C22:3	0.01	0.01	0.001	0.01	0.01	0.001	0.056	0.721	0.855
C24:1n9	**0.02[b]**	**0.01[a]**	0.002	0.01	0.01	0.002	**0.011**	0.530	0.224
C22:5n3	**0.02[b]**	**0.01[a]**	0.003	0.02	0.02	0.003	**0.007**	0.329	0.544
C22:6n3	0.03	0.03	0.003	0.03	0.03	0.003	0.514	0.811	0.888
SFA	33.12	33.52	2.410	34.77	31.87	2.688	0.897	0.419	0.477
MUFA	34.45	34.21	2.248	36.97	31.69	2.506	0.937	0.119	0.651
PUFA	3.93	3.47	0.192	3.69	3.71	0.214	0.068	0.958	0.767

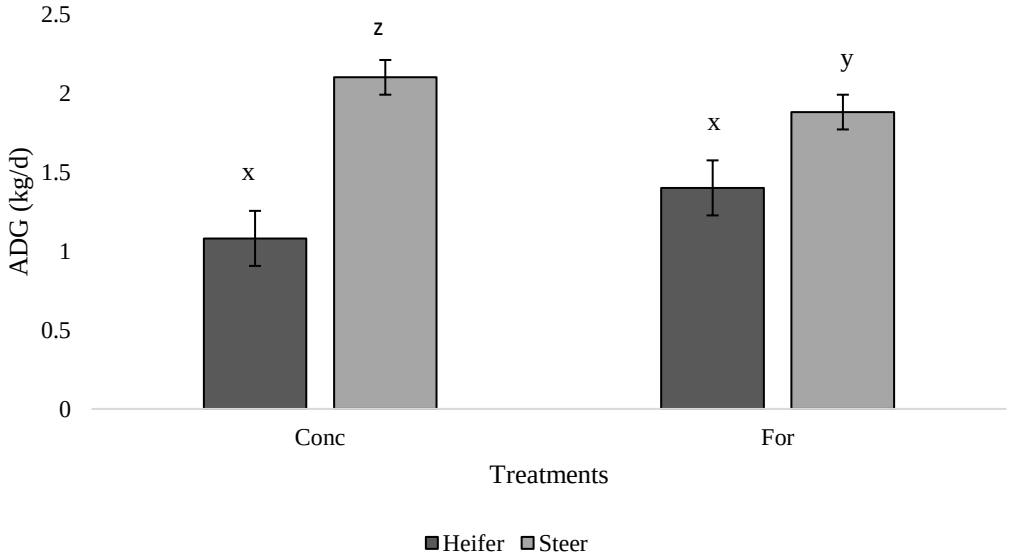
[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.
[2]Probability of difference among least square means
[3]Standard error of the mean
[ab]LSmeans lacking a common superscript differ ($P \leq 0.05$).

Table 2.12. Percentage of total lipid concentration in raw tissue (%, g/100 g total fatty acids) of lipid fatty acid categories (Saturated fatty acids, SFA; monounsaturated, MUFA; and polyunsaturated fatty acids, PUFA) from Experiment 1 progeny of dams fed a concentrate (CONC) or forage (FOR) diet during mid- and late-gestation.

	Trmt[1]			Sex			*P*-value[2]		
Fatty Acid	CONC	FOR	SEM[3]	Heifer	Steer	SEM[3]	Trmt	Sex	T x S
C10:0	0.04	0.04	0.004	0.05	0.04	0.004	0.863	0.130	0.303
C12:0	0.06	0.06	0.004	0.07	0.06	0.004	0.689	0.348	0.349
C14:0	2.97	2.90	0.082	**3.08[b]**	**2.79[a]**	0.092	0.508	**0.021**	0.202
C15:0	0.40	0.42	0.017	0.43	0.39	0.019	0.464	0.096	0.988
C16:0	26.84	27.18	0.380	27.18	26.83	0.424	0.491	0.540	0.403
C17:0	1.18	1.24	0.058	1.25	1.17	0.065	0.410	0.324	0.564
C18:0	14.38	14.80	0.360	**13.76[a]**	**15.41[b]**	0.401	0.373	**0.003**	0.886
C20:0	0.07	0.06	0.007	0.07	0.06	0.008	0.569	0.330	0.269
C14:1n5	0.81	0.73	0.041	0.82	0.71	0.045	0.158	0.082	0.389
C16:1n7	3.05	2.85	0.121	**3.15[b]**	**2.75[a]**	0.135	0.194	**0.032**	0.313
C16:1trans	0.34	0.34	0.010	0.33	0.35	0.011	0.670	0.083	0.867
C17:1	0.99	0.96	0.038	**1.05[b]**	**0.89[a]**	0.042	0.497	**0.008**	0.593
C18:1n9	38.03	38.32	0.616	38.76	37.59	0.0687	0.715	0.203	0.925
C18:1trans	3.62	3.41	0.170	3.27	3.76	0.190	0.343	0.057	0.094
C18:1n7	1.43	1.53	0.152	1.61	1.35	0.170	0.581	0.254	0.609
C18:2trans	0.005	0.005	0.0006	0.005	0.005	0.0007	0.814	0.847	0.213
C18:2n6	4.29	3.88	0.204	3.83	4.35	0.228	0.128	0.095	0.461
C18:3n6	0.02	0.02	0.002	0.02	0.03	0.002	0.346	0.078	0.348
C18:3n3	0.42	0.36	0.031	0.37	0.41	0.034	0.134	0.304	0.769
C20:2	0.09	0.08	0.007	0.08	0.10	0.008	0.428	0.936	0.720
C20:3n6	0.02	0.02	0.001	0.02	0.02	0.002	0.456	0.371	0.808
C20:4n6	0.83	0.70	0.053	0.70	0.83	0.059	0.057	0.120	0.912
C22:3	**0.02[b]**	**0.02[a]**	0.002	0.02	0.02	0.002	**0.046**	0.481	0.797
C24:1n9	**0.02[b]**	**0.01[a]**	0.003	0.02	0.02	0.003	**0.003**	0.639	0.323
C22:5n3	**0.04[b]**	**0.02[a]**	0.004	0.03	0.03	0.004	**0.007**	0.497	0.906
C22:6n3	0.05	0.05	0.006	0.04	0.05	0.007	0.384	0.229	0.936
SFA	45.94	46.70	0.681	45.89	46.75	0.681	0.390	0.397	0.516
MUFA	48.28	48.15	0.627	49.00	47.43	0.699	0.876	0.096	0.649
PUFA	5.78	5.15	0.275	5.11	5.82	0.307	0.080	0.086	0.568
PUFA:SFA	0.13	0.11	0.007	0.11	0.13	0.007	0.088	0.163	0.560
n6:n3	11.21	11.55	0.598	11.17	11.60	0.666	0.655	0.628	0.605
All Lipid	71.50	71.21	4.669	75.43	67.27	5.206	0.962	0.242	0.567

[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.
[2]Probability of difference among least square means
[3]Standard error of the mean
[ab]LSmeans lacking a common superscript differ ($P \leq 0.05$).

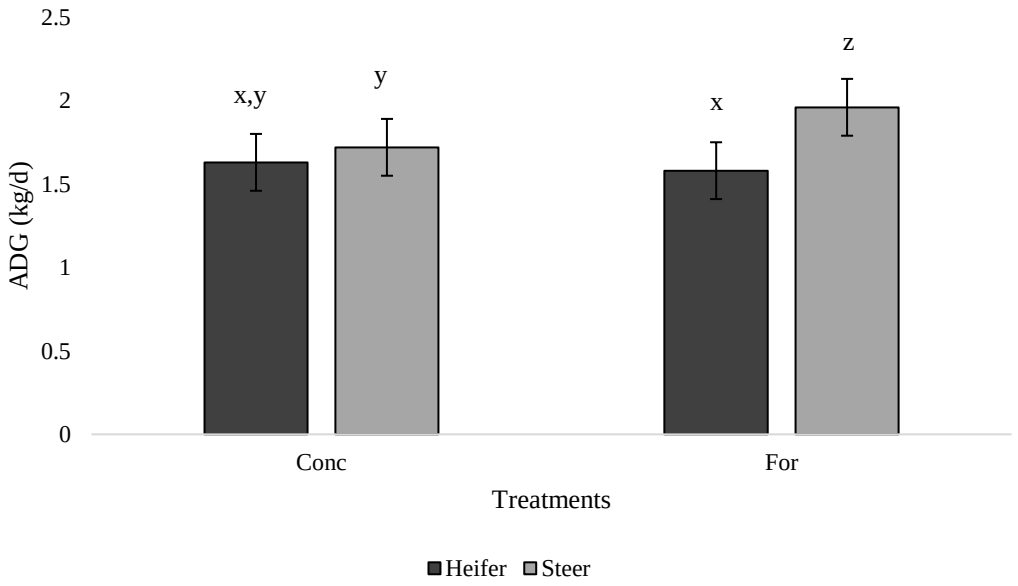
Figure 2.1. Treatment by sex interaction for ADG (kg/d) in Period 2 from Experiment 1 progeny of dams fed a concentrate (CONC) or forage (FOR) diet during mid- and late-gestation[1].



[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.

[x,y,z]LSmeans lacking a common superscript differ ($P \leq 0.05$).

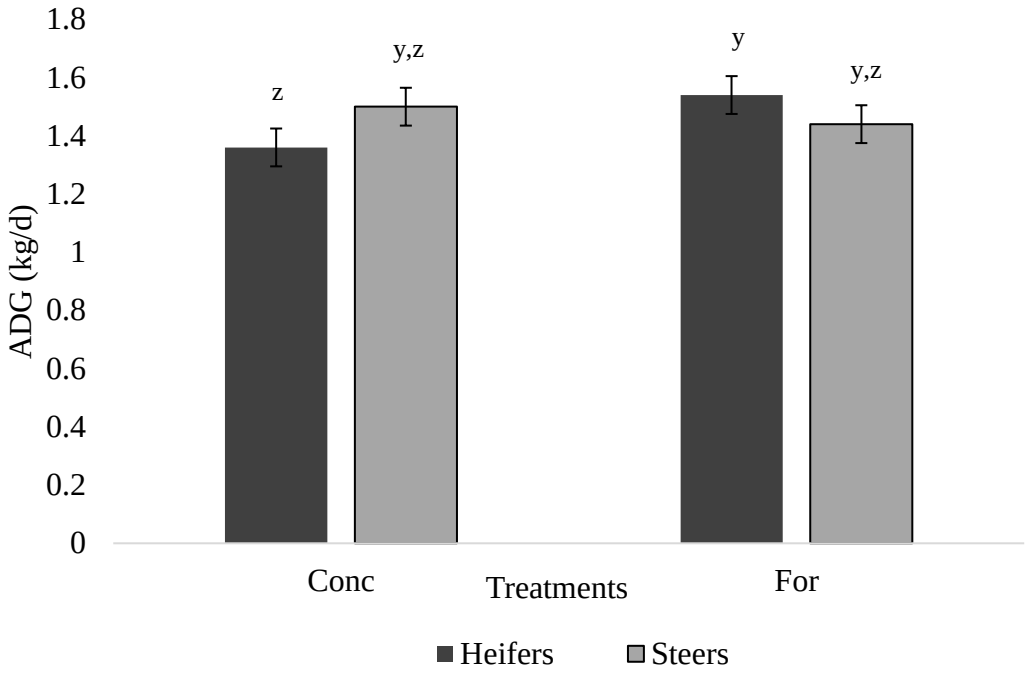
Figure 2.2. Treatment by sex interaction for ADG (kg/d) in Period 3 from Experiment 1 progeny of dams fed a concentrate (CONC) or forage (FOR) diet during mid- and/or late-gestation[1].



[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.

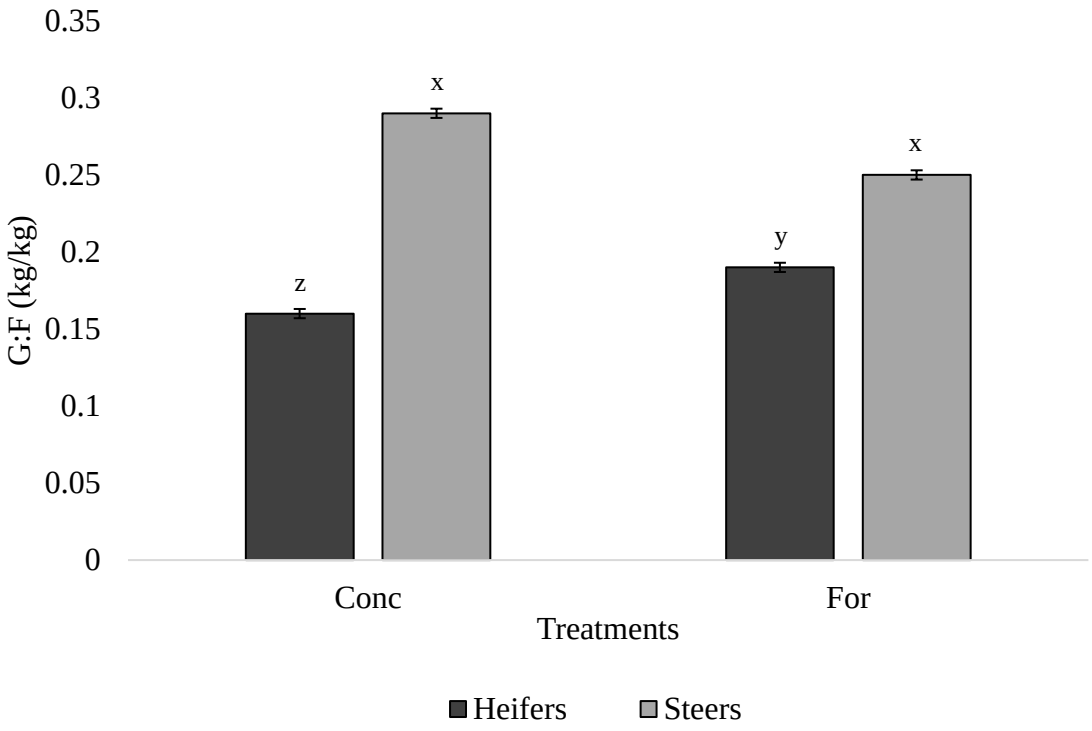
[w,x,y,z]LSmeans lacking a common superscript differ ($P \leq 0.05$).

Figure 2.3. Treatment by sex interaction for ADG (kg/d) in the Final period from Experiment 1 progeny of dams fed a concentrate (CONC) or forage (FOR) diet during mid- and/or late-gestation[1].



[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.

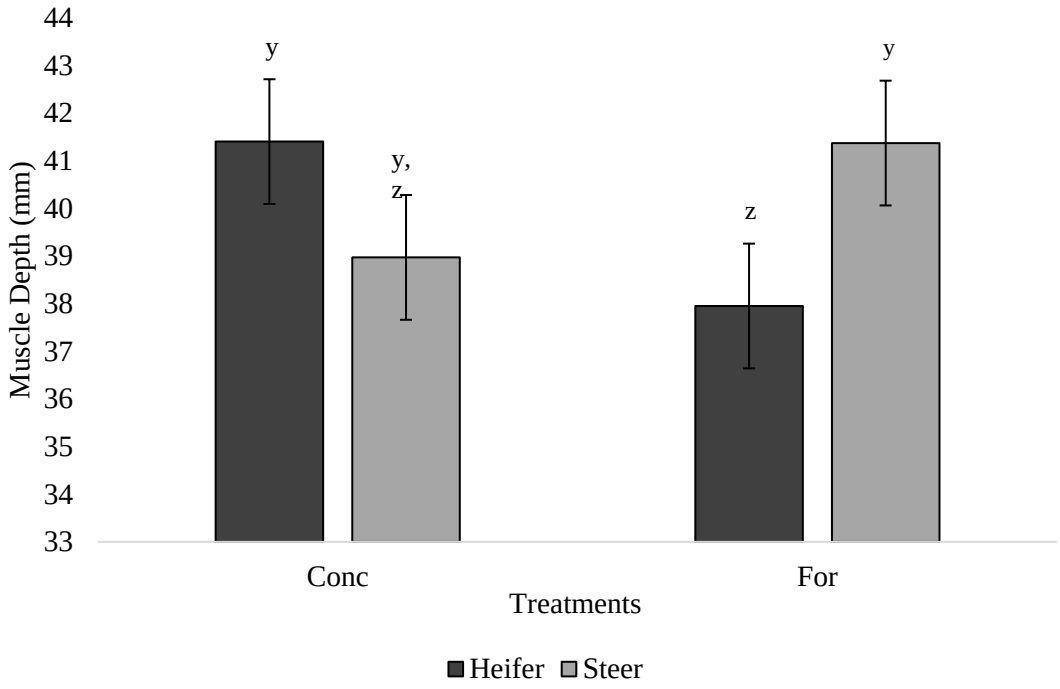
Figure 2.4. Treatment by sex interaction for G:F (kg/kg) in Period 2 from Experiment 1 progeny of dams fed a concentrate (CONC) or forage (FOR) diet during mid- and/or late-gestation[1].



[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.

[w,x,y,z]LSmeans lacking a common superscript differ ($P \leq 0.05$).

Figure 2.5. Treatment by sex interaction for muscle depth from Experiment 1 progeny of dams fed a concentrate (CONC) or forage (FOR) diet during mid- and/or late-gestation[1].



[1]Diets formulated based on NRC (2000) requirements for dams fed either a limit-fed concentrate or ad-libitum forage diet during mid- and late-gestation.

[y,z]LSmeans lacking a common superscript differ ($P \leq 0.05$).

CHAPTER III: Effects of low stress weaning on calf growth performance and carcass characteristics

Erin R. Gubbels

Department of Animal Science

South Dakota State University, 57007

ABSTRACT

The objective of this study was to compare the influence of two low stress weaning methods with conventional weaning on post-weaning performance and carcass characteristics of beef steers. Steer calves (n = 90) from a single source were stratified by body weight and dam age into three groups; one weaning treatment was randomly assigned to each group: ABRUPT (calves isolated from dams on the day of weaning), FENCE (calves separated from dams via a fence for 7 days prior to completely weaning), and NOSE (nose-flap inserted and calves remained with dams for 7 days prior to completely weaning). At day +7 post-weaning calves were transported to a commercial feedlot where they received standard step-up and finishing rations typical for a Northern Plains feedlot. To understand the influence of each weaning method on haptoglobin (an acute-phase stress protein), blood samples were collected via coccygeal venipuncture at day -7 (PreTreat), 0 (Weaning), and +7 (PostWean) from a subsample of calves (n = 10 per treatment) and analyzed using a bovine haptoglobin ELISA kit. Body weights (BW) were recorded on study day -34 (PreWean), -7 (PreTreat), 0 (Weaning), 7 (PostWean), 32 (Receiving), 175 (Ultrasound), and 253 (Final) and average daily gains (ADG) were calculated between each time period. On day 175 post-weaning BW were recorded, and

ultrasound fat thickness and intramuscular fat were determined and utilized to project marketing dates. Carcass measurements were recorded at the time of harvest and included hot carcass weight, 12th rib backfat, ribeye area, USDA Yield Grade and Quality Grade, and marbling score. Weaning method interacted ($P < 0.0001$) with time period for ADG and BW. Calf BW increased in all treatments until the PostWean period, wherein BW decreased ($P < 0.0001$) in ABRUPT and NOSE and was maintained ($P > 0.05$) in FENCE. From the Receiving to Final time periods BW increased similarly ($P > 0.05$) for all treatments. Calf ADG was greater ($P < 0.01$) in calves in the NOSE treatment at Weaning than ABRUPT or FENCE. In the PostWean period, the FENCE calves had ADG that was not different ($P > 0.05$) than zero but was greater ($P < 0.0001$) than the negative ADG of ABRUPT and NOSE calves. During the Receiving period ADG was greater ($P < 0.05$) for ABRUPT compared to NOSE and FENCE. Time influenced ($P < 0.001$) haptoglobin concentration. No difference in haptoglobin was observed between the PreTreat and Weaning or PostWean periods; however, haptoglobin concentration was greater ($P < 0.001$) at PostWean compared to Weaning. Weaning method did not influence ($P > 0.05$) carcass measurements. Collectively these data suggest low stress weaning methods do not significantly improve post-weaning growth performance or carcass merit compared to calves weaned using conventional methods.

INTRODUCTION

Weaning is known to be a stressful event for beef cattle. Weaning stress can result in behavioral, hormone and immune function alterations (Lynch et al., 2012). Stress during this time has also been shown to negatively impact calf health and performance (Boland et al., 2008). Therefore, alternative weaning strategies have been implemented as

an effort to reduce stress at weaning. Acute phase proteins (such as haptoglobin) are stimulated as a defense mechanism in response to trauma, inflammation, or infection (Hughes et al., 2014). Concentrations of acute phase proteins have shown to be indicators of stress in weaned calves (Arthington et al., 2003).

Low stress weaning strategies aim to divide the weaning process into two stages: 1) physical separation and 2) separation from milk as a nutritional source. It is suggested that two-stage methods decrease the degree of changes in behavior as opposed to simultaneous social and nutritional separation (Haley et al., 2005). Two low-stress strategies that have been utilized in the beef industry include fence-line weaning and application of anti-suckling devices. Fence-line weaning involves separation of calves from their dams via a fence such that they still remain in adjacent pens or pastures. Anti-suckling devices are inserted into a calf's nose to prevent nursing but allow contact between the calf and dam. Research has evaluated the influence of low-stress methods on calf physiology, performance, and health for a short period after the weaning process (Haley et al., 2005; Boland et al., 2008; Campistol et al., 2010a). However, the long-term performance of calves was not evaluated in these studies. Studies investigating the impact of low stress weaning methods on long-term feedlot performance and carcass characteristics of beef cattle are lacking.

At approximately 4 to 8 months of age, new fat cells are forming and existing cell growth is occurring. This timeframe is referred to as the marbling "window" by Du et al. (2013). It is also during this time when beef calves are typically weaned. Stress at this stage could potentially discourage fat cell growth and ultimately reduce the amount of intramuscular fat (marbling) cells present. Reduced marbling scores correspond to lower

USDA Quality Grades. Therefore, it is plausible that stress incurred during weaning could compromise overall intramuscular fat deposition. We hypothesized low stress weaning methods would improve post-weaning growth performance and carcass characteristics of beef cattle. The objective of this study was to compare the influence of two low stress weaning methods (fence line weaning and anti-suckling devices) with conventional abrupt weaning on post-weaning feedlot performance and carcass characteristics of beef steers.

MATERIALS AND METHODS

All animal care and experimental protocols were approved by the South Dakota State University (SDSU) Animal Care and Use Committee (approval number 17-080A). Steer calves (n = 90) from the SDSU Antelope Range and Livestock Research Station near Buffalo, SD were utilized for this study. Steers were stratified by body weight and dam age into three groups; one weaning treatment was randomly assigned to each group: ABRUPT (calves isolated from dams on the day of weaning), FENCE (calves separated from dams via a barbed wire fence for 7 days prior to complete separation), and NOSE (nose-flap inserted and calves remained with dams for 7 days prior to complete separation).

At approximately 60 days of age all steers were vaccinated with a killed vaccine for clostridial diseases (Vision 7 Somnus with SPUR, Merck Animal Health, Madison, NJ). Forty days prior to weaning all calves were administered a modified-live vaccine for prevention of bovine rhinotracheitis (IBR), bovine viral diarrhea (BVD), bovine respiratory syncytial virus (BRSV) Types 1 and 2, and parainfluenza-3 (PI_3), Haemophilus somnus, and *Mannheimia haemolytica* (Pyramid 5+ Presponse SQ,

Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO). On day -7 (relative to date of weaning), steers and dams in FENCE were placed in adjacent pastures separated by a 4-strand barb wire fence. To accomplish this, calves were returned to the pasture that these pairs had been in prior to fenceline separation and dams were placed in the adjacent pasture. Also on day -7, anti-sucking devices (QuietWean, Saskatoon, Saskatchewan, Canada) were inserted in NOSE steers and then steers were allowed to remain with dams until day of weaning (day 0). On day 0, anti-suckling devices were removed from NOSE steers and steers from all three treatments were physically separated from their dams. For all treatments, dams were moved to a distant pasture on day 0 to prevent any interaction. Also on day 0, all steers were provided a booster for the clostridial and respiratory disease vaccines and received an anthelmintic (Dectomax Pour-On, Zoetis, Parsippany, NJ). From day 0 to 7, each treatment group was placed in a separate confinement pen and provided ad libitum access to good-quality grass hay in a round-bale feeder and 1.4 kg daily of a commercial weaning supplement (Scranton Equity Exchange, Scranton, ND; 14% CP) in a separate feed bunk. At day 7 post-weaning calves were transported to a commercial feedlot (Darnall Feedyard, Harrisburg, NE) where all steers were placed in a common pen and received standard step-up and finishing rations (Table 3.1) and management typical for a Northern Plains feedlot. On day 26 post-weaning all steers were administered a moderate potency initial feedyard implant (80 mg trenbolone acetate and 16 mg estradiol; Revalor-IS, Merck Animal Health). On day 175 post-weaning BW were recorded, steers were administered a high potency finishing implant (200 mg trenbolone acetate and 20 mg estradiol; Revalor-200, Merck Animal Health), and ultrasound fat thickness and intramuscular fat content were determined and utilized to

project marketing dates. Cattle were marketed in two groups: the first group (n = 42) was marketed at d 238 post-weaning and the second group (n = 47) was marketed at d 268 post-weaning. On the day of harvest, steers were transported approximately 166 km to a commercial packing plant.

Body weights (BW) were recorded on study day -34 (PreWean), -7 (PreTreat), 0 (Weaning), 7 (PostWean), 26 (Receiving), 175 (Ultrasound), and 238 or 268 (Final) and average daily gains (ADG) were calculated between each time period. Carcass measurements were recorded at the time of harvest and included hot carcass weight, 12th rib backfat, ribeye area, USDA Yield Grade and Quality Grade, and marbling score.

To understand the influence of each weaning method on haptoglobin, blood samples were collected via coccygeal venipuncture at day -7 (PreTreat), 0 (Weaning), and +7 (PostWean) from a random subsample of calves (n = 10 per treatment). Blood was allowed to coagulate at room temperature for 1 h and centrifuged at 1,200 × g for 30 min at 4°C. Serum was harvested and stored at −20°C until analyzed using a bovine haptoglobin enzyme-linked immunosorbent assay (ELISA, Life Diagnostics, INC., West Chester, PA, Catalog Number: Hapt-11) according to manufacturer's instructions. Normal serum levels of cow haptoglobin range from ~25 to 50 µg/ml. A plate reader (ELx808; BioTek Instruments, Inc, Winooski, VT) was used to measure absorbance at 450 nm. The concentration of haptoglobin was proportional to the absorbance derived from a standard curve.

Haptoglobin, BW, and ADG data were analyzed as repeated measures using the ante-dependence covariance structure in the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) for effects of weaning treatment, day, and their interaction; birth weight was

included as a covariate for ADG and BW. Carcass traits were analyzed for the effect of weaning treatment using the MIXED procedure. Separation of least squares means was performed using LSD with a Tukey's adjustment and assuming an alpha level of 0.05.

RESULTS AND DISCUSSION

The objective of this study was to evaluate the effects of low stress weaning on feedlot performance and carcass characteristics of beef steers. Other studies have investigated the effects of low stress weaning methods on short-term measures of animal performance (Arthington et al., 2003; Price et al., 2003; Arthington et al., 2005; Haley et al., 2005; Qiu et al., 2007; Arthington et al., 2008; Boland et al., 2008; Campistol et al., 2010a; Campistol et al., 2010b; Enriquez et al., 2010; Lippolis et al., 2016). However, the long-term implications of reduced stress during weaning has not been described.

Weaning method interacted ($P < 0.05$) with time period for BW and ADG. Calf BW increased in all treatments until the PostWean period, wherein BW decreased ($P < 0.05$) in ABRUPT by 2.9% and NOSE by 3.2% and was maintained ($P > 0.05$) in FENCE (Figure 3.1). This is similar to findings by Campistol et al. (2010a) wherein calves weaned using fenceline weaning had increased ($P < 0.05$) BW one week post-weaning when compared to calves abruptly weaned. However, Lippolis et al., (2016) reported that at up to 21 days postweaning, abruptly weaned calves tended to weigh more than calves weaned using an anti-suckling noseflap. Price et al. (2003) reported that calves weaned using the fenceline weaning method gained more weight up to 10 weeks postweaning than calves weaned abruptly. However, this contradicts Campistol et al. (2010a) who reported weight gains during this time period were greater ($P < 0.05$) in calves that were abruptly weaned compared to calves that were fenceline weaned. Enriquez et al., (2010)

also observed greater body weight gains 7 days postweaning for conventionally weaned calves compared to calves weaned using fenceline weaning or noseflaps. That same study reported that calves weaned using the fenceline method had greater body weight gains compared to the noseflap method. In the present study, BW increased similarly ($P > 0.05$) from the Receiving to Final time periods.

Average daily gain was greater ($P < 0.05$) in calves in the NOSE treatment at Weaning than ABRUPT or FENCE (Figure 3.2). From the PreTreat to Wean time period ADG of calves in the NOSE treatment increased by 43% while calves in the ABRUPT and FENCE decreased by 9% and 21% respectively. In the PostWean period, the FENCE calves had ADG that was not different ($P > 0.05$) than zero but was greater ($P < 0.0001$) than the negative ADG of ABRUPT and NOSE calves. These findings are similar to results by Boland et al., (2008) where calves subjected to fenceline weaning gained more body weight 7 days postweaning, while noseflap calves lost weight. Boland et al., (2008) also observed the fenceline and abrupt groups had increased body weight gains the week prior to weaning compared to the noseflap group. Haley et al. (2005) reported greater average daily gains one-week post-weaning in calves weaned using a two-stage method (noseflap). In addition, calves weaned in two-stages spent less time walking and a greater amount of time eating than calves weaned using conventional methods (Haley et al., 2005). During the Receiving period in the current study, ADG was greater ($P < 0.05$) for the ABRUPT and FENCE treatments compared to the NOSE treatment. Calves in the NOSE treatment had ADG that were 33% less than ABRUPT and 12% less than FENCE during this period. This is similar with Boland et al., (2008) where calves weaned using the fenceline method had greater ADG compared to calves weaned using a noseflap. It

has been reported that decreases in ADG and BW could be explained by increased time walking, standing, and vocalizing instead of more time eating, laying down, and ruminating (Haley et al., 2005). Although behavior was not analyzed in the present study, it could pose an explanation for body weight and average daily gain alterations. In the present study treatment did not influence ($P > 0.05$) ADG at the Ultrasound or Final time period.

Weaning method did not influence ($P > 0.05$) hot carcass weight, 12th rib backfat, ribeye area, USDA Yield Grade and Quality Grade, or marbling score (Table 3.2). This lack of influence on carcass traits suggests that differences in stress experienced around the weaning event are not significant enough to cause long term changes in carcass composition. Further, because marbling scores were similar between treatments, potential stress experienced by calves during the weaning event was not adequate enough to cause alterations in intramuscular fat deposition.

Time influenced ($P < 0.05$) haptoglobin concentration (Figure 3.3). No difference in haptoglobin was observed between the PreTreat and Weaning or PostWean periods; however, haptoglobin concentration was greater ($P < 0.05$) at PostWean by 7% compared to Weaning. Haptoglobin concentration has been reported to increase as a result of trauma or stress (Hughes et al., 2014). It is suggested that haptoglobin is not as easily detected at basal levels and is almost undetectable in cattle that are not experiencing stress (Arthington et al., 2003). This may be an explanation as to why no treatment by time interaction was observed in the present study. This is in agreement with Lynch et al. (2012) where haptoglobin concentration post-weaning increased compared with the weaning baseline, but no treatment x time interaction was observed. Qiu et al. (2007) also

reported haptoglobin concentrations to be increased 72 hours after weaning compared to concentrations 24 hours after weaning. In addition, studies by Arthington et al., (2005) and Campistol et al., (2010b) revealed haptoglobin concentrations to be increased in the days after weaning. However, another study by Campistol et al., (2010a) reported increased haptoglobin concentration 4 days prior to the weaning event. The time after weaning is clearly a stressful event, as evidenced by the increased haptoglobin concentrations in multiple studies. Yet, the present study suggests altered weaning methods do not directly alter haptoglobin concentration.

IMPLICATIONS

Collectively these data suggest low stress weaning methods do not significantly improve postweaning growth performance or carcass merit compared to calves weaning using conventional methods. However, the weaning method a producer chooses will not negatively impact carcass traits. Moreover, it may be efficacious for producers to take into consideration and implement low stress weaning methods for improved performance at weaning early backgrounding phases.

LITERATURE CITED

Arthington, J. D., Eicher, D., Kunkle, W. E., & Martin, F. G. (2003). Effect of transportation and commingling on the acute-phase protein response, growth, and feed intake of newly weaned beef calves. *Journal of Animal Science, 81*(5), 1120-1125.

Arthington, J. D., Qiu, X., Cooke, R. F., Vendramini, J. M. B., Araujo, D. B., Chase, C. C., & Coleman, S. W. (2008). Effects of preshipping management on measures of stress and performance of beef steers during feedlot receiving. *Journal of Animal Science, 86*(8), 2016-2023. doi:10.2527/jas.2008-0968

Arthington, J. D., Spears, J. W., & Miller, D. C. (2005). The effect of early weaning on feedlot performance and measures of stress in beef calves. *Journal of Animal Science, 83*(4), 933-939.

Boland, H. T., Scaglia, G., Swecker, W. S., & Burke, N. C. (2008). Effects of alternate weaning methods on behavior, blood metabolites, and performance of beef calves. *The Professional Animal Scientist, 24*, 539-551.

Campistol, C., Kattesh, H. G., Waller, J. C., Rawls, E. L., Arthington, J. D., Engle, T. E., & Carroll, J. A. (2010a). Effects of two-stage and total vs. fenceline weaning on the physiology and performance of beef calves. *Journal of Dairy Science, 93*, 107-107.

Campistol, C., Kattesh, H. G., Waller, J. C., Rawls, E. L., Pighetti, G. M., & Carroll, J. A. (2010b). Effects of feed supplementation and method of weaning on the physiology and performance of beef calves. *Journal of Dairy Science, 93,* 394-395.

Du, M., Huang, Y., Das, A. K., Yang, Q., Duarte, M. S., Dodson, M. V., & Zhu, M. J. (2013). Meat Science And Muscle Biology Symposium: Manipulating mesenchymal progenitor cell differentiation to optimize performance and carcass value of beef cattle. *Journal of Animal Science, 91*(3), 1419-1427. doi:10.2527/jas.2012-5670

Enriquez, D. H., Ungerfeld, R., Quintans, G., Guidoni, A. L., & Hotzel, M. J. (2010). The effects of alternative weaning methods on behaviour in beef calves. *Livestock Science, 128*(1-3), 20-27. doi:10.1016/j.livsci.2009.10.007

Haley, D. B., Bailey, D. W., & Stookey, J. M. (2005). The effects of weaning beef calves in two stages on their behavior and growth rate. *Journal of Animal Science, 83*(9), 2205-2214.

Hughes, H. D., Carroll, J. A., Sanchez, N. C. B., & Richeson, J. T. (2014). Natural variations in the stress and acute phase responses of cattle. *Innate Immunity, 20*(8), 888-896. doi:10.1177/1753425913508993

Lippolis, K. D., Ahola, J. K., Mayo, C. E., Fischer, M. C., & Callan, R. J. (2016). Effects of two-stage weaning with nose flap devices applied to calves on cow body

condition, calf performance, and calf humoral immune response. *Journal of Animal Science, 94*(2), 816-823. doi:10.2527/jas.2015-9624

Lynch, E. M., McGee, M., Doyle, S., & Earley, B. (2012). Effect of pre-weaning concentrate supplementation on peripheral distribution of leukocytes, functional activity of neutrophils, acute phase protein and behavioural responses of abruptly weaned and housed beef calves. *Bmc Veterinary Research, 8*, 11. doi:10.1186/1746-6148-8-1

Price, E. O., Harris, J. E., Borgwardt, R. E., Sween, M. L., & Connor, J. M. (2003). Fenceline contact of beef calves with their dams at weaning reduces the negative effects of separation on behavior and growth rate. *Journal of Animal Science, 81*(1), 116-121.

Qiu, X., Arthington, J. D., Riley, D. G., Chase, C. C., Phillips, W. A., Coleman, S. W., & Olson, T. A. (2007). Genetic effects on acute phase protein response to the stresses of weaning and transportation in beef calves. *Journal of Animal Science, 85*(10), 2367-2374. doi:10.2527/jas.2006-843

Table 3.1. Composition of the finishing diet for steers assigned to different weaning treatments

Item	Finishing
Ingredient composition, % of DM	
Dry-rolled corn	58
Sugar beef pulp	20
Dried distiller's grains with solubles	8
Corn silage	8
Wheat straw	3
Supplement[1]	3
Nutrient composition	
NE_m, Mcal/kg	2.1
NE_g, Mcal/kg	1.4
ADF, % of DM	7.4
CP, % of DM	14.2

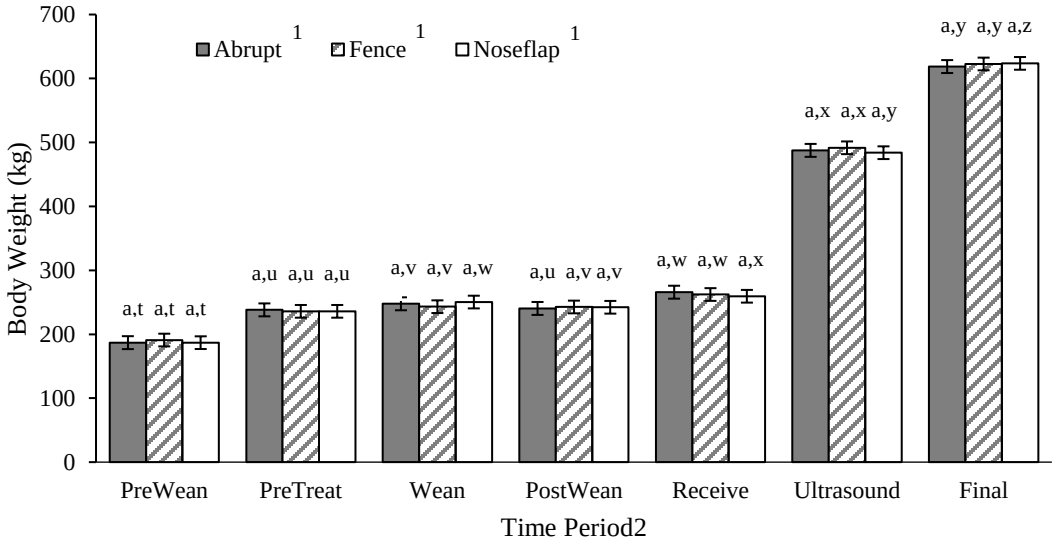
[1] Supplement contained urea, calcium carbonate, potassium chloride, roughage products, dolomitic limestone, salt, animal fat preserved with ethoxyquin, magnesium oxide, Vitamin E supplement, plant protein products, manganese sulfate, zinc sulfate ferrous sulfate, Vitamin A supplement, copper sulfate, calcium iodate, cobalt carbonate, mineral oil, zinc amino acid complex, copper amino acid complex, sodium selenite, and monensin sodium. Monensin included in diet at 30 g/ton.

Table 3.2. Least squares means for effect of weaning treatments on carcass characteristics and meat quality.

Variable	ABRUPT[1]	FENCE[1]	NOSE[1]	SEM[2]	P-value[3]
Hot carcass weight, kg	387	390	389	6.5	0.941
Ribeye area, cm^2	87.42	87.61	89.42	1.884	0.697
12^{th} rib fat thickness, cm	1.37	1.40	1.55	0.071	0.121
USDA Yield Grade	3.13	3.20	3.27	0.114	0.712
Marbling score[4]	504	541	512	18.5	0.333

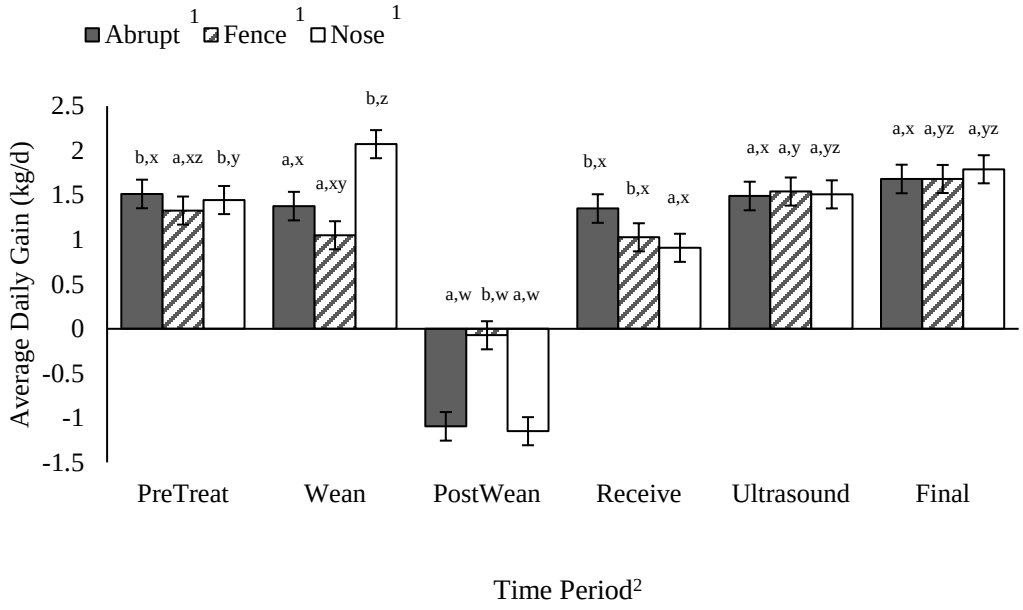
[1]Treatments; ABRUPT = n=29 steers, FENCE = n=30 steers, and NOSE = n=30 steers
[2]Standard error of the mean
[3]Probability of difference among least square means
[4]Marbling score: 400 = $Small^0$, 500 = $Modest^0$, 600 = $Moderate^0$

Figure 3.1. Body weight treatment means (kg) by time period based on weaning treatment.



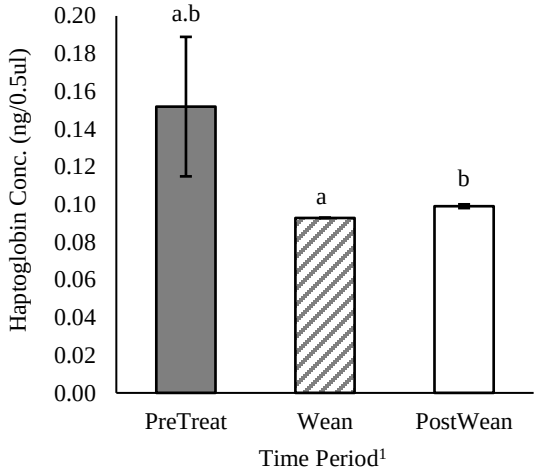
[1]Abrupt (calves isolated from dams on the day of weaning), Fence (calves separated from dams via a barbed wire fence for 7 days prior to completely weaning), and Noseflap (nose-flap inserted and calves remained with dams for 7 days prior to completely weaning).
[2]Body weights (BW) were recorded on study day -34 (PreWean), -7 (PreTreat), 0 (Weaning), 7 (PostWean), 32 (Receiving), 175 (Ultrasound), and 253 (Final).
[a]LSmeans comparing treatments within each time period lacking a common superscript differ ($P \leq 0.05$).
[t,u,v,w,x,y,z]LSmeans comparing time period within each treatment lacking a common superscript differ ($P \leq 0.05$).

Figure 3.2. Average daily gain (ADG) treatment means (kg/d) by time period based on weaning treatment.



[1]Abrupt (calves isolated from dams on the day of weaning), Fence (calves separated from dams via a barbed wire fence for 7 days prior to completely weaning), and Noseflap (nose-flap inserted and calves remained with dams for 7 days prior to completely weaning).
[2]Body weights (BW) were recorded on study day -34 (PreWean), -7 (PreTreat), 0 (Weaning), 7 (PostWean), 32 (Receiving), 175 (Ultrasound), and 253 (Final) and average daily gains (ADG) were calculated between each time period
[a.b]LSmeans comparing treatments within each time period lacking a common superscript differ ($P \leq 0.05$).
[v,w,x,y,z]LSmeans comparing time period within each treatment lacking a common superscript differ ($P \leq 0.05$).

Figure 3.3. Haptoglobin concentration means (ng/0.5ul) by time period based on weaning treatment.



[1]Blood samples were collected via coccygeal venipuncture at d -7 (PreTreat), 0 (Weaning), and 7 (PostWean) to analyze haptoglobin concentration using a bovine ELISA kit.
[a.b] Means lacking a common superscript differ $P < 0.001$