5-2019

Effects of Mid-Gestation Nutrient Restriction on Carcass Measurements and Meat Quality of Resultant Offspring

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EFFECTS OF MID-GESTATION NUTRIENT RESTRICTION ON CARCASS

MEASURMENTS AND MEAT QUALITY OF RESULTANT OFFSPRING

by

Shelby M. Quarnberg

A thesis submitted in partial fulfillment
of the requirement for the degree
of

MASTER OF SCIENCE

in

Nutrition and Food Sciences

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2019

ABSTRACT

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by

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Angus influenced calves' (N = 34) from cows who were allocated into either a restricted (n = 18) or maintenance (n = 16) group were used to investigate potential impacts of mid-gestation nutrient restriction which might be occurring in the Intermountain West, on offspring finishing feedlot performance and meat quality. Calves' were individually housed and fed a finishing ration of 76% barley dry matter concentration *ad libitum*. Loins of each carcass were wet-aged for 14 days postmortem, frozen and fabricated into individually vacuum-packed steaks for meat quality analysis. There was no difference in measurements of feedlot performance, carcass yield and quality, Warner-Bratzler Shear Force values, steak composition analysis, Hunter Lab color values, and 10/12 sensory beef attributes using a 15-point numerical scale ($P \geq 0.10$). Restricted steaks were perceived as more tender ($P = 0.05$) by a trained sensory panel. Overall, nutrient restriction during mid-gestation had no detrimental effect on feedlot performance, carcass characteristics, and meat quality measurements of offspring.

(55 pages)

PUBLIC ABSTRACT

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The goal of this study was to investigate feedlot performance and meat quality of calves born to cows that underwent a nutrient restriction during the second trimester of gestation which may be occurring in the Intermountain West. Thirty-four angus influenced calves from the same sire were used for this study. The calves were born from cows that were separated into either a maintenance group, and kept on an irrigated pasture, or a restricted group, that was placed on an unirrigated pasture and allowed to lose one body condition score during the second trimester of pregnancy. This study begins with the calves on day 85 of the finishing portion of the feedlot phase. During the finishing feedlot phase, calves were individually housed, fed ad libitum, and feedlot performance measurements were taken every 28 days. Carcasses from the calves were evaluated for yield and quality. A loin from each carcass was collected, aged, frozen, and cut into individually packaged steaks that were used to assess meat quality. There was no difference in feedlot performance and carcass measurements for either maintenance and restricted calves. Meat quality measurements revealed no difference in color, instrumental tenderness values, or composition of steaks from either group. A trained sensory panel found that ten characteristics of flavor were similar for both treatments. There was however, a trend for steaks from nutrient restricted cattle to have more of a

bloody/serumy flavor. The trained sensory panel also found that there was a difference in tenderness of steaks from nutrient restricted animals being perceived as more tender than animals from maintenance cows. The results of this study demonstrate that nutrient restriction during mid-gestation does not have negative effects on feedlot performance, carcass characteristics, or meat quality measurements. These results also indicate that steaks from calves born to nutrient restricted cows may be perceived as more tender.

ACKNOWLEDGMENTS

I would like to thank Dr. Jerrad Legako for giving me the opportunity at this master's project, which taught me about meat science and the complete process of production agriculture; putting up with my talkative joking nature and naming the cattle crazy names. Dr. Kara Thornton for helping me put my master's on paper and improving my subpar writing skills along the way. I want to thank my committee members, Drs. Kerry Rood and Chuck Carpenter for all their help and support of this project.

I would also like to give special thanks the many people that helped me with the labor of my project. Dick Whittier for being the calm in the storm, who guided me beyond what was required with everything from life to my master project, educating me about meat harvesting and fabrication, and with troubleshooting on the steaks I had to prepare each week, all with a smile on your face and a pep in your step. The USU farm beef crew for helping when I called panicked that I needed more feed or that the Rissler was not working again. My sensory panelist for being such great "champs" about eating hundreds of steaks with no sauce or seasoning. Brett Bowman, Rachael Christensen, my lab mates, colleagues, and the undergrad workers whose help made a huge contribution to this project. JBS Hyrum facility for helping throughout the process of harvesting. As well as my friends, family, and pets for their patience, understanding, and encouragement to push me to be more. I could not have done it without everyone's help. I would like to also acknowledge the cattle of this project for their contribution to meat science.

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INTRODUCTION

In certain areas of the U.S., such as the Intermountain West, pasture-fed cows may experience nutrient restriction due to fluctuations in forage quality and availability caused by drought, climate change, and time of the year (Du et al., 2015; Mohrhauser et al., 2015b). These fluctuations in nutrient availability result in a nutrient intake reduction for pregnant beef cows during various stages of gestation, potentially impacting the development and growth of the offspring (Du et al., 2013; Vavra et al., 1976). Nutrient restriction during critical periods of gestation has the potential to change energy partitioning, thereby leading to altered composition and deposition of skeletal muscle and adipose within the offspring (Du et al., 2015; Bispham et al., 2005; Edwards et al., 2005) These alterations may influence body composition long-term and possibly enhance the quality of the resulting carcass (Mohrhauser et al., 2015a; Mohrhauser et al., 2015b).

However, there are concerns that restricting the diet of animals during gestation could result in weak offspring that have low birth weights, decreased health, slower growth rate, and poor feed efficiency (Zhu et al., 2006; Zambrano et al., 2005; Stannard et al., 2004). Recently, several studies have shown that a nutritional restriction during mid-gestation does not result in negative impacts on offspring feedlot performance and may have the potential for positive effects on carcass quality (Gardner et al., 2016; Mohrhauser et al., 2015a; Mohrhauser et al., 2015b;). Thus, the aim of this study is to investigate the impacts of mid-gestation nutrient restriction on late feedlot performance and meat quality of the subsequent offspring.

HYPOTHESIS

Nutrient restriction during the second trimester of cattle gestation does not impact feedlot finishing performance, carcass traits, meat quality, or steak composition of the offspring.

OBJECTIVES

Determine whether maternal nutrient restriction during the second trimester impacts calf performance during the finishing stage of the feedlot, carcass yield or quality grade, or meat quality of steaks when comparing calves from both maintenance and restricted cows.

LITERATURE REVIEW

Introduction

Throughout gestation, a dam may encounter fluctuations in her nutrition that influence fetal development that can persist throughout postnatal growth (Du et al., 2017; Mulliniks et al., 2016; Mohrhauser et al., 2015a; Mohrhauser et al., 2015b; Du et al., 2010; Ramsay et al., 2002; Barker et al., 1995). Early research proposed that the fetus had precedence for nutrients over the dams' own requirements during times of insufficiencies; recent research has revealed that the fetus can be impacted by changes in maternal nutrition (Du et al., 2017; Mohrhauser et al., 2015a; Mohrhauser et al., 2015b; Long et al., 2012; Du et al., 2010; Vonnahme et al.,2007; Vonnahme et al., 2003; Hammond et al., 1943). This response to fluctuations in nutrition during gestation allows for calves to have plasticity during early development and react to cues from the environment to alter their phenotype (Kenyon and Blair et al., 2014; Godfrey and Baker et al., 2000). This phenomenon has been described by the term "fetal programming," which is defined as an alteration to maternal nutrition during gestation at a sensitive or critical period of development which may have both short and long-term effects on offspring growth and development both in utero and after birth (Yan et al., 2013; Du et al., 2010; Long et al., 2009; Ford et al., 2007; Zhu et al., 2006; McGrady et al., 2006; Zhu et al., 2004; Godfrey and Baker 2000; Reynolds and Redmer 1995; Lucas 1991).

The concept of fetal programming was originally studied in humans following the Dutch potato famine of 1944-1945. Under nourishment of pregnant mothers resulted in a developmental adaptation where their children developed a "thrifty" body type resulting

in an altered metabolism enabling them to be better adapted to poor nutrient availability post-birth (Kyle and Pichard, 2006; Godfrey and Barker, 2000, 1995). A thrifty body type is advantageous during food shortage, but it can be detrimental to health when the plane of nutrition is adequate (Kyle and Pichard, 2006; Godfrey and Barker, 2000, 1995). Illnesses such as obesity, metabolic disease syndrome, diabetes, hypertension, endocrine disruptions, and cardiovascular disease have all been linked to adults who were born during periods of famine (Kyle and Pichard, 2006; Godfrey and Barker, 2000, 1995). Interestingly, the stage of fetal development during which maternal undernutrition occurs is thought to impact the adulthood diseases that may later develop (Roseboom et al., 2000; Ravelli et al., 1999, 1998). The potential for offspring to have varying outcomes depends on the time point of gestation that is manipulated. Famine during early stages of pregnancy for humans showed an increased risk of obesity and coronary heart disease, whereas restriction during later stages were associated with decreased glucose tolerance (Roseboom et al., 2000; Ravelli et al., 1999, 1998). In humans, nutrient restriction during gestation has negative implications on health. However, in production animals there is potential for benefits through altered growth rate, feed efficiency, and improved carcass quality relating to muscle and fat deposition. Alternatively, there is the potential for deleterious effects whenever the plane of nutrition is manipulated during gestation. More research is needed to sort out the contradicting results and to fully understand the implications of maternal nutrition on calf performance.

Fetal Programming

Skeletal muscle and adipose development begin in utero and are of paramount importance in the beef industry as they directly contribute to the quantity and quality of the product that is produced (Greenwood et al., 2000; Cossu and Borello, 1999; Glore and Layman, 1983). Prenatally, mesenchymal stem cells can differentiate into several different lineages including muscle, fat, connective tissue, and bone; components which are important to the meat industry (Du et al., 2011a). Mesenchymal stem cell differentitation is competitively regulated by intracellular signalling pathways, such as the Wnt/β-catenin pathway (Du et al., 2013; Bonnet et al., 2010). Activation of the Wnt/β-catenin pathway causes an increase in β-catenin which pushes mesenchymal stem cells towards myogenesis, the formation of skeletal muscle (Du et al., 2013; Du et al., 2011a). When the Wnt/β-catenin pathway is downregulated, such as is the case in dams with a decresed plane of nutrition, adipogenesis is promoted (Du et al., 2010; Bispham et al., 2003).

Myogenesis occurs during fetal growth in two stages of muscle fiber development (Du et al., 2013; Beermann et al., 1978). The first stage of myogenesis for the bovine fetus occurs within the first 21 days to two months of gestation, a period termed embryonic or early fetal development (Robelin 1991; Russell & Oteruelo, 1981), and is where primary myofibers devlop to serve as sacffolding for further myogenic structure formation (Du et al., 2010; Swatland et al., 1973). The second wave of myogenesis is where the majority of muscle cells and structure are devloped which occurs during mid-gestation and can continue until shortly after birth (Du et al., 2010; Fève 2005; Russell & Oteruelo, 1981). Previous research postulates that due to the main development of muscle structure and overall mass, the second trimester of gestation is the most important period

for muscle development (Du et al., 2015; Du et al., 2013; Du et al., 2011a; Du et al., 2010; Zhu et al., 2004).

Skeletal muscle mass increases through two different mechanisms, hyperplasia (increase in cell number) or hypertrophy (increase in cell size). In mammals, hyperplasia of skeletal muscle only occurs prenatally and ceases prior to or shortly after birth, while postnatal muscle growth occurs exclusively through hypertrophy (Du et al., 2013; Du and Dodson, 2011b; Du et al., 2010; Zhu et al., 2006; Zhu et al., 2004; Brameld et al., 2000; Stickland et al., 1978). As such, changes in the maternal plane of nutrition can have a large influence on muscle fiber number of resulting offspring (Beermann et al., 1978). Conversely, Du (2010) restricted nutrition in sheep during late-gestation and observed a reduction in muscle fiber size, but not number, in subsequent offspring. Thus, the effects of maternal nutrition on offspring muscle number and size is still uncertain and warrants further research.

Unlike myogenesis, adipogenesis and fibrogenesis occur throughout the lifetime of most mammalian species (Duarte et al., 2013). Research conducted in high marbling Wagyu cattle by Duarte (2013) found that total fat deposition and collagen content were higher than that of Angus cattle; which supports the theory that adipogenesis and fibrogenesis both begin from a common cell lineage and their development is inseparable, ongoing, and positively correlated. However, Long (2012) found opposing results such that when the pathway is driven towards fat accumulation, there is less connective tissue. Further research into the manipulation of mesenchymal stem cell differentitation into adipogenic or fibrogenic lineages is needed to determine the

association between quantity of adipose versus the amount of connective tissue in a heavily marbled carcass.

In cattle, adipogenesis begins during the last five months of gestation and continues postnatally as a lifelong process (Du et al., 2010; Fève et al., 2005; Zhu et al., 2004; Russell and Oteruelo et al., 1981) which is affected by nutritional intake during fetal, postnatal, and post weaning stages of life (Mohrhauser et al., 2015b; Du et al., 2013; Long et al., 2012). Adipogenesis, specifically adipogenic commitment, overlaps secondary myogenesis and is where maternal nutrition between late-gestation and early weaning can affect adipocyte hyperplasia, development, density and ultimately, marbling (Du et al., 2013; Gupta et al., 2012; Gupta et al., 2010; Vernochet et al., 2009; Farmer, 2006; Rosen and MacDougald, 2006; Spiegelman and Flier, 1996).

Adipose is typically deposited in the following order: visceral, subcutaneous, intermuscular, and intramuscular fat (Du et al., 2013; Bonnet et al., 2010). Adipocytes developing within the skeletal muscle form sites for intramuscular fat accumulation that later develop into marbling within meat (Uezumi et al., 2011; Du et al., 2010; Joe et al., 2010; Uezumi et al., 2010; Tong et al., 2009). Altering the maternal plane of nutrition has been shown to influence the number of adipocytes during the finishing phase of the feedlot (Du et al., 2015; Du et al., 2013). Mohrhauser (2015b) found that there was a shift in the amount of fat depots deposited in calves born to cows that had a nutrient restriction during mid-gestation. Mohrhauser (2015b) findings elude to the potential to alter fat deposition in utero toward a more favorable fat depot, such as marbling, that could persist throughout life.

Feedlot Phase

The main goal of the feedlot is to grow cattle as quickly as possible while increasing cattle performance, turnover and profitability (Muir et al., 1998). Understanding the impact that dam nutrition has on calf production performance is of great significance to the beef industry in an attempt to minimize expenses, such as feed and waste, and maximize profits from growth and efficiency. Over the past 30 years, the cost of raising beef cattle has increased, and feed is one of the largest single expenses associated with raising beef cattle (Hamilton, 2010; Johnson et al., 2003; Arthur et al., 2001). The National Cattlemen's Beef Association is also concerned with the inconsistencies in end-product quality (NCBA 2001).

For calving systems in the Western states and other regions of the US, maternal nutrient restriction may inadvertently be occurring due to different weather events, seasonal changes, and drought that effect feed forage quality and availability for dams at a time when nutritional requirements are the greatest (Du et al., 2013, 2010; Olson, 2005; Schoonmaker et al., 2003; Jensen et al., 2002; Enk et al., 2001; DelCurto et al., 2000; Thomas and Kott 1995; Vavra and Raleigh, 1976). Spring calving cows in the northern great plains also experience a period of nutrient restriction at a time that often corresponds to the first one-half to two-thirds of gestation; a critical period in muscle and fat deposition (Mohrhauser et al., 2015a,b; Du et al., 2010; Olson, 2005; DelCurto et al., 2000; Russell and Oteruelo, 1981). Ford (2007) found that sheep with a severe (50%) maternal nutrient restriction during early and mid-gestation resulted in increased postnatal growth of offspring compared to their normal fed counterparts. Gardner (2016) and Taylor (2016) found no differences in calves' birthweights or feedlot performance of

cattle following mid-gestation nutrient restriction demonstrating that a reduction in maternal nutrition during mid-gestation may not have negative effects on production.

Many studies indicate that maternal nutrient restriction could decrease the amount of feed at certain stages in the production cycle without having any deleterious effects on productivity (Mohrhauser et al., 2015a; Robinson et al., 2013; Funston et al., 2012; Caton and Hess, 2010; Du et al., 2010; Wu et al., 2006). While there is potential to produce more efficient offspring by improving marbling and reducing subcutaneous fat thickness ratios relative to lean muscle during prenatal development (Mohrhauser et al., 2015b; Gonzalez-Bulnes et al., 2012; Zhu et al., 2006); it is important to ensure that restricting nutrition during gestation does not negatively impact production of the dam or her offspring.

Some literature suggests that nutrient restriction at any period of gestation may have adverse effects on calf health and productivity (Bell et al., 2016). Such as the study conducted by Greenwood (2005) which found that early maternal nutrient restriction great enough to cause a 26% reduction in birth weights, reduced the ability for compensatory growth and overall growth potential of offspring, and resulted in smaller slow growing animals at any time point of life. Additional studies indicate that maternal nutrition restrictions in late-gestation resulted in offspring that are susceptible to a variety of neonatal health issues correlating to a decrease in body weight and early growth performance (Funston et al., 2010; Wittum et al., 1994). While other studies postulated that early to mid-gestational nutrient restrictions, or less severe restrictions, had little direct impact on offspring growth and live weight post-weaning due to the plastic nature

of tissues safeguarding that there are no long-term adverse effects (Kenyon and Blair et al., 2014; Greenwood et al., 2010; Greenwood and Thompson et al., 2007).

Discrepancies observed in the literature are likely due to severity and timing of nutrient restriction during gestation, as well as the type and extent of nutrient modification, the species, breed, offspring gender, and age of the dam during gestation (Mohrhauser et al., 2015b; Long et al., 2012; Micke et al., 2010; Hennessy et al., 2002). Alterations in maternal nutrition during either the first or last trimesters of gestation have thus far, provided inconsistent results relative to the effect on the offspring. This information combined with our knowledge of the important relationship between skeletal muscle and adipose development during this period demonstrates that mid-gestation may be a promising time point for maternal nutrient restriction targeted at impacting meat production.

Carcass Measurements

Carcass yield grade is an estimate of the amount of boneless, closely trimmed retail cuts that can be taken from a carcass (Hale et al., 2013). A carcass is composed of muscle (lean), bone, connective tissue, and various fat depots. Cattle that have one inch of backfat are projected to have a USDA yield grade of 4.5, reflecting low retail yield and considerable waste for the beef industry (AMSA, 2001; Brethour et al., 2000). A change of one value on the 1-5 scale of yield grade in either direction correlates with a 3.4% change in retail products of a carcass (Dikeman et al., 1998), demonstrating the importance a better yielding carcass has for the industry. A low numerical value yield grade carcass helps to lower costs for consumers and the industry by producing large

amounts of muscle with low quantities of undesirable fat depots such as backfat and kidney, pelvic, and heart (KPH) fat (Bass et al., 2016). Studies by Mohrhauser (2015a,b) found promising results of improved USDA yield grade with no differences in HCW, dressing percent, or KPH from carcasses of calves whose dams experienced nutrient restriction during mid-gestation. However, Greenwood (2009) and Underwood (2010) each found that offspring from nutrient restricted cows during mid to late-gestation had a decrease in both hot carcass weight and retail yield.

Long (2012) found carcasses of calves from dams that underwent nutrient restriction during mid-gestation, had a decrease in muscle mass and an increase in adipocyte size. Research using sheep found that ewes nutrient restricted during various stages of gestation had an increase in numerous fat depots such as undesirable KPH fat (Ford et al., 2007; Zhu et al., 2006; Bispham et al., 2005; Edwards 2005). The relative increase in overall fat deposition of offspring from nutrient restricted dams is thought to be due to a reduction in muscle mass that lessens the consumption of nutrients by muscle and allows for excess energy to be shunted to adipose development (Du et al., 2013; Long et al., 2012; Ford et al., 2007). With the main product of the beef industry being skeletal muscle, a large reduction in this tissue is undesirable. A study conducted by Zhu (2006) found that mid-gestation nutrient restriction in sheep increased fat deposition without significantly altering lean muscle mass, indicating a potential to increase quality without diminishing the product of lean muscle.

The industry must balance increasing yield without significantly decreasing carcass quality. In the beef industry deposition of intramuscular fat, or marbling, is of great importance as it directly relates to the economic value of the carcass by determining

quality grade, and ultimately the eating experience of the consumer (Emerson et al., 2013; O'Quinn et al., 2012; Garmyn et al., 2011; Lorenzen et al., 2003; Savell et al., 1987; Smith et al., 1983; Stickland 1978; Marchello and Dryden, 1968). Quality grade, which is based on the predicted palatability and eating experience of beef from a young carcass, has rankings from USDA Prime to Select, with Prime being the highest grade (USDA 1997). Over the past 10 years, the beef industry has increased the number of Choice and Prime carcasses as compared to Select (Tatum et al., 2015). The improvement in quality grade may be due in part to producers receiving a premium for higher quality carcasses (Tatum et al., 2015). As well as in response to the 2005 National Beef Quality Audit (NBQA) which stated that marbling was the number one challenge of the industry (NBQA 2005). With such an emphasis on producing a high-quality meat product and the great potential for intramuscular fat deposition, nutrient restriction is a peak area of interest for meat science.

Meat Quality

Meat quality can be assessed using factors such as color, the content of nutrients, tenderness, and sensory analysis. The color of meat is a large factor in consumer selection and shelf life (AMSA et al., 2012). The color of meat may be measured instrumentally and expressed as Hunter Lab values, which quantify the range of light to darkness (L*), red to green (a*), and blue to yellow (b*) (AMSA et al., 2012). Mohrhauser (2015b) found no differences in L*, a*, or b* values of steaks from calves whose dam experienced a mid-gestation nutrient restriction, little data exists analyzing the effects of maternal nutrition on offspring meat color.

Chemical analysis is used to determine the composition of meat; as protein, fat, collagen, and moisture. These different macromolecules influence meat quality, juiciness, flavor, and tenderness. There is little data on the effects of fetal programing in the literature specifically looking at steak composition analysis. Mohrhauser (2015a) found no difference in percent protein, fat, or moisture of muscle when comparing offspring from dams that had a mid-gestational nutrient restriction. However, Mohrhauser (2015a) did find that nutrient restricted calves had a lower total collagen content then their non-restricted counterparts suggesting that mid-gestational maternal nutrient restriction may influence collagen content within skeletal muscle which is a key factor in meat tenderness.

Warner-Bratzler shear force (WBSF) is an instrumental measure of tenderness, with lower shear values indicative of a more tender product supported by sensory analysis (Chriki et al., 2012). Some factors that affect tenderness of meat are composition of fat, collagen, moisture, and the microstructure of muscle such as size and type of muscle fibers (Radunz 2009). Emerson (2013) and Nelson (2004) each found that increased marbling resulted in lower WBSF values of meat. Corbin (2015) found that when WBSF values are held constant, there is an increase in the percieved sensory tenderness of meat with increased marbling. This percieved tenderness could be due to the fact that fat is less dense and easier to bite through or that fat coats the mouth increasing perceived juciness, desirability, flavor, and consumer acceptability (Corbin et al., 2015; Legako et al., 2015; Webb et al., 2015; Hunt et al., 2014; O'Quinn et al., 2012; Warris, 2010; Behrends et al., 2005; Killinger et al., 2004a; Wood, 1995; Savell and Cross, 1988; Smith and Carpenter, 1974). Collagen content also affects meat tenderness,

with a greater amount of total collagen correlating to tougher meat (Chriki et al., 2012; Mandell et al., 1997; McKeith et al., 1985). Mohrhauser (2015a, b) found no differences in WBSF values from steers whose dams were nutrient restricted during mid-gestation at various aging period of steaks, except those which were aged for 21-days which had a reduction in WBSF values. Underwood (2010) reported that offspring from nutrient restricted dams had greater WBSF values after 14 days of aging. The difference in the two studies may be due to differences in the type of nutrient restriction (energy vs protein) and the sample size of each experiment. Both studies indicate there is a lasting effect of maternal nutrient restriction on beef offspring instrumental tenderness. More research needs to be done to determine if the effect is positive or negative.

A fundamental part of meat quality is how the final product tastes and the overall eating experience of the consumers. Meat scientists can use sensory analysis as a way to measure attributes that impact the eating experience of the final product. Palatability is a universal measure of overall eating experience defined by three intertwind components of flavor, tenderness, and juiciness (AMSA, 2016). Tenderness is one of the three legs of palatability with some stating that tenderness is one of the most important factors affecting beef palatability (Miller et al., 2001; Miller et al., 1995; Dikeman, 1987; Savell et al., 1987). However, other studies show that flavor is equally important, with some arguing it is more important than tenderness based on evidence showing that small changes in flavor resulted in a large change in overall consumer acceptance and palatability (Platter et al., 2003; Neely et al., 1998). Killinger (2004b) found that while flavor was more correlated (r = 0.83) towards overall acceptability, both juiciness (r =

0.76) and tenderness (r = 0.78) values are also important to consumer satisfaction solidifying that each one of the three factors of palatability are important.

Many studies confirm that marbling is an important contributor to beef palatability (tenderness, juiciness, and flavor) and increasing marbling increases beef quality and palatability (specifically flavor) (Webb et al., 2015; Hunt et al., 2014; O'Quinn et al., 2012; Garmyn et al., 2011; Behrends et al., 2005; Killinger et al., 2004a; Lorenzen et al., 2003, 1999; Savell et al., 1987; Smith et al., 1985; McBee and Wiles, 1967;). A study conducted by Emerson (2013) found that increased marbling has a positive effect on desirable sensory attributes (beef flavor r = 0.84, juiciness r = 0.67, tenderness r = 0.63, and umami r = 0.57), and overall eating experience satisfaction (r = 0.78).

Legako (2015) identified significant differences in consumer flavor acceptability of beef with modest/moderate marbling as compared to small marbling, with the higher marbled cuts having higher values for consumer acceptability. Research also demonstrates that increased marbling was associated with greater intensity of positive descriptors of flavor such as buttery and beefy, while decreasing negative attributes such as bloody and livery (O'Quinn et al., 2012). As such, intramuscular fat is fundamentally important to the development of the beef flavor profile preferred by today's consumers and finding ways to improve marbling is of great importance for the beef industry (O'Quinn et al., 2016). While there has been research on the effects of fetal programming and meat quality traits such as shear force, steak composition, and color, very little research has been conducted on the sensory attributes of meat from cattle whose dam experienced a nutrient restriction during gestation.

MATERIALS AND METHODS

Fetal Programming and Grower Feedlot Phase

All animal care and usage protocols were approved by the Utah State University institutional animal care and use committee (IACUC #2373). Management of cows and calves from conception through the early feedlot stage are described in Gardner (2016). Briefly, cows (N = 34) were naturally bred to one purebred Angus herd sire and were housed together until the second trimester where they were sorted into two treatment groups: restricted (n = 18) or maintenance (n = 16). There was no difference in initial weights ($P = 0.80$) or body condition scores (BCS) ($P = 0.72$) between the two groups. The maintenance group was kept on a larger irrigated pasture (2,309 kg/ha, dry matter (DM)), while the restricted group was kept on a smaller unirrigated pasture with lower biomass (1,662 kg/ha, DM) and allowed to lose one BCS. Following the insult period, cows were comingled and fed at maintenance. By the end of the third trimester, there was no difference ($P > 0.05$) in body weight or BCS between the groups.

Calves were weaned around 206 days of age and processed using conventional intermountain methods. Prior to the feedlot phase, calves were group housed and fed a background diet for approximately 7 weeks. The calves were then placed in individual pens and fed a grower ration (Table 1) ad libitum summarized in Gardner et al. (2016). Individual intakes were recorded daily using the clean bunk feeding system (Pritchard et al., 1962).

Table 1. Nutrient analysis of calves feedlot grower ration Gardner et al. (2016).

Item	Grower ration[1] Wet matter basis	Dry matter basis
Moisture, %	43.22	0.00
Dry matter, %	56.78	100.00
Crude protein, %	7.38	13.00
Acid detergent fiber, %	10.74	18.92
Neutral detergent fiber, %	21.81	38.41
Total digestible nutrients, %	42.04	74.04
Minerals		
Calcium, %	0.32	0.56
Phosphorus, %	0.18	0.32
Potassium, %	0.78	1.38
Magnesium, %	0.10	0.17

[1]Grower ration was fed to calves for an 84 day "grower" period and consisted of approximately 43% corn silage, 27% barley concentrate, 27% alfalfa hay, and 3% vitamin and mineral premix on dry matter basis. (Gardner et al., 2016)

Finishing Feedlot Phase

The current experiment began with the finishing feedlot phase which started on day 85 where the concentrate in the grower ration increased by approximately 10% every week until the final ration of 76.8% barley, 17.3% alfalfa, 2.8% corn silage, and 3% mineral vitamin premix based on DM was reached for the finishing phase of the feedlot. The calves' average weight was 377 kg at day 85. The calves were managed in the same manner as the grower phase, housed in individual pens in the same barns and fed ad libitum using the clean bunk system described above.

The calves' weights continued to be collected at 28-day intervals until a desired average backfat thickness of 7.0 mm and an average weight of 500 kg was reached, and then cattle were sent to harvest. Measurements of average daily gain, feed intake, feed efficiency, and body weights, were taken.

Harvesting/ Carcass Measurements

The day prior to harvest, cattle were weighed and pulled off feed with free access to water. Cattle were harvested at the JBS Hyrum, UT facility under the established humane slaughter act and USDA-FSIS beef harvesting protocols. Twenty-four hours post mortem the carcasses were graded by USDA meat quality graders as well as an instrumental grading camera (E+V Technology GmbH& Co.KG; VBG2000; Oranienburg, Germany) to determine yield and quality grade. Measurements taken from both the camera and by USU meat science faculty consisted of hot carcass weight, %KPH fat, backfat and adjusted backfat, ribeye area, marbling score, yield, and quality grade. Using equations described in Mohrhauser (2015a) marbling to backfat ratio of each carcass was determined.

Meat Quality

Preparation

The left strip loin of each carcass was retained for meat quality analysis. Strip loins were vacuum packaged and allowed to wet age for 14 days postmortem at refrigeration temperatures (4°C). After the aging period loins were frozen whole at -20°C and stored prior to being fabricated into steaks. Frozen subprimal loins were cut using a ban saw (Butcher boy; American meat equipment, LLC; Model # SA-16; Selmer, TN) into 2.5 cm thick steaks which were then placed into individual vacuum packaging and stored at -20˚C until meat quality testing. Six steaks from each loin were used for meat quality testing; one for shear force, one for composition analysis, two for sensory, and two were retained as extras. Live animal ear tag number, carcass number, loin number

and steak number identification was used to link and identify individual animal to individual steak at each stage of meat production.

Cooking procedures for sensory and WBSF analysis is described as follows. Steaks were allowed to thaw for 24 hours at 4°C refrigeration in their vacuum packaging. External fat, and muscles were removed leaving only the *longissimus lumborum* muscle. Prior to being placed on the grill, an initial internal temperature was recorded for each sample using a thermometer (IPX&- waterproof thermocouple; Cooper-Atkins; 352 Aqua Tuff, Middlefield, CT). Then the steaks were placed on a clam shell grill (Griddler Deluxe; Cuisinart; GR-150; East Windsor, NJ) at a grill surface temperature of 232°C and cooked to a medium degree of doneness (internal temperature of 70°C).

Sensory

Steaks were cooked as described above. For sensory analysis steak sample preparation followed guidelines discussed in American Meat Science Association (2015). After cooking, steaks were allowed to rest for three minutes before being cut into one 2×2 cm and three 1×1 cm samples and placed in a plastic sample cup with a plastic lid. Samples were placed on a warm clay brick (pre-heated in an oven at approximately 121°C) to maintain sample temperature during evaluation. Samples were evaluated under red lighting. Distilled water and unsalted crackers were used as pallet cleansers between each sample. Sensory evaluation was conducted at the USU Department of Nutrition, Dietetics, and Food Science facilities by a trained flavor and texture descriptive panel with 12 beef lexicon attributes on a 15-point numerical scale with 0.5 increments (Adhikari et al. 2011). Panelists training used reference anchors outlined by the beef flavor and texture lexicon describe in Adhikari (2011) to give a 1-15 numerical value of

intensity to 12 beef sensory attributes, with 1 being slight, 7 the middle point, and 15 being strong (Table 2). Each panelist evaluated each sample of steak on the 12 sensory characteristics.

Table 2. Sensory flavor panel 1-15-point numerical scale with 0.5 increments.

Sensory Aroma and Flavor References and Definitions		
Attribute	Definition	Reference associated with attribute
Beef flavor Identity*	Amount of beef flavor	Swanson's beef broth = 6.0 80% lean ground beef = 7.0 Beef brisket = 11.0
Bloody/Serumy*	Aromatics of blood on cooked meat products, closely related to metallic aromatic.	USDA choice strip steak = 5.5 Beef brisket = 6.0
Brown/roasted*	Full aromatic generally associated with broiled beef suet	Beef suet = 8.5 80% lean ground beef = 10.0
Fat-like*	Aromatics associated with cooked animal fat	Hillshire farms lit'l beef smokies = 7.0 Beef suet = 12.0
Liver-like	Aromatics associated with cooked organ meat/ liver	Flat iron steak = 3.0 Beef liver = 13.0
Oxidation	Aromatics associated with aged oil and fat	beef suet = 2.0
Bitter*	Taste factor associated with caffeine solution	0.01% caffeine solution = 2.0 0.02% caffeine solution = 3.5
Salty*	Taste factor associated with Sodium chloride solution	0.15% sodium chloride solution = 1.5 0.25% sodium chloride solution = 3.5
Sour*	Taste factor associated with citric acid solution	0.015% citric acid solution = 1.5 0.050% citric acid solution = 3.5
Umami*	Flat, salty, brothy; taste of glutamate, salts of amino acids and nucleotides	Swanson's beef broth = 4.5
Overall tenderness	Ease with which sample can be cut through with molars after 3-4 chews	
Overall Juiciness	Amount of juice released during the first 3-4 chews or the amount of moisture removed from the mouth during the first 3-4 chews (dryness)	

* Major attributes: attributes present in 99% of beef samples evaluated by adhikari et al., 2011 sensory panel

Shear Force

Warner-Bratzler shear force was used to quantify tenderness using methods outlined by the American Meat Science Association (2015). Steak preparation and cooking was done following the methods outlined above. After cooking, steaks were covered with plastic wrap on metal trays and allowed to rest 24 h at 4˚C in a refrigerator. After the resting period, steaks were removed from the refrigerator and placed on the table top and allowed to reach room temperature of approximately 23°C for a minimum of one hour before being cored. Seven 1.27 cm core samples were taken from each steak sample following the grain of the longitudinal muscle fibers to be sheared on a TMS-Pro Texture Analyzer (FTC 500N ILC, Food Technology Corporation, Sterling, Virginia) with a specific blade attachment for Warner-Bratzler shear force using 200 mm/min crosshead speed and a 500 N load cell.

Color

Instrumental measurement of raw steak color used a colorimeter (MiniScan; HunterLab; XE plus 45/0-S; Reston, VA) to determine meat color values based on Hunter Lab values. The procedure outlined in American Meat Science Association Meat color measurement guidelines (2012) was used as a reference to standardize the instrument using black and white standardizing tiles and methods to conduct color measurement of steak samples. Twenty-four hours after thawing at 4°C, steaks were removed from their vacuum packaging and allowed to bloom for 20-30 minutes. Plastic wrap was used during standardization and was placed on the surface of the raw steak sample so that a

colorimeter can be placed on the surface of the steak at a 90° angle to get a reading for the Hunter Lab values, L*, a*and b*. The scale for L* is from 0 (black) to 100 (white). Positive a* represents red and a negative a* represents green, positive b* values represent yellow and negative b* values represent blue. Hue angle was calculated using the equation HA = [arctangent (b*/a*)] from American Meat Science Association Meat color measurement guidelines (2012).

Steak Composition Analysis

Steak composition analysis was conducted at Texas Tech University facilities following the AOAC approved official method outlined in Anderson et al. (2007) employing a near infrared spectrophotometer (FoodScan, FOSS NIRsystems Inc., Laurel, MD) to determine steak protein, fat, collagen, and moisture chemical percentages. Steaks were thawed for 24 h at 4°C in vacuum packaging. Prior to testing, all external fat and muscles were removed leaving only the *Longissimus lumborum*. The steak was then ground using an electric table top meat grinder (Gander Mountain Heavy Duty 1/4 HP #5 electric meat grinder. Model no. MG-204182-13. Gander Outdoors (formerly Gander Mountain, Inc.); St. Paul, MN) to obtain approximately a 180 g homogenized sample for analysis. Care was taken to ensure the temperature was kept at 10-20°C and air pockets in the sample were avoided to minimize the chance of inaccurate readings.

Statistical Analysis

This study utilized a completely randomized design. The individual calves (N = 34) serve as the experimental unit in measuring calf feedlot performance, carcass traits, and meat quality. Measurements of calf growth, carcass values, and meat quality all use

individual calf or carcass as the experimental unit, and comparisons were made within each individual time point to determine the effects of the treatment that was placed on the dam. Analysis of feedlot performance, carcass measurements and meat quality used the general linear mixed model procedure of SAS® version 9.4 (SAS Institute, Cary, NC). Calf body weight was analyzed using the repeated measurement analysis of SAS® version 9.4 (SAS Institute, Cary, NC). Animal sex, pen, and barn where the animal was housed are each included as random variables in the model. All statistical comparisons used a significance level of 0.05.

RESULTS AND DISCUSSION

Finishing Feedlot Data

Body Weight and Average Daily Gain

Body weight did not differ at any 28-day time point ($P \geq 0.34$; Table 3) between maintenance calves and calves born to nutrient restricted cows. No difference existed between the two groups for average daily gain at any 28-day time point ($P \geq 0.20$).

Table 3. LS means of feedlot measurements of body weight and average daily gain of calves from maintenance and restricted cows.

Feedlot Measurements			
Item	Treatment[1]		P-value[2]
	Maintenance	Restricted	
BWT[3] (kg)			
Day 85	384 ± 17.41	372 ± 17.09	0.48
Day 112	418 ± 19.71	405 ± 19.41	0.45
Day 140	464 ± 22.13	448 ± 21.89	0.34
Day 169	508 ± 26.04	498 ± 25.86	0.57
Average Daily gain[4] (kg)			
Day 85-111	1.29 ± 0.09	1.19 ± 0.08	0.33
Day 112-139	1.67 ± 0.18	1.58 ± 0.17	0.61
Day 140-168	0.56 ± 0.14	0.58 ± 0.14	0.49
Day 169-186	0.91 ± 0.59	0.62 ± 0.56	0.20

[1]Maintenance cows' calves (n = 16), nutrient restricted cows' calves (n = 18)
[2]Probability value of the F-test for treatment effect
[3]Body weight in kg at 28-day time points
[4]Average daily gain at 28-day time points= total weight gain in kg/ number of days of time point

Weight Gain

When measuring weight gain over the period of the finishing feedlot phase (P <

0.001; Figure 1) Calves from both groups increased in weight over time, without any influence from treatment (P = 0.45) or the treatment*time interaction (P = 0.99). The increase in calf weight is an agreement with numerous other observations of the feedlot stage of beef production, where cattle eat high energy diets resulting in rapid growth (Owens et al., 1995).

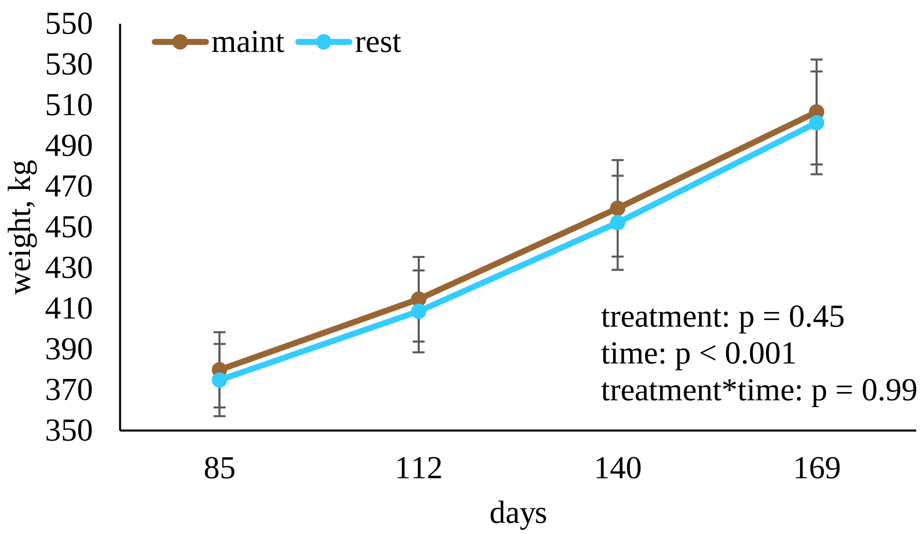

Figure 1. Repeated measures for body weight of calve whose dams underwent nutrient restricted during mid-gestation (n = 18) and calves whose did not experience nutrient restriction (n = 16) over the finishing feedlot phase and the effect of treatment, time, and treatment*time interaction based on the significance level 0.05.

There was no difference in body weight at day 85, 112, 140, or 169 (P > 0.05). Underwood (2010) determined that steers whose dams grazed native range during gestation were slightly lighter than their counterparts whose dams grazed on improved pasture at various time points. It should be noted that the current study does have a small sample size that may be influencing the statistical analysis; therefore, further investigation into weight gain of calves whose cows underwent nutrient restriction during mid-gestation using a larger sample size is warranted.

Dry Matter Intake and Feed Efficiency

Feedlot measurements of total dry matter intake throughout the finishing feedlot period ($P \geq 0.26$; Table 4), daily dry matter intake ($P \geq 0.37$) and feed efficiency ($P \geq 0.43$) were each similar between calves from maintenance or restricted dams.

Table 4. LS means of feedlot measurements of dry matter feed intake and efficiency of calves from maintenance and restricted cows.

Feedlot Measurements			
Item	Treatment[1]		P-value[2]
	Maintenance	Restricted	
Total DMI[3] (kg)			
Day 85-111	296 ± 17.52	289 ± 17.22	0.63
Day 112-139	287 ± 8.97	277 ± 8.57	0.37
Day 140-168	360 ± 16.91	363 ± 16.72	0.82
Day 169-186	173 ± 10.76	158 ± 10.28	0.26
Daily DMI[4] (kg)			
Day 85-111	10.98 ± 0.65	10.71 ± 0.64	0.63
Day 112-139	10.65 ± 0.33	10.25 ± 0.32	0.37
Day 140-168	12.42 ± 0.58	12.52 ± 0.58	0.82
Day 169-186	10.83 ± 0.39	10.49 ± 0.37	0.41
FE[5] (kg)			
Day 85-111	0.12 ± 0.01	0.11 ± 0.01	0.60
Day 112-139	0.16 ± 0.02	0.15 ± 0.01	0.70
Day 140-168	0.13 ± 0.01	0.14 ± 0.01	0.50
Day 169-186	0.24 ± 0.06	0.17 ± 0.06	0.43

[1]Maintenance cows' calves (n = 16), nutrient restricted cows' calves (n = 18)
[2]Probability value of the F-test for treatment effect
[3]Total dry matter intake in kg for the 28-day time points
[4]Average daily dry matter intake in kg for the 28-day time points. Calculated as DMTI/number of days of the time point
[5]Feed efficiency in kg for the 28-day time points. Calculated as weight gain/ total feed intake (DM basis) for that time point

In the current study, results show no effect ($P > 0.05$) of nutrient restriction during

mid-gestation on calf average daily gain, dry matter intake or feed efficiency. These results agree with a study by Taylor (2016) who found that calves from nutrient restricted dams had a lighter initial body weight and no difference in feedlot performance such as average daily gain, dry matter intake or growth efficiency at any time point. The backgrounding and early feedlot phase in Gardner et al. (2016) also found no difference in calf feedlot performance of either nutrient restricted or maintenance groups. This study reveals promising results and demonstrates that a loss of one BCS during mid-gestation may not have adverse effects on calf finishing feedlot performance. However, further investigation of calf weight during the finishing feedlot phase needs to be conducted.

Carcass Measurements

Carcass Characteristics

Carcass characteristics of calves born from both nutrient restricted dams and dams that had no nutritional restriction during mid-gestation can be seen in Table 5. There was no difference in carcass characteristics between the restricted group and the maintenance group of calves in this study ($P \geq 0.18$). There was a trend for restricted calves to have an improved marbling to backfat ratio when compared to maintenance calves ($P = 0.10$). Hot carcass weights of calves were similar between both the maintenance and restricted groups ($P = 0.15$). No difference in %KPH fat ($P = 0.49$), ribeye area ($P = 0.86$), loin weight ($P = 0.38$), or marbling score ($P = 0.44$) was identified between the maintenance and restricted groups. There was no difference in USDA Yield grade ($P = 0.16$) or adjusted 12th rib backfat ($P = 0.18$) between the two treatment groups.

Table 5. LS means of carcass measurements of calves from maintenance and restricted cows.

Carcass Measurements		
	Treatment[1]	P-value[2]

	Maintenance	Restricted	
Hot carcass weight (kg)	324.64 ± 9.33	313.66 ± 9.23	0.15
Loin weight (kg)	5.56 ± 0.30	5.29 ± 0.30	0.38
Kidney, pelvic, and heart fat (%)	2.47 ± 0.30	2.58 ± 0.30	0.49
Ribeye area (cm^2)	73.86 ± 3.38	73.48 ± 3.36	0.86
USDA Yield Grade	3.08 ± 0.24	2.82 ± 0.23	0.16
Adjusted 12th rib backfat (cm)	7.78 ± 0.42	7.10 ± 0.40	0.18
Marbling Score[3]	533.38 ± 25.18	560.56 ± 23.74	0.44
Marbling to backfat Ratio[4]	-0.36 ± 0.34	0.34 ± 0.32	0.10

[1]Maintenance cows' calves (n = 16), nutrient restricted cows' calves (n = 18)
[2]Probability value of the F-test for treatment effect
[3]Marbling score = 9 levels of marbling category (devoid-abundant) with 100 degrees of variation (0-99) within levels
[4]Marbling to backfat ratio was determined using the calculations previously described by Mohrhauser et al., 2015a. [(observation marbling score- marbling score x̄)/marbling SD]- [(observation backfat- backfat x̄)/backfat SD]

Carcasses from both maintenance and restricted calves were assessed and given a USDA quality and yield grade (Table 6). Both treatment groups had 3 carcasses each grade USDA prime with both groups having a large amount of carcasses grade USDA choice (maintenance = 13 and restricted = 14), and only one restricted carcass grading USDA select. Maintenance carcasses had no USDA YG 1 and only a small amount of yield grade 4 carcasses (6%). Restricted calf carcasses had one carcass with a YG 1 and no YG 4 demonstrating that this treatment group had the largest amount of carcasses in the ideal range of YG 2 and 3. When comparing USDA quality and yield grades the majority of carcasses graded Choice with a YG of 2 for both treatment groups demonstrating that calves from cows who underwent a nutrient restriction during mid gestation can still produce a high quality carcasses without jeopardizing yield.

Table 6. USDA carcass quality and yield grades of calves from maintenance and restricted cows.

Carcass Measurements	
Item	Treatment[1]

	Maintenance	Restricted
USDA Quality grade		
Prime	9%	9%
Choice	38%	41%
Select	0%	3%
USDA Yield grade		
YG 1	0%	3%
YG 2	24%	24%
YG 3	18%	26%
YG 4	6%	0%

[1]Maintenance cows' calves (n = 16), nutrient restricted cows' calves (n = 18)

These results are promising in that they demonstrate that if a cow undergoes nutrient restriction during mid-gestation there is no deleterious effect to her offspring carcass measurements. Studies conducted by Mohrhauser (2015a, b) and Long (2012) who both restricted nutrition during mid-gestation also found no difference in HCW, KPH, adjusted 12th rib backfat, and marbling score of offspring. Greenwood (2009) and Underwood (2010) each found that offspring from nutrient restricted cows during mid to late-gestation had a decrease in HCW, which was not seen in the present study. Mohrhauser (2015a,b) found a lower USDA YG, while Long (2012) found an increase in YG; inconclusively no change in YG was observed in the current study. Mohrhauser (2015b) also found that offspring from nutrient restricted dams during mid-gestation had an improved marbling to backfat ratio, which demonstrates a change in fat deposition that could improve carcass values. However, in the current study only a trend toward a difference in marbling to backfat ratio was observed. With restricted calves having more marbling than backfat compared to maintenance animals who had more backfat than marbling reveals that nutrient restriction during mid-gestation may not having negative effects to offspring carcass characteristics.

Meat Quality Measurements

Sensory

Sensory evaluation of calves born from both nutrient restricted dams and maintenance dams are in Table 7. Steaks from nutrient restricted animals were perceived as more tender to a trained sensory panel (P = 0.05) when compared to steaks from maintenance calves. However, the likelihood of consumers detecting this difference in tenderness is doubtful (Keady et al., 2017). There was a trend for steaks from nutrient restricted cattle to have a greater bloody/serumy flavor (P = 0.08) which is an indication of high-quality steaks described by Adhikari et al. (2011) as a major attribute found in carcasses that have a high-quality grade. However further investigation into the ability for untrained consumers to pick up this slight change in flavor characteristics of steaks from nutrient restricted animals is still uncertain. When comparing steaks between the maintenance and restricted groups, there was no difference in intensity of juiciness (P = 0.27), beef flavor identity (P = 0.35), brown/ roasted (P = 0.39), fat like (P = 0.97), liver like (P = 0.39), oxidized (P = 0.50), sour (P = 0.97), bitter (P = 0.33), salty (P = 0.18), and umami (P = 0.60).

Table 7. LS means of trained sensory flavor values of calves from maintenance and restricted cows.

Meat Quality Measurements			
Item	Treatment[1]		P-value[2]
	Maintenance	Restricted	
Sensory (15-point Numerical scale)[3]			
Beef ID	7.59 ± 0.12	7.46 ± 0.12	0.35
Blood/Serumy	3.19 ± 0.21	3.59 ± 0.22	0.08
Brown/ Roasted	7.09 ± 0.20	6.86 ± 0.21	0.39
Fat Like	2.48 ± 0.11	2.48 ± 0.11	0.97
Liver Like	0.39 ± 0.07	0.30 ± 0.07	0.39

Oxidized	0.62 ± 0.13	0.51 ± 0.13	0.50
Sour	0.63 ± 0.07	0.63 ± 0.07	0.97
Bitter	0.54 ± 0.06	0.45 ± 0.07	0.33
Salty	1.23 ± 0.05	1.14 ± 0.05	0.18
Umami	3.15 ± 0.12	3.24 ± 0.13	0.60
Tenderness	9.12 ± 0.29	9.72 ± 0.30	0.05
Juiciness	8.43 ± 0.16	8.69 ± 0.17	0.27

[1]Maintenance cows' calves (n = 16), nutrient restricted cows' calves (n = 18)

[2]Probability value of the F-test for treatment effect

[3]Sensory values obtained using a trained panel, based on a 15-point numerical scale outlined in Adhikari et al. (2011)

Shear Force and Composition Analysis

Warner-Bratzler Shear Force values and steak composition results are presented in Table 8. Warner-Bratzler Shear Force values did not differ (P = 0.76) between treatment groups. There was no difference in percent fat (P = 0.88), moisture (P = 0.84), protein (P = 0.77), and collagen (P = 0.97) content of steaks from calves in each treatment group.

Table 8. LS means of meat tenderness and composition values of calves from maintenance and restricted cows.

Meat Quality Measurements			
Item	Treatment[1]		P-value[2]
	Maintenance	Restricted	
WBSF (N)	30.93 ± 3.37	30.03 ± 3.45	0.76
Composition Analysis (%)			
Fat (%)	7.26 ± 1.01	7.40 ± 1.02	0.88
Moisture (%)	69.34 ± 0.91	69.18 ± 0.92	0.84
Protein (%)	22.10 ± 0.27	22.01 ± 0.28	0.77
Collagen (%)	1.73 ± 0.05	1.73 ± 0.05	0.97

[1]Maintenance cows' calves (n = 16), nutrient restricted cows' calves (n = 18)

[2]Probability value of the F-test for treatment effect

Interestingly this study found that steaks from restricted calves were perceived as more tender when assessed by a trained descriptive sensory panel (Table 7). However, there was no difference in WBSF instrumental values of tenderness (Table 8). Typically, when a steak is more tender it has a lower WBSF value which can be seen in the literature demonstrated as a negative correlation between tenderness and WBSF value (Chriki et al., 2012).

The amount of marbling could also explain why there was no difference in WBSF values (Table 8). Emerson (2013) found that steaks with small amounts of marbling were less tender than steaks that had modest and moderate amounts of marbling based on WBSF values, however there was no difference in WBSF between modest and moderate steaks. With the current study both the restricted and maintenance groups had a high number of carcasses that graded modest and moderate which may account for no difference in WBSF value. The WBSF findings in this study are consistent with findings by Mohrhauser (2015b) which also found there was no difference in quantitative tenderness of calves from dams that experienced either a negative or positive energy status during mid-gestion. Mohrhauser (2015a) found no difference in steak WBSF values at 2 and 14 days of aging, and that at 21 d of aging WBSF values were less for steers whose dams underwent nutrient restriction during mid-gestation. The results by Mohrhauser (2015a,b) reveal the possibility of nutrient restriction having an effect on meat tenderness. The current study however did not find any difference in instrumental measures of tenderness (Table 8) which may be due to the fact that our steaks were aged for 14 days and the relatively small sample size.

No difference in composition analysis of steaks in the current study (Table 8) is

consistent with findings by Mohrhauser (2015a) who also found no difference in percent protein, fat, or moisture of steaks when comparing offspring from dams that had a mid-gestational nutrient restriction. However, Mohrhauser (2015a) did find a difference in collagen content, with nutrient restricted cattle having a lower total collagen content then their non-restricted counterparts, never the less the current study did not find a difference in collagen content (Table 8). Which may be due to their treatment groups while our treatment groups were either maintence or restricted Mohrhauser (2015a) treatment groups were either a positive or negative engery status for the dam during mid-gestation, arguing that their comparative group positive energy status may have been obese cows. which Huang (2010) showed that obse cows had offspring with an increase in collagen content, whereas our cows were not obese and could be the reason for the difference in results.

Color

All measurements of Hunter Lab values are in Table 9. L* (P = 0.37), a* (P = 1.00), b* (P = 0.28) did not differ between restricted and maintenance calves. The calculated hue angle (P = 0.23) was similar between both treatment groups. The results of this study are in agreeance with a study conducted by Webb (2019) who also found that nutrient restriction during mid-gestation had no effect on meat color. From a retail stand point the visual appearance of steaks are important, with consumers wanting a bright cherry red color in their steaks (Suman et al., 2014). In this study, we did not remove 3 carcasses that were labeled by USDA certified graders as dark cutters from analysis. Removing dark cutters may change our results, however a study by Mohrhauser (2015b) did remove 15 dark cutter carcasses from their analysis and they too also found no

difference in color of steaks from calves whose dams were nutrient restricted during mid-gestation.

Table 9. LS means of meat color values of calves from maintenance and restricted cows.

Meat Quality Measurements			
Item	Treatment[1]		P-value[2]
	Maintenance	Restricted	
Hunter color values[3]			
L*	34.09 ± 0.99	35.04 ± 1.03	0.37
a*	10.22 ± 0.32	10.22 ± 0.33	1.00
b*	12.02 ± 0.38	12.57 ± 0.38	0.28
Hue Angle[4]	0.86 ± 0.02	0.89 ± 0.02	0.23

[1]Maintenance cows' calves (n = 16), nutrient restricted cows' calves (n = 18)

[2]Probability value of the F-test for treatment effect

[3]Color values based of off the Hunter Lab color values, found in AMSA Meat color measurement guidelines et al. (2012).

[4]Hue Angle value calculate using the equation outlined in AMSA Meat color measurement guidelines et al. (2012)

CONCLUSION

While cows underwent nutrient restriction during mid-gestation in this study, which may already be occurring in regions such as the Intermountain West due to fluctuations in climate, this did not have any negative effects to their calves finishing feedlot performance, carcass characteristics, and meat quality. The current study did find that steaks from calves whose dams underwent nutrient restriction during mid-gestation had a perceived increase in tenderness when assessed by a trained sensory panel even though WBSF values of instrumental tenderness were not different. The results of this study have implications for producers, consumers and the meat industry as a whole demonstrating that if a cow undergoes a restriction during mid-gestation will not negatively impacting calf performance or jeopardizing meat quality and that the restricted calves can still preform alongside their counterparts. This study demonstrates that cows who undergo a maternal nutrient restriction during mid-gestation can still produce a productive calf that yields a quality meat product.

LITERATURE CITED

Adhikari, K., Chambers IV, E., Miller, R., Vázquez-Araújo, L., Bhumiratana, N. and Philip, C. 2011. Development of a lexicon for beef flavor in intact muscle. Journal of Sensory Studies, 26: 413–420. doi: 10.1111/j.1745-459X.2011. 00356.x

AMSA. 2001. Meat evaluation handbook. Am. Meat Sci. Assn. and Natl. Live Stock and Meat Board, Chicago, IL.

AMSA. 2012. Meat Color Measurement Guidelines. Champaign, Illinois: American Meat Science Association.

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

AMSA. 2016. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. 2nd Ed. Version 1.02. Am. Meat Sci. Assoc. Champaign, Il.

Anderson, S. 2007. Determination of fat, moisture, and protein in meat and meat products by using the FOSS FoodScan near-infrared spectrophotometer with FOSS artificial neural network calibration model and associated database: collaborative study. Journal of AOAC International, 90(4), 1073-1083.

Arthur, P. F., J. A. Archer, D. J. Johnston, R. M. Herd, E. C. Richardson, and P. F. Parnell. 2001. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other post weaning traits in Angus cattle. J. Anim. Sci. 79:2805–2811.

Barker, D.J., 1995. Intrauterine programming of adult disease. Molecular medicine today, 1, 418-423.

Bass, P.D., 2016. The scientific basis of the Certified Angus Beef® Brand Carcass Specifications.

Beermann, D.H., Cassens, R.G. and Hausman, G.J., 1978. A second look at fiber type differentiation in porcine skeletal muscle. Journal of animal science, 46(1), pp.125-132.

Behrends, J.M., K.J. Goodson, M. Koohmaraie, S.D.Shackelford, T.L. Wheeler, W.W. Morgan, J.O. Reagan, B.L. Gwartney, J.W. Wise, and J.W. Savell. 2005. Beef customer satisfaction: USDA quality grade and marination effects on consumer evaluations of top round steaks. J. Anim. Sci. 83:662-670.

Bell, A.W. and Greenwood, P.L., 2016. Prenatal origins of postnatal variation in growth, development, and productivity of ruminants. Animal Production Science, 56(8), pp.1217-1232.

Bispham, J., G. S. Gopalakrishnan, J. Dandrea, V. Wilson, H. Budge, D. H. Keisler, F. Broughton Pipkin, T. Stephenson, and M. E. Symonds., 2003. "Maternal endocrine adaptation throughout pregnancy to nutritional manipulation: consequences for maternal plasma leptin and cortisol and the programming of

fetal adipose tissue development." Endocrinology 144: 3575-3585.

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 peroxisosome proliferator-activated and prolactin receptors. Endocrinology, 146: 3943-3949.

Bonnet, M., I. Cassar-Malek, Y. Chilliard, and B. Picard. 2010. Ontogenesis of muscle and adipose tissues and their interactions in ruminants and other species. Anim. Consort. 4:1093–1109.

Brameld, J. M., a Mostyn, J. Dandrea, T. J. Stephenson, J. M. Dawson, P. J. Buttery, and M. E. Symonds. 2000. Maternal nutrition alters the expression of insulin-like growth factors in fetal sheep liver and skeletal muscle. J. Endocrinol. 167:429–437.

Brethour, J.R., 2000. Using serial ultrasound measures to generate models of marbling and backfat thickness changes in feedlot cattle. Journal of animal science, 78(8), pp.2055-2061.

Caton, J.S. and Hess, B.W., 2010, July. Maternal plane of nutrition: Impacts on fetal outcomes and postnatal offspring responses. In Proc. 4th Grazing Livestock Nutrition Conference. BW Hess, T. DelCurto, JGP Bowman and RC Waterman (eds.) West. Sect. Am. Soc. Anim. Sci., Champaign, Ill (pp. 104-122).

Chriki, S., Gardner, G.E., Jurie, C., Picard, B., Micol, D., Brun, J.P., Journaux, L. and Hocquette, J.F., 2012. Cluster analysis application identifies muscle characteristics of importance for beef tenderness. BMC biochemistry, 13(1), p.29.

Corbin, C. H., T. G. O'Quinn, A. J. Garmyn, J. F. Legako, M. R. Hunt, T. T. N. Dinh, R. J. Rathmann, J. C. Brooks, and M. F. Miller. 2015. Sensory evaluation of tender beef strip loin steaks of varying marbling levels and quality treatments. Meat Sci. 100:24–31.

Cossu, G. and Borello, U., 1999. Wnt signaling and the activation of myogenesis in mammals. The EMBO journal, 18(24), pp.6867-6872.

DelCurto, T., D. Bohnert, and C. Ackerman. 2000. Characteristics and challenges of sustainable beef production in the western U.S. Station Bulletin 683. Agriculture Experiment Station. Oregon State Univ., Corvallis, OR. p. 6–16.

Dikeman, M. E. 1987. Fat reduction in animals and the effects on palatability and consumer acceptance of meat products. Pages 93–103 in Recip. Meat Conf.

Dikeman, M. E., L. V. Cundiff, K. E. Gregory, K. E. Kemp, and R. M. Koch. 1998. Relative contributions of subcutaneous and intermuscular fat to yields and predictability of retail product, fat trim, and bone in beef carcasses. J. Anim. Sci. 76:1604–1612.

Du, M., Tong, J. Underwood, K. R. Zhu, M. Ford, S. P. & Nathanielsz, P.W. 2010. Fetal programming of skeletal muscle development in ruminant animals. Journal of Animal Science, 88: 51-60

Du, M., and M. V Dodson. 2011b. Advanced techniques to enhance marbling in meat. Control Meat Qual. 661:105–115.

Du, M., J. X. Zhao, X. Yan, Y. Huang, L. V Nicodemus, W. Yue, R. J. McCormick, and M. J. Zhu. 2011a. Fetal muscle development, mesenchymal multipotent cell differentiation, and associated signaling pathways. J. Anim. Sci. 89:583–90.

Du, M., Y. Huang, a. K. Das, Q. Yang, M. S. Duarte, M. V. Dodson, and M.-J. Zhu. 2013. Manipulating mesenchymal progenitor cell differentiation to optimize performance and carcass value of beef cattle. J. Anim. Sci. 91:1419–1427.

Du, M., Wang, B., Fu, X., Yang, Q., & Zhu, M. J. 2015. Fetal programming in meat production. Meat science, 109, 40-47.

Du, M., Ford, S.P. and Zhu, M.J. 2017. Optimizing livestock production efficiency through maternal nutritional management and fetal developmental programming. Animal Frontiers, 7(3), pp.5-11.

Duarte, M.S., Paulino, P.V.R., Das, A.K., Wei, S., Serao, N.V.L., Fu, X., Harris, S.M., Dodson, M.V. and Du, M., 2013. Enhancement of adipogenesis and fibrogenesis in skeletal muscle of Wagyu compared with Angus cattle. Journal of animal science, 91(6), pp.2938-2946.

Edwards, L. J., McFarlane, J. R. Kauter, K. G. & McMillen, I. C. 2005. Impact of periconceptional nutrition on maternal and fetal leptin and fetal adiposity in singleton and twin pregnancies. American Journal of Physiology: Regulatory Integrative Comparative Physiology, 288: R39-45.

Emerson, M. R., D. R. Woerner, K. E. Belk, and J. D. Tatum. 2013. Effectiveness of USDA instrument-based marbling measurements for categorizing beef carcasses according to differences in longissimus muscle sensory attributes 1. :1024–1034

Enk, T. A., H. O. Picton, and J. S. Williams. 2001. Factors Limiting a Bighorn Sheep Population in Montana Following a Dieoff. Northwest Sci. 75.

Farmer, S.R., 2006. Transcriptional control of adipocyte formation. Cell metabolism, 4(4), pp.263-273.

Fève, B., 2005. Adipogenesis: cellular and molecular aspects. Best Practice & Research Clinical Endocrinology & Metabolism, 19(4), pp.483-499.

Ford, S. P., B. W. Hess, M. M. Schwope, M. J. Nijland, J. S. Gilbert, K. A. Vonnahme, W. J. Means, H. Han, and P. W. Nathanielsz. 2007. Maternal undernutrition during early to mid-gestation in the ewe results in altered growth, adiposity, and glucose tolerance in male offspring. J. Anim. Sci. 85:1285-1294.

Funston, R. N., D. M. Larson, and K. a. Vonnahme. 2010. Effects of maternal nutrition on conceptus growth and offspring performance: implications for beef cattle production. J. Anim. Sci. 88:205–215.

Funston, R. N., A. F. Summers, and A. J. Roberts. 2012. Alpharma beef cattle nutrition symposium: Implications of nutritional management for beef cow-calf systems. J. Anim. Sci. 90: 2301-2307.

Gardner J. M. 2016. Effects of gestational dietary intake on calf growth and early feedlot performance of offspring. Logan, Utah: Thesis.

Garmyn, A. J., Hilton, G. G. Mateescu, R. G. Morgan, J. B. Reecy, J. M. Tait, R. G. Beitz, D. C. Duan, Q. Schoonmaker, J. P. Mayes, M. S. Drewnoski, M. E. Liu, Q. & VanOverbeke, D. L. 2011. Estimation of relationships between mineral concentration and fatty acid composition of longissimus muscle and beef palatability traits. Journal of Animal Science, 89: 2849-2858.

Glore, S.R. and Layman, D.K., 1983. Cellular growth of skeletal muscle in weanling rats during dietary restrictions. Growth, 47(4), pp.403-410.

Godfrey, K.M. and Barker, D.J., 1995. Maternal nutrition in relation to fetal and placental growth. European Journal of Obstetrics & Gynecology and Reproductive Biology, 61(1), pp.15-22.

Godfrey, K., and D. Barker. 2000. Fetal nutrition and adult disease. Am. J. Clin. Nutr. 71:1344–1352.

Gonzalez-Bulnes, A., Ovilo, C., Lopez-Bote, C.J., Astiz, S., Ayuso, M., Perez-Solana, M.L., Sanchez-Sanchez, R. and Torres-Rovira, L., 2012. Gender-specific early postnatal catch-up growth after intrauterine growth retardation by food restriction in swine with obesity/leptin resistance. Reproduction, 144(2), pp.269-278.

Greenwood, P. L., A. S. Hunt, J. W. Hermanson, and A. W. Bell. 2000. Effects of birth weight and postnatal nutrition on neonatal sheep: II. Skeletal muscle growth and development. J. Anim. Sci. 78:50–61.

Greenwood, P.L., Cafe, L.M., Hearnshaw, H. and Hennessy, D.W., 2005. Consequences of nutrition and growth retardation early in life for growth and composition of cattle and eating quality of beef. Recent Advances in Animal Nutrition in Australia, 15, pp.183-195.

Greenwood, P.L. and Thompson, A.N., 2007. Consequences of maternal nutrition during pregnancy and of foetal growth for productivity of sheep. Recent advances in animal nutrition in Australia, 16, pp.185-196.

Greenwood, P. L., L. M. Cafe, H. Hearnshaw, D. W. Hennessy, and S. G. Morris. 2009. Consequences of prenatal and preweaning growth for yield of beef primal cuts from 30-month-old Piedmontese- and Wagyu-sired cattle. Anim. Prod. Sci. 49:468–478. doi:10.1071/EA08160

Greenwood, P.L., Thompson, A.N. and Ford, S.P., 2010. Postnatal consequences of the maternal environment and of growth during prenatal life for productivity of ruminants. In ‘Managing the prenatal environment to enhance livestock productivity’.(Eds PL Greenwood, AW Bell, PE Vercoe, GJ Viljoen) pp. 3–36.

Gupta, R.K., Arany, Z., Seale, P., Mepani, R.J., Ye, L., Conroe, H.M., Roby, Y.A., Kulaga, H., Reed, R.R. and Spiegelman, B.M., 2010. Transcriptional control of preadipocyte determination by Zfp423. Nature, 464(7288), pp.619-623.

Gupta, R.K., Mepani, R.J., Kleiner, S., Lo, J.C., Khandekar, M.J., Cohen, P., Frontini, A., Bhowmick, D.C., Ye, L., Cinti, S. and Spiegelman, B.M., 2012. Zfp423

expression identifies committed preadipocytes and localizes to adipose endothelial and perivascular cells. Cell metabolism, 15(2), pp.230-239.

Hale, D. S., Goodson, K., & Savell, J. W. (2013). USDA beef quality and yield grades. Department of Animal Science Texas A&M AgriLife Extension Service College Station TX 77843, 2471.

Hamilton, T. 2010. Basic beef cattle nutrition. Minist. Agric. Food Rural Aff. Available from: http://www.omafra.gov.on.ca/english/livestock/beef/facts/91-066.htm

Hammond, J. 1943. Physiological factors affecting birth weight. Proc. Nutr. Soc. 2:8–12.

Hennessy, D.W., Hearnshaw, H., Greenwood, P.L., Harper, G.S. and Morris, S.G. (2002). The effects of low or high quality pastures on the liveweight of cows at calving and on birth weight of calves sired by Wagyu or Piedmontese. Animal Production in Australia 24, 311.

Huang, Y., Yan, X., Zhu, M.J., McCormick, R.J., Ford, S.P., Nathanielsz, P.W., et al. (2010). Enhanced transforming growth factor-beta signaling and fibrogenesis in ovine fetal skeletal muscle of obese dams at late gestation. American Journal of Physiology- Endocrinology and metabolism, 298, E1254-E1260.

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 Sci. 98:1–8.

Jensen, K. B., D. A. Johnson, K. H. Asay, and K. C. Olson. 2002. Seasonal-accumulated growth and forage quality of range grasses for fall and winter grazing. 6300:329–336.

Joe, A.W., Yi, L., Natarajan, A., Le Grand, F., So, L., Wang, J., Rudnicki, M.A. and Rossi, F.M., 2010. Muscle injury activates resident fibro/adipogenic progenitors that facilitate myogenesis. Nature cell biology, 12(2), pp.153-163.

Johnson, D. E., C. L. Ferrell, and T. G. Jenkins. 2003. The history of energetic effi ciency research: Where have we been and where are we going? J. Anim. Sci. 81(E-Suppl.):E27–E38.

Keady, S.M., Waters, S.M., Hamill, R.M., Dunne, P.G., Keane, M.G., Richardson, R.I., Kenny, D.A. and Moloney, A.P., 2017. Compensatory growth in crossbred Aberdeen Angus and Belgian Blue steers: Effects on the colour, shear force and sensory characteristics of longissimus muscle. *Meat* science, *125*, pp.128-136.

Kenyon, P.R., and Blair, H.T., 2014. Foetal programming in sheep–effects on production. Small Ruminant Research, 118(1), pp.16-30.

Killinger, K. M., C. R. Calkins, W. J. Umberger, D. M. Feuz, and K. M. Eskridge. 2004a. A comparison of consumer sensory acceptance and value of domestic beef steaks and steaks from a branded, Argentine beef program. J. Anim. Sci. 82:3302–3307.

Killinger, K. M., C. R. Calkins, W. J. Umberger, D. M. Feuz, and K. M. Eskridge. 2004b. Consumer sensory acceptance and value for beef steaks of similar tenderness, but differing in marbling level. J. Anim. Sci. 82:3294–3301.

Kyle, U.G. and Pichard, C., 2006. The Dutch Famine of 1944–1945: a pathophysiological model of long-term consequences of wasting disease. Current Opinion in Clinical Nutrition & Metabolic Care, 9(4), pp.388-394.

Legako, J. F., J. C. Brooks, T. G. O'Quinn, T. D. J. Hagan, R. Polkinghorne, L. J. Farmer, and M. F. Miller. 2015. Consumer palatability scores and volatile beef flavor compounds of five USDA quality grades and four muscles. Meat Sci. 100:291–300.

Long, N. M., K. A. Vonnahme, B. W. Hess, P. W. Nathanielsz, and S. P. Ford. 2009. Effects of early gestational undernutrition on fetal growth, organ development, and placentomal composition in the bovine. J. Anim. Sci. 87:1950–1959.

Long N.M., C. B. Tousley, K. R. Underwood, S. I. Paisley, W. J. Means, B. W. Hess, M. Du, S. P. Ford. 2012. Effects of early- to mid-gestational undernutrition with or without protein supplementation on offspring growth, carcass characteristics, and adipocyte size in beef cattle, Journal of Animal Science, Volume 90, Issue 1, 1 January 2012, Pages 197–206.

Lorenzen, C.L., T.R. Neely, R.K. Miller, J.D. Tatum, J.W. Wise, J.F. Taylor, M.J. Buyck, J.O. Reagan, and J.W. Savell. 1999. Beef customer satisfaction: cooking method and degree of doneness effects on the top loin steak. J. Anim. Sci. 77:637-644.

Lorenzen, C. L., Miller, R. K., Taylor, J. F., Neely, T. R., Tatum, J. D., Wise, J. W., Buyck, M. J., Reagan, J. O., & Savell, J. W. 2003. Beef customer satisfaction: Trained sensory panel ratings and Warner-Bratzler shear force values. Journal of Animal Science 81: 143-149.

Lucas, A., 1991. Programming by early nutrition in man. The childhood environment and adult disease, 1991, pp.38-55.

Mandell IB, Gullett EA, Wilton JW, Kemp RA, Allen OB: Effects of gender and breed on carcass traits, chemical composition, and palatability attributes in Hereford and Simmental bulls and steers. Livest Prod Sci 1997, 49(3):235–248.

Marchello, J. A., and F. D. Dryden. 1968. Meat Quality is Defined. Progress. Agric.:14-15.

McBee, Jr., J. L., & Wiles, J. A. 1967. Influence of marbling and carcass grade on the physical and chemical characteristics of beef. Journal of Animal science, 26: 701-704.

McGrady, T. A., P. J. Quinn, E. S. Fitzpatrick, and M. T. Ryan. 2006. Veterinary Embryology. 1st ed. Blackwell Publishing Ltd., Oxford, UK

McKeith FK, Devol DL, Miles RS, Bechtel PJ, Carr TR: Chemical and sensory properties of thirteen major beef muscles. J Food Sci 1985, 50(4):869–872.

Micke, G. C., T. M. Sullivan, R. J. Soares Magalhaes, P. J. Rolls, S. T. Norman, and V. E. A. Perry. 2010. Heifer nutrition during early- and mid-pregnancy alters fetal growth trajectory and birth weight. Anim. Reprod. Sci. 117:1–10. http://dx.doi.org/10.1016/j. anireprosci.2009.03.010.

Miller, M. F., K. L. Huffman, S. Y. Gilbert, L. L. Hamman, and C. B. Ramsey. 1995.

Retail consumer acceptance of beef tenderized with calcium chloride. J. Anim. Sci. 73:2308–2314.Miller, M. F., M. A. Carr, C. B. Ramsey, K. L. Crockett, and L. C. Hoover. 2001. Consumer thresholds for establishing the value of beef tenderness. J. Anim. Sci. 79:3062–3068.

Miller, M. F., M. A. Carr, C. B. Ramsey, K. L. Crockett, and L. C. Hoover. 2001. Consumer thresholds for establishing the value of beef tenderness. J. Anim. Sci. 79:3062–3068.

Mohrhauser, D. A., A.R. Taylor, M.G. Gonda, K.R. Underwood, R.H. Pritchard, A.E. Wertz-Lutz 1, A.D. Blair 2015a. The influence of maternal energy status during mid-gestation on beef offspring tenderness, muscle characteristics, and gene expression. Meat Science 110: 201-211.

Mohrhauser, D.A, A.R. Taylor, M.G. Gonda, K.R. Underwood, R.H. Pritchard, A.E. Wertz-Lutz 1, A.D. Blair 2015b. The influence of maternal energy status during midgestation on beef offspring carcass characteristics and meat quality. Journal of animal science **93**(2): 786-793.

Muir, P. D., J. M. Deaker, and M. D. Bown. 1998. Effects of forage- and grain-based feeding systems on beef quality: A review. N. Z. J. Agric. Res. 41:623–635.

Mulliniks, J. T., et al. 2016. Effect of late gestation bodyweight change and condition score on progeny feedlot performance. Animal Production Science 56.12.

NCBA (National Cattlemen's Beef Association). 2001. Defining Change for the Future. Research Annual Report, p. 39. Denver, CO. http://www.beef.org/documents/annual01.pdf (accessed April 2004).

Neely, T. R., C. L. Lorenzen, R. K. Miller, J. D. Tatum, J. W. Wise, J. F. Taylor, M. J. Buyck, J. O. Reagan, and J. W. Savell. 1998. Beef customer satisfaction: Role of cut, USDA quality grade, and city on in-home consumer ratings. J. Anim. Sci. 76:1027–1033.

Nelson, J.L., H.G. Dolezal, F.K. Ray, and J.B. Morgan. 2004. Characterization of Certified Angus Beef steaks from the round, loin, and chuck. J. Anim. Sci. 82:1437-1444.

Olson, K. C. 2005. Range management for efficient reproduction. J. Anim. Sci. 83(E. Suppl.):E107–E116.

O'Quinn, T. G., Brooks, J. C. Polkinghorne, R. J. Garmyn, A. J. Johnson, B. J. Starkey, J. D. Rathmann, R. J. & Miller, M. F. 2012. Consumer assessment of beef strip loin steaks of varying fat levels. Journal of Animal Science, 90: 626-634.

O'Quinn, T. G., D. R. Woerner, T. E. Engle, P. L. Chapman, J. F. Legako, J. C. Brooks, K. E. Belk, and J. D. Tatum. 2016. Identifying consumer preferences for specific beef flavor characteristics in relation to cattle production and postmortem processing parameters. Meat Sci. 112:90-112.

Owens, F. N., Gill, D. R., Secrist, D. S., & Coleman, S. W. 1995. Review of some aspects of growth and development of feedlot cattle. Journal of animal science, 73(10), 3152-3172.

Platter, W. J., J. D. Tatum, K. E. Belk, P. L. Chapman, J. A. Scanga, and G. C. Smith. 2003. Relationships of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. J. Anim. Sci. 81:2741–2750.

Pritchard, G. I., L. P. Folkins, and W. J. Pigden. 1962. The In Vitro digestibility of whole grasses and their parts at progressive stages of maturity. Can. J. Plant Sci.

Radunz, A.E., Loerch, S.C., Lowe, G.D., Fluharty, F.L. and Zerby, H.N., 2009. Effect of Wagyu-versus Angus-sired calves on feedlot performance, carcass characteristics, and tenderness. Journal of animal science, 87(9), pp.2971-2976.

Ramsay, J.E., Ferrell, W.R., Crawford, L., Wallace, A.M., Greer, I.A. and Sattar, N., 2002. Maternal obesity is associated with dysregulation of metabolic, vascular, and inflammatory pathways. The Journal of Clinical Endocrinology & Metabolism, 87(9), pp.4231-4237.

Ravelli, A.C., van der Meulen, J.H., Michels, R.P.J., Osmond, C., Barker, D.J., Hales, C.N. and Bleker, O.P., 1998. Glucose tolerance in adults after prenatal exposure to famine. The Lancet, 351(9097), pp.173-177.

Ravelli, A.C., van der Meulen, J.H., Osmond, C., Barker, D.J. and Bleker, O.P., 1999. Obesity at the age of 50 y in men and women exposed to famine prenatally. The American journal of clinical nutrition, 70(5), pp.811-816.

Reynolds, L.P. and Redmer, D.A., 1995. Utero-placental vascular development and placental function. Journal of animal science, 73(6), pp.1839-1851.

Robelin, J., Lacourt, A., Bechet, D., Ferrara, M., Briand, Y. and Geay, Y., 1991. Muscle differentiation in the bovine fetus: a histological and histochemical approach. Growth, development, and aging: GDA, 55(3), pp.151-160.

Roeber, D. L., Cannell, R. C., Belk, K. E., Miller, R. K., Tatum, J.D., & Smith, G. C. (2000). Implant strategies during feeding: impact on carcass grades and consumer acceptability. Journal of Animal Science, 78(7), 1867–1874.

Robinson, D. L., L. M. Cafe, and P. L. Greenwood. 2013. Meat Science and Muscle Biology Symposium: Developmental programming in cattle: Consequences for growth, efficiency, carcass, muscle and beef quality characteristics. J. Anim. Sci. 91:1428–1442.

Roseboom, T.J., van der Meulen, J.H., Osmond, C., Barker, D.J., Ravelli, A.C., Schroeder-Tanka, J.M., van Montfrans, G.A., Michels, R.P. and Bleker, O.P., 2000. Coronary heart disease after prenatal exposure to the Dutch famine, 1944–45. Heart, 84(6), pp.595-598.

Rosen, E.D. and MacDougald, O.A., 2006. Adipocyte differentiation from the inside out. Nature reviews Molecular cell biology, 7(12), pp.885-896.

Russell, R.G. and Oteruelo, F.T., 1981. An ultrastructural study of the dufferentiation of skeletal muscle in the bovine fetus. Anatomy and embryology, 162(4), pp.403-417.

Savell, J. W., Branson, R. E. Cross, H. R. Stiffler, D. M. Wise, J. W. Griffin, D. B. &

Smith, G. C. 1987. National consumer retail beef study: palatability evaluations of beef loin steaks that differed in marbling. Journal of Food Science, 52: 517-519.

Savell, J.W., and H.R. Cross. 1988. The role of fat in the palatability of beef, pork, and lamb. In: National Research Council. Designing Foods, Animal Product Options in the Marketplace. Natl. Acad. Press, Washington, D.C.

Schoonmaker, J. P., M. J. Cecava, D. B. Faulkner, F. L. Fluharty, H. N. Zerby, and S. C. Loerch. 2003. Effect of source of energy and rate of growth on performance, carcass characteristics, ruminal fermentation, and serum glucose and insulin of early-weaned steers. J. Anim. Sci. 81:843–855.

Smith, G.C., and Z.L. Carpenter. 1974 Eating quality of animal products and their fat content. Proc. of the Symposium on Changing the Fat Content and Composition of Animal Products. Washington, D.C.: National Academy of Sciences.

Smith, G. C., Savell, J. W., Cross, H. R., & Carpenter, Z. L. 1983. The relationship of USDA quality grade to beef flavor. Food Technology, 37(5), 233-238.

Smith, G. C., Z.L. Carpenter, H.R. Cross, C.E. Murphey, H.C. Abraham, J.W. Savell, G.W. Davis, B.W. Berry, and F.C Parrish, Jr. 1985. Relationship of USDA marbling groups to palatability of cooked beef. J. Food Qual. 7:289-308.

Spiegelman, B.M. and Flier, J.S., 1996. Adipogenesis and obesity: rounding out the big picture. Cell, 87(3), pp.377-389.

Stannard, S. R., & Johnson, N. A. 2004. Insulin resistance and elevated triglyceride in muscle: More important for survival than “thrifty” genes? Journal of Physiology, 554(Pt 3), 595–607.

Stickland, N. C. 1978. A quantitative study of muscle development in the bovine foetus (bos indicus). Anat. Histo. Embryol. 7: 193-205.

Suman, S.P., Hunt, M.C., Nair, M.N. and Rentfrow, G., 2014. Improving beef color stability: Practical strategies and underlying mechanisms. Meat Science, 98(3), pp.490-504.

Swatland, H.J. 1973. Muscle growth in the fetal and neonatal pig. J. Anim. Sci. 37:536-545.

Tatum, J.D., 2015. Recent trends: beef quality, value, and price. Certified Angus Beef, Wooster, OH.

Taylor, A.R., Mohrhauser, D.A., Pritchard, R.H., Underwood, K.R., Wertz-Lutz, A.E. and Blair, A.D., 2016. The influence of maternal energy status during mid-gestation on growth, cattle performance, and the immune response in the resultant beef progeny. The Professional Animal Scientist, 32(4), pp.389-399.

Thomas, V. M., and R. W. Kott. 1995. A review of Montana winter range ewe nutrition research. Sheep and Goat Research Journal.

Tong, J. F., X. Yan, M. J. Zhu, S. P. Ford, P. W. Nathanielsz, and M. Du. 2009. Maternal obesity downregulates myogenesis and beta-catenin signaling in fetal skeletal muscle. Am. J. Physiol. Endocrinol. Metab. 296: E917–24.

Uezumi, A., Fukada, S.I., Yamamoto, N., Takeda, S.I. and Tsuchida, K., 2010. Mesenchymal progenitors distinct from satellite cells contribute to ectopic fat cell formation in skeletal muscle. Nature cell biology, 12(2), pp.143-152.

Uezumi, A., Ito, T., Morikawa, D., Shimizu, N., Yoneda, T., Segawa, M., Yamaguchi, M., Ogawa, R., Matev, M.M., Miyagoe-Suzuki, Y., and Takeda, S.I., 2011. Fibrosis and adipogenesis originate from a common mesenchymal progenitor in skeletal muscle. J Cell Sci, 124(21), pp.3654-3664.

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 Sci. 86:588–593.

USDA. 1997. United States standards for grades of carcass beef. Livestock and Seed Program. Agric. Market. Serv., Washington, DC.

Vavra, M., and R. J. Raleigh. 1976. Coordinating beef cattle management with the range forage resource. J. Range Manage. 29:449–452.

Vernochet, C., Peres, S.B. and Farmer, S.R., 2009. Mechanisms of obesity and related pathologies: transcriptional control of adipose tissue development. The FEBS journal, 276(20), pp.5729-5737.

Vonnahme, K.A., Hess, B.W., Hansen, T.R., McCormick, R.J., Rule, D.C., Moss, G.E., Murdoch, W.J., Nijland, M.J., Skinner, D.C., Nathanielsz, P.W. and Ford, S.P., 2003. Maternal undernutrition from early-to mid-gestation leads to growth retardation, cardiac ventricular hypertrophy, and increased liver weight in the fetal sheep. Biology of reproduction, 69(1), pp.133-140.

Vonnahme, K.A., Zhu, M.J., Borowicz, P.P., Geary, T.W., Hess, B.W., Reynolds, L.P., Caton, J.S., Means, W.J. and Ford, S.P., 2007. Effect of early gestational undernutrition on angiogenic factor expression and vascularity in the bovine placentome. Journal of animal science, 85(10), pp.2464-2472.

Warris, P.D. 2010. Meat Quality. In: P.D. Warris, author, Meat Science. 2nd Ed. Cambridge University Press, Cambridge, MA. p. 77-96.

Webb, M., D. Woerner, D. Pendell, T. Engle, J. Henson, H. Zerby, R. Delmore, K. Belk, and J.D. Tatum. 2015. Identifying consumer preferences for different beef types based on flavor. Meat Sci. 101: 146 (Abstr.) doi: 10.1016/j.meatsci.2014.09.107.

Webb, M.J., Block, J.J., Funston, R.N., Underwood, K.R., Legako, J.F., Harty, A.A., Salverson, R.R., Olson, K.C. and Blair, A.D., 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*, pp.31-37.

Wittum, T. E., M. D. Salman, M. E. King, R. G. Mortimer, K. G. Odde, and D. L. Morris. 1994. Individual animal and maternal risk factors for morbidity and mortality of neonatal beef calves in Colorado, USA. Prev. Vet. Med. 19:1–13.

Wood, J.D. 1995. The influence of carcass composition on meat quality. In: Morgan Jones S.D., editor, Quality, and grading of carcasses of meat animals. CRC Press,

Boca Raton, FL, p. 131-155.

Wu, G., Bazer, F.W., Wallace, J.M. and Spencer, T.E., 2006. Board-invited review: intrauterine growth retardation: implications for the animal sciences. Journal of animal science, 84(9), pp.2316-2337.

Yan, X., M.-J. Zhu, M. V Dodson, and M. Du. 2013. Developmental programming of fetal skeletal muscle and adipose tissue development. J. genomics 1:29–38.

Zambrano, E., Martinez-Samayoa, P. M., Bautista, C. J., Deas, M., Guillen, L., Rodriguez-Gonzalez, G. L., et al. 2005. Sex differences in transgenerational alterations of growth and metabolism in progeny (F2) of female offspring (F1) of rats fed a low protein diet during pregnancy and lactation. Journal of Physiology, 566(Pt 1), 225–236.

Zhu, M.-J., S. P. Ford, P. W. Nathanielsz, and M. Du. 2004. Effect of maternal nutrient restriction in sheep on the development of fetal skeletal muscle. Biol. Reprod. 71:1968–73.

Zhu, M. J., S. P. Ford, W. J. Means, B. W. Hess, P. W. Nathanielsz, and M. Du. 2006. Maternal nutrient restriction affects properties of skeletal muscle in offspring. J. Physiol. 575:241–250.