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Effects of Gestational Dietary Intake on Calf Growth and Early Feedlot Performance of Offspring

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EFFECTS OF GESTATIONAL DIETARY INTAKE ON CALF GROWTH AND
EARLY FEEDLOT PERFORMANCE OF OFFSPRING

by

Jose Gardner

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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2017

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ABSTRACT

Effects of Gestational Dietary Intake on Calf Growth and Early Feedlot
Performance of Offspring

by

Jose M. Gardner, Master of Science

Utah State University, 2017

Major Professor: Dr. Jerrad F. Legako
Department: Nutrition, Dietetics, and Food Science

This study determined the impacts of maternal dietary restriction during the second trimester on offspring growth and feedlot performance. Angus influenced commercial cows ($N = 32$) were naturally bred to a purebred Angus sire. For 84 days of mid-gestation, cows were split into maintenance ($n = 15$) and restricted ($n = 17$) groups. Cows were stratified by initial weights ($P = 0.804$) and body condition score ($P = 0.723$). Restricted cows were provided with lower forage biomass (1,662 kg/ha, DM) than maintenance (2,309 kg/ha, DM), and had a mean body condition score 1.55 lower ($P = 0.001$) than maintenance cows and a body weight difference of 85.3 kg ($P = 0.024$) at the end of the period. Dams were comingled and managed uniformly following mid-gestation. Calves were weaned at an average 206 days of age, and placed on a background diet for 7 weeks before entering the feedlot phase. Cattle were penned individually and fed a grower ration *ad libitum*. Calf body weight was measured at birth, weaning, and every 28 days of the feedlot phase. Ultrasound was used to estimate back

fat and ribeye area during the feedlot phase. Calf temperament was evaluated at weaning and during the feedlot phase. Blood was drawn at weaning, one week prior to the feedlot phase, and day 84 of the feeding trial for determination of glucose, insulin, insulin-like growth factor-I, and cortisol. Calf body weight at birth, weaning, and at all points during feeding showed no differences between treatments ($P \geq 0.245$). No differences were determined for average daily feed intake ($P \geq 0.428$), average daily gain ($P \geq 0.338$), gain to feed ratio ($P \geq 0.273$), ribeye area ($P \geq 0.285$), or back fat ($P \geq 0.416$) at any point during the feedlot stage. Concentrations of glucose ($P \geq 0.504$), insulin ($P \geq 0.224$), insulin-like growth factor-1 ($P \geq 0.107$), and cortisol ($P \geq 0.709$) were similar between treatments at all points. Restricted calves had greater temperament scores at weaning ($P = 0.026$). This study determined little impact on calf performance during early feedlot stages.

(54 pages)

PUBLIC ABSTRACT

Effects of Gestational Dietary Intake on Calf Growth and Early Feedlot Performance of Offspring

Jose M. Gardner

Fetal programming is a relatively new and quickly growing field of research in the livestock industry. The concept of fetal programming is simply defined as the effects a change in maternal nutritional intake has on offspring, whether it be a genetic or physical change. The intention of this study was to specifically look at the effects of nutrient restriction of cows during the second trimester of gestation on the growth and performance of the resulting calves.

In this study, thirty-two cows of predominantly angus influence from the Utah state university herd were chosen, naturally bred to a pure bred angus sire, and then allocated into two treatments: maintenance and restricted. These groups were treated uniformly for first and third trimesters of gestation, while in the second trimester, they were managed in a way that the maintenance group maintained a greater level of body condition and weight compared with the restricted group. Calf growth and performance was measured and compared for effects of fetal programming.

Previous studies in beef found positive effects on carcass characteristics. However, little work has been done to ensure that fetal programming is not detrimental to calves early in life. Though this study did find that nutrient restriction resulted in more excitable cattle, no negative effects caused by programming were found in growth and performance of the offspring.

DEDICATION

I dedicate this thesis first and foremost to my loving, intelligent, and extremely patient wife, Kourtney. From feeding cows in the freezing snow to helping me find the missing semi-colon in SAS code, she has been such an amazing helper and encourager. She has also been an incredible classmate and the best study partner. Without her, pursuing this degree and completing this project would have been near impossible. For that, I thank and love you, Kourtney!

This thesis is also dedicated to my incredible parents, Dan and Norma Gardner, who always instilled in me that education is an utmost priority, superseded only by Faith and family. They always invested in my educational pursuits, and pushed me to excel, even at times that I did not want to push myself. I will never be able to repay the sacrifices made and tough love administered in order to ensure I was successful. Thank you, dad and mom!

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I would also like to thank a great committee in doctors Charles Carpenter, Kerry Rood, Kara Thornton-Kurth, and Dale Zobell. Their sincere willingness and care to ensure I followed a curriculum that aligned with my interests and challenged me at the same time is greatly appreciated. Furthermore, the success of this project would have been greatly hampered without their advice and expertise.

I would like to thank my lab mates Kourtney Gardner, Shelby Quarnberg, ToniRae Gardner, and Jessie McClellan for all their contributions to this project. From weigh dates in single digit temperatures to feeding cows on your free time, I would have been a complete failure without your help. A huge thank you goes to Brett Bowman for making time in his packed schedule to evaluate cattle and keep track of calves all over the valley. Finally, I would like to thank Dick Whittier for being my father away from home, being an incredible voice of reality, and sincerely investing in my research and my life.

Jose M. Gardner

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INTRODUCTION

Maternal dietary intake during gestation is known to have long term effects on carcass composition of offspring through a phenomenon known as fetal programming (Godfrey and Barker, 2000). Recent research has shown that dietary changes during gestation affect carcass quality and red meat yield in beef animals (Blair et al., 2013). Reduction of maternal nutrition during periods of embryonic muscle and adipose development causes increased adipogenesis in calves (Bispham and Gardner, 2005). This results in advantageous phenotypic changes such as increased ratios of intramuscular fat to subcutaneous fat (Blair et al., 2013).

Fetal programming research is a relatively new field of study, especially in consideration of livestock performance (Du. et al. 2010). Much of the current research, such as that done by Blair et al. (2013) or Radunz et al. (2012), focuses on overall growth and carcass characteristics with very little emphasis put on changes during specific periods of growth. This study will further our understanding of the effect of dietary intake during gestation on calf growth and early feedlot performance of beef cattle.

HYPOTHESIS

There are differences in growth and early feedlot performance of calves born to mothers that maintain or lose body condition during the second trimester of gestation.

LITERATURE REVIEW

Introduction

Prenatal nutrition and environment impact fetal development, specifically muscle, adipose, and bone tissue (Zhu et al., 2004; Tong et al., 2009; Du et al., 2010; Blair et al., 2013; Yan et al., 2013). Ultimately, these prenatal effects may impact carcass composition of meat animals. In certain regions gestation occurs at a time where forage quality is quite low, and this may be exasperated because most small farms and ranches use little supplementation for most of gestation (Thomas and Kott 1995; Enk et al., 2001; Jensen et al., 2002; Du et al., 2010).

Differential levels of forage quality and nutrient supplementation during gestation can have lasting postnatal effects. Godfrey and Barker (2000) define fetal programming as the process whereby a nutritional change occurs during a critical period of fetal development. Research suggests that the lowering of maternal nutrition at midgestation may cause a change in the phenotypic development of the offspring leading to a greater adipose to muscle ratio (Zhu et al., 2004; Du et al., 2011; Blair et al., 2013; Yan et al., 2013).

Tissue Development and Fetal Programming

The concept of fetal programming originally developed from human epidemiology studies that linked low birth weights and poor maternal nutrition with an array of adult diseases (Godfrey and Barker, 2000; Du et al., 2010). Fetal programming is the term for the effects of a change, or insult, of maternal nutrition during gestation

on development or cell differentiation of the fetus that carries on after birth. Myogenic, adipogenic, and fibrogenic cells all differentiate from a common mesenchymal cell (Du et al., 2013). Skeletal muscle development is roughly categorized into embryonic, fetal, and adult stages; the embryonic and fetal stages are commonly referred to as the prenatal stage (Du et al., 2010; Du et al., 2013). According to Du et al. (2013), myogenesis occurs almost entirely during the prenatal stage, with negligible post-natal increase in muscle fiber number. Furthermore, this myogenesis is divided into two stages: primary myogenesis during early gestation and secondary myogenesis during mid gestation (Du et al., 2013). Primary myogenesis occurs during the embryonic stage of gestation and forms templates for further muscle cell formation (Swatland, 1973; Du et al., 2013). In a bovine fetus, the majority of muscle cells develop during secondary myogenesis in the fetal stage, which lasts from about the third month to the eighth month of gestation (Du et al., 2010; Blair et al., 2013; Figure 1). In addition, the fat cell development is thought to span the latter half of gestation and continue postnatally (Zhu et al., 2004; Du et al., 2010; Figure 2). The sequence of adipocyte development is commonly understood to go in the order of visceral, subcutaneous, intermuscular, and intramuscular fat (Bonnet et al., 2010; Du et al., 2013). Adipogenesis begins mid-gestation and hyperplasia carries on postnatally, though sharply declining towards the end of adolescence or around 250 days of age in cattle (Goessling et al., 2009; Du et al., 2013). Because most livestock are slaughtered at a relatively young

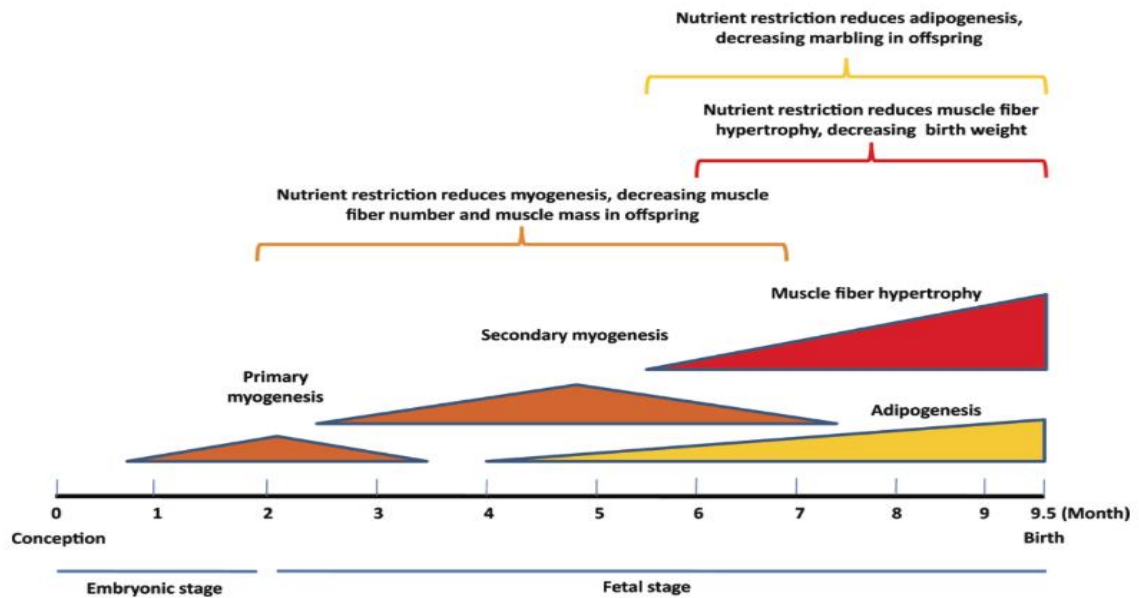


Figure 1. Effects of maternal nutrition on bovine fetal skeletal muscle development. The dates are estimated mainly based on data from studies in sheep, rodents, and humans and represent the progression through the various developmental stages. Nutrient restriction during mid-gestation reduces muscle fiber numbers, whereas restriction during late gestation reduces both muscle fiber sizes and the formation of intramuscular adipocytes (adapted from Zhu et al., 2004; Du et al., 2010).

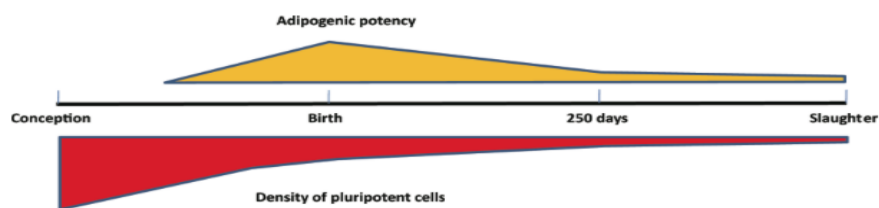


Figure 2. Density of multipotent cells and adipogenic potency of bovine skeletal muscle. The dates are approximate and represent the progression through the various developmental stages. Adipogenesis is initiated around midgestation in ruminant animals and peaks near the term. The adipogenic potency gradually declines postnatally because of depletion of multipotent cells (adapted from Zhu et al., 2004; Du et al., 2010).

age (18-30 months), adipogenesis is effectively a lifelong process affected by nutritional intake during fetal, postnatal, and post weaning stages of life and having tremendous implications on meat quality (Du et al., 2013)

It is understood that tissue development is controlled by a multitude of regulatory proteins and factors such as paired box transcription factors 3 and 7, and the myogenic regulatory factors (Du et al., 2013). One very important regulatory factor to the development of pre-natal myogenic or adipogenic cells is the cell signaling pathway known as Wnt signaling (Du et al., 2010). Activation of the Wnt signaling pathway, through increased maternal nutrition approaching optimal levels, causes increases in the presence of beta-catenin which shifts the specialization of mesenchymal stem cells towards an increase in myogenesis and inhibited adipogenesis. Wnt signaling is, however, downregulated during gestation when a mother is over-nourished or undernourished (Bispham et al. 2003; Du et al. 2010). Because myogenesis occurs before adipogenesis in fetal development, strategic control of maternal nutrient intake during key points of gestation can be used to enhance either myogenesis or adipogenesis (Du et al., 2010).

Adipose Deposition

Intramuscular fat, also known as marbling, contributes to both juiciness and flavor and is crucial for the palatability of beef (Francis, 1977). Number and size of intramuscular adipocytes determine the amount of intramuscular fat. During the fetal stage, both skeletal muscle cells and adipocytes are derived from the same pool of mesenchymal stem cells. A small portion of these cells in skeletal muscle differentiate

into adipocytes and form sites for intramuscular fat accumulation that later form marbling (Tong et al., 2009; Du et al., 2010). An increasing amount of animal and epidemiological evidence suggests the amount of feed consumed by the mother through pregnancy has a significant impact on fetal and later adipose tissue development (Bispham and Gardner, 2005). Typically a higher degree of marbling, or intramuscular fat, is correlated with a higher degree of back fat, or earlier developing subcutaneous fat (McBee and Wiles, 1967). However, a study by Blair et al. (2014) found offspring from cows in a negative energy state during mid-gestation finished with increased marbling to subcutaneous fat ratio and percent intramuscular fat to subcutaneous fat ratio as compared to offspring from positive energy mothers. Results from a study on midgestational nutrition restriction in sheep showed an increase in fat deposition without significant change in lean muscle mass (Zhu et al., 2006). These studies indicate that this phenomenon occurs in more than one industry relevant livestock species. These effects highlight potential for significant fat development alteration during gestation that have lasting effects and can add carcass value through higher quality grades.

Fetal Programming and Postnatal Growth

While much research has been done on fetal programming and its effects on prenatal growth, relatively little has been done regarding the direct effects of programming on postnatal growth, particularly in livestock (Funston et al., 2010). One indirect effect on postnatal growth is, due to the fact that the number of muscle fibers in an animal is generally set at birth, nearly all postnatal muscle growth occurs through an

increase in muscle fiber size (Brameld et al., 2000; Du et al., 2013). A more direct effect of fetal programming on postnatal growth is impacts due to animal health. Studies have shown that offspring from late gestational nutrient restricted mothers became susceptible to a variety of neonatal health issues including respiratory conditions, diarrhea, cold stress, and morbidity in general (Wittum et al., 1994; Funston et al., 2010). These issues have been directly correlated to performance issues including significantly decreased weaning weight. In contrast, a study on early gestational nutrient restriction in lambs found that offspring from the restricted mothers had higher birth weights, higher immunoglobulin protein concentrations in serum, and higher survivability to weaning, all positive impacts on lamb performance (Munoz et al., 2008; Funston et al., 2010). Gonzalez et al. (2013) found significant compensatory growth in fetal muscle fiber diameter in beef fetuses from early gestational nutrient restricted mothers. We can speculate that early versus late fetal nutrient change may allow for a compensatory adaptation, similar to the aforementioned Gonzalez study, on organ and endocrine system development in the fetus without adding any insult during skeletal muscle development later in gestation. A study by Larson et al. (2009) in steer performance from late gestational nutrient supplemented mothers found a multitude of improvements in feedlot performance of the offspring as compared to offspring from control mothers. These differences included higher weight at time of implant, higher feed consumption, and higher weight at slaughter in offspring from supplemented mothers (Larson et al., 2009). Steers in this same study also showed significant differences at slaughter where offspring from supplemented cows finished with higher

quality grades and no difference in yield grade compared with non-supplemented cows (Larson et al., 2009). These findings imply an increase in nutrient partitioning towards intramuscular fat resulting in an increased intramuscular fat to subcutaneous fat ratio.

Mechanisms of Postnatal Growth

It is well understood that the vast majority of postnatal skeletal muscle growth occurs through muscle hypertrophy (Du et al., 2010; Du and Dodson, 2011). It is obvious that nutrient intake is critical for growth, and thus understanding the mechanisms that control intake is critical as well. Leptin, a hormone produced in adipose tissue, is an important factor in growth, as it regulates animal appetite, and thus nutrient intake, through creating satiation response (Hollenberg et al., 1997; Zhang et al., 2008; Hausman et al., 2009; Mohrhauser et al., 2015) Leptin is known to increase as fat levels in an animal increase (Delavaud et al., 2000; Jennings et al., 2010). Ghrelin is another hormone that influences energy intake and partitioning. Ghrelin is known to influence metabolism and fat deposition, with concentrations generally increasing with decreased nutrient availability (Tschop et al., 2000; Patel et al., 2006; Wertz-Lutz et al., 2006 and 2008; Jennings et al., 2010). Jennings et al. (2010) found that differing concentrations of plasma leptin and ghrelin were associated with rate of gain in beef animals of different body compositions. Data concerning leptin and ghrelin effects in animals of varying body compositions has not been previously reported. Further research is warranted as both hormones play a vital role in production efficiency (Jennings et al., 2010). Insulin-like growth factor-I (IGF-I) is another important hormone in the consideration of growth potential and feed efficiency (Elsasser et al.,

1989; Blanco et al., 2009). Insulin-like growth factor-I is an indicator of nutritional status and growth potential (Elsasser et al., 1989). Blanco et al. (2009) found that IGF-I concentrations correlated positively with average daily gain, especially during early stages of growth and feeding. A positive relationship was also found between IGF-I concentration and protein deposition (Hayden et al., 1993). Johnston et al. (2001) found that IGF-I not only positively correlated to performance measures such as weaning weight and average daily gain, but also to carcass traits such as percent intramuscular fat. It is possible that IGF-I concentrations could specifically be susceptible to fetal programming effects.

Beyond understanding the effects of hormones on body composition, we must also understand how nutrient composition affects body composition. Adipose deposition, especially intramuscular fat, is vital for beef quality. A study by Smith and Crouse (1984) found that glucose provides about 50-75% of acetyl units for deposition of lipid into intramuscular fat and about 1-10% for subcutaneous fat, while acetate provides 70-80% of acetyl units for lipid deposition into subcutaneous fat and only 10-25% for intramuscular fat. Interestingly, as an animal matures, glucose becomes less effective in intramuscular fat growth, and acetate starts to play more of a role (Smith et al., 2014). Thus, it can be inferred that carbohydrate source, and the synthesis of the aforementioned sugars play a crucial role in adipose accretion. Insulin and glucose concentrations are two components of interest in this matter (Vasconcelos et al., 2009). Higher levels of glucose leads to increased insulin secretion, which can trigger increased marbling development in cattle (Vasconcelos et al., 2009). Schoonmaker et al.

(2003) found that steers with increased insulin levels had an increased uptake of glucose to the peripheral tissues. Steers with higher insulin levels were found to have higher ultrasound marbling scores, likely a consequence of starch fermentation leading to higher glucose levels in the peripheral tissues (Schoonmaker et al., 2003). It is also understood that, with time, an animal can develop a resistance to insulin (Shoup 2011). Insulin resistance is a term used to describe a body's increased resistance to the effects of insulin on glucose uptake into different tissues (Kahn and Flier, 2000). Gardner et al. (2005) found that late gestational undernutrition of sheep can lead to significant increases in insulin resistance early in life in offspring. Studies have shown that a relationship exists between adipogenesis and insulin resistance in beef cattle, though the mechanism is unknown (Shoup 2011).

Carcass Quality

In the consideration of carcasses, quality refers to the amount of marbling, the texture of grain of the meat, the firmness and color of the lean, the firmness and color of the fat, and the character of the bone. The characteristic that receives the most emphasis is marbling, for many reasons (Marchello and Dryden, 1968). Tenderness, juiciness, and flavor have been shown to have a direct relationship with change in quality grade of beef (McBee and Wiles, 1967). Instrumentally measured marbling scores were very closely related to a sensory panel's evaluation of beef flavor ($r=0.84$) and there were moderately strong correlations of marbling with panel evaluations of juiciness ($r=0.67$), tenderness ($r=0.63$), and umami ($r=0.57$; Emerson et al., 2013)). In addition, the panels overall experience satisfaction was closely correlated with the aforementioned

characteristics as well as strongly, positively associated with the instrumental marbling measurements ($r=0.78$). Thus, it can be concluded that increasing deposition of intramuscular fat, or marbling, should have positive effects on carcass quality and consumer acceptance of beef. As previously stated, growth and development of a beef animal can be strategically altered via maternal nutrition during gestation. According to Mohrhauser et al. (2015), when comparing the offspring of mothers in differing energy status groups during midgestation, no difference was found in hot carcass weight, dressing percent, ribeye area, marbling score, and percent intramuscular fat. This is especially intriguing as the period in which energy status is altered coincides with what is suggested to be the period of maximal fetal muscle development (Mohrhauser et al., 2015). If desired marbling and marbling to back fat ratios can be achieved while other important carcass traits can be held from negative effects, it could mean big implications for future beef production.

Animal Temperament

As mentioned in section 3.1, carcass quality is affected by prenatal and neonatal development. Recent studies have shown that certain beef carcass quality characteristics correlate with animal temperament as well (Behrends et al., 2009). Growing evidence exists in human studies that maternal micronutrient levels during gestation can have long-term behavioral effects (Colombo et al., 2004; Zhou et al., 2006; Hibbeln et al., 2007; Gale et al., 2008; Parsons et al., 2008; Schlotz et al., 2009;). A human study in Spain found that iron deficiency at different points of gestation had significant effects on offspring autonomous nervous response and even motor skills (Hernández-Martínez

et al., 2011). Sullivan et al. (2010) found that a chronic high fat diet during pregnancy in nonhuman primates resulted in increased anxiety levels in the offspring. While no research could be found on fetal programming effects on behavior and temperament in livestock, these studies lead us to speculate the same mechanisms could be involved. Temperamental effects on animal development have been seen as early as the feedlot stage where animals with more excitable temperaments had significantly lower average daily gains than calmer tempered animals (Voisinet et al., 1997; Behrends et al., 2009). Furthermore, excitable cattle tended to result in carcasses that decreased in pH more rapidly than calmer animals (King et al., 2006). This could result in meat that is pale, soft, and exudative; or dark, firm, and dry; either of which result in a less favorable eating experience for consumers. King et al. (2006) also found that excitable cattle tended to have carcasses that negatively correlated with meat tenderness. Finally, excitable cattle showed a negative correlation in ribeye area as compared to calmer animals (Behrends et al., 2009). Cortisol is a valid and useful biochemical marker that can be measured to predict excitability in cattle (Grandin, 1997; von Borrell, 2001; Möstl and Palme, 2002; Buckham Sporer et al., 2008). Furthermore, cortisol has been found to positively correlate with certain beef cattle temperament indicators, such as chute exit velocity and pen behavior scores (Curley et al., 2006). Animal temperament is an underappreciated, and thus little studied aspect when considering factors that affect carcass quality.

MATERIALS AND METHODS

Initiation

All animal care and usage protocols (IACUC-2373) were approved by the Utah State University Animal Care and Use Committee. Thirty-two commercial cows of heavy Angus influence were selected from the Utah State University beef research based on similar expected genetics. All cows were naturally bred to the same pure bred Angus sire in order to minimize effects due to genetic variation. Cows were evaluated for pregnancy, length of gestation, and weight and body condition score (BCS; 1 to 9, 1 = extremely emaciated and 9 = obese). BCS was determined by the same evaluator at all time points. Weight of all animals were taken using a Digistar SW300 indicator, Stockweigh load cells, and Wrangler alleyway platform (Digi-star LLC, Fort Atkinson, WI). Body Condition was evaluated visually according to the parameters as described by Richards et al. (1986) and shown in Figure 3.

Fetal Programming Phase

Overview

Prior to the 2nd trimester, cows were allocated to one of two BCS groups (maintenance, managed with a goal of maintaining BCS of 5.0-5.5 and restricted, managed with a goal of losing 1 BCS over an 84 day period). Groups were sorted to be initially similar in age, weight, and BCS. Cows were weighed and evaluated for BCS at days 0, 28, 56, and 84 of mid-gestation. Within each calving group, maintenance cows (n = 15) were allowed to graze on approximately 54 acres of irrigated pasture and

Body Condition Score Evaluation Parameters

Group	BCS	Description
Thin condition	1	EMACIATED – Cow is extremely emaciated with no palpable fat detectable over spinous processes, transverse processes, hip bones or ribs. Tail-head and ribs project quite prominently
	2	POOR – Cow still appears somewhat emaciated but tail head and ribs are less prominent. Individual spinous processes are still rather sharp to the touch but some tissue cover exists along the spine
	3	THIN – Ribs are still individually identifiable but not quite as sharp to the touch. There is obvious palpable fat along spine and over tail-head with some tissue cover over dorsal portion of ribs
Borderline condition	4	BORDERLINE—Individual ribs are no longer visually obvious. The spinous processes can be identified individually on palpation but feel rounded rather than sharp. Some fat cover over ribs, transverse processes and hip bones
Optimum moderate condition	5	MODERATE – Cow has generally good overall appearance. Upon palpation, fat cover over ribs feel spongy and areas on either side of tail-head now have palpable fat cover
	6	HIGH MODERATE – Firm pressure now needs to be applied to feel spinous processes. A high degree of fat is palpable over ribs and around tail head
	7	GOOD – Cow appears fleshy and obviously carries considerable fat. Very spongy fat cover over ribs and around tail-head. In fact “rounds” or “pones” beginning to be obvious. Some fat around vulva and in crotch
Fat condition	8	FAT – Cow very fleshy and over-conditioned. Spinous processes almost impossible to palpate. Cow has large fat deposits over ribs, around tail-head and below vulva. “Rounds” or “pones” are obvious
	9	EXTREMELY FAT – Cow obviously extremely wasty and patchy and looks blocky. Tail-head and hips buried in fatty tissue and “rounds” or “pones” of fat are protruding. Bone structure no longer visible and barley palpable. Animal’s motility may even be impaired by large fatty deposits

Figure 3. Parameters for body conditioning score evaluation. (adapted from Richards et al. 1986)

supplemented as needed to maintain a constant BCS according to nutrient requirements of beef cattle (NRC, 2000). Meanwhile, restricted cows (n = 17) were held to 6.4 acres of non-irrigated pastures and were not supplemented until the 3rd trimester, at which point both groups were comingled and treated uniformly for the duration of gestation. At seven weeks past comingling, both groups were once again evaluated for weight and BCS to assess compensatory gain during recovery.

Maternal Feedstuff Nutrient Content

During the restriction and recovery phases, samples from all pastures were taken for nutrient availability. Plant cover in each pasture was assessed by taking 5 random readings of a 0.1-m² Daubenmire frame (Bonham 1989). Samples were taken each month of the growing season. Collected samples were placed in paper bags and dried in a forced-air oven at 60°C for 48 h. Samples were subsequently ground in a Wiley mill with a 1-mm screen, and analyzed for dry matter (Method 930.15 AOAC, 2000), neutral detergent fiber, acid detergent fiber (Van Soest et al. 1991), and crude protein (CP) (Method 990.03 AOAC, 2000). Total digestible nutrients were then calculated from CP and fiber concentration based on equations by Weiss et al. (1992) as an estimate of digestible energy content of the plant samples (Swift, 1957; NRC, 2000). Table 1 shows results of the analyses.

Table 1. Pasture yields and nutrient analysis of maintenance and restricted pastures.

Item	Maintenance pasture ¹		Restricted pasture ¹	
	Wet matter basis	Dry matter basis	Wet matter basis	Dry matter basis
Moisture %	43.09	---	39.72	---
Dry matter %	56.91	100.00	60.28	100.00
Crude protein %	6.21	10.91	8.70	14.43
Acid detergent fiber %	23.77	41.76	18.55	30.78
Neutral detergent fiber %	36.30	63.80	29.25	48.52
Total digestible nutrients %	31.52	55.38	40.36	66.96
Pasture yield (kg/ha)	4057.66	2309.04	2757.24	1662.08

¹Maintenance pasture was a 54 acre well-irrigated pasture grazed by the maintenance cows of the study. Restricted pasture was a 6.4 acre poorly irrigated pasture grazed by the restricted cows of the study.

Maternal Behavioral Measurements

During days 29 through 56 of the second trimester, 6 cows each from groups BCS1 and BCS2 were randomly selected and equipped with IceTag Sensors (Ice Robotics, Edinburg, Scotland, UK) secured on the lateral side of the left hind leg above the metatarsophalangeal joint (Hafla et al., 2014) in order to measure daily steps, as well as standing and laying bouts. The tags were once again applied to 6 randomly selected cows from each group for the duration of the recovery phase to take the same measurements. All IceTag sensor data was downloaded using Ice Tag Analyzer software (Ice robotics, Edinburg, Scotland, UK) and exported to a spreadsheet.

Postpartum Management

At birth, all calves' birthdate and heart girth measurement were recorded. Heart girth was taken by tape measure (beef weight tape, Nasco, Fort Atkinson, WI) drawn snug around the girth of the calf just behind the shoulders. Heart girth was used to approximate birth weight according to ratios defined in Table 2. Weights in pounds

were then converted to kg for any further analysis. All resulting cow-calf pairs remained within the same dietary management system as the comingled third trimester (i.e. quality pasture with supplemental hay as needed) until weaning. All bull calves were castrated within 3 months of birth. At approximately 75 days of age, all calves were processed in order to take blood samples and be administered shots and vaccines. These included a Piliguard Pinkeye-1 Trivalent vaccine (Intervet Inc., Madison, NJ) for Conjunctivitis, an Ultrabac 8 vaccine (Zoetis Inc., Florham Park, NJ), a Bovi-Shield Gold 5 vaccine (Zoetis Inc., Florham Park, NJ), and a Multimin 90 supplement shot (Multimin North America Inc., Fort Collins, CO). Calves were given another dose of Bovi-Shield Gold 5 and Ultrabac 8 at weaning.

Table 2. Index of estimated birth weights for corresponding heart girth measurements.

Table for birth weight (lb) estimated from heart girth (in) ¹					
Inches	Pounds	Inches	Pounds	Inches	Pounds
22.5	42	27.5	67	32.5	90
23.0	45	28.0	69	33.0	92
23.5	48	28.5	71	33.5	94
24.0	50	29.0	74	34.0	96
24.5	53	29.5	76	34.5	98
25.0	55	30.0	78	35.0	101
25.5	57	30.5	80	35.5	103
26.0	60	31.0	83	36.0	105
26.5	62	31.5	85	36.5	107
27.0	65	32.0	87	37.0	110

¹Heart girth measured in inches by pulling a tape measure tight around the chest of the calf just behind the Shoulders

Feedlot Phase

Calves were weaned at an average of 206 days of age with a range of 156 to 227 days of age, and then transported to the Utah State University Research Feedlot (Wellsville, UT). Upon arrival at the feedlot, calves received sequential Ralgro Implant (Merck Animal Health, Summit, NJ) to represent common feedlot hormonal growth promotants. Initially, calves were fed a background diet of approximately 20% concentrate from barley, 33% alfalfa hay, and 47% corn silage on a dry matter basis for approximately 7 weeks. The calves were then sorted into individual pens, and switched to a grower ration. The growing ration consisted of approximately 27% barley concentrate on a dry matter basis, along with approximately 27% alfalfa and 43% corn silage. Additionally, 3% of the diet was a feedlot vitamin and mineral premix from Walden Feed West (Cache Junction, UT) containing Rumensin (Elanco Animal Health, Greenfield, IN). A summary of the nutrient content of this ration can be found in Table 3. While in the feedlot, feed was administered using a Rissler 610 TMR feed cart (E Rissler MFG LLC., New Enterprise, PA). Feed offered and feed refused was measured daily in order to determine the feed disappearance. Feeding was carried out similar to the clean-bunk management system as described by Pritchard et al. (2003). Calves were again weighed at 28, 56, and 84 days past entering the grower phase. Feed efficiency was determined by dividing total amount of body weight gain during the 84 day growing period by total dry matter intake for the same period.

Table 3. Nutrient analysis of feedlot grower ration.

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

¹Grower 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

Additionally, during the feedlot phase, an Exago Ultra Portable ultrasound with 5 cm muscle probe (Universal Imaging, Bedford Hills, NY) was used to take predictive measurements of back fat thickness, and ribeye area at 28, 56, and 84 days of feeding. Readings were taken between the 12th and 13th rib similar to the methods used by Greiner et al. (2003). Blood samples were taken from the jugular vein using both ethylenediaminetetraacetic acid-anticoagulated tubes and no additive tubes to collect serum and plasma. These samples were taken at an average calf age of 60 days, 7 days before starting the grower ration, and after 84 days on previously described grower ration. Blood samples were used for serum and plasma metabolite profiling described in section 4.6.

Offspring Behavioral Measurements

At weaning, as well as on days 0, 28, 56, and 84 of feeding the grower ration, calves were evaluated for a temperament score. This temperament score was calculated using two measurements: Exit Velocity (EV; m/s) and Chute Score (CS). Exit velocity was measured similarly to King et al. (2006), with the modification that rather than use of infrared eyes, lines were drawn at 1 meter and 4.6 meters in front of the weigh chute. The time it took the animal to traverse the distance between the two lines was measured manually via stopwatch. Chute score was measured using a scoring system similar to Grandin (1993). During restraint in the weigh chute, calf behavior was visually evaluated and given a score of 1-5 based on the following criteria: 1: calm, no movement; 2: restless shifting; 3: squirming occasional shaking of chute; 4: continuous vigorous movement and shaking of chute; 5: rearing, twisting, or violently struggling (Voisinet et al., 1997). The temperament score was calculated as the sum of the animal's EV and CS divided by two.

Blood Metabolite Profiling

Blood samples were analyzed to measure concentrations of the following compounds: insulin, IGF-I, glucose, and cortisol. Insulin, and IGF-I were measured using the following available commercially available ELISA kits that have previously been shown to work with bovine samples: insulin (10-1201-01, Mercodia AB, Uppsala, Sweden) and IGF-I (SG100, R&D Systems, Minneapolis, MN). Both of these assays were performed using a Synergy H1 hybrid multi-mode microplate reader (Biotek,

Winooski, VT, US), and concentrations were reported in micrograms per deciliter. Glucose in plasma and cortisol in serum were both measured at the Utah State University Veterinary Diagnostics Laboratory (Logan, UT). Glucose concentrations were measured by an automated wet biochemistry analyzer (Dimension Xpand Plus, Siemens Healthcare Diagnostics Inc., Newark, DE) and reported in milligrams per deciliter. Cortisol levels were measured using an IMMULITE 1000 Immunoassay system (Siemens Medical Solutions USA, INC., Malvern, PA) and were reported in micrograms per liter.

Statistical Analysis

Analysis of weight and BCS for the mothers during mid-gestation and the recovery phase used the individual mother as the experimental unit. Least square means of weight and BCS were calculated using the general linear mixed model of procedure of SAS® version 9.4 (SAS Institute, Cary, NC). Differences due to the main effect of maintenance vs. restriction were considered significant at $P < 0.05$.

Measurements pertaining to calf growth, behavior, or performance all used each individual calf as the experimental unit, and comparisons were made within each individual time point. These were all analyzed using the general linear mixed model procedure of SAS® version 9.4 (SAS Institute, Cary, NC). Calf, sex, birthdate, and pen location were used as random effects. Differences due to the main effect of maintenance vs. restriction were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

Growth Data

Gestation Weight and Body Condition Score

Cows in maintenance and restricted groups had similar initial BW ($P = 0.804$; Table 4) and BCS ($P = 0.723$), prior to the 84-day treatment period. At the end of this 84-day period, restricted cows were determined to have lower BW ($P < 0.001$) and BCS ($P < 0.001$) compared with their maintenance counterparts. Seven weeks after the two groups were comingled, their respective weights ($P = 0.120$) and BCS ($P = 0.255$) were once again similar. This data indicates that a significant nutritional insult occurred, with regard to the restricted group, specifically during 84 days of midgestation. During the 7 weeks of tracked recovery, the weight difference ($P < 0.001$) and BCS difference ($P < 0.001$) was significant. Interestingly, maintenance cows had a declining BCS during late gestation while restricted BCS greatly increased. This is likely due to the seasons in which midgestation and late gestation occurred. With midgestation occurring from August to October and late gestation from November to February, Nutrient quality and availability decreased for the maintenance cows while it increased for the restricted cows during comingling. A study by Ford et al. (2007) on midgestational undernutrition in sheep also reported maternal weights at term. In contrast to our study, mothers did not return to similar weights by end of gestation, with restricted ewes being lighter. With a restriction period of approximately 50 days and starting at day 28 of gestation, Ford et al. did restrict mothers earlier and longer than our study in terms of relative gestation length. Thus it may be possible the restriction was too great for compensatory

gain to overcome. Further research is warranted determine if an optimal period of gestation for nutrient restriction exists.

Table 4. LS means of weights and body condition scores of mothers during 84 days of mid-gestation and at seven weeks post mid-gestation.

Item	Treatment ¹		SEM	P-value ²
	Maintenanc e	Restricted		
Weight (kg)				
Start of midgestation	536.57	528.26	24.474	0.804
End of midgestation	578.48	493.42	25.609	0.024
Change during midgestation	41.91	-32.15	4.738	<0.001
7 weeks post midgestation	609.63	558.27	23.694	0.120
Change during late gestation	31.15	69.15	3.297	<0.001
BC score ³				
Start of midgestation	5.47	5.31	0.332	0.723
End of midgestation	5.83	4.28	0.328	0.001
Change during midgestation	0.37	-1.03	0.139	<0.001
7 weeks post midgestation	5.43	5.00	0.276	0.255
Change during late gestation	-0.40	0.72	0.120	<0.001

¹Maintenance cows were allowed to graze 54 acres of irrigated pasture and supplemented with hay for 84 days of midgestation. Restricted cows grazed 6.4 acres of non-irrigated pasture and received minimal hay for 84 days of midgestation. Nutrient content of these pastures is defined in Table 1. For the 7 weeks post midgestation, both groups were comingled in the 54 acre maintenance pasture.

²Probability value of the F-test for treatment effect

³Body condition score was evaluated visually using a scale of 1-9 where 1 is emaciated, 5 is moderate, and 9 is extremely fat

Birth and weaning weight

Calves born to nutrient restricted mothers (restricted calves; 12 female and 6 male) showed no difference ($P = 0.988$; Table 5) in birth weight when compared to

calves born to nutrient maintained mothers (maintenance calves; 7 female and 9 male). Calf weaning weights did not differ ($P = 0.245$). Studies such as Radunz et al. (2012) and Martin et al. (2007) determined that change in maternal nutrient intake, through differing food sources or supplementation, during late gestation could lead to significant changes in birth weight. However, in these studies, offspring weights normalized post adolescence. As mentioned, the period of differing nutrient intake occurred mid-gestation in this study, and cows returned to a similar weight ($P = 0.120$; Table 4) and BCS ($P = 0.255$) during late gestation where diets were uniform. Therefore, it can reasonably be inferred that compensatory growth is having a strong influence on both the cow fetus. This seems to be consistent with the findings of a study by Gonzalez et al. (2013). Gonzalez et al. (2013) found that fetal muscle growth differed at the end of nutrient restriction during early and midgestation. However, realimentation of restricted mothers resulted in similar fetal muscle fiber size between treatments by end of term due to compensatory growth. A current concern with nutrient restriction is the possibility of negatively effecting offspring health and productivity (Bell 2006). This study showed that mid-gestational nutrient restriction combined with abundant late

Table 5. LS means of birth and weaning weights of maintenance and restricted calves.

Item	Treatment ¹		SEM	P-value ²
	Maintenance	Restricted		
Birthweight (kg)	40.80	40.76	2.1369	0.988
Weaning weight (kg)	242.10	228.01	8.664	0.245

¹Maintenance calves (n = 16) were born to maintenance mothers. Restricted calves (n = 18) were born to nutrient restricted mothers.

²Probability value of the F-test for treatment effect

gestational nutrient availability had no adverse effects on birth or weaning weights.

Feedlot Weights

Weight gain did not differ between maintenance and restricted cattle at each time point of the 84 day grower phase ($P \geq 0.464$; Table 6). Average weight gain for this 84 day period was also determined not to differ ($P = 0.815$). These results are in agreement with Radunz et al. (2012) and Shoup (2011) who found no fetal programming effect on weights during the feedlot phase. These studies differed in dietary makeup during only the third trimester rather than dietary restriction. However, ration nutrient analysis shown in these aforementioned studies and Table 1 of this study show that there were

Table 6. LS means of weight in pounds of maintenance and restricted calves at 0, 28, 56, and 84 days of grower ration.

Item	Treatment ¹		SEM	P-value ²
	Maintenance (kg)	Restricted (kg)		
Days on Grower Ration ³				
0	282.70	269.59	14.565	0.464
28	317.30	309.63	19.109	0.694
56	344.63	336.20	18.153	0.666
84	383.25	371.50	18.348	0.567
Average weight gain ⁴	100.15	101.37	5.260	0.815

¹Maintenance calves (n = 16) were born to maintenance mothers. Restricted calves (n = 18) were born to nutrient restricted mothers.

²Probability value of the F-test for treatment effect

³Grower ration consisted of approximately 43% corn silage, 27% barley concentrate, 27% alfalfa hay, and 3% vitamin and mineral premix on wet matter basis

⁴Average weight gain over the entirety of the 84-day grower period

nutrient availability differences between treatments in both the cited studies and this study.

Feed Intake, Average Daily Gain, and Gain: Feed

During the 84 days the calves were on the grower ration, average daily feed intake (ADFI) for any given 28 day period, as well as over the entire period was similar between treatments ($P \geq 0.428$; Table 7). Additionally, average daily gain (ADG) was similar throughout the period and overall ($P \geq 0.345$). Finally, gain: feed was also similar between treatments for each period and overall ($P \geq 0.273$). These findings are consistent with Martin et al. (2007), who studied fetal programming through differing diets in the third trimester and found no differences in ADFI, ADG, or gain: feed. Similarly, Shoup (2011), who studied fetal programming through differing diets and supplementation, found ADG, feed intake, and gain: feed of the calves to be similar between treatments. It should be noted, these two studies looked at these measurements for the entire feedlot phase while this study only looked at the first 84 days. Interestingly, Larson et al. (2009) found feed intake to differ over the entirety of the feedlot phase, implying that later fetal programming may more greatly impact later feedlot stages. According to Du et al. (2010), maternal nutrient restriction during midgestation primarily alters muscle fiber number while late gestational restriction affects both muscle fiber number and adipocyte deposition in a fetus. Guenther et al. (1965) claims that the majority of skeletal development and muscle growth has occurred by weaning and early in the feedlot phase. Furthermore, Guenther et al. (1965) claims that feed intake is greatest during the initial portion of the feedlot phase. Compensatory

Table 7. LS means of daily feed intake, average daily gain, and gain: feed ratio measurements for maintenance and restricted calves during the 84 days or grower ration ($P < 0.05$).

Item	Treatment ¹		SEM	P-value ²
	Maintenance	Restricted		
Daily feed intake ³				
Days 0-28	14.73	14.92	0.843	0.759
Days 29-56	18.41	17.42	1.154	0.428
Days 57-84	18.80	18.57	1.185	0.841
Days 0-84 ⁴	17.34	16.95	0.875	0.699
Average daily gain ⁵				
Days 0-28	1.25	1.41	0.185	0.338
Days 29-56	0.96	0.95	0.077	0.930
Days 57-84	1.36	1.26	0.074	0.345
Days 0-84 ⁴	1.19	1.21	0.063	0.815
Gain : Feed ⁶				
Days 0-28	0.09	0.09	0.008	0.398
Days 29-56	0.05	0.06	0.007	0.581
Days 57-84	0.07	0.07	0.007	0.243
Days 0-84 ⁴	0.07	0.07	0.004	0.792

¹Maintenance calves (n = 16) were born to maintenance mothers. Restricted calves (n = 18) were born to nutrient restricted mothers.

²Probability value of the F-test for treatment effect

³Daily feed intake was calculated as total food intake in kg for the given period divided by 28 days

⁴Average of the entire 84-day grower period

⁵Average daily gain was calculated as total weight gain in kg for the given period divided by 28 day

⁶Gain to feed ratio was calculated as total weight gain for the given period divided by total feed intake for the same period

growth is a proven phenomenon in beef cattle, especially in regards to muscle growth (Gonzalez et al., 2013). Therefore, it was not surprising that no difference is found in weight gain, which is driven primarily by skeletal development and muscle growth up

to this point in calf development. Taking into consideration that this is the highest point in daily feed intake in the calves' lives, any differences in the calves caused by fetal programming could likely be masked. These two factors would also explain our findings of no difference in gain to feed ratio between treatments as well. Additionally, it is known that leptin, an important factor in controlling long-term nutritional intake, is produced in adipocytes (Edwards et al. 2005). When considering that adipocyte deposition is effected by late gestational nutrient intake, this could be an explanation as to how the findings of Larson et al. (2009) pertaining to feed intake do not contradict the findings of this study.

Ultrasound Measurements

Ribeye area measured by ultrasound was found to be similar between treatments at each time point ($P \geq 0.285$; Table 8). Additionally, No difference was found in ultrasound measured back fat thickness ($P \geq 0.416$) between maintenance and restricted calves. These results seem consistent with studies such as that by Blair et al. (2013), which found no effect of midgestational dietary restriction on ribeye area or yield grade, an indicator of back fat thickness, at harvest. Similarly, Radunz et al. (2012) and Larson et al. (2009) found no effect of fetal programming on ribeye area or fat thickness on adolescent cattle. Gonzalez et al. (2013) found that, at the end of midgestation, fetal muscle fiber diameter differed between maternal nutrient restriction and control. However, by the end of term, muscle fiber diameter had returned to similar between treatments, implying that compensatory growth occurs as quickly as nutrient availability allows. Considering calves had similar diets, and therefore similar nutrient availability,

it is logical that ribeye area be similar between treatments. Guenther et al. (1965) found that fat deposition significantly onsets towards the latter part of the feedlot phase, after approximately 11 months of age. Given the calves in this study averaged 9 to 11 months of age by the end of the grower phase, it is likely any possible differences in backfat have not had time to develop.

Table 8. LS means of ultrasound measures ribeye area and back fat thickness of maintenance and restricted calves ($P < 0.05$).

Item ³	Treatment ¹		SEM	P-value ²
	Maintenance	Restricted		
Ribeye area (cm ²)				
Day 28	46.20	45.91	2.043	0.909
Day 56	50.20	49.96	2.346	0.921
Day 84	56.97	54.19	1.738	0.285
Back fat thickness (mm)				
Day 28	2.42	2.76	0.485	0.416
Day 56	3.08	3.38	0.508	0.602
Day 84	4.57	4.58	0.893	0.983

¹Maintenance calves (n = 16) were born to maintenance mothers. Restricted calves (n = 18) were born to nutrient restricted mothers

²Probability value of the F-test for treatment effect

³Measurements were taken using a portable ultrasound and muscle probe and taken between the 12th and 13th rib

Blood Metabolites

Glucose, IGF-I, and insulin in plasma were measured at three points in the calves' adolescence: approximately 75 days of age, 7 days prior to the calves starting the grower ration, and after 84 days on the grower ration. Cortisol in serum was measured twice during the calves' adolescence: 7 days prior to the calves starting the grower ration, and after 84 days on the grower ration. Glucose concentrations at all three

Samplings were similar between maintenance and restricted calves ($P \geq 0.504$; Table 9). No differences were found in IGF-I concentrations between maintenance and restricted calves at any of the sampling time points ($P \geq 0.107$). Insulin concentrations in maintenance and restricted calves were similar at all sampling time points ($P \geq 0.224$). Finally, cortisol was found to be similar between the maintenance and restricted calves at each sampling time point ($P \geq 0.709$). Ford et al. (2007) found early and midgestational nutrient restriction resulted in increased insulin and glucose concentrations in offspring. Gardner et al. (2005) found that late gestational undernutrition led to increased glucose intolerance and insulin resistance in offspring. While we found no difference in concentrations of these analytes, it is possible that sampling more often and at different times could yield different results. Brameld et al. (2000) found no maternal nutrition effect on IGF-1 concentrations in sheep fetuses, which is consistent with the findings of this study. However, a review by Holt (2002) proposes that maternal nutritional status quite likely has a significant effect on the growth hormone – insulin-like growth factor axis of the offspring in humans. Based on this hypothesis, similar mechanisms may be present in livestock species. Further research is warranted to identify if maternal nutritional status in livestock is having a direct effect on these and other growth related.

Table 9. LS means of concentrations of glucose, IGF-I and insulin from plasma; and cortisol from serum in maintenance and restricted calves ($P < 0.05$).

Item	Treatment ¹		SEM	P-value ²
	Maintenance	Restricted		
Glucose (mg/dL)				
75 days of age	134.25	130.69	6.925	0.719
7 days before grower ration	88.86	87.82	3.357	0.821
End of grower ration	73.75	76.78	3.258	0.504
IGF-1 (µg/L)				
75 days of age	178.35	171.51	17.525	0.781
7 days before grower ration	73.77	100.87	12.346	0.107
End of grower ration	178.84	162.84	18.466	0.533
Insulin (µg/L)				
75 days of age	0.41	0.53	0.105	0.224
7 days before grower ration	0.53	0.65	0.177	0.443
End of grower ration	0.74	0.94	0.223	0.449
Cortisol (µg/dL)				
7 days before grower ration	4.42	4.47	0.776	0.939
End of grower ration	2.73	2.59	0.329	0.709

¹Maintenance calves (n = 16) were born to maintenance mothers. Restricted calves (n = 18) were born to nutrient restricted mother

²Probability value of the F-test for treatment effect

Behavioral Measurements

Maintenance cows were more active than restricted cows during midgestation as shown by steps value ($P = 0.003$; Table 10) and motion index ($P < 0.001$). No difference was found in lying bouts between treatments during midgestation ($P = 0.331$). During recovery, differences in motion index ($P = 0.715$), steps ($P = 0.818$), and lying bouts ($P = 0.445$) were all statistically insignificant. The steps value and motion index differences during midgestation were likely due to the differing pastures. Considering that the maintenance pasture was 9 times larger with approximately 12 times more food available (estimated from Table 1 on a dry matter basis), it is likely

that the restricted mothers lack of motion was due to confinement. This seems consistent with the results of the recovery period, in which the two groups were comingled in the same pasture, and all behavioral measurements were similar.

Table 10. LS means of maternal behavior data during mid-gestation and recovery ($P < 0.05$).

Item	Treatment ¹		SEM	P-Value ²
	Maintenance	Restricted		
Mid-gestation				
Motion Index ³	14035.00	8538.26	222.410	<0.001
Steps ⁴	3082.21	2095.27	167.650	0.003
Lying bouts ⁵	613.13	471.27	96.964	0.331
Recovery				
Motion Index ³	15040.00	14809.00	452.220	0.715
Steps ⁴	3062.24	3029.18	102.940	0.818
Lying bouts ⁵	401.66	522.97	112.030	0.445

¹Maintenance cows were allowed to graze 54 acres of irrigated pasture and supplemented with hay for 84 days of mid-gestation. Restricted cows grazed 6.4 acres of non-irrigated pasture and received minimal hay for 84 days of mid-gestation.

Nutrient content of these pastures is defined in Table 1. For the 7 weeks post mid-gestation “recovery” period, both groups were comingled in the 54 acre maintenance pasture. Tags were worn for days 29-56 of mid-gestation and all 7 weeks of recovery.

²Probability value of the F-test for treatment effect

³Motion index is a function of motion that describes the vigorousness of activity, or energy expenditure during motion

⁴Average total steps taken by cows during the described period

⁵Average total of times cow laid down during the described period

Calf chute scores were similar between treatments at all time points ($P \geq 0.103$; Table 11). Exit velocities did not differ between groups for the first four time points ($P \geq 0.135$). At day 84 on grower ration, restricted calves showed a tendency towards faster exit velocities than the maintenance calves ($P = 0.089$). Finally, while no difference was found in temperament scores of the two treatments during the grower ration phase ($P \geq 0.256$), at weaning, restricted calves had greater temperament scores

compared with maintenance calves ($P = 0.026$). No research was found on the effects of fetal programming and animal temperament. Sullivan et al. (2010) found that nonhuman primates with high fat diets during gestation gave birth to more anxious offspring.

Additionally, Hernández-Martínez et al. (2011) found that certain mineral deficiencies during gestation in humans effected autonomous nervous responses in children. Our results are, however, consistent with animal temperament studies such as Behrends et al. (2009) that found more differentiation in behavior at weaning than measurements taken during the feedlot phase. Behrends et al. (2009) also found a negative relationship between temperament and carcass characteristics such as ribeye area, yield grade, and Warner-Bratzler shear force.

Table 11. LS means of chute scores, exit velocities, and temperament scores of maintenance and restricted calves at weaning and 0, 28, 56, & 84 days on the grower ration ($P < 0.05$).

	Treatment ¹		SEM	P-value ²
	Maintenanc e	Restrict ed		
Chute Score ³				
Weaning	2.50	2.99	0.219	0.103
Day 0	2.58	2.24	0.313	0.305
Day 28	2.33	2.29	0.333	0.917
Day 56	1.76	1.74	0.261	0.931
Day 84	1.90	1.90	0.199	0.991
Exit Velocity ⁴ (m/s)				
Weaning	2.61	2.99	0.183	0.135
Day 0	2.58	3.01	0.247	0.224
Day 28	2.57	2.75	0.319	0.571
Day 56	2.39	2.70	0.320	0.312
Day 84	2.08	2.66	0.336	0.089
Temperament Score ⁵				
Weaning	2.56	3.01	0.142	0.026
Day 0	2.60	2.66	0.236	0.851
Day 28	2.42	2.56	0.152	0.482
Day 56	1.96	2.26	0.213	0.347
Day 84	1.99	2.26	0.246	0.256

¹Maintenance calves (n = 16) were born to maintenance mothers. Restricted calves (n = 18) were born to nutrient restricted mothers

²Probability value of the F-test for treatment effect

³Chute score was evaluated visually and given a score between 1 and 5, where 1 means animal was calm, no movement, and 5 means animal reared, twisted or struggled violently.

⁴Exit velocity was measured by making lines at 1 and 4.66 meters in front of shooting and measuring how quickly the calf traversed the distance.

⁵Temperament score was calculated by taking the sum of the chute score and the exit velocity in meters per second, and dividing that sum by 2.

CONCLUSION

While this study identified few differences caused by midgestational nutrient restriction, it is quite possible that the animals simply were not developed enough to fully show any induced effects. In a study looking at age and nutritional plane effect of development of different tissues, Guenther et al. (1965) found that as much as 87% of skeletal muscle growth had occurred by the early portion of the feed lot phase. Furthermore, Guenther et al. (1965) found that as high as 96% of skeletal development had occurred by 11 months of age, and that feed efficiency was greatest in the initial period of the feedlot phase. This steep phase of the growth curve could be masking differences caused by our treatment that may be revealed at later stages of growth and development. Furthermore, the similar results between treatments in growth and performance data found in this study should help alleviate concerns raised by those, such as a Bell (2006), who worry gestational nutrient restriction could have adverse effects on calf health and productivity. While restricted calves were more excitable at weaning than their maintenance counter parts, this did not cause animal handling issues, as temperament scores between treatments became similar by the end of backgrounding. However, special attention should be paid to see if similar correlations are found between weaning temperament and negative carcass characteristics at harvest as those reported by Behrends et al. (2009).

While these findings are novel and intriguing, it is also noteworthy that they are part of a bigger story. These calves will be finished at the university feedlot and then harvested at a local facility. Carcass data (to include hot carcass weight, dressing

percentage, quality grade, yield grade, and ribeye area) will be collected and compared according to treatment. Pre-rigor Muscle tissue biopsies will be taken at the harvest facility from the posterior end of the loin in order to carry out muscle fiber typing. A loin from each carcass will also be collected in order to carry out a descriptive sensory panel and Warner–Bratzler shear force test. By combining the findings from this study with this upcoming research, we will have a novel, complete picture of midgestational fetal programming effects from gestation to harvest.

Fetal programming is a vastly growing field of research that warrants further study in many areas. It is still a relatively novel concept, and some studies have conflicting results. Studies such as Larson et al. (2009) have found that maternal nutritional intake for the entirety of gestation, especially when insufficient, can have negative effects on offspring. This study and similar studies, such as Blair et al. (2013), reveal that maternal nutritional changes at strategic and opportune periods of gestation can in fact avoid negative effects on offspring.

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