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D. A Mohrhauser
South Dakota State University

A.R. Taylor
South Dakota State University

K.R. Underwood
South Dakota State University

R.H. Pritchard
South Dakota State University

A.E. Wertz-Lutz
South Dakota State University

See next page for additional authors

Authors
D. A Mohrhauser, A.R. Taylor, K.R. Underwood, R.H. Pritchard, A.E. Wertz-Lutz, and A.D. Weaver

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The influence of maternal energy status during mid-gestation on beef offspring carcass characteristics and meat quality[1]

D.A. Mohrhauser, A.R. Taylor, K.R. Underwood, R.H. Pritchard, A.E. Wertz-Lutz[2], and A.D. Weaver

Department of Animal Science, South Dakota State University

SUMMARY

Research has suggested that maternal under-nutrition may cause the development of a thrifty phenotype in the offspring, potentially resulting in greater adiposity and reduced muscle mass. These alterations in fat and muscle development could have lasting impacts on offspring growth, carcass characteristics, and meat quality. Thus, the objective of this study was to determine the influence of maternal energy status during mid-gestation on offspring carcass characteristics and meat quality. To alter maternal energy status, cows either grazed pasture or were fed in a dry-lot at 80% of the energy requirements for body weight maintenance during a mean period of 109 to 207 d of gestation. Changes in body condition score (BCS), body weight, ribeye area (REA), and 12th rib backfat were measured throughout mid-gestation and were used to determine cow energy status [Positive (PES) or Negative (NES)]. Cows in the NES group had a significantly greater reduction in BCS, body weight, REA, and 12th rib backfat during mid-gestation. Maternal energy status had no influence on offspring hot carcass weight, dressing percent, REA, percent kidney, pelvic, and heart fat, marbling score, percent intramuscular fat, objective color, or Warner-Bratzler shear force. A tendency was seen for NES calves to have improvements in 12th rib backfat and USDA Yield Grade. A greater MRatio and IRatio (calculations used to compare the ratio of marbling (MRatio) and percent intramuscular fat (IRatio) with 12th rib backfat) were discovered in calves from cows experiencing a negative energy status during mid-gestation. These results suggest that maternal energy status during mid-gestation may impact fat deposition in intramuscular and subcutaneous fat depots without impacting muscle mass.

INTRODUCTION

In many places in the U.S., cows graze pastures as the primary source of nutrients during gestation. In the upper Great Plains, beef cattle producers implement low cost feeding programs during mid-gestation wherein cows typically graze dormant forage or other poor quality forages, potentially causing a deficiency in both protein and energy if cows are not supplemented. As a result, this could cause the fetus to receive inadequate nutrients, potentially altering fetal development and, ultimately, body composition of the offspring. Research has suggested that maternal under-nutrition during pregnancy may result in offspring developing a 'thrifty phenotype' that is more prepared to deal with sparse nutrient availability, and, thus, maternal nutrition has the potential to impact the development of muscle and adipose tissue in the offspring (Barker, 1995; Zhu et al., 2004; Du et al., 2011; Yan et al., 2012). In the bovine fetus, the majority of muscle cells are generated during secondary muscle fiber

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[2]Present address: ADM Alliance Nutrition, Inc., Quincy, IL 62305-3115

development, beginning at about the third month of gestation and lasting until about seven or eight months of gestation (Russell and Oteruelo, 1981; Du et al., 2010). Additionally, adipogenesis is thought to span across the last 5 months of gestation while continuing after birth (Du et al., 2010). Therefore, with the understanding that mid-gestation is a critical period in fetal development, insults to maternal nutritional status during mid-gestation may cause alterations in carcass characteristics and meat quality.

While it has been reported that restricted maternal nutrition can increase adiposity in the offspring of other livestock species (Bispham et al., 2005; Karunaratne et al., 2005), the impact of maternal nutrition on bovine offspring carcass traits remains unclear; thus, predicated by the hypothesis that a negative bovine maternal nutritional status will alter fetal muscle and fat development, the objective of this study was to determine the influence of maternal energy status during mid-gestation on offspring carcass characteristics and meat quality.

MATERIALS AND METHODS

All animal care and experimental protocols were approved by the South Dakota State University Animal Care and Use Committee. One hundred fifty-one crossbred, 3- and 4-year-old cows from 2 South Dakota State University research stations in western South Dakota were bred naturally to Angus and SimAngus bulls over a 60-d breeding period to begin calving at the end of March. Thirty-eight days after bulls were removed from cow pastures, cows were evaluated for pregnancy, length of gestation, calf gender, weight, and BCS, allowing for the allotment of cows into mid-gestation management groups based on conception date, source, body weight, age, and body condition score (BCS; 1 to 9, 1 = extremely emaciated, 9 = obese). At this time, calves from the previous year were weaned and pregnant cows from both research stations were co-mingled to be managed similarly in native range pastures on one research station. At 56 d after bull removal, cows with a mean gestation length of 84 d ± 11.3 (based on pregnancy ultrasound; 109 d ± 10.9 based on calf birth date with a 283-d gestation length) were allotted into 2 management strategies: 1) fed to achieve and/or maintain a BCS of 5.0-5.5 (Maintenance; n=76); or 2) fed to lose 1 BCS over a 98-d period of mid-gestation (Restricted; n=75). Body condition scores were determined by the average of 4 trained evaluators at the beginning and end of the second trimester, while cows were weighed every 28 d throughout mid-gestation. Initial body weights and final body weights of the mid-gestation period were normalized for fill, as cows were managed as a common group for a week prior to and after the mid-gestation treatment. Additionally, ultrasound measurements were collected for 12th rib subcutaneous fat and ribeye area at the beginning and the end of mid-gestation.

Cows managed to maintain BCS were left on dormant, native range pasture consisting primarily of western wheatgrass, with some green needle grass, little bluestem, buffalo grass, and blue grama. The cows on pasture were provided a pelleted supplement (Table 1; 45.7% CP, 0.74 Mcal/lb NE_m) every other day at 0.54% body weight per supplementation delivery. During this study, mid-gestation (October 2010 through January 2011) was unusually mild and dry, resulting in pastures that were free of snowpack until mid-January. In January, cows on pasture were supplemented with grass hay at 21.5 lb DM/head/d. Cows fed to lose 1 BCS were managed in 10 dry-lot pens, blocked by weight, and each day were fed mature brome hay at 1.42% body weight and a protein supplement (Table 1; 31.4% CP, 0.72 Mcal/lb NE_m) at 0.255% body weight. Cows in the dry-lot pens were fed a diet consisting of 84.8% hay and 15.2% supplement (Table 1).

Table 1. Formulations and compositions of mid-gestation treatment diets.[1]

Diet Composition	Maintenance[2]	Restricted[3]
Dormant, Native Range, %[4]	87.50	-
Mature Brome Hay, %	-	84.80
Pelleted Supplement, %[5]	12.50	15.20
Soybean Meal[6]	(52.20)	(2.75)
Sunflower Meal[6]	(20.00)	(20.00)
Wheat Middlings[6]	(19.30)	(69.33)
Urea[6]	(3.06)	(3.04)
Dry Matter Intake, lb/head/d[7]	23.74	16.92

Nutrient Composition	Maintenance[2]		Restricted[3]	
	Dormant Range[4]	Supplement[8]	Mature Brome Hay[8]	Supplement[8]
Dry Matter, %	80.00	95.83	97.25	95.37
Crude Protein, %	4.70	45.65	5.76	31.39
Neutral Detergent Fiber (NDF), %	66.10	22.06	71.80	37.54
Ash, %	10.00	11.55	7.94	9.85

[1]All values except DM on DM basis

[2]Cows managed to maintain BCS during mid-gestation

[3]Cows managed to lose 1 BCS during mid-gestation

[4]Intake and composition estimated using Nutrient Requirements of Beef Cattle (NRC, 2000) estimates for winter range

[5]Fortified with vitamins and minerals to meet or exceed NRC requirements

[6]Values in parentheses are percent of pelleted supplement

[7]Average dry matter intake (DMI) per head per day throughout mid-gestation treatment; Maintenance DMI based on Nutrient Requirements of Beef Cattle (NRC, 2000) estimates for intake of winter range

[8]Analyzed values determined through lab assays

After completion of the 98-d mid-gestation period, all cows were co-mingled and managed as a common group on range through calving. Final body weight was taken 7 d into this phase to normalize fill across treatments. During calving, calf birth weight, date of birth, and gender were recorded and bull calves were banded at birth. Birth dates of the calves in this study spanned from March 30 to May 19, with a median birth date of April 11. After calving, cows and calves were managed as a common group following research station protocol until weaning. At weaning (October 13), calves meeting study protocol (133 head) were shipped to the South Dakota State University Research Feedlot in Brookings, SD. Calves were then sorted into pens by gender and management strategy where each gender/management strategy combination consisted of 4 pens containing 7 or 8 head per pen. Common receiving, backgrounding, and finishing diets were fed across treatment and gender. Calves were marketed when all of the progeny were estimated to average 0.4 in of 12th rib backfat thickness (208 d on feed). Both at 21 d and at 208 d in the feedlot, a subsample (n=12) of steers was harvested at the SDSU Meat Lab reducing the number of animals in this report to 109.

Prior to harvest, calves were weighed in the morning and then shipped approximately 150 mi to a commercial abattoir (Tyson Foods, Dakota City, NE). Calves were allowed free access to water overnight and were harvested the following morning. Calves were tracked through the harvest floor to maintain animal identification throughout harvest, carcass chilling, and carcass fabrication. Hot carcass weight (HCW) for each individual carcass was recorded while ribeye area (REA), 12th rib backfat, and marbling score were determined using camera grading following carcass chilling (approximately 30 h) (n=108 due to inability to rib one carcass). Additionally, percentage of kidney, pelvic and heart fat (KPH) was estimated by a USDA grader. Hot carcass weight, REA, 12th rib backfat, and KPH were then used to calculate USDA yield grades. At 2 d postmortem, carcasses were tracked through the fabrication floor, where full strip loins were collected from one side of each carcass. Recovered strip loins (n=103) were vacuum packaged, boxed, and transported to the SDSU Meat Lab. At 3 d postmortem, strip loins were processed for the analysis of percent intramuscular fat, objective lean color, and tenderness evaluation through Warner-Bratzler shear force (WBSF). Steaks were removed from the anterior end of the strip loin, beginning with a sample for the evaluation of percent intramuscular fat, followed by three 2.54-cm steaks utilized for WBSF while the first of the WBSF steaks was also used for objective lean color measurements. Steaks for the analysis of WBSF were vacuum-packaged and stored at 4°C for postmortem aging periods of 3, 14, or 21 d.

The MRatio and IRatio were determined in order to compare marbling and percent intramuscular fat, respectively, with external carcass fat. MRatio was calculated as:

$$\left[\frac{(Obs\ Marb - Marb\ \bar{x})}{Marb\ S_d}\right] - \left[\frac{(Obs\ BF - BF\ \bar{x})}{BF\ S_d}\right]$$

to allow for the comparison of marbling score and 12th rib backfat as an indicator of the relationship of marbling to subcutaneous fat deposition. Similarly, IRatio was calculated as:

$$\left[\frac{(Obs\ \%IMF - \%IMF\ \bar{x})}{\%IMF\ S_d}\right] - \left[\frac{(Obs\ BF - BF\ \bar{x})}{BF\ S_d}\right]$$

for the comparison of percent intramuscular fat and 12th rib backfat as an additional tool to evaluate changes in fat deposition.

Because some cows within each management strategy were unable to achieve our goals of the study for biological differences in metabolic energy status, cows and the carcasses of their progeny were re-classified based on energy status (positive or negative) calculated from indicators measured during mid-gestation including changes in cow body condition score (BCS Δ), ribeye area (REA Δ), and body weight (BW Δ). The formula used is as follows:

$$\left[\frac{(Obs\ BCS\ \Delta - BCS\ \Delta\ \bar{x})}{BCS\ \Delta\ S_d}\right] + \left[\frac{(Obs\ REA\ \Delta - REA\ \Delta\ \bar{x})}{REA\ \Delta\ S_d}\right] + \left[\frac{(Obs\ BW\ \Delta - BW\ \Delta\ \bar{x})}{BW\ \Delta\ S_d}\right]$$

Means and standard deviations of each variable were from the whole population. The formula resulted in a bimodal distribution of cows around 0. Cows with a positive value were deemed to be in a positive energy status (PES) while cows with a negative value were deemed to be in a negative energy status (NES) during mid-gestation. Two cows between the two groups were removed, leaving the PES group with 79 head and the NES group with 70 head. Overall, the re-classification resulted in 6 cows that were re-classified from the original Restricted group to the PES group and 3 cows that moved from the original Maintenance group to the NES group. Two cows originally part of the Restricted group were removed because their energy status index was 0 and different from either energy status grouping.

Least squares means for cow measurements taken during mid-gestation were computed using PROC GLM procedures of SAS (SAS Inst. Inc., Cary, NC). Cow measurements were analyzed using a randomized, complete block design where cows were blocked by weight. Although Maintenance cows were managed as one group on pasture, cows were blocked into ten groups by weight to match the ten dry-lot pens that were blocked by weight within the Restricted group. Differences due to the main effects of cow energy status and block were tested using the interaction of these main effects as the error term. Means were tested to a predetermined significance level of 0.05.

Statistical analyses on calf carcass data were conducted using each calf as the experimental unit. Least squares means for all data were computed using PROC GLM procedures of SAS, determining differences due to the main effects of cow energy status and calf gender, as well as the interaction, cow energy status x calf gender. Means were tested to a predetermined significance level of 0.05.

RESULTS AND DISCUSSION

The cows used in this study were manipulated to be in either a positive or negative energy status during the important developmental period of mid-gestation. Changes in cow body weight, BCS, fat thickness, and ribeye area due to mid-gestation energy status were determined using measurements taken at the beginning and end of the mid-gestation period (Table 2). Cows in the NES group displayed a significantly greater reduction in BCS, body weight, 12th rib fat thickness, and REA relative to the PES cows ($P < 0.05$) during mid-gestation (Table 2).

Table 2. Least squares means for days of gestation at mid-gestation and cow body condition score (BCS), body weight (BW), ribeye area (REA), and fat thickness at the beginning and end of the mid-gestation treatment period.[1]

	Cow Energy Status			*P*-value	
Trait	**Positive**	**Negative**	**SEM**	**Status**	**Block**
Days of Gestation[2]	84	84	1.3	0.9730	**0.0215**
Initial BCS	4.78	4.94	0.051	0.1028	**0.0076**
Final BCS	4.92	4.29	0.046	**0.0001**	**0.0128**
Change in BCS	0.14	-0.65	0.050	**<0.0001**	0.4076
Initial BW, lb	1017	1017	5.2	0.9907	**<0.0001**
Final BW, lb	1126	967	6.7	**<0.0001**	**<0.0001**
Change in BW, lb	109	-50	5.6	**<0.0001**	0.3197
Initial REA, in^2	8.85	9.24	0.146	0.1035	**0.0007**
Final REA, in^2	9.38	8.25	0.155	**0.0003**	**0.0004**
Change in REA, in^2	0.53	-0.99	0.111	**<0.0001**	0.4460
Initial 12th Rib Fat Thickness, in	0.15	0.16	0.005	0.7228	**0.0081**
Final 12th Rib Fat Thickness, in	0.16	0.14	0.004	**0.0251**	**0.0418**
Change in 12th Rib Fat Thickness, in	0.01	-0.02	0.004	**0.0083**	0.2907
Energy Status[3]	2.09	-2.32	0.146	**<0.0001**	0.9888

[1]Measurements taken at beginning and end of mid-gestation period normalized by fill

[2]Days of gestation at beginning of mid-gestation treatment as estimated by pregnancy ultrasound

[3]Energy status = $\left[\frac{(Obs\ BCS\ \Delta - BCS\ \Delta\ \bar{x})}{BCS\ \Delta\ S_d}\right] + \left[\frac{(Obs\ REA\ \Delta - REA\ \Delta\ \bar{x})}{REA\ \Delta\ S_d}\right] + \left[\frac{(Obs\ BW\ \Delta - BW\ \Delta\ \bar{x})}{BW\ \Delta\ S_d}\right]$

Carcass characteristics of progeny from this study can be found in Table 3. As expected, steers were harvested with a heavier HCW, less 12th rib backfat and KPH, reduced marbling score and percent intramuscular fat, and a larger REA than their heifer contemporaries ($P < 0.05$). At the same time, no differences in HCW, dressing percent, REA, KPH, marbling score, and percent intramuscular fat ($P > 0.05$) occurred due to mid-gestation energy status. Of note, maternal energy status had no influence on the degree of muscling as measured by REA, although alterations in maternal energy status occurred during what has been suggested to be the period of maximal fetal muscle fiber development. There were no cow status by calf gender interactions for carcass traits ($P > 0.05$). Tendencies for reduced 12th rib backfat and lower USDA Final Yield Grade were observed in calves from NES cows ($P < 0.06$), indicating that maternal nutritional status may have an impact on beef carcass characteristics.

Calves from NES dams in this study produced a significantly improved MRatio and IRatio ($P < 0.05$) when compared to calves from PES dams. The significant improvements found in calves from dams in a negative energy status during mid-gestation for both MRatio and IRatio highlight the potential for significant alterations to occur in adipogenesis *in utero* that persist throughout life and could improve carcass value. Additionally, alterations in fat deposition may create new management opportunities to positively impact marbling and subcutaneous fat thickness relative to lean muscle during prenatal development.

Further analysis of quality attributes can be found in Table 4, highlighting differences in objective color measurements (L*, a*, and b* values) and WBSF of *Longissimus dorsi* steaks with various aging periods. In this study, 10 head were classified as dark cutters by USDA graders, including 8 heifers and 2 steers. Of these, 6 head were from NES cows and the other 4 from PES cows, indicating that the incidence of dark cutters was unlikely to be related to maternal energy status. Still, to prevent skewed results in objective color and WBSF, we removed 15 head (12 heifers and 3 steers; 9 NES and 6 PES calves) based on L* value. Criteria followed guidelines set by Wulf and Wise (1999), who concluded that beef carcasses with an L* value below 36.5 should be classified as dark cutters. Removal of these 15 head from this portion of the analysis resulted in the evaluation of objective color and WBSF consisting of samples from 86 head. Objective color measurements performed at 3 d postmortem indicated a tendency for increased L* values ($P < 0.10$) and a higher a* value ($P < 0.05$) in the strip loins of steers when compared to heifers. Meanwhile, no differences due to maternal energy status were discovered for L*, a*, and b* values ($P > 0.05$). At 3, 14, and 21 d postmortem, WBSF of steaks from steers were lower than WBSF of steaks from heifers ($P < 0.05$). No differences were observed for WBSF at any aging period when comparing steaks from calves of NES or PES ($P > 0.05$).

Table 3. Carcass characteristics of calves from dams in a positive or negative energy status during mid-gestation.

	Cow Energy Status			Gender			*P*-value		
Trait	**Positive**	**Negative**	**SEM**	**Heifers**	**Steers**	**SEM**	**Status**	**Gender**	**S x G**
Hot Carcass Weight, lb[1]	728	714	8.9	682	761	9.0	0.2373	**<0.0001**	0.7968
Dressing Percent[1, 4]	63.12	62.97	0.194	63.23	62.86	0.196	0.5500	0.1563	0.3510
12th Rib Backfat, in [2]	0.49	0.44	0.018	0.50	0.43	0.018	**0.0585**	**0.0084**	0.8652
REA, in^2 [2]	13.00	13.10	0.172	12.78	13.32	0.172	0.6839	**0.0205**	0.5890
KPH, %[2]	2.09	2.10	0.029	2.25	1.94	0.029	0.8722	**<0.0001**	0.9601
USDA Yield Grade[2]	2.86	2.64	0.084	2.82	2.69	0.084	**0.0502**	0.2635	0.8688
Marbling Score[2, 5]	430	440	8.6	451	418	8.6	0.3857	**0.0053**	0.8287
MRatio[2, 6]	-0.24	0.29	0.178	0.04	0.01	0.178	**0.0275**	0.8888	0.7563
Intramuscular Fat, %[3]	4.09	4.46	0.184	4.58	3.97	0.181	0.1332	**0.0136**	0.1673
IRatio[3, 7]	-0.32	0.33	0.167	-0.02	0.04	0.164	**0.0044**	0.7956	0.2568

[1]Positive: n = 59; Negative: n = 48; Heifers: n = 60; Steers: n = 47

[2]Positive: n = 59; Negative: n = 47; Heifers: n = 59; Steers: n = 47

[3]Positive: n = 57; Negative: n = 44; Heifers: n = 55; Steers: n = 46

[4]Calculated using final live body weight with 4% shrink

[5]300 = Slight^{00}; 400 = Small^{00}

[6]MRatio = ratio of marbling score to 12th rib fat thickness

[7]IRatio = ratio of % intramuscular fat to 12th rib fat thickness

Table 4. Maternal energy status effects on offspring objective color (Minolta L*, a*, b* values) and Warner-Bratzler shear force (WBSF) of *longissimus dorsi* steaks.

	Cow Energy Status			Gender			*P*-value		
Trait	**Positive[4]**	**Negative[5]**	**SEM**	**Heifers[6]**	**Steers[7]**	**SEM**	**Status**	**Gender**	**S x G**
L*[1]	42.02	42.11	0.345	41.66	42.48	0.318	0.8428	**0.0700**	0.9078
a*[2]	22.75	22.58	0.214	22.39	22.95	0.198	0.5369	**0.0493**	0.6502
b*[3]	8.07	8.00	0.170	7.89	8.17	0.157	0.7362	0.2092	0.7145
3-d WBSF, kg	4.17	4.18	0.188	4.63	3.73	0.173	0.9553	**0.0004**	0.9688
14-d WBSF, kg	3.14	3.08	0.103	3.26	2.96	0.096	0.6604	**0.0279**	0.4716
21-d WBSF, kg	3.16	3.10	0.116	3.29	2.97	0.106	0.6654	**0.0322**	0.7000

[1]L*: 0 = Black, 100 = White; taken 3 d postmortem
[2]a*: Negative values = green; Positive values = red; taken 3 d postmortem
[3]b*: Negative values = blue; Positive values = yellow; taken 3 d postmortem
[4]n=51
[5]n=35
[6]n=43
[7]n=43

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