The influence of gestational body weight gain rate on the development of two generations of beef cattle

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Maternal weight gain during early pregnancy in beef heifers affects the growth and metabolic development of the offspring, with observable effects across multiple generations. A moderate increase in the rate of maternal body weight gain during early gestation improves the performance of F1 heifers and elevates their glucose levels. Conversely, lower rates of maternal weight gain increase placental and mammary gland mass, in addition to positively regulating genes in the intestines of F2 fetuses, suggesting a compensatory mechanism.

Summary

A study was conducted to understand how early pregnancy weight gain in beef heifers affects their daughters and granddaughters. One hundred crossbred Angus heifers (F0 generation) were randomly assigned at mating into two groups: a low-gain group (LG; n = 50), fed to achieve a gain of 0.28 kg/day, and a moderate-gain group (MG; n = 50), targeting a gain of 0.79 kg/day. During the first 84 days of gestation, the LG group received a basal total mixed ration (TMR) consisting of 53% hay, 37% corn silage, and 10% DDGS. The MG group received the same ration plus an energy/protein supplement, provided at 0.58% of body weight per day. After the 84 days, all heifers were fed the same diet. When the daughters (F1 generation) of the F0 heifers were born, they were raised similarly until weaning. At 15 months of age, eight heifers from each group were selected to continue the study. These heifers were inseminated and slaughtered at 84 days of pregnancy to evaluate various aspects, such as maternal body weight, blood glucose and hormone levels, organ weights, and fetal (F2 generation) development. Additionally, gene expression in the intestines of F1 heifers and F2 fetuses was analyzed. It was found that F1 heifers from the MG group tended to be heavier at birth ($P = 0.06$) and during post-weaning growth ($P = 0.07$) and had greater blood glucose levels ($P = 0.03$). F1 heifers from the LG group tended to have heavier placentas at day 84 of their first pregnancy ($P = 0.10$). Interestingly, F2 fetuses from the LG group showed greater expression of some genes in the intestines (NDUFC1, SDHA, UQCR1, ATP5E, and PPARG; $P < 0.05$) and heavier mammary glands ($P = 0.05$). These results show that heifer weight gain during early pregnancy can affect their daughters and granddaughters. This suggests that nutritional management during this period can have long-term effects on the herd, which is essential knowledge for producers seeking to improve the productivity and sustainability of their operations.

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Introduction

Proper nutrition for replacement heifers in cow-calf systems is crucial for the farm's long-term success. Pastures are the primary food source, but their quality and availability vary dramatically throughout the year (Drouillard, 2018). Good nutrition is essential in early pregnancy because, during this period, the fetal organs and placenta are forming, which affects calf growth and future performance. Research shows that cow nutrition during this phase can influence the offspring and

the subsequent generation. This phenomenon is called developmental programming (Reynolds et al., 2019).

Previous studies have demonstrated that heifer weight gain and supplementation with vitamins and minerals during pregnancy affect fetal development, including organs, metabolism and placental function (Menezes et al., 2021). However, we still need to learn more about how these affect subsequent generations of beef cattle (Caton et al., 2020; Reynolds et al., 2023).

Therefore, we conducted a study to determine how different rates of heifer (F0 generation) weight gain during the first 84 days of pregnancy affect the growth of their daughters (F1 generation), the reproductive capacity of F1 heifers and the development of the next generation of F2 fetuses. We hypothesized that the rate of body weight gain in replacement heifers during early pregnancy can cause significant changes in the growth and metabolic state of their daughters, and further that these effects may even extend to the granddaughters. Understanding this is important to improving the nutritional management of replacement heifers, which will increase the productivity and sustainability of operations in the long term.

Procedures

One hundred crossbred Angus heifers (F0 generation) were synchronized for estrus using a seven-day Select Synch + CIDR protocol and were artificially inseminated with sexed (X) semen from a single bull. After insemination, the F0 heifers were randomly divided into two dietary treatment groups: a low-gain group, targeting a body weight gain rate of 0.28 kg/day (n = 50), and a moderate-gain group, with a body weight gain rate of 0.79 kg/day (n = 50) during the first 84 days of gestation. The weight gains of the LG and MG dams were achieved by adjusting the dietary energy density, with the MG group receiving an energy/protein supplement composed of a mixture of ground corn, dried distillers grains with solubles, wheat bran, fish oil, urea and ethoxyquin.

After the first 84 days of gestation, all F0 dams were managed as a single group and fed a common forage-based diet per the NASEM (2016) recommendations until calving. All F0 dams and their F1 offspring were kept together and received the same nutritional management until weaning. After weaning, the F1 heifers from both dietary treatment groups continued to receive the same dietary management during the prebreeding development period (Table 1). At 15 months of age, a subset of F1 heifers (n = 16; eight from the LG group and eight from the MG group) was selected, artificially inseminated and slaughtered on the 84th day of gestation. The heifers were weighed, and blood samples were collected on the day of insemination and on days 42 and 84 of gestation. Blood was analyzed to measure glucose, nonesterified fatty acids (NEFA), progesterone, insulin, and insulin-like growth factor 1 (IGF-1) concentrations.

At slaughter, carcass weight of the F1 heifers was recorded before and after a 24-hr cooling period. Carcass characteristics, including Longissimus muscle area and subcutaneous fat measured between the 12th and 13th thoracic vertebrae, were evaluated after 24 hr of cooling. Additionally, the following organs and viscera from the F1 heifers were removed and weighed at slaughter: mammary gland, liver (gallbladder removed), heart, lungs, kidneys, pancreas, spleen, small intestine (1 m section of the jejunum), brain and gravid uterus. The uterus was weighed before and after the removal of the conceptus, and the weight of the placenta and fetus (F2 generation) was recorded.

The F2 fetuses were weighed and photographed laterally using the Omni ASH digital videoscope system. Each fetus was dissected, and the following organs were individually weighed: liver, heart, lungs, pancreas, small intestine, rumen, kidneys, spleen, brain, femur, Longissimus dorsi, hindlimb, uterus, ovaries and mammary gland. The recorded fetal images were analyzed using image analysis software for the following measurements: straight crown-rump length, curved crown-rump length, horizontal eye diameter, nose-to-crown distance, body depth (the vertical distance from the backbone to the midventral line) at shoulder level and body depth (the vertical

Table 1. Chemical composition of diet provided to F1 heifers during development until harvest at d 84 of gestation

Chemical Composition	Development Diet[1]
Dry matter, %	65.6
Ash, %	10.7
Crude Protein, % DM	12.3
Acid Detergent Fiber, % DM	32.9
Neutral Detergent Fiber, % DM	59.1
Ether Extract, % DM	1.44
Calcium, g/kg DM	0.66
Phosphorus, g/kg DM	0.44

[1]Proportion of ingredients on dry matter basis: prairie grass hay (70%), corn silage (20%) and premix (10%) with the premix containing dried distillers grains with solubles (5%), ground corn (2.9%), urea (0.87%), limestone (0.4%), dicalcium phosphate (0.55%), monensin (0.02%), vitamin premix (0.01%), mineral premix (0.05%) and NaCl (0.2%).

distance from the backbone to the midventral line) directly behind the navel. Jejunum samples from the F1 heifers and F2 fetuses were collected and stored at -80 C for later mRNA expression analyses. Relative mRNA expression was assessed using RT-qPCR, focusing on genes related to mitochondrial respiratory chain enzymes.

Data were statistically analyzed using the MIXED procedure in SAS 9.4, with significance at $P \leq 0.05$.

Results and Discussion

The F1 heifers from the MG group tended to be heavier (P = 0.06) than those from the LG group, with an average body weight of 413.0 ± 4.45 kg compared to 401.1 ± 4.39 kg in LG heifers during the growth phase. However, slaughter weight and carcass measurements of the F1 heifers were not influenced by their (F0) dams' body weight gain rate during early gestation. Maternal organ and reproductive tract mass of the F1 heifers also did not show significant differences (P > 0.10) due to their dams' rate of body weight gain, except for placental weight, which tended to be greater (P = 0.10) in F1 heifers from the LG group compared to those from the MG group (204.1 g vs. 152.6 g for LG vs. MG; Table 2).

As for the concentrations of NEFA, progesterone, insulin and IGF-1 in the blood of F1 heifers, no effects of their dams' rate of body weight gain during early gestation were observed (P > 0.05; Table 3). However, blood glucose concentrations in F1 heifers were greater (P = 0.03) in the MG (74.1 ± 1.35 mg/dL) compared to the LG group (69.8 ± 1.35 mg/dL; Table 3). These results suggest that the maternal body weight gain rate during early gestation may influence the metabolic status of their F1 offspring, particularly in terms of glucose homeostasis, aligning with findings from previous studies (Wu et al., 2006; Vonnahme et al., 2010).

Table 2. Effect of low and moderate rate of body weight gain in F0 dams during early gestation on body weight, carcass characteristics, organ mass, and reproductive tract characteristics of F1 heifers harvested at 84 days of gestation

	Treatment[1]			
Item	LG	MG	SEM	*P*-value
Live BW, kg	420.6	423.8	10.87	0.84
HCW, kg	218.1	213.2	5.79	0.55
Dressing percentage, %	51.8	51.6	0.51	0.73
Longissimus muscle area, cm2	61.9	61.8	2.69	0.96
Back fat, cm	0.43	0.53	0.077	0.35
Maternal organ mass, g				
Mammary gland	2680.3	2913.5	264.79	0.54
Liver	4383.6	4524.9	114.19	0.40
Lungs	2212.4	2138.5	65.88	0.44
Pancreas	335.3	311.2	18.26	0.35
Kidneys	847.5	863.1	20.27	0.60
Spleen	569.3	547.9	22.09	0.49
Brain	369.0	392.7	13.83	0.21
Heart	1537.4	1526.7	45.08	0.80
Maternal reproductive tract, g				
Gravid Uterus	1568.7	1461.9	58.08	0.21
Empty Uterus	402.1	400.1	14.10	0.92
Placenta	204.1	152.6	21.79	0.10

[1]Treatment diets provided to F0 generation from breeding until d 84 of gestation: 1) a basal mixed ration targeting gain of 0.28 kg/d (LG, n = 8), or 2) the basal diet plus an energy/protein supplement to achieve targeted gain of 0.79 kg/d moderate gain (MG, n = 8).

Table 3. Effect of low and moderate rate of body weight gain in F0 dams during early gestation on serum metabolites and hormone concentrations of F1 heifers during prebreeding and the first trimester of gestation

	Treatment[1]			*P*-values		
Item	LG	MG	SEM	Treatment	Day	Treatment × Day
Glucose, mg/dL						
Prebreeding[2]	66.9	68.4				
d 42 of gestation[3]	70.4	75.4	2.34	0.03	<0.01	0.549
d 83 of gestation[4]	72.1	78.7				
NEFA, umol/L						
Prebreeding	298.8	211.5				
d 42 of gestation	249.6	207.7	35.87	0.16	0.02	0.46
d 83 of gestation	154.7	157.8				
Progesterone, ng/mL						
Prebreeding	2.06	3.01				
d 42 of gestation	6.56	6.49	0.726	0.71	<0.01	0.68
d 83 of gestation	6.49	6.27				
IGF-1, ng/mL						
Prebreeding	145.4	146.6				
d 42 of gestation	94.3	106.0	10.13	0.60	<0.01	0.82
d 83 of gestation	97.7	98.0				
Insulin, uIU/mL						
Prebreeding	5.25	3.15				
d 42 of gestation	6.51	6.02	0.842	0.17	0.04	0.53
d 83 of gestation	4.63	4.32				

[1]Treatment diets provided to F0 generation from breeding until d 84 of gestation: 1) a basal mixed ration targeting gain of 0.28 kg/d (LG, n = 8), or 2) the basal diet plus an energy/protein supplement to achieve targeted gain of 0.79 kg/d moderate gain (MG, n = 8).
[2]Blood samples were collected prebreeding coinciding with the beginning of estrus synchronization (CIDR insertion – 10 d before artificial insemination).
[3]Blood samples were collected at the midpoint of the first trimester (d 42 following artificial insemination).
[4]Blood samples were collected at the time of harvest (d 84 ± 0.26 post artificial insemination).

The morphological measurements and organ mass of F2 fetuses were not affected (P > 0.10; Table 4) by the F0 body weight gain rate during early gestation. However, F2 fetuses from the LG group showed an increase in mammary gland mass relative to fetal weight (P = 0.05) and a tendency toward greater absolute mammary gland mass compared with F2 fetuses from the MG group (P = 0.10). Gene expression (mRNA) analysis revealed positive regulation of genes associated with energy metabolism in the small intestine of F2 fetuses from LG compared to those from MG dams (Figure 1). The genes NDUFC1, SDHA, UQCR1 and PPARG were significantly more expressed (P ≤ 0.05), whereas ATP5E also showed a tendency to be more expressed (P = 0.06). These differences in gene expression suggest that the lower maternal weight gain rate during early gestation may prepare the intestines of F2 fetuses for enhanced nutrient absorption and energy utilization, possibly as an adaptive response to lower nutrient availability in utero. This aligns with the concept of developmental programming (Sookoian et al., 2013) and indicates that the maternal nutritional environment can have long-term effects, manifesting across subsequent generations. Although the nutritional intervention was applied to the F0 dams, its effects were evident in the F2 fetuses, highlighting the lasting influence of early gestational nutrition on fetal organ development. This observation builds on the broader understanding of developmental programming as discussed by Reynolds et al. (2019) and Caton et al. (2020).

Conclusion

This study demonstrates that maternal body weight gain rate during the first 84 days of gestation can have lasting effects across multiple generations. Moderate gain results in F1 heifers with better performance and higher glucose levels. At the same time, lower rate of gain increased the weight of F1 heifer placentas, mammary gland mass and the expression of energy metabolism-related genes in the intestines of F2 fetuses, possibly as an adaptive response to lower nutrient availability during gestation. These findings underscore the importance of proper nutritional management during early gestation to ensure the healthy development of future generations of beef cattle.

Table 4. Effect of low and moderate rate of body weight gain in F0 dams during early gestation on body measurements and organ weights of F2 fetuses harvested at 84 days post-conception

	Treatment[1]			
Item	**LG**	**MG**	**SEM**	***P*-value**
Fetal mass, g				
Body	125.9	117.1	4.09	0.23
Liver	4.66	4.59	0.268	0.86
Heart	1.20	1.24	0.077	0.72
Lungs	4.61	4.20	0.270	0.29
Small Intestine	2.61	2.42	0.168	0.44
Pancreas	0.11	0.14	0.017	0.25
Rumen	4.74	4.54	0.632	0.82
Kidneys	1.27	1.15	0.081	0.29
Spleen	0.14	0.12	0.016	0.35
Brain	4.75	4.67	0.323	0.86
Femur	0.33	0.32	0.020	0.80
Longissimus dorsi	1.93	1.78	0.177	0.53
Hindlimb	3.26	2.70	0.331	0.24
Ovaries	0.08	0.07	0.010	0.68
Uterus	0.06	0.06	0.008	0.82
Mammary gland	0.59	0.53	0.020	0.07
Fetal mass, % of fetal BW				
Liver	3.70	3.91	0.117	0.21
Heart	0.95	1.07	0.049	0.10
Lungs	3.65	3.57	0.126	0.66
Small Intestine	2.04	2.07	0.103	0.84
Pancreas	0.09	0.10	0.012	0.35
Rumen	3.80	3.85	0.491	0.94
Kidneys	1.01	0.98	0.041	0.58
Spleen	0.11	0.10	0.010	0.50
Brain	3.78	4.00	0.226	0.50
Femur	0.26	0.25	0.012	0.66
Longissimus dorsi	1.54	1.49	0.106	0.74
Hindlimb	2.59	2.29	0.240	0.38
Ovaries	0.06	0.06	0.007	0.99
Uterus	0.04	0.05	0.006	0.76
Mammary gland	0.48	0.44	0.016	0.05
Measurements, cm				
Biparietal distance	3.16	3.13	0.064	0.73
Crown rump length	13.3	13.0	0.11	0.13
Curved crown rump length	16.1	15.7	0.26	0.29
Eye diameter	0.99	0.98	0.025	0.81
Nose to poll	4.96	4.94	0.067	0.85
Body depth at front shoulder	4.09	3.92	0.065	0.08
Body depth behind umbilicus	4.08	3.97	0.096	0.41

[1]Treatment diets provided to F0 generation from breeding until d 84 of gestation: 1) a basal mixed ration targeting gain of 0.28 kg/d (LG, n = 8), or 2) the basal diet plus an energy/protein supplement to achieve targeted gain of 0.79 kg/d moderate gain (MG, n = 7).

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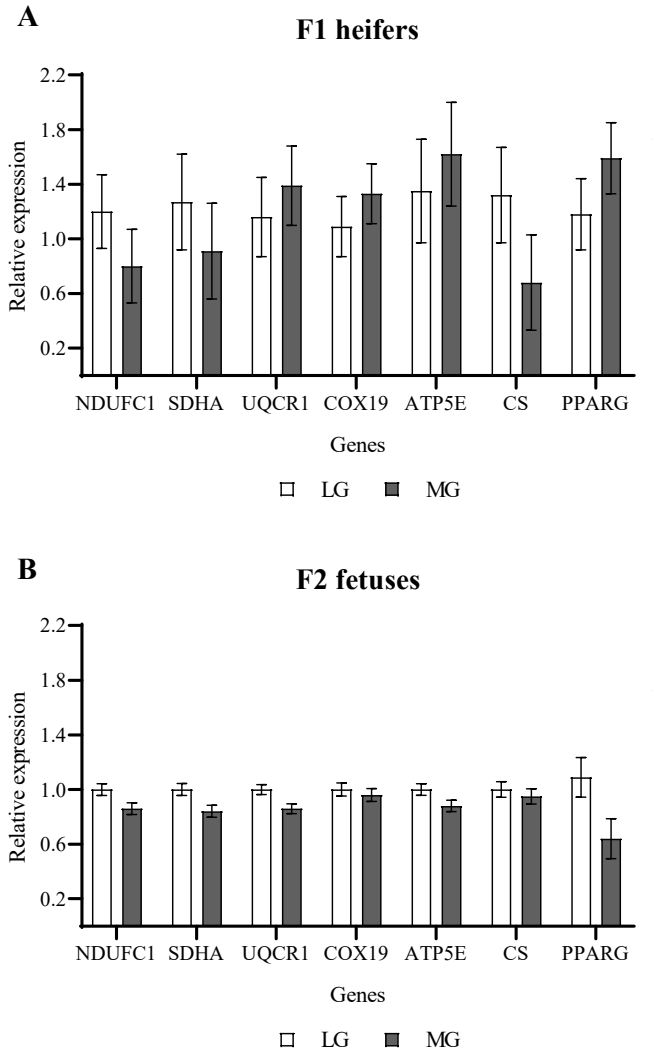

Figure 1. Effect of low and moderate rate of body weight gain in F0 dams during early gestation on mRNA expression in the small intestine of F1 heifers (Panel A) and F2 Fetuses (Panel B) harvested at 84 days of gestation. Data are presented as expression relative to the HPRT1 gene. NDUFC1: NADH: ubiquinone oxidoreductase subunit C1; SDHA: Succinate dehydrogenase complex flavoprotein subunit A; UQCR1: Ubiquinol-cytochrome c reductase core protein 1; COX19: Cytochrome c oxidase assembly factor COX19; ATP5E: ATP synthase F1 subunit epsilon; CS: Citrate synthase; PPARG: Peroxisome proliferator activated receptor gamma. Values are least squares means, with error bars depicting standard error.