Impacts of limit-feeding high-concentrate diets to beef heifers during the first 180 days of gestation on performance, carcass characteristics and gastrointestinal tract morphometrics

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This study evaluated the strategy of limit-feeding high-concentrate diets on carcass characteristics and gastrointestinal tract morphometrics in crossbred beef heifers. Limit-feeding replacement heifers with high-concentrate diets can alter body composition and gastrointestinal tract morphometrics, favoring fat and muscle accumulation. Feeding strategies that limit intake but aim for the same daily weight gain, whether using high-concentrate or high-forage diets, can lead to different carcass characteristics and metabolic profiles. Notably, limit-feeding high-concentrate diets can favor fat and muscle accumulation, altering dam efficiency throughout her productive life.

Summary

Traditional heifer feeding strategies typically involve modest rates of body weight (BW) gain and include a relatively low proportion of concentrate feeds. The objective of this study was to evaluate the strategy of limit-feeding high-concentrate diets on performance, carcass characteristics and gastrointestinal tract (GIT) morphometrics in replacement beef heifers. The hypothesis was that providing high-concentrate diets in limited amounts, aiming for the same average daily gain (ADG) as high-forage diets, will alter the body composition and GIT morphometrics in beef heifers. Crossbred beef heifers (n = 20) received either a high forage (75% forage:25% concentrate [HF], n = 10) or high concentrate diet (25% forage:75% concentrate [HC] n = 10) starting 85 days (d) before breeding until 180 d of gestation. Heifers were inseminated with male-sexed semen from a single bull. Individual intake data were recorded using the Insentec Roughage Intake Control system. Heifers were weighed, and diet deliveries were adjusted every two weeks to target a gain of 1 lb/d for both groups. Data were analyzed using the MIXED procedure of SAS, with heifer as the experimental unit. No differences between treatments were observed in final BW, ADG or body condition score ($P \geq 0.18$). Heifers receiving the HF diet had a greater ($P < 0.05$) dry matter intake (DMI), full GIT weight, GIT weight as a percentage of body weight, empty rumen-reticulum weight, total digesta, ruminal pH and cecal pH, and tended ($P \leq 0.10$) to have a greater empty abomasum and serum cortisol concentration compared to HC heifers. Conversely, heifers fed the HC diet showed greater ($P < 0.05$) marbling score, mesenteric fat and ruminal digesta dry matter, number of ruminal papillae, percentage of papillae per absorptive surface area and concentrations of IGF-1 concentrations, and tended ($P \leq 0.10$) to have greater carcass weight, ribeye area and empty large intestine weight. These findings demonstrate that, despite similar gain rates, limit-feeding high-concentrate diets can alter the composition of weight gain, favoring fat, muscle, and GIT morphometry, potentially altering dam efficiency throughout her productive life.

Introduction

Traditional feeding strategies for beef heifers typically involve modest rates of body weight gain

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and a relatively low proportion of concentrated feeds. However, in situations of limited forage availability or high feeding costs, high-concentrate diets fed in a restricted manner can be a viable alternative. This approach aims to increase nutrient utilization efficiency and reduce cattle feeding costs. A study by Loerch (1996), which used a 100% concentrate diet with restricted intake for pregnant Simmental crossbred cows, reported no significant differences in performance and reduced feeding costs compared to feeding high-forage (HF) diets. A key concept when feeding high-concentrate (HC) diets is to provide them in smaller quantities compared to HF diets to achieve targeted daily gains (Brickell et al., 2009; Wathes et al., 2014) due to greater energy content, greater ruminal fermentation potential and digestibility per unit of dry matter (NASEM, 2016).

The literature contains numerous studies, primarily on confined young cattle, reporting that HC diets stimulate ruminal development, increase insulin-like growth factor I (IGF-I) and insulin concentrations, and modify the composition of gain, favoring greater muscle and fat deposition compared to HF diets. Conversely, HF diets are known to increase ruminal volume, lower fat gain and increase DMI compared to HC diets (Diao et al., 2019). However, in these studies, animals typically exhibit different weight gains due to the different compositions of the diets resulting in cattle receiving greater amounts of concentrate generally having greater ADG.

Few studies have evaluated the use of limit-feeding of replacement beef heifers with the same weight gain, particularly regarding performance, carcass characteristics and GIT morphometrics. The objective of this study was to evaluate the strategy of limit-feeding HC diets on performance, carcass characteristics and GIT morphometrics in replacement beef heifers. The hypothesis was that providing HC diets in limited amounts, aiming for the same ADG as high-forage diets, will alter body composition and GIT morphology in crossbred Angus-based heifers.

Procedures

Twenty crossbred Angus-based heifers (initial body weight [BW] = 727.5 ± 69 lb and age 13) were housed at the NDSU Beef Cattle Research Complex. Heifers were divided into pens equipped with Insentec feeders (Hokofarm Group B.V., Marknesse, The Netherlands) and randomly assigned to one of two treatments: HF group (n = 10) received a diet composed of 75% forage and 25% concentrate, while the HC group (n = 10) received a diet composed of 75% concentrate and 25% forage. Treatments were fed from 90 d before until 180 d after breeding, through artificial insemination (AI), all heifers to male-sexed semen from a single sire. Pregnancy status was confirmed 28 days post-breeding, and fetal sex was determined 65 days post-breeding to confirm male pregnancies.

The heifers were distributed based on initial weight into two pens (n = 10) with eight feeders each and free water access, and each pen receiving one of the treatment diets. The heifers were weighed bi-weekly and diet deliveries were adjusted to target a gain of 1 lb/d for both groups. The diets were formulated using the Beef Cattle Nutrient Requirements Model (2016 - Version 1.0.37.12).

Table 1. Proportion of ingredients and chemical composition (BCNR prediction) of experimental diets.

Ingredients[1], % DM	High concentrate	High forage
Corn silage	20.0	20.0
Distillers grain plus soluble	7.18	7.88
Corn grain	55.0	5.00
Oat hay	15.0	65.0
Limestone	0.90	0.50
Dicalcium phosphate	0.30	0.00
Sodium chloride	0.20	0.20
Urea	0.85	0.85
Monovet 90 Monensin	0.02	0.02
Trace Mineral	0.05	0.05
Vit A	0.20	0.20
Vit D	0.20	0.20
Vit E	0.10	0.10
Chemical composition[2], %DM		
Dry Matter	66.4	67.1
Crude protein	13.4	15.9
Ether extract	3.85	3.13
Ash	4.48	6.64
Neutral detergent fiber	29.1	52.4
Lignin	2.34	4.13
Nonfibrous carbohydrates	50.7	23.4
Starch	47.2	13.2
Total digestible nutrients[2]	77.1	63.9
ME[3], Mcal/kg	0.59	0.48

[1]Composition of Monovet 90 Monensin: 200g of monensin in 1 kg.
[2]Calculated from equations from Weiss et al. (1992).
[3]ME = metabolizable energy (NRC, 1984)

Performance measures evaluated from AI until d 180 of gestation included DMI and ADG, which were used to calculate gain efficiency (lb gain per lb of feed). Body condition score (BCS; scale of 1–9, with 1 [emaciated] and 9 [obese]) was determined on d 180.

Heifers were harvested at 180 days of gestation at a federally inspected meat processing facility. Hot carcass weight was determined at slaughter, and carcass characteristics including back fat, ribeye area, rib fat, and marbling grade were measured after a 24-h chill.

To evaluate GIT characteristics, the stomach complex (rumen-reticulum, omasum and abomasum), the small intestine and the large intestine were separated, and each was weighed without removal of digesta (i.e., full weight). Then the digesta and mesenteric fat were removed, and the stomach complex, small and large intestine, and mesenteric fat were weighed (i.e., empty weight). The empty body weight was determined from subtracting the digesta weight from the final body weight. A sample of rumen wall (approximately 1 cm^2) was collected from the ventral cranial sac from each heifer, and papillae were counted. Following papillae counting, 12 papillae were cut from the ruminal wall at their base and arranged on a glass slide for a photo for subsequent morphological evaluation. The evaluated macroscopic morphological variables included the area tissue (AT); number of papillae per cm^2 of the wall (NPP); height, width and average area of the papillae (AMP); absorptive surface area per cm^2 of the wall (ASA); and percentage of papillae per absorptive surface area (% papillae/ASA). The absorptive surface area of the wall (ASA) in cm^2 was calculated as AT + (NPP × AMP)/(NPP × APB). The area of the papillae, expressed as a percentage of ASA, was calculated as (NPP × AMP)/(ASA × 100) (Ribeiro et al., 2019; Pereira et al., 2020).

Blood samples collected on d 0, 28, 56, 91 and 180 relatives to AI were used to determine serum cortisol, insulin and IGF-I concentration. Seric insulin, cortisol and IGF-I concentrations were determined by chemiluminescence immunoassay by using a commercial kit of Immulite 1000 (Siemens Healthcare Diagnostics Products, Llanberis, UK).

Data were analyzed as a single measure using the MIXED procedure of Statistical Analysis System (SAS, version 9.4, 2018), with heifer as the experimental unit and were considered statistically significant when $P \leq 0.05$ and a trend when $0.05 < P \leq 0.10$.

Results and Discussion

By design, ADG and final BW were similar between treatments ($P = 0.18$, $P = 0.22$; Table 2). Although HF heifers had greater DMI than HC heifers ($P < 0.001$), tend to have lower empty body weight ($P = 0.06$) and there were no differences in feed efficiency ($P =0.30$).

Regarding hormone concentrations, heifers fed HF tended to have greater cortisol ($P = 0.10$) and lower IGF-I ($P < 0.001$) concentrations compared to heifers fed HC, and no differences in insulin concentration were observed (Table 3).

Heifers fed the HC diet had greater marbling score ($P = 0.04$) and tended to have greater carcass weight ($P = 0.06$) and ribeye area ($P = 0.07$) than heifers fed the HF diet (Table 4).

Heifers fed the HF diet had greater full gastrointestinal tract weight ($P < 0.001$), gastrointestinal tract weight as a percentage of body weight ($P < 0.001$), stomach complex full ($P < 0.001$), empty rumen-reticulum weight ($P < 0.05$), total digesta weight ($P < 0.001$) and stomach complex digesta weight ($P < 0.001$), and tended to have greater empty abomasum weight ($P = 0.07$; Table 4). Conversely, heifers fed the HC diet had greater mesenteric fat (P

Table 2. Performance of heifers subjected to different diet compositions in AI at 180 days of gestation.

Items[1]	High concentrate	High forage	SEM[2]	P-Value
Initial Body weight, lb	905.0	835.0	20.19	0.08
Final Body weight, lb	1,107.0	1,096.5	22.07	0.22
Empty Body weight, lb	982.57	919.32	16.84	0.06
Dry matter intake, lb/day	12.9	16.7	0.04	<0.001
Average gain, lb/day	1.17	1.34	0.11	0.18
Feed efficiency, ADG/DMI	0.09	0.08	0.01	0.30

[1]N. Heifers: Number of heifers, DMI: Dry matter intake, ADG: Average daily gain.
[2]SEM: Standard error of the mean.

Table 3. Blood metabolite parameters in heifers are subjected to limit feeding high-concentrate diets to beef heifers during the first 180 d of gestation.

Items	High concentrate	High forage	SEM[1]	P-Value
Cortisol, pmol/L	1.44	1.76	0.10	0.10
IGF-I[2], pmol/L	186.2	126.6	4.47	<0.001
Insulin, pmol/L	5.54	4.80	0.31	0.52

[1]SEM: Standard error of the mean.
[2]IGF-I: Insulin-like growth factor type I.

< 0.001) and tended to have greater empty large intestine absolute weight than heifers fed the HF diet (*P* = 0.06; Table 4). Furthermore, heifers fed HC had lower ruminal and cecal pH, and greater number of ruminal papillae and percentage of papillae/ASA (Table 4).

These results indicate that, despite the greater DMI for HF heifers, there was no difference in feeding efficiency (FE) due to the similar ADG (Table 2), demonstrating that even with limited intake, the HC diet has better energy efficiency, requiring 3.77 lb less DM to ensure the same performance. This can be attributed to the greater energy in the HC diet per kg of DM, requiring lower DMI to achieve the same energy intake.

However, despite no difference in ADG (Table 2) and BSC (Table 4), the composition of gain was different, as HC heifers had a greater percentage of the gain represented by muscle development, indicated by the larger ribeye area, and of fat as indicated by mesenteric fat (Table 4). In contrast, HF heifers tended to have a greater portion of their gain represented by digesta and heavier weights of the rumen-reticulum and abomasum directly reflecting in the lower empty body weight (Table 4). Besides the lower digestibility potential of the HF diet, diets with high forage inclusion have longer retention times in the GIT (Allen et al., 2009; Arndt et al., 2014). This is supported by the larger stomach complex digesta, with this value being numerically higher than the DMI for heifers fed the HF diet. Additionally, the larger size of the rumen-reticulum and abomasum contributes to digesta representing a greater proportion of body weight in HF heifers compared to HC heifers.

The reduced ruminal and cecal pH in HC heifers allows us to hypothesize that a greater concentration of short-chain fatty acids (SCFAs) may be present, which could explain the greater number of ruminal papillae, percentage of papillae/ASA and heavier large intestine compared to HF heifers. The greater concentration of SCFAs, especially butyrate, has indicated in several studies as stimulating GIT development, as the butyrate is almost entirely used to energy font by the GIT epithelium (Górka et al., 2018). Further, elevated concentrations of butyrate are associated with cellular proliferation in the ruminant GIT (Górka et al., 2018) and increased IGF-I production (Baldwin VI et al., 2017). These results are consistent with the present study, in which HC heifers had greater concentrations of IGF-I, more ruminal

Table 4. Characterization of gastrointestinal organs and corporeal fat in heifers subjected to limit feeding high-concentrate diets to beef heifers during the first 180 d of gestation.

Items	High-concentrate	High-forage	SEM[1]	P-Value
Body condition score[2]	5.35	5.30	0.10	0.71
Carcass, lb	592.6	550.9	11.24	0.06
Back fat, mm	12.2	10.2	0.98	0.31
Ribeye area, mm²	249.7	229.6	5.61	0.07
Rib fat, mm	5.59	4.47	0.61	0.37
Marbling score	394.0	332.0	15.06	0.04
Gastrointestinal tract Full, lb	206.6	256.7	5.78	<0.001
Gastrointestinal full tract % of body weight	15.7	21.1	0.47	<0.001
Gastrointestinal empty tract % of body weight	4.82	4.90	0.13	0.66
Stomach complex, full, lb²	139.91	195.43	4.45	<0.001
Rumen-reticulum empty, lb	19.1	20.8	0.53	0.04
Abomasum empty, lb	3.73	5.09	0.51	0.07
Large intestine empty, lb	10.43	9.19	0.42	0.06
Mesenteric fat, lb	34.2	25.7	2.76	<0.001
Mesenteric % of body weight	3.09	2.33	0.22	0.03
Digesta total, lb	119.6	177.2	4.92	<0.001
Stomach complex digesta, lb of dry matter	16.60	21.28	0.87	<0.01
Ruminal pH	6.17	6.84	0.09	<0.001
Cecal pH	7.02	7.34	0.04	<0.001
Number of papillae	58.3	46.3	2.96	0.04
%papillae/ASA²	69.2	61.0	3.15	<0.001

[1]SEM: Standard error of the mean.
[2]Body condition score (scale of 1 – 9, with 1 [emaciated] and 9 [obese] (Wagner et al., 1988); Stomach complex includes rumen, reticulum, omasum, and abomasum., %papillae/ASA: Percentage of papillae per absorptive surface area.

papillae and heavier intestinal empty weight compared to HF heifers.

These findings demonstrate that, despite similar gain rates, limit-feeding a high-concentrate diet, compared to a high-forage diet, can alter the composition of weight gain (favoring fat and muscle) and GIT development, potentially altering dam productivity. Additionally, there is a need for further studies evaluating the impact of restricted feeding on ruminal fermentation and fetal development in heifers.

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