Effects of restricted feeding of beef heifers during the postweaning period on growth, efficiency, and ultrasound carcass characteristics[1]

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ABSTRACT: Traits used for identification of replacement beef heifers and feeding levels provided during postweaning development may have major financial implications due to effects on maintenance requirements and level of lifetime production. The current study evaluated the effects of 2 levels of feeding during the postweaning period on growth, G:F, and ultrasound carcass measurements of heifers, and the associations among these traits. Heifers (½ Red Angus, ¼ Charolais, and ¼ Tarentaise) born in 3 yr were randomly assigned to a control (fed to appetite; n = 205) or restricted (fed at 80% of that consumed by controls adjusted to a common BW basis; n = 192) feeding during a 140-d postweaning period. Heifers were individually fed a diet of 68% corn silage, 18% alfalfa, and protein-mineral supplement (DM basis) in pens equipped with Calan gates. Ultrasound measurements of LM area, intramuscular fat, and subcutaneous fat thickness over the LM were made on d 140 (382 ± 0.8 d of age). Average daily DMI was 4.1 and 5.6 kg/d for restricted and control heifers, respectively ($P < 0.001$). Feed restriction decreased ($P < 0.001$) BW (292 vs. 314 kg), ADG (0.52 vs. 0.65 kg/d), LM area (55 vs. 59 cm^2), intramuscular fat (3.2 vs. 3.5%), and subcutaneous fat thickness over the LM (3.2 vs. 3.9 mm), but increased G:F (0.12 vs. 0.11) when compared with control at the end of the 140-d study. The magnitude of the associations of DMI with ADG (r = 0.32 vs. 0.21), 140-d BW (r = 0.78 vs. 0.36), hip height (r = 0.57 vs. 0.17), LMA (r = 0.30 vs. 0.18), and BCS (r = 0.17 vs. 0.11) was greater in restricted- than control-fed heifers. Variance of residual feed intake, calculated within each treatment, was greater ($P < 0.01$) in control (0.088) than restricted (0.004) heifers, and magnitude of association between residual feed intake and average DMI was greater in control (r = 0.88) than restricted (r = 0.41) heifers. Pregnancy rate tended (P = 0.11) to be reduced in heifers that had been developed on restricted feeding (86.3 ± 2.3 vs. 91.5 ± 2.3%). However, ADG was greater ($P < 0.001$) in restricted than control heifers (0.51 vs. 0.46 kg/d) while grazing native range in the 7 mo after restriction. In summary, restricted heifers consumed 22% less feed on a per-pregnant-heifer basis during the development period and had a greater magnitude of association between DMI and several growth-related traits at the end of the 140-d postweaning feeding period, which is indicative of improved efficiency.

Key words: carcass, cattle, gain:feed, feed level, growth, heifer development

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INTRODUCTION

Feed resources used in developing replacement females are a major factor influencing cost of production (Freetly et al., 2001; Clark et al., 2005). Guidelines were established several decades ago for developing replacement heifers to ensure attainment of puberty at an age that permits calving at 2 yr old (reviewed by Patterson et al., 1992). However, recent research provides evidence that input of harvested feed can be reduced without major adverse affects on reproductive performance by altering pattern of gain (Lynch et al., 1997; Freetly et al., 2001) or by feeding to lighter target weights than those typically recommended (Funston and Deutscher, 2004), thereby reducing expense of raising heifers.

In addition to the direct costs associated with developing replacement heifers, return on investment may

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be influenced by traits that affect maintenance requirements, and the quantity and quality of calf production. Although there is great interest in selection of animals for improved G:F, application has been minimal due to costs associated with measuring feed intake. Much of the research in this area has focused on efficiency of growing animals (reviewed by Herd et al., 2003) with limited research on measures of efficiency in mature beef cows (Jenkins et al., 2000; Archer et al., 2002). Interest in selection for carcass traits has also increased in the last several years, due to potential premiums received for these traits. Therefore, efficiency, growth, reproduction, and carcass merit should be considered when identifying replacement heifers. The present research is a portion of a long-term project to evaluate associations of measures made during the first year of life with lifetime productivity.

Our objective was to determine if associations among measures of feed intake, growth, G:F, and ultrasound carcass characteristics differed between heifers developed under 2 levels of feeding during a 140-d postweaning period.

Table 1. Composition (DM basis) of diets fed each year

Item	Yr 1	Yr 2, first 40 d	Yr 2, remainder[1]	Yr 3
	% of DM			
Ingredient				
Corn silage	67	70.9	63.5	68.4
Alfalfa	18	16	20.2	16.8
Barley	9	7.8	9.8	8.8
Soybean meal	4.2	3.7	4.6	4.2
Urea	0.9	0.8	1.0	0.9
Calcium carbonate	0.5	0.4	0.5	0.5
Salt	0.2	0.2	0.2	0.2
Vitamin ADE[2]	0.1	0.1	0.1	0.1
Trace mineral[3]	0.1	0.1	0.1	0.1
Chemical composition[4]				
DM, %	36.1	41.1	32.5	37.3
CP, %	15.1	14.4	15.8	17.1

[1]A change in source of silage resulted in slightly different dietary formulation.

[2]Contained 44,000,000 IU/kg of vitamin A; 880,000 IU/kg of vitamin D; and 880 IU/kg of vitamin E.

[3]Contained 20.0% Mg; 0.2% K; 2.6% S; 18,000 ppm of Cu; 60,000 ppm of Zn; 40,000 ppm of Fe; 300 ppm of Se; 60,000 ppm of Mn; 180 ppm of Co; and 1,140 ppm of I.

[4]Based on analyzed chemical composition of individual ingredients.

MATERIALS AND METHODS

Animals

All research protocols were approved by a local Animal Care and Use Committee. Heifers were a stable composite population (½ Red Angus, ¼ Charolais, ¼ Tarentaise). Heifers represent a randomly selected population produced by mating composite dams and sires (n = 31), with consideration given to minimize inbreeding but without emphasis on production traits. Heifers were born during a 3-yr period. Heifers from yr 1 were born between 28 March and 26 May 2003 (13 April ± 13 d, mean ± SD) and weaned on 8 October 2003 (177 ± 13 d of age and 196 ± 29 kg of BW, mean ± SD). Heifers from yr 2 were born between 9 March and 18 May 2004 (14 April ± 13 d, mean ± SD) and weaned on 23 October 2004 (174 ± 13 d of age and 196 ± 24 kg of BW, mean ± SD). For the third year, heifers were born between 10 March and 17 May 2005 (5 April ± 18 d, mean ± SD) and weaned on 12 October 2005 (190 ± 18 d of age and 214 ± 27 kg of BW, mean ± SD).

After weaning, heifers were stratified into groups of 6 based on weaning weight and randomly assigned to 1 of 22 to 24 pens, depending on the number of heifers available each year. Each pen was approximately 5.8 × 11 m, and contained 6 individual feed bunks equipped with electronic Calan gates (American Calan, Northwood, NH) to allow individual feeding. Heifers were allowed approximately 1 mo for adaptation to the pens and to become trained to the head gates. During this time, heifers were allowed ad libitum access to the test diet fed once daily. Heifers were randomly assigned within pens to a control or restricted level of feeding. Total numbers of heifers that became trained to the individual feeders and remained for the duration of the 140-d test period on each of the 3 yr were 62 and 64, 64 and 73, and 66 and 69 for control and restricted feeding treatments in yr 1, 2, and 3, respectively. Feed restriction was initiated between 1 and 10 December of each year. Control heifers were fed to appetite, and restricted heifers were fed at 80% of that consumed by controls adjusted to a common BW basis, as described below. Composition of the diet determined on a DM basis for each year is shown in Table 1. Weight of feed offered was recorded daily. Orts were removed from the feed bunk and weighed as necessary to ensure that fresh feed was provided for each heifer on a daily basis.

Measures of BW and hip height were recorded at the initiation (December) and conclusion (approximately 1 yr of age, April) of the 140-d study. Ultrasound measurements of LM area and ratio (width to length), intramuscular fat, and subcutaneous fat thickness over the LM were collected at d 140, using an Aloka SSD-500 ultrasound equipped with a 17.2-cm, 3.5 MHz, linear array transducer (Aloka Co. Ltd., Wallingford, CT) and the Beef Image Analysis software (Designer Genes Technologies LLC, Gustine, TX). Single measures of BW were recorded at approximately 28-d intervals throughout the study. These serial BW measures were collected before feeding, but water was not withheld. These measures of BW were used to adjust the feed level of restricted heifers using the following formula: [0.80 × (mean BW of restricted/mean BW control) × mean daily feed intake (as-fed basis) of controls over the 28-d period].

Gain to feed ratio was calculated for each heifer by dividing BW change during the 140-d period by the amount of feed consumed (DM basis). An average of the on-test BW and 140-d BW was calculated for each heifer, then adjusted to $BW^{0.75}$ to provide a midpoint metabolic BW. Average daily gain was calculated for the 140-d period for each heifer using the linear regression of BW on the day on which the measures were made. Residual feed intakes (**RFI**) were obtained within feeding treatment for each heifer using the regression of daily DMI on average, midpoint metabolic BW and ADG for the 140-d period, with year as a class variable.

At the end of the 140-d study, heifers were combined and fed together ad libitum under drylot conditions. Approximately 30 to 40 d after the end of restriction, heifers were weighed, assigned a BCS using a 9-point scale (1 = severely emaciated and 9 = very obese; Herd and Sprott, 1986), and were then subjected to an estrous synchronization protocol and AI. Heifers were then placed on native range and exposed to bulls for a 6-wk clean up breeding season that began after AI. Approximately 1 mo after bull removal, heifers were evaluated for pregnancy by transrectal ultrasonography using a 5 MHz transducer. A final BW measurement was made in late November (yr 1 and 3) or early December (yr 2).

Table 2. Feed intake, growth, BW, hip height, weight to height (BW:Ht), G:F, and ultrasonic measures of area (LMA), shape (LM ratio of width to length), intramuscular fat (IMF), and fat thickness (fat) of the LM in heifers subjected to ad libitum access to feed (control; n = 205) or restricted (80% of control; n = 192) during a 140-d period of development after weaning (ending at approximately 380 d of age), and BCS and pregnancy rate determined at approximately 1 and 4 mo after the study

Variable	Control	Restricted	SE	*P*-value
DMI, kg/d	5.62	4.11	0.05	0.001
ADG, kg/d	0.65	0.52	0.07	0.001
BW, kg	314	292	7	0.001
Hip height, cm	118.9	118.6	0.3	0.28
BW:Ht, kg/cm	2.64	2.46	0.06	0.001
G:F, ADG/DMI	0.11	0.12	0.002	0.001
LMA, cm^2	58.8	55.1	0.5	0.001
LM ratio	0.59	0.58	0.02	0.013
IMF, %	3.52	3.23	0.29	0.001
Fat, mm	3.96	3.28	0.42	0.001
BCS	5.9	5.6	0.15	0.001
Pregnancy, %	91.5	86.3	2.3	0.118

Statistical Analysis

Homogeneity of variances for response variables in the 2 levels of feeding were evaluated using the Hartley's Fmax test (Ott, 1984). Effects of feeding level on measures of growth, efficiency, and ultrasound carcass characteristics were evaluated using the MIXED procedure (SAS Inst. Inc., Cary, NC), with a model that included heifer age (in days) at onset of the test as a covariate, age of dam (2, 3, 4, and 5 or older) and treatment as fixed effects, and birth year of heifers as a random effect. Effects of treatment on changes in BW over time were analyzed with PROC MIXED using an analysis of repeated measures, with animal within year and treatment as the subject. The MANOVA option of PROC GLM of SAS was used to compute residual variance-covariance matrices for each feed level after fitting year as a classification effect, and linear effects of age of dam (2, 3, 4, and 5 or older) and heifer age (in days) at onset of the test. Four hypotheses were then tested sequentially using a χ^2 test coded in PROC IML of SAS: 1) residual variance-covariance matrices of untransformed data from each treatment were not different (indicating that associations among variables were similar across feeding treatments); 2) reevaluation of hypothesis 1, after removing the row and column of estimates associated with average daily DMI from the matrices to remove influences of differences in variances of DMI expected to occur by design of the experiment; 3) variance-covariance matrices of standardized data from each treatment were not different (indicating the absence of scaling effect); and 4) reevaluation of hypothesis 3, after removing the row and column of estimates associated with average daily DMI from the matrices. Subsequently, treatment-dependent effects of average daily DMI on each of the primary growth and carcass traits were evaluated with a model that included heifer age (in days) at onset of the test as a covariate, age of dam (2, 3, 4, and 5 or older), and treatment as fixed effects, and birth year of heifers as a random effect, implemented in PROC MIXED. Correlations presented in the results represent the residual correlations obtained after accounting for effects age of dam, heifer age, and birth year.

RESULTS AND DISCUSSION

Effects of Feeding Level on Growth, Carcass, and Reproduction Traits

As dictated by experimental design, average daily DMI was less ($P < 0.001$; Table 2) for restricted heifers than for control heifers and variation in DMI was reduced in restricted heifers (Fmax = 6.96, $P < 0.01$) compared with the control-fed group. Heifers in the restricted treatment had lower ($P < 0.001$) mean ADG (Table 2) and decreased BW from 4 wk after initiation of feed restriction through the last measurement made at approximately 7 mo after conclusion of the 140-d study (Figure 1). When compared at d 140 of the study, feed restriction decreased BW to hip height ratio, LM area, intramuscular fat, and fat thickness (Table 2). Feed restriction improved F:G (compare DMI required for unit of ADG in Figure 2) and decreased BCS and the width to length ratio of the LM (Table 2), but did not influence LM area/unit BW (data not shown). Hip height at d 140 (119 ± 4 cm; $P = 0.28$) did not differ due to feeding level. Thus, differences observed between the 2 levels of feeding are consistent with slower accretion of lean and fat tissue in the restricted group, but no detectable difference in skeletal size.

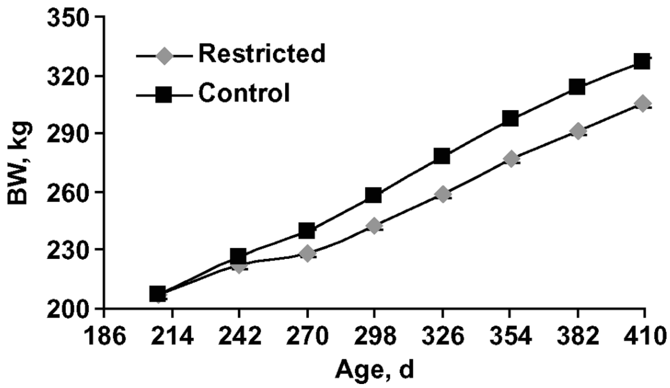

Figure 1. Changes in BW (least squares means) over time for heifers that had ad libitum (control) or restricted (80% of control) access to feed during a 140-d postweaning period, beginning at approximately 240 d of age (second time point on figure) and ending at approximately 380 d of age. Restricted feeding resulted in lighter ($P < 0.001$) BW from 4 wk after initiation of restriction (third time point) through the prebreeding BW measurement at approximately 409 d of age (largest SE = 2.2 kg).

Pregnancy rate after the first breeding season tended ($P = 0.11$) to be less for the restricted heifers than control heifers (Table 2). A consequent reduction in pregnancy rate is important to consider when determining economic advantages of restricted feeding during the postweaning period. However, numbers of animals evaluated in the current study are insufficient to provide adequate power-of-the-test to draw the conclusion that pregnancy rates were similar for restricted and control heifers. Further, a 5% difference in pregnancy rate, if real, would be of practical importance. The observed 5% reduction in pregnancy rate was accompanied by 27% more feed over the 140-d period of restriction, which resulted in a 22% reduction in quantity of feed required per pregnant heifer over the 140-d study. A comprehensive benefit-cost analysis of this trade off is beyond the scope of the present paper, but should also take into account differences in selection intensity and alternative markets for heifer calves vs. nonpregnant long-yearling heifers, as was recently evaluated by Clark et al. (2005). In previous research by Funston and Deutscher (2004), pregnancy rates were not different between 2 groups of composite heifers developed at similar growth rates and bred at similar weights as those in the current study. The potential contradiction between this previous research and the current study indicates the need for additional research evaluating the impact of different methods used for achieving differences in growth rate (i.e., restriction of DMI vs. feeding diets differing in energy density) on reproductive response.

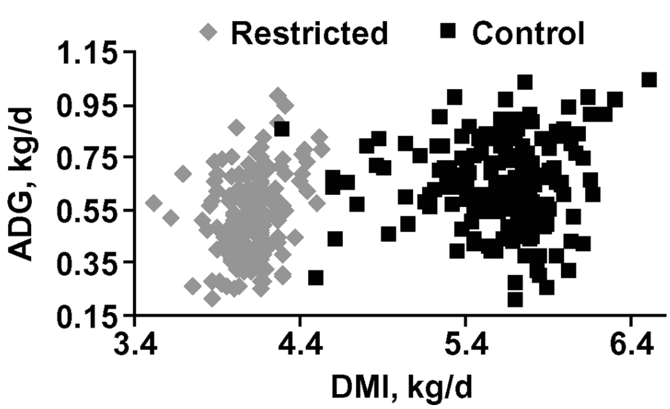

Figure 2. Relationship of average daily DMI and ADG for heifers that had ad libitum (control) or restricted (80% of control, when compared on a similar BW basis) access to feed during a 140-d postweaning period, beginning at approximately 240 d of age and ending at approximately 380 d of age. Magnitude of the association was greater in restricted- than control-fed heifers ($P < 0.001$ for the interaction effect of feed level and DMI on ADG).

Effects of Feeding Level on Associations Between Growth, Carcass, and Reproduction Traits

Variance-covariance matrices from multivariate analyses of the 9 primary response variables (Table 3) were different (Chi square = 359, $P < 0.001$) between treatments, indicating differences in the joint phenotypic distributions of traits between control and restricted-fed heifers. However, residual variance-covariance matrices from the 2 levels of feeding did not differ ($P = 0.80$) after removing row and column estimates associated with average daily DMI from the matrices. Thus, relationships of DMI with the other traits were concluded to be the primary basis for differences in initial comparison. As stated previously and shown in Table 3 and Figures 2 to 4, feeding strategy for the restricted group reduced variation in DMI, and thus heterogeneity of variances could contribute to the difference detected in the initial comparison of matrices. However, variance-covariance matrices calculated using transformed z-scores still differed ($P < 0.001$) between treatments when all rows and columns were evaluated, and did not differ ($P = 0.90$) after removing the row and column associated with DMI. These results provide evidence that associations between DMI and other response variables differed by treatment, that the differences in associations between treatments were not simply a consequence of heterogeneity of variance, and that other interrelationships were similar for both treatments. Estimates of regression of ADG (0.32 vs. 0.08; $P = 0.002$, coefficients for restricted vs. control, respectively), off-test BW (170 vs. 26; $P < 0.001$), hip height (16.6 vs. 1.6; $P < 0.001$), LM area (17.7 vs. 4.0; $P = 0.016$), and BCS (0.85 vs. 0.20; $P = 0.09$) on DMI also differed due to treatment, being of greater magnitude under restricted feeding than control feeding. Differences in muscle and fat deposition between the 2 groups would influence efficiency due to differences in mainte-

Table 3. Residual variance-covariance matrices from multivariate analyses[1] of BW, hip height (Ht), ADG, LM area (LMA), fat thickness (fat), intramuscular fat (IMF), BCS, pregnancy rate, and DMI in heifers subjected to ad libitum access to feed (control) or restricted (80% of control) during a 140-d period of development after weaning

Treatment	Trait	BW	Hip Ht	ADG	LMA	FAT	IMF	BCS	Pregnancy	DMI
Restricted	BW	654.98	50.35	2.22	59.18	4.69	0.026	5.13	–0.53	2.35*
Control	BW	599.44	40.69	1.94	53.49	8.92	–0.136	4.97	0.42	2.74*
Restricted	Ht		11.51	0.101	0.421	–0.59	–0.013	–0.225	–0.040	0.225*
Control	Ht		9.27	0.075	1.242	–0.49	–0.153	–0.158	–0.033	0.158*
Restricted	ADG			0.014	0.174	0.028	0.006	0.029	–0.001	0.005*
Control	ADG			0.014	0.156	0.031	0.002	0.025	0.005	0.008*
Restricted	LMA				55.56	1.72	–0.343	0.829	–0.025	0.264*
Control	LMA				58.97	2.19	0.022	0.868	0.017	0.429*
Restricted	Fat					1.19	0.190	0.210	0.014	0.017
Control	Fat					1.88	0.271	0.193	0.032	0.035
Restricted	IMF						0.35	–0.001	–0.001	–0.004
Control	IMF						0.35	0.001	–0.001	0.004
Restricted	BCS							0.33	–0.007	0.011*
Control	BCS							0.31	0.009	0.020*
Restricted	Pregnancy								0.115	–0.001
Control	Pregnancy								0.081	–0.004
Restricted	DMI									0.014*
Control	DMI									0.096*

[1]Model included effects of birth year, age of dam and age of heifer; df = 178 and 190 for restricted and control, respectively.

*Values differ ($P < 0.10$) between treatments.

nance requirements for protein and fat (Ferrell and Jenkins, 1998). Also, lighter BW of restricted heifers ($P < 0.001$) and, potentially, reduced visceral organ mass due to restriction (Burrin et al., 1990; Johnson et al., 1990) or simply due to lighter BW, would also decrease maintenance requirements. Lower maintenance requirements and the greater association between DMI and other traits are consistent with restricted heifers being more efficient than control heifers during the treatment period. Previous research indicated that differences in efficiency observed between heifers developed at different rates may not persist if comparisons were made at a common BW endpoint (Freetly et al., 2001). In the current study, differences in BW observed between treatments persisted up to the final BW measure at approximately 608 d of age, when restricted heifers were lighter than control heifers (406 vs. 416 ±

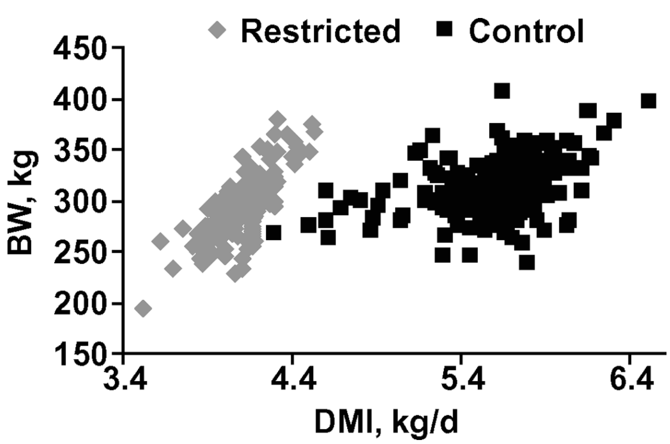

Figure 3. Association of average daily DMI and BW at the end of a 140-d postweaning study in which heifers had ad libitum (control) or restricted (80% of control) access to feed, beginning at approximately 240 d of age and ending at approximately 380 d of age. Magnitude of the association was greater in restricted- than control-fed heifers ($P < 0.001$ for the interaction effect of feed level and DMI on BW).

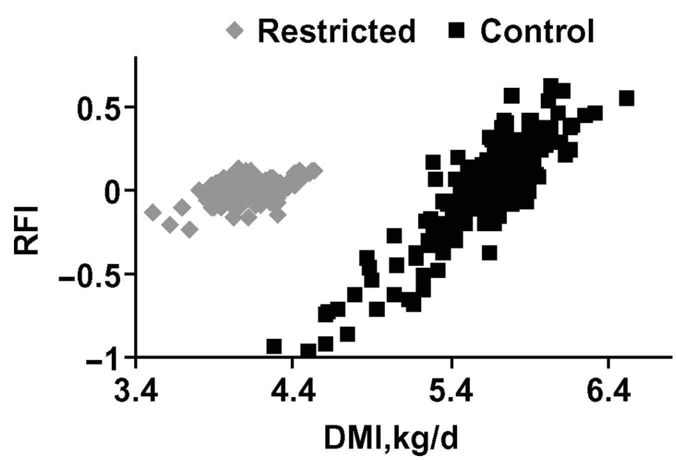

Figure 4. Association of average daily DMI and residual feed intake (RFI) in heifers that had ad libitum (control) or restricted (80% of control) access to feed during a 140-d postweaning period, beginning at approximately 240 d of age and ending at approximately 380 d of age. Magnitude of the association was greater in control heifers than restricted heifers.

3 kg, respectively; $P = 0.03$). However, ADG from the end of the 140-d study to the final BW was greater ($P < 0.001$) in restricted (0.51 ± 0.01 kg/d) than control (0.46 ± 0.01 kg/d) heifers, indicating that differences in efficiency due to differences in BW appeared to persist beyond the restricted feeding period.

Effects of Feeding Level on RFI

In the current study, RFI was calculated within treatments (mean = 0 in both treatments). Restricting feed intake using regression on BW reduces variation in feed intake. As a consequence, variation in RFI was reduced ($P < 0.01$ for Fmax test for homogeneity of variances; Figure 4). Several biologic mechanisms contributing to variation in RFI have been identified (Richardson and Herd, 2004) including variation in appetite. It would be expected that the contribution of variation in appetite toward variation in RFI would be much more evident in control than restricted-fed heifers. Therefore, restricted feeding might have application in identifying and selection for specific biological processes, other than appetite, that contribute to differences in RFI.

Although the concept of utilizing RFI as a method for evaluating efficiency in cattle was published over 40 yr ago (Koch et al., 1963), much of the limited research on RFI has occurred in the last decade (reviewed by Herd et al., 2003). One favorable characteristic of RFI is its independence from BW and gain. Thus, selection on RFI may result in less correlated responses in growth traits than selection for other measures of efficiency. In the current study, positive phenotypic associations were evident ($P < 0.001$) between RFI and average daily DMI under the control (r = 0.91) and restricted (r = 0.61) levels of feeding, but associations of RFI with other traits were not evident. Previous studies have also reported strong positive phenotypic (r > 0.70; Arthur et al., 2001; Nkrumah et al., 2004) and genetic (r > 0.64; reviewed by Herd et al., 2003; Crews, 2005) correlations between RFI and feed intake.

Results from this study provide evidence that limit feeding of heifers during the postweaning development period may be a feasible option for producers to consider. The level of feed restriction applied in this study resulted in a 27% reduction in harvested feed utilized during the 140-d postweaning development period and improved efficiency of gain that appeared to persist throughout the subsequent grazing period. Although a 5% reduction in pregnancy rate was observed in restricted heifers, harvested feed requirements per pregnant heifer were reduced by 22% during the 140-d development period, representing a major potential for cost reduction, depending on disparity of market values associated with differences in numbers of heifer calves retained and lighter BW of open heifers. The observation that feed restriction resulted in reduced variation in RFI may have implications in the identification and selection of specific biological components not associated with appetite that influence RFI.

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