Feed efficiency differences and reranking in beef steers fed grower and finisher diets[1]

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ABSTRACT: This 3-yr study used 490 steers to determine whether feedlot steers changed their feed efficiency (FE) ranking when fed a grower diet, then a finisher diet. The steers were crossbreds and were between 5 to 7 mo of age. There were 2 feeding periods each year. Within each year, approximately 90 steers had their diet switched from a grower to a finisher diet (feed-swap group), whereas another 90 steers were fed either the grower (grower-fed group) or the finisher (finisher-fed group) diet throughout the feeding trial. Each feeding test lasted for a minimum of 10 wk, and all steers were fed ad libitum. Individual animal feed intakes were collected using the GrowSafe feeding system, and BW were measured every 2 wk. Residual feed intake (RFI), G:F, and Kleiber ratio (KR) were computed at the end of each feeding period. For each measure of efficiency, animals were classified as low, medium, or high based on 0.5 SD from the mean. The majority of steers did not maintain the previous efficiency class in the second period. Approximately 58, 51, and 51% of steers in the feed-swap group, finisher-fed group, and the grower-fed group, respectively, changed their RFI measure by 0.5 SD. A low rank correlation occurred in all test groups but was less in the feed-swap group. Spearman rank correlations between the 2 feeding periods in the feed-swap group were 0.33, 0.20, and 0.31 for RFI, G:F, and KR, respectively. Classifications based on G:F and KR showed that a greater number of steers ($P < 0.05$) in the feed-swap group did not maintain their FE class from 1 feeding regimen to the other, whereas classification based on RFI did not show any difference ($P > 0.05$) between the proportions of individuals that changed or maintained their FE class. In the groups without a feed-swap, there was no difference ($P > 0.05$) in the proportion of steers that changed or maintained the same FE class for all FE measures. Our results suggest that diet type and feeding period affect the FE ranking in beef steers. A feedlot diet is ideal for evaluating the FE potential of steers for feedlot profitability; however, we suggest that tests involving less dense diets should be examined in an effort to understand the relationships between FE and feeder profitability.

Key words: beef cattle, feed efficiency, finisher diet, grower diet, reranking, residual feed intake

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INTRODUCTION

Many studies have investigated phenotypic measures of feed efficiency (**FE**) in beef cattle (Koch et al., 1963; Arthur et al., 2001a), but limited information exists on these measures taken at different times in the life of an animal or on rations differing in energy content. Few studies have investigated the effect of diets differing in energy density on the FE performance of group-fed cattle (Fan et al., 1995), but none has looked at the FE ranking of beef cattle fed different diets successively. The lack of information on multiple FE measurements may be due to the increased cost associated with multiple measures and longer trials using the same animals. This information is necessary to improve lines of efficient cattle at all ages and all diets, thereby helping beef producers in any sector reduce their feeding costs. The evidence available suggests that one measure of FE, residual feed intake (**RFI**), measured in cattle at young ages is highly correlated with those measured later in life (Arthur et al., 2001b; Archer et al., 2002). Goonewardene et al. (2004) reported high rank correla-

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tions between RFI measured at 63-d, 84-d, and 105-d test periods on the same animals.

Feedlot steers often receive a backgrounding or grower diet before receiving a high energy feedlot diet. It is not known whether animals that are efficient on a backgrounding diet or grazing pasture would also be efficient on a high grain diet. Knowledge about this relationship is important for selection decisions regarding which animals to use as replacements and when to measure or evaluate animals for FE. Consequently, our objective was to investigate if steers change their FE rankings when the diet is switched from a grower to a finisher diet. The null hypothesis tested was that the FE rank of an animal would not be different when fed these 2 diets.

MATERIALS AND METHODS

All animals were located at the University of Alberta ranch at Kinsella, Alberta, Canada, and were cared for according to the Canadian Council on Animal Care (CCAC, 1993) guidelines.

Animals and Management

A total of 490 steers were used in the 3-yr trial (2006–2009). These steers were born in the spring of 2006, 2007, and 2008 from multiple sires mated to hybrid dams on pasture. The hybrid dams were crosses between Angus or Charolais bulls and composite dams generated from 3 composite cattle lines, namely, Beef Synthetic 1, Beef Synthetic 2, and Dairy × Beef Synthetic (Nkrumah et al., 2004). The 3 composite dam lines had different original breed compositions. The Beef Synthetic 1 line was composed of 16.5% Angus, 16.5% Charolais, 20% Galloway, and 47% of other beef breeds. The Beef Synthetic 2 line was composed of 60% Hereford and 40% of other beef breeds, whereas the Dairy × Beef Synthetic line was made up of 60% dairy breeds (Brown Swiss, Holstein, and Simmental) and 40% beef breeds (Angus and Charolais). The sires used were hybrid or Angus bulls. The hybrid sires were selected bulls from crosses between Angus or Charolais bulls and the hybrid dams.

The steers grazed with their dams until they were weaned in October of each year. All animals had been vaccinated [CoVexin 8 (Intervet, Kirkland, Canada), Starvac 4 (Norvatis, Mississauga, Canada), Somnu-star PH (Norvatis), and Somnugen Express 5-PHM (Boehringer Ingelheim, Burlington, Canada)] for infectious bovine rhinotracheitis, parainfluenza-3 virus, bovine viral diarrhea, bovine respiratory syncytial virus, *Haemophilus somnus*, *Pasteurella multocida*, and clostridial diseases 4 wk before arriving at the feeding facility. Upon arrival, each steer was treated with a pour-on parasiticide (Ivomec, Merial, Baie d'Urfe, Canada) that controls warble larvae, mites, lice and horn fly. Each steer was identified with a radio frequency transponder button (half duplex RFID, Allflex USA Inc., Dallas/Ft. Worth Airport, TX) in its right or left ear. The transponder button was located 5 to 6 cm from the base of the ear, in the middle, with the transponder button on the inside part of the ear.

The test facility was a fenced area divided into 2, each containing 1 of the 2 test groups of steers. The design of the test facility was such that the lying area was at one end and where they were offered feed was at the other end. For each group, the distance between the 2 ends was about 50 m with the water trough located in the middle of the 2 ends. Feed and clean drinking water were offered ad libitum throughout the test periods. Each group had access to 10 GrowSafe System (GrowSafe Systems Ltd., Airdrie, Alberta, Canada) feeding bunks, which were housed in a shed. The lying area for each group was a large outdoor pen with wheat straw as bedding. Wheat straw was used as a bedding material because of its poor nutritive quality. Fresh wheat straw was added when the old straw bedding was wet; however, the effect of potential straw intake on our results, especially the finisher diet, is unknown.

There were 2 feeding periods in each of the 3 yr. The first feeding period (**P1**) ran from November to January, whereas the second feeding period (**P2**) ran from February to May. Each year (except for yr 1), the animals were divided into 2 groups. In yr 1, all steers (n = 175) were in the feed swap group and were fed a grower diet in P1 followed by the finisher diet in P2. In yr 2 and 3, the feed-swap groups had 84 steers and 72 steers, respectively. The control groups were fed the same diet in the 2 periods: finisher diet in the second year (n = 88) and grower diet in the third year (n = 71).

The composition of the grower diet on an as-fed basis was 74% oats, 20% smooth brome hay, and 6% feedlot supplement (Table 1), whereas the finisher diet contained 10% alfalfa pellets, 28.3% oats, 56.7% barley, and 5% feedlot supplement. Weekly samples of feed were collected and pooled into monthly samples and were subsequently analyzed for DM, CP, crude fat, NDF, and ADF. Dry matter was determined by an overnight oven-drying to a constant weight at 110°C. Crude protein was measured by determining the N content in feed using the Kjeldahl procedure (AOAC, 1980). Neutral detergent fiber was determined according to the procedure of Van Soest et al. (1991), whereas acid detergent fiber was determined according to AOAC (1997). The NDF and ADF were determined using the Ankom 200 fiber analyzer (Ankom Technology Corp., Fairport, NY).

The steers were adjusted to their trial diets during a pre-test adjustment period of 21 to 30 d. This initial adjustment period enabled the animals to acclimate to the GrowSafe System feeding units and test diets. At the end of the first period, a 2-wk adjustment period was allowed before the commencement of feed intake data collection in the second period. During this period, the diet (for the feed-swap group) was gradually adjusted to the finisher diet.

Table 1. The ingredients (%, as fed) and composition of the grower and finisher diets

Feed composition	Grower diet	SD (n = 5)[1]	Finisher diet	SD (n = 5)[1]
Alfalfa pellets	0.0	—	10.0	—
Oat grains	74.0	—	28.3	—
Barley grains	0.0	—	56.7	—
Grass hay (smooth brome)	20.0	—	0.0	—
Feedlot-32 supplement[2]	6.0	—	5.0	—
ME content, MJ/kg	10.9	—	12.1	—
Chemical composition, % of DM				
DM	85.5	0.8	87.0	0.2
CP	13.0	0.5	13.5	0.4
Crude fat	4.3	0.4	3.3	0.3
ADF	17.9	1.8	10.3	0.6
NDF	39.4	3.1	29.5	4.7

[1]Five subsamples were analyzed for each component.

[2]Contained 440 mg/kg of monensin (Elanco Animal Health, Greenfield, IN), 1.6 mg/kg of Se, 5.0% Ca, 0.58% P, 0.76% K, 16 mg/kg of I, 80 mg/kg of Fe, 170 mg/kg of Cu, 480 mg/kg of Mn, 485 mg/kg of Zn, 4.3 mg/kg of Co, 1.98% Na, 0.17% S, 0.38% Mg, 80,500 IU/kg of vitamin A, 8,000 IU/kg of vitamin D, and 1,111 IU/kg of vitamin E.

Data Collection

Table 2 shows the number of animals, length of the different periods, and data integrity checks for all years and test groups. Data collected from the feed-swap groups over the 3 yr were pooled for subsequent data analyses. Fourteen steers were excluded from the data analyses because of incomplete phenotypic data.

In yr 1, the test ran from November 1, 2006, to May 2, 2007. In yr 2 and 3, the test ran from November 6, 2007, to May 1, 2008, and November 2, 2008, to May 1, 2009, respectively. Details are shown in Table 2. Although a minimum of 63 to 70 d (Archer et al., 1997; Wang et al., 2006) of reliable data is required for RFI calculations, the number of days exceeded the requirement to make up for days that were excluded due to temporary malfunctions in the feeding system, power outages, or days with low data integrity values. The BW of all steers were measured once every 2 wk throughout the test periods, whereas ultrasound back-fat (**UBF**) thickness was measured at the beginning and at the end of the feeding period with an Aloka 500V real-time ultrasound with a 17.5-cm, 3.5-MHz probe (Overseas Monitor Corporation Ltd., Richmond, British Columbia, Canada). Feed intake was measured daily on each steer using the GrowSafe feeding system. The system consisted of radio frequency identification tag on each animal, 20 feeding nodes located in a covered feeding shed, a data logging reader panel, and a computer that contained the data acquisition software. Each feeding node consisted of a feed tub on 2 load bars and an antenna embedded in the rim of each tub.

The antenna detects and identifies each animal through radio waves emitted by the transponder encased in the ear tag. Subsequent feeding and behavioral data are recorded as the animal is feeding from the bunks. Data generated from the feeding units are stored in the data logging reader panel and are transferred wirelessly to the personal computer located about 100 m away. The GrowSafe data acquisition and analysis software in the computer converts the data into readable formats for subsequent analyses. For data integrity and quality control purposes, the GrowSafe system has an internal audit system that calculates the daily assigned feed disappearance (**AFD**) for each node by dividing the total daily feed delivered to each tub by the daily sum of individual animal feed intakes as attributed by the GrowSafe System for a specific tub. The AFD (Table 2) should be sufficiently large (>95%) for the data from each day to be included for data analysis. Data collected on the days that had small AFD were excluded from all analyses. The small AFD were due to power outages, heavy winds, heavy rains or snow, or temporary malfunctions in the system. Other data integrity shown (in Table 2) includes the correlation of DMI with mid metabolic BW (**MWT**), ADG, UBF, and expected feed intake. The correlations are used to examine the data for known relationships among the variables. Serious deviations from the allowable limits of the correlations would call into question the integrity of the data. This also includes the proportion of the variation in DMI accounted by ADG, MWT, and UBF.

Trait Derivations and Statistical Analysis

The ADG, initial BW, and mid-point BW of each animal were computed from the regression coefficients of the linear growth path of each animal using the PROC REG procedure (SAS Inst. Inc., Cary, NC). The mid-point BW was converted to MWT by calculating $BW^{0.75}$. Daily feed intake (as fed) was obtained as the average feed intake for valid test days. This was multiplied by the DM content of the feed to derive the DMI for each steer. The DMI observed was standardized across diets and years to 10 MJ of ME·kg^{-1} of DM. The ME of each diet was estimated with the CowBytes ration balancing software (Alberta Agriculture and Rural Development, Edmonton, Canada). Expected DMI was obtained as a regression of ADG, MWT, and UBF on standardized

Table 2. Integrity checks for the data collected on each feeding regimen for the 3 groups for the 3 yr[1]

	Feed-swap group						Control groups			
							Finisher-fed		Grower-fed	
Item[2]	Yr 1-P1	Yr 1-P2	Yr 2-P1	Yr 2-P2	Yr 3-P1	Yr 3-P2	Yr 2-P1	Yr 2-P2	Yr 3-P1	Yr 3-P2
No. of animals	175	175	84	84	72	72	88	88	71	71
Mean age, d	193	—	195	—	200	—	195	—	201	—
Total days on test	83	93	90	71	79	82	90	71	79	82
No. of days excluded	1	28	24	7	1	1	5	5	1	2
No. of days included	82	65	66	64	73	81	85	66	73	80
Average feed disappearance (AFD), %	98.8	96.6	98.2	97.1	99.1	97.9	99.4	97.3	99.1	98.0
Total feed station days (FSD)	1,061	1,860	900	710	1,406	820	900	710	1,406	820
Feed station days <95% AFD	29	627	115	117	22	64	19	128	22	69
Percentage of FSD <95% AFD	2.7	33.7	12.8	16.5	1.6	7.8	2.1	18.0	1.6	8.4
Feed station days <90% AFD	19	241	60	27	5	12	8	17	5	6
Pearson correlation										
Correlation between DMI and MWT	0.73	0.65	0.59	0.68	0.72	0.78	0.70	0.55	0.67	0.68
Correlation between DMI and ADG	0.58	0.48	0.46	0.57	0.61	0.69	0.63	0.41	0.52	0.33
Correlation between DMI and EFI	0.82	0.71	0.69	0.73	0.86	0.86	0.84	0.60	0.78	0.72
Correlation between DMI and UBF	0.40	0.32	0.46	0.29	0.60	0.50	0.39	0.12	0.40	0.33
Coefficient of determination										
Variation in DMI ~ADG, MWT	0.64	0.48	0.42	0.54	0.71	0.75	0.70	0.36	0.58	0.48
Variation in DMI ~ADG, MWT, UBF	0.67	0.50	0.49	0.54	0.74	0.76	0.71	0.36	0.60	0.52

[1]The feed-swap group was fed the grower in period 1 (P1) followed by the finisher diet in period 2 (P2), the finisher-fed group was fed the finisher diet in both periods, and the grower-fed group was fed the grower diet in both periods.

[2]Feed station days (FSD) is calculated as the product of the days on test and the number of feeding nodes or bunks; MWT = mid metabolic BW; UBF = ultrasound backfat; EFI = expected feed intake.

DMI using PROC GLM of SAS. The residuals from the equation (shown below) were output as RFI, which was calculated within contemporary groups defined by year of test, feeding group, and feeding period. The equation is shown below:

$$\text{DMI} = \text{ADG} + \text{MWT} + \text{UBF} + \text{CG} + \text{RFI},$$

where CG is the contemporary group classification, and the RFI indicates the residuals (Basarab et al., 2003).

Other FE measures were calculated for each animal within contemporary groups. The G:F ratio was calculated as the ratio of daily ADG to DMI. Kleiber ratio (**KR**) was calculated as the ratio of ADG to MWT (Tedeschi et al., 2006). In addition to calculating FE measures within each period and year, across period within year (P1 and P2) FE measures were also calculated for each animal.

The steers were grouped into 3 classes based on the FE (i.e., RFI, G:F, or KR) SD of each contemporary group. They were classified as low (<0.5 SD), medium (±0.5 SD), and high (>0.5 SD). The objective of this approach was to have 3 RFI classes and an approximately equal number of steers in each RFI class. Assuming a normal distribution, we know that 68% of the steers would be ±1 SD from the mean. Therefore, about 34% of the steers would be about ±0.50 SD from the mean; the actual SD to obtain one-third in each group is not 0.5 SD, but this would be close. The classification would also help to identify steers that changed FE classes. A class change occurs when the FE class of any steer is different in each of the 2 periods. We also looked into the proportion of steers that changed their RFI by 0.25 SD, 0.5 SD, and 1 SD in P2. To determine the extent to which ranks changed within each group of steers, the Spearman's rank correlation statistic between P1 and P2 was calculated. The Pearson correlation statistic was used to determine the relationship among FE measures taken in the 2 periods. Part-whole correlations (Pearson) between the within- and across-period FE measures were also calculated. The part-whole correlations were done to identify the similarities between the within FE measures and the FE measured from the entire trial. Equality of correlations was tested using transformed Z-scores (Stockburger, 1996). The FE measures in P1 and P2 were tested for equal variances within each test group using PROC TTEST of SAS. Least square differences among test group means were tested with the GLM procedure in SAS using the PDIFF option.

The proportion of steers that changed their FE class from 1 feeding period to the other was compared with the proportion that maintained the same FE class using a χ^2 test executed using PROC FREQ of SAS. Using the same procedure, we compared the proportion of steers that changed from the low FE class to the high FE class with those that changed from the high class to the low class.

RESULTS

Table 2 shows the average age, number of days-on-test, as well as some integrity checks for the data collected on each feeding regimen. The ADG, MWT, and UBF used to compute RFI for the pooled feed-swap group accounted for 58 and 57% of the variation in DMI in P1 and P2, respectively. Corresponding values for the finisher-fed group and the grower-fed group were 71 and 36%, and 60 and 52%, respectively.

Differences in FE Among Test Groups

Table 3 shows the results for the different periodic FE and its components obtained for the 3 test groups. In P1, the mean DMI, ADG, MWT, and KR for the feed-swap group were similar ($P > 0.05$) to that of the grower-fed group but different from that of the finisher-fed group. There was no difference ($P > 0.05$) in RFI among all groups. The G:F was similar between the feed-swap and the finisher-fed group, but the G:F of the feed-swap group was greater than ($P < 0.05$) that of the grower-fed group. However, in P2, ADG, DMI, and KR were different ($P < 0.05$) among all 3 groups of steers. The G:F was not different between the 2 control groups, but the feed-swap group was different ($P < 0.05$) from either of them. The grower-fed group had the smallest ($P < 0.05$) G:F in P1 and P2, whereas the finisher-fed group had the greatest in P1.

The RFI variance in P1 was different ($P < 0.05$) from that in P2 for the 3 groups (Table 3), but the variances were greater in P2 than in P1. For each of the feed-swap and finisher-fed groups, the G:F variances were different between P1 and P2 within the feed-swap and the finisher-fed groups, but the KR variances in the 2 feeding periods were similar ($P > 0.05$).

FE Reranking

For all test groups, there were unequal proportions of steers in the low, medium, and high classes (Table 4) with more steers in the medium FE class than in either the high FE or the low FE classes. For RFI and G:F (Table 4), a greater proportion of steers in the feed-swap group changed their FE class from P1 to P2. On the other hand for RFI, the proportion of steers that changed their FE class was not different ($P > 0.05$) from those that maintained the same FE class. The 2 proportions (change vs. no change) were different when evaluated with G:F and KR. Similar proportions of steers in the 2 control groups changed or maintained the same FE class from P1 to P2. Within each of the 3 groups, the proportion that switched from the low to the high class (Table 5) was not significantly different ($P > 0.05$) from the proportion that switched from the high class to the low class. On the other hand, a small proportion of the steers maintained the same efficiency class (from P1 to P2) across all FE measures evaluated in the different test groups. About 5.4, 3.4, and 8.5% maintained the same class for the 4 FE measures in the feed-swap, finisher-fed, and grower-fed groups, respectively.

In both P1 and P2, the majority of the steers were in the medium class. Although some steers maintained the low or high classes in both feeding periods, others changed from the medium class (in P1) to either the high or low classes in P2 and vice versa. On the other hand, 17, 5, and 0 steers switched from the low to the high RFI class for the feed-swap, finisher-fed, and grower-fed groups, respectively, whereas 12, 3, and 6 steers switched from high to low RFI class for the feed-swap, finisher-fed, and grower-fed groups, respectively. We do not know the reasons behind the switches, and these steers may require further investigation into the reasons for such transitions. Considering the SD changes in P2, the proportion of steers that changed their RFI measure by 1 SD were 31, 30, and 23% for the feed-swap group, finisher-fed group, and grower-fed group, respectively. Corresponding values for the 0.5 SD and 0.25 SD were 58, 51, and 51%, and 79, 69, and 77% for the feed-swap group, finisher-fed group, and grower-fed group, respectively.

Further evidence of reranking is observed in the correlation coefficients between FE measured in P1 and P2. The Pearson correlations (data not shown) were similar but greater than the Spearman correlations. A low rank (Spearman) correlation within a group indicates that most steers changed their relative positions in P2. The FE rank correlation for all test groups were below 0.5, but the feed-swap group (Table 6) had smaller rank correlations between P1 and P2 than the control groups (Tables 7 and 8). Greater rank correlations for the 2 control groups indicate that the FE ranks of steers in P1 and P2 were similar. The RFI rank correlations between P1 and P2 were greatest within the feed-swap and finisher-fed groups. The grower-fed group had greater and more consistent correlations across the 4 FE measures.

Table 9 shows the part-whole Pearson correlation coefficients between the FE calculated from entire feeding period (P1 and P2) with each FE calculated in P1 and P2. For the feed-swap and the grower-fed groups, the FE from P1 and P2 had a greater correlation with the FE calculated from P2 than that from P1. The finisher-fed group had a greater correlation between the P1 and P2 FE and the FE in P1, indicating that the FE measured during P1 was more similar to the FE measured during the entire feeding period (P1 and P2 combined).

DISCUSSION

In the design of this experiment, practices obtainable in the commercial beef sector were considered. Steers are usually fed a grower diet before they are transitioned to a finisher diet. It is very unlikely and impractical to feed high energy diets before low energy diets,

Table 3. Means and SD of traits[1]

	Feed-swap group				Finisher-fed group				Grower-fed group			
	P1, grower		P2, finisher		P1, finisher		P2, finisher		P1, grower		P2, grower	
Trait[2]	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Initial BW, kg	260	31.6	381	39.0	259	29.6	413	35.8	268	30.4	392	35.4
Final BW, kg	364	37.1	539	50.2	398	34.7	535	43.0	357	34.2	516	40.6
DMI, kg/d	7.5	0.9	10.3	1.3	8.3	0.9	10.0	1.2	7.8	0.8	10.3	1.1
ADG, kg/d	1.2	0.2	1.8	0.3	1.5	0.2	1.6	0.3	1.2	0.2	1.5	0.2
MWT	74	6.0	99	6.9	77	5.4	102	6.1	74	5.6	98	6.0
RFI, kg of DM/d	0.00	0.56	0.00	0.95	0.00	0.59	0.00	0.93	0.00	0.57	0.00	0.79
G:F	0.15	0.02	0.14	0.02	0.15	0.02	0.14	0.02	0.14	0.02	0.13	0.02
KR (×100)	1.7	0.3	1.8	0.2	2.0	0.3	1.6	0.3	1.6	0.3	1.5	0.2

[1]The feed-swap group was fed the grower diet in period 1 (P1) followed by the finisher diet in period 2 (P2), the finisher-fed group was fed the finisher diet in both periods, and the grower-fed group was fed the grower diet in both periods.

[2]MWT = mid metabolic BW; RFI = residual feed intake; KR = Kleiber ratio.

Table 4. Proportion of the steers that changed or maintained the same feed efficiency class between periods

Feed efficiency measure[1]	Feed-swap group				Finisher-fed group				Grower-fed group			
	Changed		No change		Changed		No change		Changed		No change	
	n	%	n	%	n	%	n	%	n	%	n	%
RFI	181	54.7[a]	150	45.3[a]	45	51.1[a]	43	49.9[a]	36	50.7[a]	35	49.3[a]
G:F	204	61.6[a]	127	38.4[b]	52	59.1[a]	36	40.9[a]	38	53.5[a]	33	46.5[a]
KR	188	56.8[a]	143	43.2[b]	50	56.8[a]	38	43.2[a]	36	50.7[a]	35	49.3[a]

[a,b]Within each group, different superscripts indicate that the proportions of changed vs. no change are different at $P < 0.05$.
[1]RFI = residual feed intake (kg/d); KR = Kleiber ratio.

and this option was not considered in the study design. Using feed-efficient animals in the cow-calf and feedlot production systems would reduce the cost of production and produce less greenhouse gases such as methane, thereby having a less negative impact on the environment than inefficient steers (Nkrumah et al., 2006; Hegarty et al., 2007). Most studies on FE have focused on single-period measurements on a single diet (Arthur et al., 2001a,b; Nkrumah et al., 2004). Archer et al. (2002) evaluated FE measured on heifers at postweaning and as mature cows, whereas J. Christopher and T. Marston (unpublished) compared the RFI rankings of heifers fed low and then high energy-dense diets at Kansas State University (Manhattan).

Measuring FE twice showed class changes in all the test groups, implying that diet and the feeding period affect the FE performance of steers. The effect of diet is observed in the greater number of steers that changed their efficiency class when the diets were switched. Steers in the feed-swap group that were efficient under both diets may perform well under diverse diets and may be sought after in an integrated beef sector. Those that maintained their RFI classes in both periods, whether efficient or not, could offer a platform for understanding the genetic mechanisms surrounding FE.

Having so few animals maintain the same class across the 4 FE measures may have selection consequences. Although some animals may be considered very efficient using a particular FE measure, the animals become less efficient when evaluated with another FE measure. This then implies that different animals may be considered for selection depending on the FE measure of choice. For example, a producer that does not have access to automatic feeding system to compute RFI may select a different set of efficient animals using G:F.

The switch from 1 FE class to another for the feed-swap group may be attributed to some factors that may limit any the ability of the animal to adjust to a new feed. Guan et al. (2008) reported that the ability of an animal to use feed is associated with the population of rumen microbes. Feeding a concentrate or high-energy diet after a low energy diet changes the pH and the population of rumen microbes in cattle, reducing the cellulolytic bacteria but, on the other hand, reducing intake (Calsamiglia et al., 2008). Apart from rumen microbes, individual animal variations may also be caused by the feeding rate or ruminal activities (Hegarty, 2004). For these reasons, different animals may perform differently on various diets (Russell et al., 1992) or different periods, thereby determining the FE class of an animal.

Greater growth rates may have contributed to the changes in the FE classes observed in the feed-swap group. The steers within this group may have experienced greater growth rate in P2 than other groups due to compensatory growth. Drouillard et al. (1991) observed greater finishing performance when diets of steers were energy-restricted. Similar trend was observed when McCarthy et al. (1985) studied feedlot cattle fed different energy density diets. Those fed low-high diets had greater BW gains in the finishing period than those fed high-high diets. Compensatory gains have been reported in heifers fed a high energy-dense diet after an initial period of a less energy-dense diet (Barash et al., 1994).

Table 5. The proportion of steers that changed between the low and high classes

Feed efficiency measure[1]	Feed-swap group				Finisher-fed group				Grower-fed group			
	Low-to-high		High-to-low		Low-to-high		High-to-low		Low-to-high		High-to-low	
	n	%	n	%	n	%	n	%	n	%	n	%
RFI	16	55.2[a]	13	44.8[a]	4	57.1[a]	3	42.9[a]	0	0	5	100
G:F	24	54.5[a]	20	45.5[a]	7	77.8[a]	2	22.2[a]	4	50[a]	4	50[a]
KR	15	48.4[a]	16	51.6[a]	3	42.9[a]	4	57.1[a]	3	42.9[a]	4	57.1[a]

[a]Within each group, different superscripts indicate that the proportions of changed vs. no change are different at $P < 0.05$.
[1]RFI = residual feed intake (kg/d); KR = Kleiber ratio.

Table 6. Spearman correlations among the feed efficiency measures for the group fed the grower diet in P1 and finisher diet in P2[1,2]

Trait	RFI2	G:F1	G:F2	KR1	KR2
RFI1	0.33***	−0.46***	−0.11	0.04	0.10
RFI2		−0.05	−0.57***	0.11*	−0.01
G:F1			0.20***	0.81***	0.20***
G:F2				0.15**	0.72***
KR1					0.31***

[1]Feed efficiency measures with suffix 1 were measured in the first feeding period (P1), whereas those with suffix 2 were measured in the second feeding period (P2).

[2]RFI = residual feed intake (kg/d); KR = Kleiber ratio.

$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Feeding the finisher diet in the first feeding period of the finisher-fed group may have also contributed to the switches in their FE classes in the subsequent period. The greater DMI and ADG in P1 for the finisher-fed group compared with the feed-swap or grower-fed groups may be driven by the rumen fill. Such greater intake may avail the steers with more energy for metabolic processes. Differences may exist among animals in their abilities to use greater ME at an early age. Steers that partitioned more protein during this period may have a different efficiency performance from those that partitioned more fat. This may eventually affect their maintenance requirement and subsequent FE performance in P2.

It is important to consider the variability underlying phenotypic RFI (Crews, 2005). The RFI measurements that changed by 0.5 SD or more (from P1 to P2) could be regarded as important shifts in FE status. The steers that had such shifts could provide insight into mechanisms underlying reranking. It is not surprising that a large percentage of steers changed their RFI in P2 by 0.25 SD, which is a small margin. Majority of such changes may have arisen from random errors that occurred during BW measurement of the steers or during the estimation of ADG. Errors in BW measurements would affect the MWT as well as the ADG, resulting in inaccurate estimates. These would subsequently affect the RFI estimated within any period and may cause reranking from 1 period to another by a small margin. The gut fill of the steers at the time of measurement may also influence individual BW and cause greater variation in BW (Archer and Bergh, 2000). Steps were taken to control these random errors. The steers were weighed first in the morning before they were fed to avoid disrupting feeding patterns (Archer et al., 1997), and this pattern was maintained throughout the trials. Further errors were minimized by taking multiple BW measurements (Koch et al., 1963) and using linear regression to estimate ADG (Archer and Bergh, 2000). Random errors that may have arisen from measurement of intake were minimized by frequent monitoring of the GrowSafe system, conducting data integrity checks, as well as excluding days that may contain invalid feed intake data.

Another evidence of reranking is observed in the low to moderate correlation estimates between FE measured in P1 and P2. The low correlation estimates for all FE measures in all test groups may show that majority of the steers performed differently on the different diet types and different periods. A low correlation estimate may indicate that efficient animals in P1 may not be efficient in P2 or vice versa. The low correlation estimates observed in the 2 control groups may point out that the FE ranking of an animal may be affected by time or feeding period. That the correlations observed in the control groups were not different from those observed in the feed swap may show that both diet and feeding period may have contributed to the reranking and variation. The grower-fed group had greater and more uniform correlations than other groups; however, the reasons behind these are unclear. J. Christopher and T. Marston (unpublished, Kansas State University, Manhattan) reported no correlation between RFI measured in the 2 feeding periods, which contrasts our find-

Table 7. Spearman correlations for the control group fed the finisher diet in P1 and P2[1,2]

Trait	RFI2	G:F1	G:F2	KR1	KR2
RFI1	0.42***	−0.52***	−0.35***	0.02	−0.17
RFI2		0.02	−0.49	0.31	−0.05
G:F1			0.29**	0.78***	0.34**
G:F2				0.06	0.86
KR1					0.22*

[1]Feed efficiency measures with suffix 1 were measured in the first feeding period (P1), whereas those with suffix 2 were measured in the second feeding period (P2).

[2]RFI = residual feed intake (kg/d); KR = Kleiber ratio.

$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Table 8. Spearman correlations for the control group fed the grower diet in P1 and P2[1,2]

Trait	RFI2	G:F1	G:F2	KR1	KR2
RFI1	0.44***	−0.46***	−0.14	−0.01	0.0
RFI2		−0.16	−0.41***	0.07	0.06
G:F1			0.38***	0.84***	0.42***
G:F2				0.31**	0.84***
KR1					0.46***

[1]Feed efficiency measures with suffix 1 were measured in the first feeding period (P1), whereas those with suffix 2 were measured in the second feeding period (P2).

[2]RFI = residual feed intake (kg/d); KR = Kleiber ratio.

$^{**}P < 0.01$; $^{***}P < 0.001$.

ings. Their results were probably due to a small number of subjects (n = 26). The phenotypic correlations between RFI1 and RFI2 obtained here may indicate that RFI1 and RFI2 are different traits. Even though RFI had greater correlations between P1 and P2 than other FE measures, a lot needs to be understood about the characteristics of RFI.

The low RFI correlations for the feed-swap group were similar to those obtained from other species. Studies in mice reported low correlations between RFI measured at postweaning and at mature stages. Archer et al. (1998) reported a phenotypic correlation of 0.29 between the RFI measured at the same stages in mice. On the other hand, the phenotypic correlations for the control groups were similar to the findings of Arthur et al. (2001b) who reported 0.43 for RFI.

The reranking reported for phenotypic FE in this study may call into question the appropriate time to measure the trait, especially for individuals intended to be used as replacements. Even though early identification of efficient individuals is important for genetic improvement of FE in the beef industry, reranking may become a hindrance. The part-whole correlation may clarify some important points. The greater correlations between P1 and P2 with P2 in the feed-swap and grower-fed groups may show that conducting the FE evaluations in P2 seem to give a better efficiency potential of each animal. At this time, the steers were 290 d on average, indicating that FE evaluations may be more appropriate at an older age when the animals are close to their mature BW. Apart from the effect of feeding period, the type of diet may also affect the level at which an animal expresses its FE potential. The result from the finisher-fed group suggests that the efficiency of an animal may be determined earlier by offering a high energy diet.

Results of the current study were similar to those reported by Goonewardene et al. (2004) indicating that RFI measured later in a feed test was more correlated to the overall FE of animals. Goonewardene et al. (2004) reported greater Pearson correlation estimates for the part-whole correlations for RFI. The reasons behind the greater correlation are unclear but may be due to the use of different feed ingredients having different nutrient values. In addition, the sample size (n = 10) for their study was small and may bias results.

Conclusions

We set out to investigate if diet type influences the FE ranking of beef cattle by investigating the FE-class changes and correlation estimates between the 2 feeding regimens. The majority of the steers did not maintain their previous FE classes in P2. A greater proportion of steers in the feed-swap group changed their RFI measure in P2 by 0.25 SD, 0.5 SD, or 1 SD. The correlation estimates between the 2 feeding periods for all test groups were low but were less for the feed-swap group. We observed that switching diets as well as feeding period or stage of maturity affects the FE and FE ranking of steers. Residual feed intake had the greatest correlation between the 2 periods for the majority

Table 9. The Pearson correlations between combined-period feeding efficiency (FE) with periodic FE

	Feed-swap group		Finisher-fed group		Grower-fed group	
Trait[1]	P1[2]	P2[2]	P1[2]	P2[2]	P1[2]	P2[2]
RFI	0.74[a]	0.83[b]	0.85[a]	0.78[a]	0.72[a]	0.87[b]
G:F	0.52[a]	0.59[a]	0.80[a]	0.59[b]	0.76[a]	0.84[a]
KR	0.61[a]	0.71[b]	0.79[a]	0.63[b]	0.79[a]	0.81[a]

[a,b]Within each group, different superscripts indicate that both correlation coefficients are different at $P < 0.05$.

[1]RFI = residual feed intake (kg/d); KR = Kleiber ratio.

[2]Indicates the part-whole correlation between the FE trait in the period specified and the FE measured for the entire (period 1 and period 2: P1 and P2, respectively) feeding period.

of the groups. Given that reranking exists, we suggest that finisher diet is still ideal for RFI evaluation in feedlot animals. We also suggest that RFI evaluation on decreased energy diets should be examined in an effort to understand the relationships between FE and feeder profitability. More studies are needed to understand the mechanisms surrounding the reranking in all groups.

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