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EVALUATION OF FEED EFFICIENCY TRAITS IN GROWING BULLS AND RELATIONSHIPS WITH FEEDING BEHAVIOR AND ULTRASOUND CARCASS ESTIMATES

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ABSTRACT: Objectives of this study were to characterize feed efficiency traits and examine phenotypic correlations with performance, ultrasound, and feeding behavior traits in growing bulls. Individual DMI and feeding behavior were measured in Angus (n = 214) and Brangus (n = 26) bulls (initial BW 368.4 ± 46.1 kg) fed a corn silage based diet (ME = 2.78 Mcal/kg) using a GrowSafe feeding system. DMI and 14-d BW were measured for 84 and 91 d in test 1 and 2, respectively, and ultrasound subcutaneous fat depth (BF) measured at start and end of each test. Residual feed intake (RFI) and residual gain efficiency (RGE) were computed as the residuals from appropriate linear regression models involving DMI, ADG and mid-test $BW^{.75}$ (MBW). Partial efficiency of growth (PEG) was computed as ADG divided by DMI for growth. Overall ADG and DMI were 1.44 (SD = 0.26) and 8.51 (SD = 1.10) kg/d in test 1 and 1.73 (SD = 0.28) and 10.07 (SD = 1.35) kg/d in test 2, respectively. RFI was correlated with DMI (0.59) and FCR (0.53), but not ADG or MBW. Bulls with low RFI (< 0.5 SD) consumed 15% less DMI and had 16% lower FCR than bulls with high RFI (> 0.5 SD). PEG was strongly correlated with DMI (-0.51) and RFI (-0.85), but moderately correlated with ADG (0.29) and MBW (-0.25). Bulls with low RFI had favorable PEG (0.36 vs 0.26) compared to bulls with high RFI. RGE was correlated with RFI (-0.61), but was strongly correlated with ADG (0.74). Gain in BF was correlated with ADG (0.31) and DMI (0.29), and tended ($P < 0.10$) to be correlated with RFI (0.11). Feeding duration was not correlated with DMI or ADG, but was correlated with RFI (0.41) and PEG (-0.20). Feeding frequency was not correlated with DMI or ADG, but was correlated with RFI (0.17). Bulls with low RFI had lower ($P < 0.01$) feeding duration and frequency than bulls with high RFI. Compared to other feed efficiency traits examined in this study, RFI will facilitate selection for improved feed efficiency with minimal responses in growth or composition traits.

Key Words: residual feed intake, beef cattle, feeding behavior

Introduction

Cost of feeding animals is the largest expense to the beef industry, particularly the cow/calf enterprise with approximately 65% of the total feed requirements being used to maintain the cowherd (Arthur et al., 2001b). Thus, a large improvement in profitability could be realized by reducing the amount of feed required for maintenance (i.e. improved feed efficiency). The typical efficiency trait measured is feed conversion ratio (FCR), but FCR is negatively correlated with growth and mature size. Selection against FCR would most likely result in increased mature cow size and thereby increased feed requirements for maintenance (Herd and Bishop, 2000).

Arthur et al. (2001b) suggested that residual feed intake, which is the deviation between actual feed intake and predicted feed intake calculated by linear regression of feed intake on growth rate and body size, would be an improved measure of feed efficiency due to independence from growth traits. These researchers have demonstrated that residual feed intake is moderately heritable and genetically independent of growth traits. Herd and Bishop (2000) demonstrated adequate potential for selection against RFI to improve FCR and efficiency of maintenance energy expenditure without increasing mature cow size.

Recent research has shown feeding behavior to be related to feed intake and growth rate (Schwartzkopf-Genswein et al., 2002). Growth rate is negatively correlated to FCR, thus feeding behavior may be correlated with FCR. Schwartzkopf-Genswein et al. (2002) demonstrated that FCR was negatively correlated with feeding duration; therefore, RFI may also be correlated with feeding behavior traits.

Residual feed intake is negatively correlated to carcass lean composition (Herd and Bishop, 2000). Fox et al. (2004) also found that bulls with low RFI had lower subcutaneous fat depth than those with high RFI. The objectives of this study were to characterize feed efficiency traits and examine phenotypic correlations with performance, ultrasound body composition, and feeding behavior traits in growing bulls.

Materials and Methods

Data from two postweaning performance tests conducted at the Beef Development Center in Millican, TX with Angus and Brangus purebred bulls were used in this study. The first test (n = 99 Angus and 16 Brangus) was initiated in June 2004, whereas, test 2 (n = 115 Angus and 10 Brangus) was initiated in November 2004. Bulls were fitted with a radio frequency transponder tag and adapted to the test diet and feeding system for a minimum of 28 d before the start of the tests. The test diet (2.78 Mcal ME/kg DM) consisted of 49% cracked corn, 38.5% corn silage, 5% cottonseed meal, 3% molasses and 4.5% supplement and was fed ad libitum twice daily.

To measure feed intake and feeding behavior traits, bulls were placed into one of two pens each equipped with nine feed bunk units (GrowSafe Systems Ltd., Airdrie, AB). GrowSafe Data Acquisition software was used to record feed intake and feeding behavior data for 84 and 91 d during test 1 and 2. Daily feed intake and feeding behavior traits were computed using GrowSafe Feed Intake Analysis software. Bulls were weighed at 14-d intervals, and ultrasound measurements of subcutaneous fat depth (**BF**) and longissimus muscle area (**LMA**) obtained at the start and end of each test. End-of-test LMA data was not available for test 2, thus LMA data were not considered in the analysis of this study. Hip height (**HH**) and scrotal circumference (**SC**) were measured at the end of each test.

Growth rates of individual bulls were modeled by linear regression of BW against day on test using the regression procedure of SAS (SAS Inst., Cary, NC). These regression coefficients were used to compute metabolic BW (**MBW**; mid-test $BW^{.75}$) during the 84- and 91-d feed intake measurement periods for test 1 and 2, respectively. Moisture analyses of feed ingredient samples (composites of weekly samples) were used to compute average daily DMI from feed intake data.

Four different feed efficiency measures were derived from growth and DMI traits for each bull. Feed conversion ratio (**FCR**) was computed as the ratio of daily DMI to ADG. Partial efficiency of growth (**PEG**) was computed as the ratio of ADG to the difference between actual DMI and predicted DMI for maintenance (Arthur et al., 2001a). The predicted DMI to meet maintenance requirements was calculated as 0.077*MBW ÷ NEm concentrations of the test diets.

Residual feed intake (**RFI**) was computed as the deviation of actual DMI from DMI predicted to meet growth and maintenance energy requirements (Koch et al., 1963). For individual bulls, predicted DMI was derived from a phenotypic regression model of actual DMI on ADG and MBW (Arthur et al., 2001a). This model was fitted separately for each test using the Proc GLM procedure of SAS (R^2 = 0.68 and 0.65 for test 1 and 2, respectively). Within test, RFI was calculated as actual DMI minus predicted DMI. Residual gain efficiency (**RGE**) was computed as the deviation between actual ADG and ADG predicted from MBW and DMI as described by Koch et al. (1963). A separate regression model of ADG on MBW and DMI was fitted for each test (R^2 = 0.47 and 0.43 for test 1 and 2, respectively), and RGE for individual bulls computed as actual ADG minus predicted ADG.

To further characterize RFI, bulls were separated into low, medium and high RFI groups that were < 0.5 SD, ± 0.5 SD, and > 0.5 SD, respectively, from the mean RFI of 0.0 kg/d. RFI SD were 0.62 and 0.80 kg/d for test 1 and 2, respectively. Least squares procedures (PROC GLM of SAS) were used to examine effects of RFI group on performance, feed efficiency, ultrasound and scrotal circumference traits. The statistical model included the fixed effects of RFI group, breed, test and all significant (P > 0.10) interaction terms. The effects of breed on traits examined in this study will not be presented due to limited number of Brangus bulls in the two tests. Phenotypic correlations among traits were determined using PROC CORR of SAS with the partial correlation option used to adjust for fixed effects of breed and test.

Results and Discussion

Summary statistics are presented in Table 1 for the two performance tests. The bulls in test 1 were approximately one mo younger, but had similar initial BW compared to bulls in test 2. Numerically, bulls in test 2 had 20% higher ADG and consumed 18% more feed than bulls in test 1. These differences were likely due to divergent environmental conditions (25 vs 10 °C mean temperature during test 1 and 2, respectively) and(or) genetic background of bulls between the two tests. The phenotypic SD for feed efficiency traits in Table 1 were similar to those reported in previous studies with growing bulls (Arthur et al., 2001a,b; Fox et al., 2004; Schenkel et al., 2004).

Table 1. Summary statistics (mean ± SD) for traits measured during the two postweaning performance tests with Angus and Brangus bulls

Trait[a]	Test 1	Test 2
AGE, d	261.2 ± 25.1	289.6 ± 33.5
Initial BW, kg	368.7 ± 43.4	368.3 ± 48.0
Final BW, kg	489.4 ± 48.3	525.6 ± 58.7
ADG, kg/d	1.44 ± .26	1.73 ± .28
DMI, kg/d	8.51 ± 1.10	10.07 ± 1.35
RFI, kg/d	0.00 ± .62	0.00 ± .80
RGE, kg/d	0.00 ± .19	0.00 ± .22
PEG	0.32 ± .05	0.29 ± .05
FCR, DMI/ADG	6.05 ± .96	5.91 ± .79
Final BF, cm	0.66 ± .19	0.61 ± .19
Final HH, cm	126.2 ± 4.66	127.9 ± 4.34
Final SC, cm	35.0 ± 2.61	37.2 ± 3.03
DUR, min/d	109.4 ± 24.1	121.9 ± 20.9
FREQ, events/d	5.03 ± .66	4.91 ± .55
RATE, g DM/min	80.8 ± 17.1	84.9 ± 18.0

[a]AGE = age at start of test; RFI = residual feed intake; RGE = residual gain efficiency; PEG = partial efficiency of growth; FCR = feed conversion ratio; BF = subcutaneous fat depth; HH = hip height; SC = scrotal circumference; DUR = feeding duration; FREQ = feeding frequency; RATE = Eating rate.

Phenotypic correlations among growth and feed efficiency traits are presented in Table 2. Dry matter intakes were strongly correlated with ADG and MBW, and are consistent with phenotypic and genetic correlations previously reported with growing calves (Arthur et al., 2001a,b; Schenkel et al., 2004; Fox et al., 2004; Nkrumah et al., 2004). Strong phenotypic correlations (> 0.50) were found among the four feed efficiency traits measured in this study. Residual feed intake was strongly correlated with DMI, but not with ADG or MBW, as the use of linear regression to compute this trait forces RFI to be phenotypically independent of its component traits. In this study, RFI ranged from –2.26 (most efficient) to 2.26 kg/d (least efficient). Bulls with low RFI (< 0.5 SD) consumed 15% less feed than bulls with high RFI (> 0.5 SD) even though there were no differences in ADG and BW between low and high RFI bulls (Table 4). In general, RFI has been shown to be genetically independent of growth and body size (Arthur et al., 2001a,b; Schenkel et al., 2004) in growing bulls.

Residual feed intake was strongly correlated (-0.85) with PEG in a favorable direction. Bulls with low RFI had a higher PEG than bulls with high RFI (0.36 vs 0.26 ADG/DMI for growth). Corresponding phenotypic correlations reported by Arthur et al. (2001b) and Nkrumah et al. (2004) were -0.65 and -0.89 in growing bulls and steers, respectively. Arthur et al. (2001b) reported that the genetic correlation between RFI and PEG was -0.94 suggesting that these two feed efficiency traits are highly related. This is not surprising in that both of these traits attempt to partition variation in feed intake into maintenance and growth components. In this study, PEG was highly correlated with DMI (-0.51), but less so with ADG (0.29) and MBW (-0.25). Arthur et al. (2001b) and Nkrumah et al. (2004) reported similar phenotypic correlations between PEG and these production traits. Thus, responses to selection for PEG may not be as independent of growth and body size as responses to selection for RFI.

Table 2. Partial correlations[a] among growth, feed intake and measures of feed efficiency in growing bulls

Trait[b]	ADG	DMI	RFI	RGE	PEG	FCR
MBW	**0.26**	**0.64**	-0.00	-0.04	**-0.25**	**0.23**
ADG		**0.61**	-0.02	**0.74**	**0.29**	**-0.67**
DMI			**0.59**	-0.05	**-0.51**	0.13
RFI				**-0.61**	**-0.85**	**0.53**
RGE					**0.83**	**-0.92**
PEG						**-0.83**

[a]Correlations in bold are different from zero at $P < 0.05$.
[b]RFI = residual feed intake; RGE = residual gain efficiency; PEG = partial efficiency of growth; FCR = feed conversion ratio; MBW = mid-test metabolic body weight.

In contrast to the lack of a correlation between RFI and ADG, and a weak correlation between PEG and ADG, strong phenotypic correlations existed between ADG and FCR (-0.67) and RGE (0.74). Likewise, strong genetic correlations between FCR and ADG (> -0.50) have been reported in recent studies (Arthur et al., 2001a,b; Schenkel et al., 2004). Residual feed intake was strongly correlated with FCR (0.53) and RGE (-0.61). Bulls with low RFI had more ($P < 0.01$) efficient RGE (0.15 vs -0.13 kg/d) and FCR (5.4 vs 6.4) than bulls with high RFI. The negative correlations between ADG and FCR and RGE suggest that applying selection pressure against these feed efficiency traits may lead to increases in growth rate and cow mature size, and thus increases in feed requirements for cow maintenance (Herd and Bishop, 2000).

Final BF and gain in BF were positively correlated with ADG and DMI (Table 3), which is in agreement with Schenkel et al. (2004). Gain in BF tended ($P < 0.10$) to be correlated to RGE (0.12), but not with FCR or PEG. In contrast, Nkrumah et al. (2004) reported a positive correlation between FCR and gain in BF. Final BF and gain in BF tended ($P < 0.10$) to be positively correlated with RFI. A number of studies have reported positive correlations between RFI and carcass fat traits (Arthur et al., 2001b; Fox et al., 2004; Nkrumah et al., 2004; Schenkel et. al., 2004). In this study, bulls with low RFI had numerically less final BF (0.56 vs 0.61 cm) and gain in BF (0.25 vs 0.30 cm) compared to high RFI bulls, respectively (Table 4). Likewise, Fox et al. (2004) reported that low RFI bulls tended ($P < 0.10$) to have less final BF than high RFI bulls (0.53 vs 0.58 cm, respectively). These results suggest that adjusting RFI for variation in carcass composition may be warranted.

Table 3. Partial correlations[a] among measures of feed efficiency and feeding behavior, scrotal circumference, and ultrasound fat traits in growing bulls

Trait[b]	ADG	DMI	RFI	RGE	PEG	FCR
AGE	-0.06	**0.24**	0.03	**-0.22**	**-0.22**	**0.30**
DUR	0.08	0.13	**0.41**	-0.12	**-0.20**	-0.01
FREQ	0.04	-0.03	**0.17**	-0.00	-0.02	-0.09
RATE	**0.29**	**0.47**	-0.02	0.08	-0.12	0.08
Final HH	**0.24**	**0.37**	-0.08	0.08	-0.05	0.06
Final SC	**0.24**	**0.25**	-0.03	**0.14**	-0.03	-0.07
Final BF	**0.25**	**0.41**	0.10	0.02	**-0.14**	0.04
BF gain	**0.29**	**0.31**	0.11	0.12	-0.05	-0.08

[a]Correlations in bold are different from zero at $P < 0.05$.
[b]RFI = residual feed intake; RGE = residual gain efficiency; PEG = partial efficiency of growth; FCR = feed conversion ratio; AGE = day of age at start of test; DUR = feeding duration; FREQ = feeding frequency; RATE = Eating rate; SC = scrotal circumference; HH = hip height; BF = subcutaneous fat depth.

Age of bulls at the start of the test was phenotypically correlated with DMI, RGE, PEG and FCR, but not RFI (Table 3). Likewise, initial BW was correlated with DMI (0.55), RGE (-0.23), PEG (-0.33) and FCR (0.41), but not RFI. These phenotypic correlations suggest that younger bulls (lighter BW) were more efficient as measured by RGE, PEG or FCR. In contrast, variation in age and BW at the start of the test did not influence RFI. Nkrumah et al. (2004) also found that initial age and BW affected other feed efficiency traits but not RFI. These results suggest that RFI may be less affected by pretest management conditions compared to other feed efficiency traits (Schenkel et al., 2004; Herd and Bishop, 2000).

Final HH and SC were correlated with ADG and DMI (Table 3), which are similar to the results of Schenkel et al. (2004) and Nkrumah et al. (2004). Final SC was not correlated with RFI, PEG or FCR, but was correlated with RGE (0.14), suggesting that selection for improved RGE would tend to increase SC.

Feeding duration and frequency were not correlated with DMI or ADG, however, eating rate was correlated with both DMI (0.47) and ADG (0.29; Table 3). Schwartzkpf-Gensein et al. (2002) reported positive correlations between feeding duration and DMI (0.38) and ADG (0.14). RFI was positively correlated with both feeding duration (0.41) and frequency (0.17). Bulls with low RFI had lower ($P < 0.01$) feeding duration and frequency than bulls with high RFI (Table 4). Cammack et al. (2005) reported positive genetic correlations between RFI and feeding duration (0.22) and frequency (0.20) in growing lambs. Feeding duration was correlated with PEG (-0.20), but not RGE or FCR. Feeding frequency and eating rate were not correlated with RGE, PEG or FCR.

Implications

Residual feed intake is a moderately heritable feed efficiency trait that is independent of growth traits. Feeding duration and frequency were phenotypically correlated with RFI, suggesting that feeding behavior traits may be predictive of RFI. Compared to other feed efficiency traits examined in this study, RFI was minimally affected by initial age and BW, suggesting that RFI may be a more robust feed efficiency trait to use in selection programs.

Literature Cited

Arthur, P.F., G. Renand, and D. Krauss. 2001a. Genetic and phenotypic relationships among different measures of growth and feed efficiency in young Charolais bulls. Livest. Prod. Sci. 68:131-139.

Arthur, P.F., J.A. Archer, D.J. Johnston, R.M. Herd, E.C. Richardson and P.F. Parnell. 2001b. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency and other postweaning traits in Angus cattle. J. Anim. Sci. 79:2805-2811.

Cammack, K.M., K.A. Leymaster, T.G. Jenkins, and M.K. Nielsen. 2005. Estimates of genetic parameters for feed intake, feeding behavior, and daily gain in composite ram lambs. J. Anim. Sci. 83:777-785.

Fox, J.T., G.E. Carstens, E.G. Brown, M.B. White, S.A. Woods, T.H. Welsh, Jr., J.W. Holloway, B.G. Warrington, R.D. Randel, D.W. Forrest, and D.K. Lunt. 2004. Net feed intake of growing bulls and relationships with performance, fertility and ultrasound composition traits. Beef Cattle Research in Texas, pp. 117-120.

Herd, R.M., and S.C. Bishop. 2000. Genetic variation in residual feed intake and its association with other production traits in British Hereford cattle. Livest. Prod. Sci. 63:111-119.

Koch, R.M., L.A. Swiger, D. Chambers, and K.E. Gregory. 1963. Efficiency of feed use in beef cattle. J. Anim. Sci. 22:486-494.

Nkrumah, J.D., J.A. Basarab, M.A. Price, E.K. Okine, A. Ammoura, S. Guercio, C. Hansen, C. Li, B. Benkel, B. Murdoch, and S.S. Moore. 2004. Different measures of energetic efficiency and their phenotypic relationships with growth, feed intake, and ultrasound and carcass merit in hybrid cattle. J. Anim. Sci. 82:2451-2459.

Schenkel, F.S., S.P. Miller, and J.W. Wilton. 2004. Genetic parameters and breed differences for feed efficiency, growth, and body composition traits of young beef bulls. Can. J. Anim. Sci. 84:177-185.

Schwartzkopf-Gensein, K.S., S. Atwood, and T.A. McAllister. 2002. Relationships between bunk attendance, intake and performance of steers and heifers on varying feeding regimes. Appl. Anim. Behavior Sci. 76:179-188.

Table 4. Characterization of performance, ultrasound composition, and feeding behavior traits in growing bulls with low, medium and high residual feed intake (RFI).

Trait[a]	Low RFI (n = 79)	Med RFI (n = 88)	High RFI (n = 73)	SE	P-value
Growth Traits					
Initial BW, kg	364.3	361.9	360.3	6.46	.86
Final BW, kg	505.3	502.7	500.0	7.55	.83
Daily gain, kg/d	1.61	1.61	1.59	0.04	.92
Final hip height, cm	129.6	128.6	128.6	0.59	.24
Feed Efficiency Traits					
Dry matter intake, kg/d	8.52[a]	9.31[b]	10.03[c]	0.15	<.0001
Residual feed intake, kg/d	-0.78[a]	0.03[b]	0.83[c]	0.05	<.0001
Residual gain efficiency, kg/d	0.15[a]	0.01[b]	-0.13[c]	0.02	<.0001
Partial eff. of growth, ADG/DMI for growth	0.36[a]	0.30[b]	0.26[c]	0.01	<.0001
Feed conversion ratio, DMI/ADG	5.39[a]	5.84[b]	6.44[c]	0.11	<.0001
Ultrasound and Scrotal Circumference Traits					
Final subcutaneous fat depth, cm	0.56	0.60	0.61	0.03	.20
Gain in subcutaneous depth, cm	0.25	0.25	0.30	0.03	.25
Final scrotal circumference, cm	36.19	35.58	35.95	0.40	.38
Feeding Behavior Traits					
Feeding duration, min/d	110.9[a]	120.8[b]	131.3[c]	2.90	<.0001
Feeding frequency, events/d	4.83[a]	5.04[b]	5.07[b]	0.08	.02
Eating rate, g DMI/min	80.1	80.0	78.8	2.47	.89

[a]Means with different superscripts in the same row differ ($P < 0.05$).