

# Bringing Feed Efficiency Technologies to the Beef Industry: Challenges and Opportunities

*Gordon E. Carstens<sup>1</sup>, Phillip Lancaster<sup>1</sup>, and Luis Tedeschi<sup>1</sup>*  
*Department of Animal Science*  
*Texas A&M University*

## Introduction

While beef production continues to be the largest agricultural enterprise in the U.S. (20.5% of total farm cash receipts in 2006; ERS, 2008), rising feed costs, global competition, and societal concerns about food safety, energy policy and the environment have created new economic challenges for the industry. Productivity of the U.S. cattle industry has improved substantially over the last 50 years, with beef production per total inventory increasing from 137 pounds in 1955 to over 250 pounds in recent years (Elam and Preston, 2004). Most of these productivity gains were realized through use of grain-fed beef production systems, adoption of nutrition, reproductive and pharmaceutical (e.g., ionophores) based technologies, and the application of crossbreeding systems and selection programs that focused on output traits. It is remarkable that these beef productivity gains were achieved in the absence of direct selection to improve feed efficiency. In fact, there is little evidence that genetic merit for feed efficiency or maintenance energy requirements in beef cattle has improved in the past 50 years (Archer et al., 1999, Johnson et al. 2003).

A number of factors have limited genetic progress in feed efficiency of beef cattle including focus on output traits, emphasis on population vs individual animal variation, lack of consistent selection goals and the high costs of acquiring feed intake data (Johnson et al., 2003). The lack of an appropriate trait for use in selection programs has also curtailed genetic progress in feed efficiency. Traditional ratio-based efficiency traits like feed conversion ratio (**FCR**; feed:gain) are confounded by variation due to maturity patterns, and are strongly correlated in a negative manner with production traits (e.g., growth). Thus, selection to reduce post-weaning FCR will increase growth and mature size of replacement females, resulting in concomitant increases in the costs of feed required to maintain the breeding herd. An alternative feed efficiency trait is residual feed intake (**RFI**), which quantifies inter-animal variance in feed intake that is unexplained by variation related to body weight (**BW**) and growth rate—efficient animals are those that consume less feed than expected for a given BW and growth rate. Residual feed intake has been shown to be moderately heritable and genetically independent of growth traits (Arthur et al., 2001a,b). In contrast to ratio-based feed efficiency traits, RFI tends to better reflect inherent variations in biological processes linked with efficiency of feed utilization.

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<sup>1</sup>Contact at: 2471 TAMU, Animal Science Department, Texas A&M University, College Station, TX 77843-2471; (979) 845-5065, Email: [g-carstens@tamu.edu](mailto:g-carstens@tamu.edu)

Recent technologies advances have reduced the costs of acquiring feed intake data, prompting innovative seedstock producers to initiate breeding programs that include feed intake or RFI as selection criterion. While RFI has been fairly well characterized in growing cattle in recent years, few studies have examined the genetic associations between feed intake and efficiency measured in growing calves and these same traits measured in mature cows. Moreover, there is a need to more closely examine the associated responses to selection for postweaning RFI on other economically relevant traits (e.g., carcass quality and reproductive traits).

### **Phenotypic and Genetic Variation in Feed Efficiency of Beef Cattle**

Generally absent from current breeding programs are avenues for exploiting genetic variation in feed efficiency, even though providing feed for cattle is the single largest input costs for beef operations. Given that the vast majority of feed inputs are used by the breeding herd compared to slaughter progeny, and that substantial genetic variation exist in maintenance energy requirements (Hotovy et al., 1991), it would seem logical to directly target reductions in feed inputs of breeding females to improve the feed efficiency. Unfortunately, large-scale measurement of forage intake by mature cows is not practical, which necessitates measuring feed inputs and feed efficiency in growing animals. Expectations are that use of an appropriate feed efficiency trait in growing cattle to account for genetic variation in efficiency of feed used for maintenance and growth requirements, will generate progeny that are efficient in all sectors of the industry.

Regulation of feed intake and efficiency of feed utilization by animals involves a complex set of biological processes and metabolic pathways, which can be influenced by numerous management and environmental factors. Moreover, feed intake is highly correlated in a positive manner with animal size and productivity, such that single-trait selection for increased growth will lead to higher feed intakes and maintenance energy requirements (Almeida et al., 2007). Similarly, single-trait selection for lower feed intake will reduce genetic merit for growth resulting in undesirable affects on productivity. Numerous feed efficiency traits, that incorporate both input and output traits, have been proposed for use in breeding programs (Archer et al., 1999). Most early research that examined genetic variation in feed efficiency of growing cattle focused on the use of ratio-based traits like gross feed efficiency, or its inverse feed conversion ratio (**FCR**; feed:gain ratio). While ratio-based traits are useful to evaluate the effects of diet quality or management practices on feed efficiency of growing cattle, these traits have limited value for genetic selection programs. Feed conversion ratio has been shown to be moderately heritable (Koots et al., 1994; Crews, 2005). However, FCR is influenced by maturity pattern, and is strongly correlated ( $r_g > -0.50$ ) with growth traits (Arthur et al., 2001a; Crews, 2005) so that selection to improve FCR in growing cattle will increase genetic merit for growth and mature size of breeding females (Herd and Bishop, 2000). Although selection for improved FCR may improve efficiency of feedlot progeny, it will not likely improve efficiency of progeny destined to become replacement females. Archer et al. (2002) reported that FCR measured in post-weaning heifers was strongly correlated ( $r_g = -0.54$ ) with cow mature weight. Moreover, despite finding that feed intake of post-weaning heifers was strongly correlated ( $r_g = 0.94$ ) with feed intake of

mature cows, they found weak correlations between FCR measured in post-weaning heifers and feed intake and FCR ( $r_g = 0.15$  and  $0.20$ ) measured in mature cows. These studies demonstrate that selection to improve FCR in growing cattle will lead to indirect selection for increased cow mature size and feed costs, with minimal effects on efficiency of feed utilization in mature cows.

Several alternative traits to FCR involve partitioning feed intake into portions needed to support maintenance or growth requirements. Examples include maintenance efficiency, which is defined as feed intake used for maintenance (actual feed intake minus expected feed for growth) per unit of metabolic body size ( $BW^{0.75}$ ), and partial efficiency of growth (**PEG**), which is the ratio of ADG per unit of feed used for growth (actual feed intake minus expected feed for maintenance). To compute both traits, expected feed intakes to meet maintenance or growth requirements are derived from population-based formulas used in feeding standards (e.g., NRC, 2000). Partial efficiency of growth has apparent advantages compared to FCR as a feed efficiency trait for selection because the genetic (Arthur et al., 2001b) and phenotypic correlations (Nkrumah et al., 2004; Lancaster et al., 2005) between ADG and PEG are substantially lower than to those reported between ADG and FCR, and feed intake is more strongly associated with PEG in a favorable direction compared to FCR.

Koch et al. (1963) was the first to propose the concept of residual feed intake (**RFI**) for beef cattle. Feed intake was adjusted for variation in weight and gain to effectively partition feed intake into an expected feed intake portion based on level of production and a “residual portion”. They found that the residual portion was moderately heritable, and could be used to rank animals by feed efficiency, based on deviations of their actual intake from expected feed intake. Residual feed intake is calculated as the difference between actual and expected feed intake. Expected feed intake is typically derived from linear regression of feed intake on mid-test  $BW^{0.75}$  and ADG for growing calves, whereas, in lactating or pregnant cows intake can be regressed on weight and milk and(or) fetal growth (Basarab et al., 2007). Thus, RFI is a feed efficiency trait that quantifies inter-animal variance in feed intake that is unexplained by variation related to weight and ADG and growth rate—efficient animals are those that consume less feed than expected for a given BW and growth rate. Due to properties of linear regression, RFI can be expected to be independent of the component traits (e.g., BW) used in the base model to compute expected feed intakes. Residual feed intake can also be calculated as the difference between actual and expected feed intake derived from feeding standards or mathematical models (Tedeschi et al., 2004). Although strong correlations exist between these RFI traits, irrespective of how they are computed, Arthur et al. (2001b) found that RFI based on expected intake predictions from feeding standards were not phenotypically or genetically independent of ADG.

Residual feed intake has been well characterized in growing heifers, steers and bulls across diverse biotypes (Arthur et al., 2001a,b; Schenkel et al., 2004; Nkrumah et al., 2004, 2007; Hoque et al., 2006). These studies have demonstrated that RFI is moderately heritable (0.35-0.40), which is comparable to heritability estimates of growth traits. As importantly, these studies also demonstrated that RFI was genetically

independent of BW and ADG. Lancaster et al. (2006) conducted a meta analysis of eight studies to characterize feed efficiency traits and examine their correlations with performance and carcass traits in growing and finishing calves. Two databases, analyzed separately, included four studies with growing steers and heifers (N = 514) fed high-roughage diets (2.0 to 2.2 Mcal ME/kg), and four studies with finishing steers (N = 320) fed high-grain diets (2.7 to 3.0 Mcal ME/kg). The model  $R^2$  of the multiple regression equations used to compute RFI were 0.68 and 0.67 for growing and finishing databases, respectively, indicating that about two thirds of the variation in feed intake was explained by variation in weight and ADG. In both growing and finishing databases, FCR was strongly correlated with ADG (-0.60 and -0.58) and initial weight (0.28 and 0.40), but weakly correlated with feed intake (0.12 and 0.25), demonstrating that favorable FCR phenotypes had substantially lighter initial weights and higher ADG, and consumed slightly less feed. In contrast, RFI was strongly correlated with intake ( $\approx 0.65$ ) in both growing and finishing studies, but was not correlated phenotypically with initial weights or ADG. The phenotypic correlations between efficiency, intake and growth traits in growing calves were remarkably similar to those found in finishing calves.

Results from the meta analysis revealed that the phenotypic correlations between both feed efficiency traits and ultrasound measurements of rib-fat depth were weak (0.11 to 0.12) for growing calves, such that the favorable phenotypes tended to be leaner. Carcass rib fat thickness was also positively correlated (0.21 to 0.33) with RFI in finishing calves. However, the magnitude of these correlations was higher in finishing compared to growing calves, suggesting that carcass fatness was more strongly correlated with feed efficiency when calves were fed high-energy diets. In general, phenotypic correlations between feed efficiency traits and final ribeye area were either weak or not different from zero in both growing and finishing calves. These phenotypic correlations between RFI and carcass traits are consistent with other studies in growing (Arthur et al., 2001a,b; Schenkel et al., 2004) and finishing calves (Basarab et al., 2003; Nkrumah et al., 2004; 2007). These results indicate that inclusion of carcass fatness traits in the model used to derive expected feed for RFI may be warranted to minimize potential unfavorable responses (marbling, conception rates) to selection for RFI (Crews, 2005).

To illustrate the magnitude of phenotypic variation in RFI and relationships with other component traits in growing calves, data from a recent study with growing Brangus heifers is presented in Table 1. In this study, heifers with low RFI ( $< 0.50$  SD from mean RFI) phenotypes consumed 16.5% less feed and had 15.6% lower FCR than heifers with high RFI ( $> 0.50$  SD from the mean RFI) phenotypes, even though initial on-test body weights and ADG during the study were similar for both RFI phenotype groups. In this study, ultrasound measurements of off-test rib-fat depth, ribeye area and intramuscular fat percentage were similar for RFI phenotype groups. Although final rib-fat depth was not significantly different, gain in rib-fat depth during the test was less ( $P < 0.01$ ) for low compared to high RFI heifers (0.23 vs  $0.31 \pm 0.02$ ). In economic terms, the difference in feed costs between these growing heifers with low and high RFI equates to \$0.38/day or \$45.40/head using a 120-day feeding period and ration costs of \$200/ton (dry matter basis).

**Table 1.** Performance, feed efficiency and ultrasound traits for Brangus heifers with divergent phenotypes for residual feed intakes (RFI)<sup>1</sup>

	RFI Phenotype Group <sup>2</sup>			SE	P-value
	Low RFI	Medium RFI	High RFI		
Number of heifers	112	138	98	--	--
Initial (on-test) age, d	232	231	235	1.5	0.07
Initial (on-test) BW, kg	274.8	272.5	274.4	3.6	0.76
ADG, kg/d	0.98	0.98	1.0	0.02	0.58
Dry matter intake, kg/d	8.73 <sup>a</sup>	9.45 <sup>b</sup>	10.45 <sup>c</sup>	0.11	1.01
Residual feed intake, kg/d	-0.77 <sup>a</sup>	0.00 <sup>b</sup>	0.88 <sup>c</sup>	0.04	0.01
Feed conversion ratio, DMI/ADG	8.98 <sup>a</sup>	9.71 <sup>b</sup>	10.64 <sup>c</sup>	0.16	1.01
Final rib-fat depth, cm	0.65	0.66	0.69	0.02	0.18
Final ribeye area, cm <sup>2</sup>	71.0	70.9	71.0	1.1	0.98
Final intramuscular fat, %	3.36	3.42	3.47	0.08	0.45

<sup>1</sup>Adapted from Lancaster et al. (2007); diet ME was 2.1 Mcal/kg DM.

<sup>2</sup>Heifers with low and high RFI were < 0.50 and > 0.50 SD from the mean RFI (0.0 ± 0.71 kg/d).

### Biological Basis for Variation in RFI

Inter-animal variation in total energy expenditures of animals that are of similar biotype and management backgrounds may arise from a host of cellular energy-consuming processes. Possible physiological processes that may account for inter-animal variation in energy expenditures include ion pumping (Na<sup>+</sup>/K<sup>+</sup>ATPase), mitochondrial proton leak, uncoupling proteins (**UCP**), thyroid hormones, leptin, IGF-1, lipid metabolism enzymes or sympathetic activity (Johnson et al., 2003). Of these physiological processes, it has been estimated that mitochondrial proton leak, Na<sup>+</sup>/K<sup>+</sup>ATPase, and protein turnover each contribute approximately 20% to the total inter-animal variation in basal energy expenditures (Rolfe and Brown, 1997; Ramsey et al., 2000).

Castro Bulle et al. (2007) found that maintenance energy requirements of steers were phenotypically correlated ( $r_p = 0.76$ ) with fractional protein degradation rates, confirming that protein turnover of myofibrillar protein is a significant source of inter-animal variation in energy expenditures. In rats, Harper et al. (2002) concluded that approximately 26 and 52% of variation in basal energy expenditures were related to inter-animal differences in proton-leak-dependent O<sub>2</sub> consumption in liver and skeletal muscle tissues, respectively. Early hypotheses regarding the function of mitochondrial uncoupling proteins (**UCP**) postulated that these proteins 'uncoupled' the mitochondrial proton motive force, thereby altering whole-animal energy expenditures through changes in efficiency of ATP synthesis. Michal et al. (2004) found that hepatic mitochondrial proton leak varied in proportion to maintenance energy expenditures in Angus, but not Wagyu heifers.

Herd et al. (2004) estimated that approximately one-third of the biological variation in RFI of growing calves could be explained by inter-animal differences in digestion, heat increment, composition of gain and activity, and posited that the remaining two-thirds of variation in RFI may be linked to inter-animal differences in energy expenditures associated with biological processes like protein turnover and mitochondrial proton leakage. Using slaughter-balance technique, Basarab et al. (2003) found that energy expenditures were 10% higher and proportional liver mass (g/kg empty body weight) 7% heavier in steers with high compared to low RFI phenotypes. Likewise, Castro Bulle et al. (2007) reported that maintenance energy requirements of steers tended to be phenotypically correlated ( $r_p = 0.42$ ) with RFI. Nkrumah et al. (2006) measured whole-animal energy expenditures of steers using indirect calorimetry, and found that RFI was positively correlated with energy expenditure and methane energy losses ( $r_p = 0.68$  and  $0.44$ ). Using broilers with divergent phenotypes for feed:gain ratios, Bottje (2002) found that respiratory-chain coupling of muscle mitochondria was higher in broilers with low compared to high feed:gain ratios. Steers with low RFI phenotypes had higher rates of muscle mitochondrial respiration compared to steers with high RFI phenotypes (Kolath et al., 2006). Lancaster et al. (2007) found that calves with divergent RFI phenotypes had similar proton leak-dependent oxygen consumption rates in hepatic mitochondria, but that low-RFI calves had better ADP-control of oxidative phosphorylation than high-RFI calves.

Steer progeny from parents selected for low RFI tended ( $P = 0.09$ ) to have higher dry matter digestibilities (795 vs  $773 \pm 10$  g/kg DM) than steers born to high-RFI parents (Oddy and Herd, 2004). Krueger et al. (2008) reported that heifers with low RFI phenotypes had higher dry matter digestibilities (731 vs  $705 \pm 12$  g/kg DM) and protein digestibilities (691 vs.  $657 \pm 13$  g/kg DM) than heifers with high RFI phenotypes. Animal behavioral responses can alter physical activity and thus influence total energy expenditure and feed efficiency. Using pedometers, Richardson et al. (2004) found that differences in energy expenditure associated with physical activity accounted for 10% of the variation in RFI of growing calves. In growing bulls, feeding duration (time spent at feed bunk) was positively correlated with RFI (Lancaster et al., 2005). Bulls with low RFI spent about 25 min/d less time at the feed bunk than bulls with high RFI. Collectively, these studies indicate that RFI is a trait that reflects inherent inter-animal variation in biologically relevant processes that are related to feed efficiency.

### **Responses to Selection for RFI**

Few studies to date have examined direct and correlated responses to selection for RFI in beef cattle. In an Australian study, Angus bulls and replacement females were divergently selected for postweaning RFI for 5 years (approximately 2 generations). Significant divergence between the 2 selection lines was reported with direct selection responses in RFI equating to 0.25 kg/d per year (Arthur et al., 2001c). Progeny from parents selected for low RFI were similar in yearling BW (384 vs  $381 \pm 7$  kg) and ADG (1.44 vs  $1.40 \pm 0.03$  kg/d), but consumed 11.3% less feed compared to progeny from parents selected for high RFI. The FCR of progeny from low-RFI parents was 15.4% lower than in progeny born to high-RFI parents. Richardson et al. (1998) evaluated feed efficiency of steers fed a feedlot ration following a single generation of divergent

selection for RFI. Steers from low-RFI parents had lower RFI ( $-0.20$  vs  $0.17 \pm 0.11$  kg/d), consumed less feed ( $9.2$  vs  $9.8 \pm 0.02$  kg/d) and had lower FCR ( $7.0$  vs  $7.6 \pm 0.20$  kg/d) compared to steers from high-RFI parents, even though ADG and BW of the steers were similar. Richardson et al. (1998) concluded that selection for improved RFI would facilitate improvements in feed efficiency and profitability of feedlot progeny.

### **Associated Responses of Economically Relevant Traits to Postweaning RFI**

*Cow efficiency.* Basarab et al. (2007) recently examined the phenotypic relationships between RFI of steer and heifer progeny fed a high-grain diet (2.8 Mcal ME/kg DM) and the efficiency of their dams while fed a high-roughage diet (2.3 Mcal ME/kg DM) during mid gestation. Cows that produced calves with low RFI phenotypes had lower RFI ( $-0.05$  vs  $1.88 \pm 0.5$  kg/d) and consumed less feed ( $10.8$  vs  $12.2 \pm 0.3$  kg/d) than cows that produced calves with high RFI phenotypes. The RFI of cows was phenotypically correlated ( $r_p = 0.30$ ) with RFI of calves, but the low magnitude of this relationship suggests cow RFI measured while fed a roughage diet may be a different trait than RFI measured in finishing calves. Archer et al. (2002) measured RFI in heifers and again in the same females following the birth of their second calf. In this study, the mature cows were fed the same diet as was fed to the heifers during the RFI tests. Strong genetic correlations were observed between postweaning RFI of heifers and feed intake and RFI ( $r_g = 0.64$  and  $0.98$ ) of mature open cows, although the corresponding phenotypic correlations between heifer RFI and feed intake and RFI of the cows was lower ( $r_p = 0.34$  and  $0.40$ ).

*Maternal reproductive traits.* Two recent studies have examined the relationships between postweaning RFI and maternal productivity of mature cows. Arthur et al. (2005d) examined the effects of divergent selection for RFI on the maternal productivity of Angus cows across three mating seasons. The cows used in this study represented an average of 1.5 generations of selection for RFI. As expected, mature BW obtained four times during the production cycle were similar for cows divergently selected for low and high RFI. However, average rib-fat depth at the start of the mating seasons was 15% less for the low RFI cows compared to the high RFI cows. As shown in Table 2, there were no significant differences between the selection lines in pregnancy rates, calving rates or weaning rates. Additionally, there were no differences in calf birth or weaning weights between the two selection lines. It is notable that a drought-induced reduction in rib-fat depth and reproductive rate of the cows during one year of the study affected both selection lines equally (non-significant selection line x year interaction).

Basarab et al. (2007) examined maternal productivity data across ten production cycles of crossbred (Angus-Hereford and Charolais-Maine Anjou) cows that produced calves that were found to have divergent ( $\pm 0.50$  SD from mean RFI) phenotypic differences in postweaning RFI while fed a high-grain diet. Cow weights at weaning, pre-calving and pre-weaning averaged over the ten production cycles were similar between dams that produced progeny with divergent RFI phenotypes. Dams that produced low-RFI calves averaged 2 to 3 mm more rib-fat depth throughout the production cycle, and lost less weight during early lactation than dams that produced high-RFI calves. There were no differences in pregnancy or calving rates between RFI

progeny groups (Table 2). Twinning rate and calf death loss were higher in dams that produced high-RFI calves, although calf birth weight and weaning rates were similar between dams that produced calves with divergent RFI.

Although calving interval was similar between RFI progeny groups, dams that produced low-RFI calves actually calved 5 days later than dams that produced high-RFI calves. Lack of a significant age of dam by RFI progeny group interaction for calving date, suggests that the difference in calving date between the two RFI progeny groups was initiated in first-calf heifers. It is remarkable that dams divergently selected for low RFI also tended ( $P = 0.07$ ) to calve 5 days later than high-RFI divergently selected dams. These studies indicate the need to monitor age at puberty and post-calving return to estrus in order to minimize potential unfavorable responses to selection for low RFI.

Reasons for the discrepancy in the results of these two studies in the associated responses between rib-fat depth of dams and RFI is not readily apparent. Dams selected for low RFI were leaner than dams selected for high RFI, whereas, dams that produced low-RFI calves were actually fatter than dams that produced high-RFI calves. This difference may be related to the nature of the experimental design (direct selection vs phenotypic association) or to differences in the environment or breedtype used in the respective studies. Regardless, these results demonstrate the need to further examine the associated responses in maternal productivity traits due to selection for RFI in postweaning calves to better understand the potential genotype by environmental interactions that most likely exist.

**Table 2.** Relationships between RFI and maternal productivity of beef cows.

Trait	Arthur et al. (2005) <sup>1</sup>			Basarab et al. (2007) <sup>2</sup>		
	RFI Selection Line			Progeny RFI Phenotype Group		
	Low RFI	High RFI	P-value	Low RFI	High RFI	P-value
Pregnancy rate, %	90.5	90.2	NS	95.6	96.0	NS
Calving rate, %	89.2	88.3	NS	84.9	86.3	NS
Weaning rate, %	81.5	80.2	NS	81.5	82.3	NS
Calving date, Julian d	215	210	0.07	96	91	0.01
Twinning rate, %		not reported		0.0	3.8	0.001
Calf death loss, %		not reported		4.0	8.1	0.09
Calf birth weight, kg	36.9	36.2	NS	41.9	41.2	NS
Weaning weight, kg	230.8	230.6	NS	264.6	268.3	NS

<sup>1</sup>Data generated from 3 mating seasons for 185 Angus cows divergently selected for RFI for an average of 1.5 generations.

<sup>2</sup>Historical data summarized over 10 mating seasons for 136 crossbred cows that produced calves identified as having divergent phenotypes for RFI ( $\pm 0.50$  SD from mean RFI).

Lancaster et al. (2006) reported the first-year results of a four-year study designed to examine the phenotypic relationships between RFI in postweaning heifers and reproductive traits through first calving. Preliminary results from the first 3 years of the study are presented in Table 3. The corresponding performance and feed efficiency



data from these heifers were presented in Table 1. Progesterone analyses of weekly blood samples collected during the 70-d study periods were used to determine onset of puberty. Heifers exhibiting a progesterone concentration  $\geq 2$  ng/mL for one wk or  $\geq 1$  ng/mL for two consecutive wk were considered to be pubertal. Ovarian ultrasound performed at the end of each year's study was used to confirm pubertal heifers. Chi-square analysis revealed that the percentage of heifers cycling by the end of the study (average age at end of study was 300 d) was not affected by RFI phenotype group. Additionally, age of puberty of those heifers that were cycling by the end of the tests was not influenced by postweaning RFI. The pregnancy data presented in Table 3 is based on rectal palpation results, and indicates the RFI phenotype group did not affect pregnancy rates by the end of AI or natural mating in these heifers.

**Table 3.** Age of puberty and pregnancy rates for Brangus heifers with divergent phenotypes for residual feed intakes (RFI)

	RFI Phenotype Group <sup>1</sup>			SE	P-value
	Low RFI	Medium RFI	High RFI		
Number of heifers	112	138	98	--	--
Proportion cycling by end of test, %	32.1	28.3	29.6	--	0.80
Age of puberty, d	279	273	271	5.8	0.29
Pregnant after 1 <sup>st</sup> AI, %	57.1	52.7	49.3	--	0.60
Pregnant after 2 <sup>nd</sup> AI, %	67.0	60.0	59.8	--	0.48
Pregnant after AI and natural service	89.4	85.7	79.3	--	0.17

<sup>1</sup>Heifers with low and high RFI were  $< 0.50$  and  $> 0.50$  SD from the mean RFI ( $0.0 \pm 0.71$  kg/d).

*Carcass quality traits.* Few studies have examined the relationships between RFI and carcass quality traits. McDonagh et al. (2001) examined carcass quality traits in steers produced from a single generation of divergent selection for low and high RFI. In this study, selection for RFI had no effect on marbling scores, meat or fat color, or LD muscle shear force. However, steers from the low-RFI parents had a lower index of myofibril fragmentation in LD muscle and higher levels of calpastatin activity compared to steers from the high-RFI parents. These later findings suggest the possibility that long-term selection for low RFI may be associated with a reduction in the rate of postmortem protein degradation, which could potentially have a negative impact on tenderness. Baker et al. (2006) examined the phenotypic relationships between postweaning RFI and carcass quality traits in Angus steers. They found no difference between RFI phenotype groups in USDA carcass quality or yield grades. Additionally, RFI phenotype group did not affect calpastatin activity, Warner-Bratzler shear force or sensory panel tenderness or flavor scores. Given the economic impact of carcass quality traits, more research is warranted to examine potential associated responses to selection for RFI.

## Conclusions

There is now considerable evidence that genetic variation exists in beef cattle for feed intake unaccounted for by differences in weight and growth rate—residual feed intake, thereby providing opportunities to improve profitability of beef production systems through reductions in feed inputs, with minimal influences on growth or mature size. Moreover, significant reductions in manure nitrogen and phosphorus excretion as well as in greenhouse gas emissions (methane, nitrous oxide) are achievable through selection for improved RFI. While research results to date have demonstrated that major antagonist responses to selection for RFI are not evident, our knowledge of the genetic relationships between RFI in postweaning animals and other economically relevant traits is not complete. Recent advances in RFID and computing technologies have reduced the costs of acquiring feed intake data, and prompted innovative seedstock producers to initiate breeding programs that target feed efficiency as a selection criteria. To facilitate industry adoption, it will be critical to establish uniform guidelines for the collection of data required to appropriately measure RFI and to generate EPD and other selection tools (biomarkers, genetic markers) to reduce the cost and improve the accuracy of identifying animals with superior genetic merit for RFI.

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# **SESSION NOTES**