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Evaluation of Wagyu for residual feed intake: Optimizing feed efficiency, growth, and marbling in Wagyu cattle

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ABSTRACT

Ninety-two yearling Wagyu bulls were evaluated for residual feed intake (RFI) and other performance variables during a 70-d testing period. Bulls were fed a diet in which ingredients were formulated to match the nutritional equivalent of the diet fed to finishing Wagyu cattle. After RFI testing, bulls were classified into the following groups: efficient (RFI >0.5 SD below the mean; n = 32), marginal (RFI ± 0.5 SD of the mean; n = 34), and inefficient (RFI >0.5 SD above the mean; n = 26). Residual feed intake was positively correlated with DMI (r = 0.56; P < 0.01) but was not correlated (r = 0.01; P = 0.91) with ADG. Metabolic BW was not correlated (r = −0.10; P = 0.33) with RFI. Intramuscular fat percentage tended to be negatively correlated with RFI (r = −0.17; P = 0.11). Efficient, marginal, and inefficient groups showed differences in G:F (P < 0.01) and DMI (P < 0.01), but no differences were observed for metabolic BW or ADG (P = 0.71 and P = 0.96, respectively). Inefficient bulls had greater DMI (P < 0.01) than did efficient bulls. Marginal bulls also had greater DMI (P < 0.01) than did efficient bulls. All groups did not differ (P > 0.05) in ultrasound measures for rib fat, LM area, and intramuscular fat. No differences (P > 0.05) were observed between groups for the other performance variables tested. Observations from the current study suggest that Wagyu sires that are superior for both feed efficiency and marbling can be identified with assistance from RFI analysis.

Key words: feed efficiency, marbling, residual feed intake, Wagyu

INTRODUCTION

Production systems in the beef cattle industry aim to produce high-quality beef. To this end, enhanced product quality attributes of tenderness, juiciness, and flavor are highly favored by exclusive restaurants and the general consumers. Beef products from Japanese black cattle (Wagyu) are priced with a premium because of superior palatability, as well as exclusivity. Wagyu and Wagyu-influenced cattle have demonstrated superior marbling traits (Mir et al., 1999). Increased marbling has been associated with greater tenderness and reduced cooking loss (Mitsumoto et al., 1992). Wagyu cattle are typically fed costly high-grain finishing diets, which enhance their propensity to deposit intramuscular fat (**IMF**), improving quality grade scores. Although marbling is increased, the literature reports that Wagyu cattle show inferior red meat yield and feedlot performance when compared with other breeds (Mir et al., 1999; Ueda et al., 2007). Because of this tradeoff between quantity and quality, it is important to maximize profits by identifying feed-efficient animals that also have high IMF and a desirable growth rate.

The incorporation of evaluation of residual feed intake (**RFI**) along with IMF, ADG, and feed intake measurements in identifying superior animals provides a possible approach to improve the profitability of Wagyu cattle. Residual feed intake is moderately heritable, with values ranging from 0.16 to 0.43 (Herd et al., 2003). Residual feed intake has been researched extensively in British and Continental breeds; however, only a few large scale evaluations of Wagyu or Wagyu-influenced cattle have been

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reported (Sasaki et al., 1982; Lejukole et al., 1993; Mukai et al., 1995; Oikawa et al., 2000; Shojo et al., 2005). The present study provides a quantitative phenotypic evaluation of yearling Wagyu bulls for RFI, ADG, DMI, and subcutaneous fat and IMF deposition.

MATERIALS AND METHODS

Animal Acquisition and Acclimation

Procedures involving the use of animals in this study were approved by the University of Idaho Animal Care and Use Committee. Ninety-two yearling Wagyu bulls (starting BW = 415 ± 55 kg; age = 474 ± 17 d) obtained from Snake River Farms (AgriBeef Co., Boise, ID) were transported to the University of Idaho Nancy M. Cummings Research Education and Extension Center (**NMCREEC**), Carmen. Prior to delivery, animals were fed a diet similar to the one used during the test period. After arrival, all animals were allotted a 14-d adaptation period before a 70-d postweaning RFI test to normalize intake as well as acclimation to the GrowSafe system (GrowSafe Systems Ltd., Airdrie, Alberta, Canada). The GrowSafe system at NMCREEC is composed of 4 (21.34 × 54.86 m) pens, with each pen containing 5 feeding nodes (GrowSafe bunks). The pens are located outside without cover. Bulls were randomly allocated to 1 of 3 pens of the GrowSafe feed-intake monitoring system. The 3 pens contained 30, 31, and 31 bulls at initiation of the adaptation period.

Feeding and Management Practices

Bulls were provided a diet (PerforMix Nutrition Systems, Nampa, ID) formulated to match the nutritional equivalent of the diet fed to finishing Wagyu cattle containing (on an as-fed basis) alfalfa hay early bloom, 21%; corn grain cracked, 56%; dried distillers grains, 13%; and a proprietary liquid supplement, Rumax FL10, 10% (PerforMix Nutrition Systems). Nutrient analysis of the diet is provided in Table 1. During the test period, the diet remained consistent, with samples taken daily for DM as well as weekly composite samples for proximate analysis performed by a commercial laboratory (SDK Laboratories, Hutchinson, KS). Feed was mixed daily and provided in a single feeding to all animals to facilitate ad libitum intake each morning between 0800 and 1000 h. At the beginning of the 70-d RFI test period, bulls were weighed on 2 consecutive days and again at the completion of the 70-d RFI test period. Within the test period, bulls were weighed every 2 wk.

Ultrasound Measurements

An independent technician performed ultrasound measurements for rib fat (**RF**) thickness, IMF, and LM area recorded on d 0 and 70 without hair removal between the 12th and 13th ribs. Ultrasound images were captured by an Aloka 500ssd Scanner (Hitachi Aloka Medical Ltd., Wallingford, CT).

Table 1. Nutrient analysis of ration (DM basis)

Analysis	Unit of measure	Value
DM	%	87.1
CP	%	15.2
NE_m	Mcal/cwt[1]	84.4
NE_g	Mcal/cwt	57.4
Forage DM	%	22.0
ADF	%	11.1
NDF	%	19.9
Fat	%	4.3
Calcium	%	0.7
Phosphorus	%	0.5
Magnesium	%	0.2
Sulfur	%	0.2
Salt	%	0.7
Vitamin A	IU/kg	782.8
Vitamin D	IU/kg	78.3
Vitamin E	IU/kg	1.3
Zinc	mg/kg	59.8
Copper	mg/kg	20.5
Selenium	mg/kg	0.4

[1]cwt = hundred weight.

Statistical Analysis

Analyses were conducted using SAS (SAS Institute Inc., Cary, NC). Residual feed intake was calculated as the difference between actual and predicted feed intake by regressing DMI on mid-test $BW^{0.75}$ and ADG (Koch et al., 1963) with the addition of RF thickness (Basarab et al., 2003) to the model. Thus, the final model for predicting RFI was

$$\text{DMI} = -0.2851 - 0.1134(\text{ADG}) + 0.1076(\text{BW}^{0.75}) - 0.5505(\text{RF thickness}).$$

Correlations were calculated among growth efficiency, performance, and ultrasound measurements via the CORR procedures of SAS (SAS Institute Inc.).

After RFI test, bulls were classified into the following groups: efficient (RFI >0.5 SD below the mean; n = 32), marginal (RFI ± 0.5 SD of the mean; n = 34), and inefficient (RFI >0.5 SD above the mean; n = 26). Least squares means were compared using the Studentized *t*-test.

RESULTS AND DISCUSSION

Mean performance values for all bulls were DMI, 10.35 kg/d; ADG, 1.39 kg/d; G:F, 0.13 kg/kg; $BW^{0.75}$, 102.96 kg; LM area, 86.46 cm^2; and IMF, 6.26% (Table 2). Residual feed intake was not correlated with ADG (r = 0.01; $P = 0.91$; Figure 1A). A positive correlation was observed between RFI and DMI (r = 0.56; $P < 0.0001$; Figure 1B). Residual feed intake tended to be negatively correlated with IMF (r = −0.17; $P = 0.11$) in our test population (Table 3 and Figure 1C). As expected, RFI was not correlated with RF thickness ($P = 0.80$; Figure 1D), because RF thickness was included in the model to estimate RFI (Nkrumah et al., 2004; Baker et al., 2006; Ahola et al., 2011). Average daily gain and IMF were correlated (r = −0.34; $P < 0.01$; Figure 1E). Longissimus muscle area and IMF were negatively correlated (r =

Table 2. Mean performance traits and ultrasound measurements of Wagyu bulls

Trait	Mean	SD	Median	Minimum	Maximum
DMI, kg/d	10.35	1.49	10.12	7.36	15.87
ADG, kg/d	1.39	0.30	1.35	0.79	2.30
RFI,[1] kg/d	—	0.85	−0.02	−1.71	1.99
F:G, kg of DM/kg of gain	7.65	1.29	7.47	5.39	12.01
G:F, kg of gain/kg of DM	0.13	0.02	0.13	0.08	0.19
Metabolic BW, kg of $BW^{0.75}$	102.96	10.02	101.37	83.45	141.40
LM area, cm^2	86.46	9.57	85.81	65.16	119.36
IMF,[2] %	6.26	1.25	6.18	3.88	10.84

[1]RFI = residual feed intake.

[2]IMF = percentage of intramuscular fat measurement via ultrasound.

−0.30; $P = 0.004$; Figure 1F). Metabolic BW and RFI were not correlated (r = −0.10; $P = 0.33$; Table 3). Residual feed intake was negatively correlated with G:F (r = −0.49; $P < 0.01$; Table 3).

Performance traits were plotted to determine relationships within the study population (Figure 2). Traits chosen (RFI, ADG, and IMF) identify a population of efficient cattle that meet industry needs in terms of market demanded characteristics. To this end, a small group, encircled, represents animals that are highly desirable for all traits within the population of bulls used in this experiment (Figure 2).

Efficient, marginal, and inefficient RFI groups exhibited differences in G:F ($P < 0.01$) and DMI ($P < 0.01$), but no differences were observed for metabolic BW or ADG ($P = 0.71$ and $P = 0.96$, respectively; Table 4). The group classified as marginal also had greater DMI ($P < 0.01$) than did the efficient group. All classification categories of bulls showed similar ($P > 0.05$) ultrasound measures for RF, LM area, and IMF. No differences were observed between the marginal group and the efficient or inefficient groups for other performance variables assessed.

In early experiments, a testing period of 112 d was cited as an industry standard for RFI determinations (Franklin, 1987). It was later estimated that a 70-d test period is suitable for accurate RFI measurements (Archer et al., 1997). As mentioned by Wang et al. (2006), the reduction of days on test would be cost efficient because of savings in management and feed costs.

Data from the current experiment show the correlation of RFI and ADG as approaching 0.00, which is consistent with previous experiments (Koch et al., 1963; Archer et al., 1997; Baker et al., 2006; Cruz et al., 2010). Thus, it can be inferred that RFI is independent of ADG, which potentially increases the value of RFI as part of a selection index.

Positive correlations of RFI and DMI have been previously reported in several British and Continental breeds (Herd and Bishop, 2000; Arthur et al., 2001a,b; Herd et al., 2003; Schenkel et al., 2004). Additionally, experiments in crossbred cattle similarly support this observation (Basarab et al., 2003; Nkrumah et al., 2004, 2007; Elzo et al., 2009). The current experiment also found a positive correlation (r = 0.56; $P < 0.01$) between RFI and DMI of Wagyu bulls.

The G:F ratio in the current experiment was negatively correlated (r = −0.49; $P < 0.01$) with RFI as seen in similar studies for feed conversion ratio of British, Continental, and crossbred cattle (Arthur et al., 2001a,b; Basarab et al., 2003; Herd et al., 2003; Nkrumah et al., 2004; Schenkel et al., 2004; Nkrumah et al., 2007; Elzo et al., 2009). The current experiment also shows that this relationship is consistent in Wagyu cattle. Dry matter intake was greater in inefficient and marginal groups when compared with the efficient group in the current experiment. The efficient group of bulls showed superior G:F to the inefficient group (Table 4). Analysis suggests that animals classified as efficient consume less feed, improving G:F, and produce similar BW gains compared with marginal and inefficient bulls. Baker et al. (2006) reported that low RFI steers (efficient) consumed less feed (DMI = 9.3 kg/d) than did high RFI steers (inefficient DMI = 10.3 kg/d) with similar ADG in an experiment with purebred Angus steers, which is also consistent with data from other researchers (Basarab et al., 2003).

There was no correlation between RFI and LM area (r = −0.06; $P = 0.54$; Table 3). Importantly, these data provide a preliminary suggestion that the yield grade of Wagyu cattle is not antagonistic with RFI. Estimates of final RF thickness, LM area, and IMF were similar among efficiency groups, consistent with findings from previous studies of Cruz et al. (2010). It should be noted that in the present experiment, the model used to determine RFI included ultrasound RF thickness. This procedure accounts for variability in subcutaneous fat thickness between RFI groups. It is well accepted that about 5% of the total variation in RFI is attributable to differences in body composition (Richardson and Herd, 2004), with more efficient animals tending to be leaner. Richardson et al. (1998) also reported that in steers selected for RFI, there was no compromise in meeting carcass specifications for market-demanded beef.

Within each RFI classification group, IMF variation was similar for both initial and final measurements. Thus, IMF variability with respect to RFI did not change during the test period. This was also true for RF thickness and LM area. Thus, inclusion of final RF thickness in the model that predicts DMI is further corroborated by the parallels in tem-

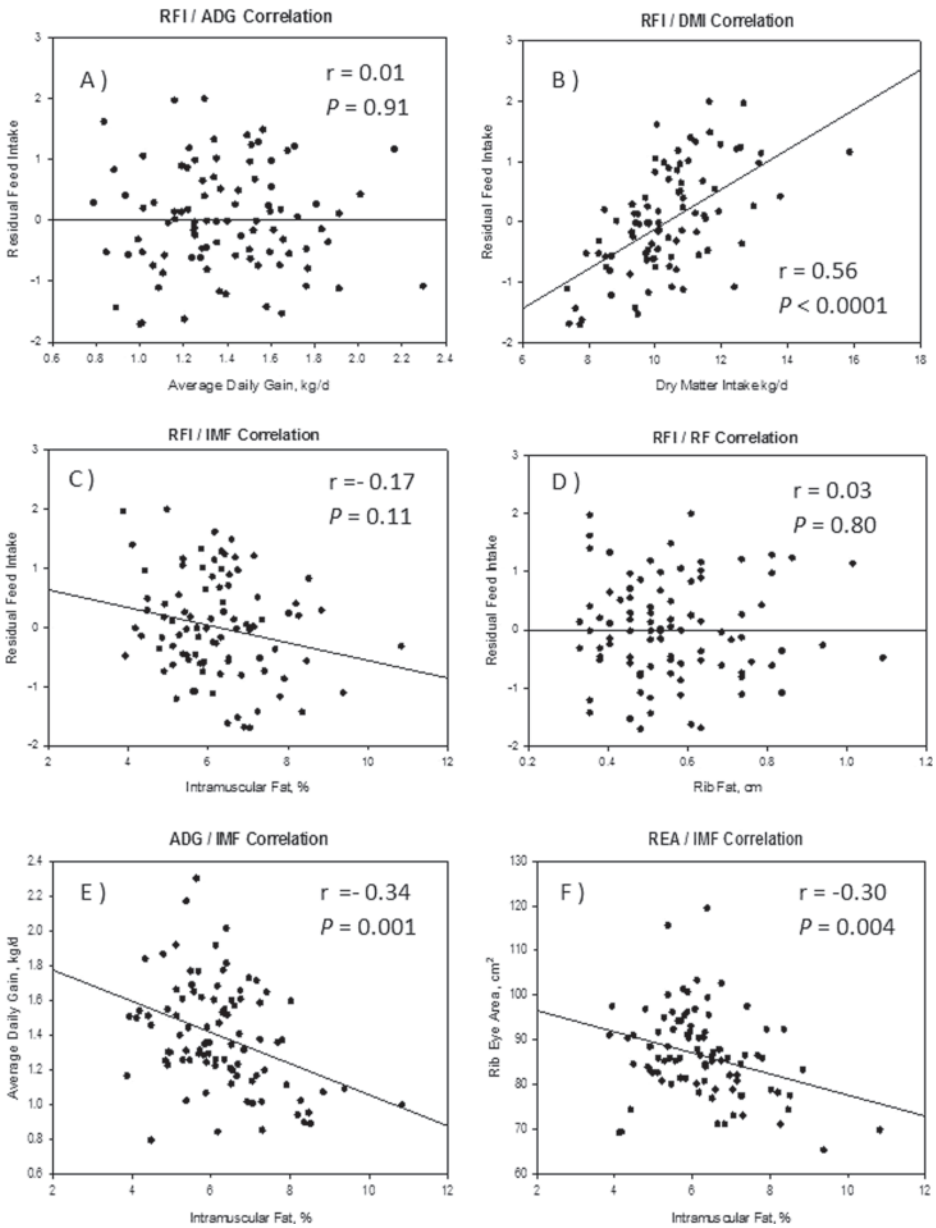

Figure 1. Correlations of Wagyu performance traits: A) residual feed intake (RFI) with ADG, B) RFI with DMI, C) RFI with percent intramuscular fat via ultrasound (IMF), D) RFI with rib fat (RF) thickness, E) ADG with IMF, F) LM area with IMF. REA = rib eye area.

Table 3. Partial correlations (*P*-values) of residual feed intake (RFI) with other performance measures in Wagyu bulls

Trait	RFI
ADG, kg/d	0.01 (0.91)
DMI, kg/d	0.56 (<0.0001)
RFI, kg/d	—
G:F, kg of gain/ kg of DM	−0.49 (<0.01)
Metabolic BW, kg of $BW^{0.75}$	−0.10 (0.33)
LM area, cm^2	−0.06 (0.54)
IMF,[1] %	−0.17 (0.11)

[1]IMF = percentage of intramuscular fat measurement via ultrasound.

poral measurements and these data suggest little comparative change in body composition over time.

Robinson et al. (1999) and McDonagh et al. (2001) found a small positive correlation (r = 0.17) and no correlation, respectively, between RFI and IMF. Contrasting these experiments, Herd and Bishop (2000) reported negative correlations (r = −0.22) between these 2 variables. Evidence of RFI and IMF correlations should be further investigated for use in Wagyu bull selection. The present experiment suggests a trend toward a favorable correlation between RFI and ultrasound IMF (r = −0.17; P = 0.11; Table 3). This observation is especially important in the context of the present study. It should be noted that in the present experiment, RF thickness was included in the model to predict RFI. Analyses and estimations of RFI in previously mentioned studies were not adjusted for animal compositional variance. Thus, the variation observed in IMF in the current experiment is independent of RF thickness, and the favorable correlation between IMF and RFI is encouraging. Given the potential importance of this correlation as a possible favorable relationship, evaluation of additional Wagyu cattle will provide much needed clarification of the relationship between IMF and RFI. Experiments by Okanishi et al. (2008) noted the heritability of RFI in Wagyu cattle ranged from 0.10 to 0.33, higher than their observed estimates for feed-conversion ratios. Estimated genetic correlations between IMF and RF thickness were low in an experiment conducted by Hoque et al. (2006), indicating the possibility of improving marbling while reducing subcutaneous fat in Wagyu cattle. Other studies have also reported a low negative correlation between IMF and FT ranging from −0.10 to −0.04 (Yang et al., 1985; Hoque et al., 2005). An experiment by Exton et al. (2004) reports examples of high-yielding Angus bulls that had desirable estimated breeding values (**EBV**) for RFI and IMF. This observation has clear implications for selection of sires of superior progeny for markets in which improved feed efficiency as well as marbling are important. Exton et al. (2004) were able to identify bulls having both low

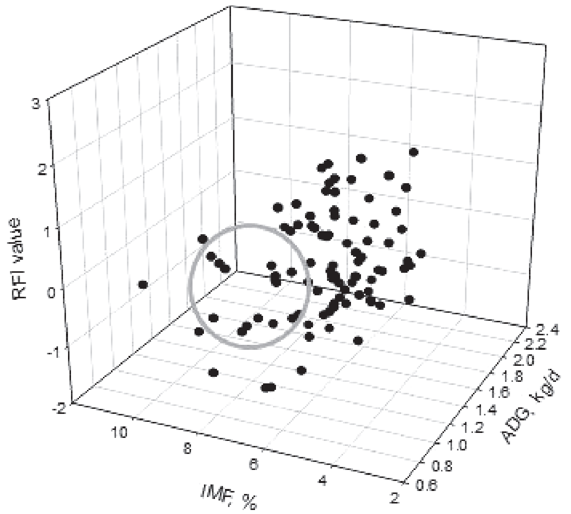

Figure 2. Relationships of desirable Wagyu performance traits. Points within the circle represent bulls having the combination of the most desirable traits: residual feed intake (RFI), ADG, and intramuscular fat (IMF) percentage.

RFI EBV values and high IMF EBV values without accompanying changes in fat depth EBV in their experiment. These latter observations suggest that it should also be possible to identify Wagyu bulls that can sire progeny with lower RFI and yield carcasses with similar or even superior IMF.

Feed efficiency is a plausible means to increase profitability in many beef cattle production systems. Because of rising feed costs, it is important to use animals that are highly efficient and produce the necessary carcass values for marketability. Research by Archer et al. (2004) estimates long-term improvement in profitability between 9 and 33% via use of efficient animals consuming less feed. Because of the small number of animals used in the present experiment, it is not possible to provide a meaningful genetic analysis. Wagyu cattle are well known for substantial marbling abilities, and marketing for these cattle is based around this trait. However, the use of RFI as an added measure of feed efficiency could improve profitability of Wagyu beef production. A more complete genetic analysis incorporating additional animals will be required before selection strategies can be recommended. Experience indicates the dangers of single-trait selection, and it is strongly recommended that a multitrait index approach be considered to optimize desired high IMF with balance for other performance and quality traits. Measures for market value (e.g., IMF, LM area, and RF thickness) should also be examined.

Table 4. Relationship of residual feed intake (RFI, kg of DM/d) of Wagyu bulls (n = 92) with performance measures (least squares means ± SE)[1]

	RFI classification			
Item	Efficient	Marginal	Inefficient	*P*-value
No. of bulls	32	34	26	
Initial BW, kg	421.6 ± 47.3	403.9 ± 58.1	417.3 ± 63.1	0.41
Final BW, kg	489.6 ± 55.2	477.2 ± 66.4	484.5 ± 70.8	0.73
Metabolic BW, kg of $BW^{0.75}$	104.0 ± 1.8	101.9 ± 1.7	103.1 ± 2.0	0.71
DMI, kg/d	9.51 ± 0.23^{a}	10.31 ± 0.22^{ab}	11.44 ± 0.25^{b}	<0.01
ADG, kg/d	1.38 ± 0.05	1.40 ± 0.05	1.39 ± 0.06	0.96
RFI, kg/d	-0.90 ± 0.06^{a}	0.02 ± 0.06^{b}	1.07 ± 0.07^{c}	<0.01
G:F, kg of gain/kg of DM	0.14 ± 0.02^{a}	0.14 ± 0.02^{ab}	0.12 ± 0.02^{b}	<0.01
Initial RF thickness, cm	0.44 ± 0.09	0.39 ± 0.09	0.43 ± 0.09	0.80
Final RF thickness, cm	0.58 ± 0.16	0.54 ± 015	0.57 ± 0.17	0.69
Initial LM area, cm^2	66.69 ± 7.49	67.25 ± 6.94	68.63 ± 8.22	0.61
Final LM area, cm^2	86.79 ± 9.35	86.38 ± 9.88	86.15 ± 9.80	0.97
Initial IMF,[2] %	5.55 ± 1.08	5.19 ± 1.09	5.02 ± 0.94	0.15
Final IMF, %	6.47 ± 1.17	6.28 ± 1.45	5.98 ± 1.04	0.34

[a,b]Means within a row lacking a common superscript letter differ ($P < 0.05$).

[1]Bulls were classified into groups: efficient (RFI <0.5 SD below the mean; n = 32), marginal (RFI ± 0.5 SD of mean; n = 34), and inefficient (RFI >0.5 SD above the mean; n = 26).

[2]IMF = intramuscular fat.

IMPLICATIONS

The present experiment shows that there is phenotypic variability of RFI within Wagyu bulls that may be useful for eventual consideration in a selection index. However, a full genetic analysis will be needed before this step can be recommended. There is a lack of research providing definitive answers toward the use of RFI as a possible component of a selection index for improved performance of Wagyu cattle. It is necessary to conduct further experiments that investigate detailed genotypic parameters of RFI in Wagyu cattle as well as extensive exploration of genetic correlations of RFI with IMF, and RFI with other performance measures.

LITERATURE CITED

Ahola, J. K., T. A. Skow, C. W. Hunt, and R. A. Hill. 2011. Relationship between residual feed intake and end product palatability in longissimus steaks from steers sired by Angus bulls divergent for intramuscular fat expected progeny difference. Prof. Anim. Sci. 27:109–115.

Archer, J. A., P. F. Arthur, R. M. Herd, P. F. Parnell, and W. S. Pitchford. 1997. Optimum postweaning test for measurement of growth rate, feed intake, and feed efficiency in British breed cattle. J. Anim. Sci. 75:2024–2032.

Archer, J. A., S. A. Barwick, and H. U. Graser. 2004. Economic evaluation of beef cattle breeding schemes incorporating performance testing of young bulls for feed intake. Aust. J. Exp. Agric. 44:393–404.

Arthur, P. F., J. A. Archer, D. J. Johnston, R. M. Herd, E. C. Richardson, and P. F. Parnell. 2001a. 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.

Arthur, P. F., G. Renand, and D. Krauss. 2001b. Genetic parameters for growth and feed efficiency in weaner versus yearling Charolais bulls. Aust. J. Agric. Res. 52:471–476.

Baker, S. D., J. I. Szasz, T. A. Klein, P. S. Kuber, C. W. Hunt, J. B. Glaze Jr., D. Falk, R. Richard, J. C. Miller, R. A. Battaglia, and R. A. Hill. 2006. Residual feed intake of purebred Angus steers: Effects on meat quality and palatability. J. Anim. Sci. 84:938–945.

Basarab, J. A., M. A. Price, J. L. Aalhus, E. K. Okine, W. M. Snelling, and K. L. Lyle. 2003. Residual feed intake and body composition in young growing cattle. Can. J. Anim. Sci. 83:189–204.

Cruz, G. D., J. A. Rodríguez-Sánchez, J. W. Oltjen, and R. D. Sainz. 2010. Performance, residual feed intake, digestibility, carcass traits, and profitability of Angus-Hereford steers housed in individual or group pens. J. Anim. Sci. 88:324–329.

Elzo, M. A., D. G. Riley, G. R. Hansen, D. D. Johnson, R. O. Myer, S. W. Coleman, C. C. Chase, J. G. Wasdin, and J. D. Driver. 2009. Effect of breed composition on phenotypic residual feed intake and growth in Angus, Brahman, and Angus × Brahman crossbred cattle. J. Anim. Sci. 87:3877–3886.

Exton, S. C., R. M. Herd, and P. F. Arthur. 2004. Identifying bulls superior for net feed intake, intramuscular fat and subcutaneous fat. Anim. Prod. Aust. 25:57–60.

Franklin, C. L. 1987. Factors affecting gain of beef bulls consigned to a central test station. MS Thesis. West Virginia Univ., Morgantown.

Herd, R. M., J. A. Archer, and P. F. Arthur. 2003. Reducing the cost of beef production through genetic improvement in residual feed intake: Opportunity and challenges to application. J. Anim. Sci. 81:(E-Suppl. 1):E9–E17.

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.

Hoque, M. A., P. F. Arthur, K. Hiramoto, and T. Oikawa. 2006. Genetic relationship between different measures of feed efficiency and its component traits in Japanese Black (Wagyu) bulls. Livest. Sci. 99:111–118.

Hoque, M. A., K. Hiramoto, and T. Oikawa. 2005. Genetic relationship of feed efficiency traits of bulls with growth and carcass traits of their progeny for Japanese Black (Wagyu) cattle. Anim. Sci. J. 76:107–114.

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

Lejukole, H., R. Sakuma, K. Moriya, and Y. Sasaki. 1993. Restricted maximum likelihood estimation of heritabilities for growth and feed utilization traits in Japanese Black using performance-test records. Anim. Feed Sci. Technol. 64:659–668.

McDonagh, M. B., R. M. Herd, E. C. Richardson, V. H. Oddy, J. A. Archer, and P. F. Arthur. 2001. Meat quality and the calpain system of feedlot steers following a single generation of divergent selection for residual feed intake. Aust. J. Exp. Agric. 41:1013–1021.

Mir, P. S., D. R. C. Bailey, Z. Mir, T. Entz, S. D. M. Jones, W. M. R. Tson, R. J. Weselake, and F. J. Lozeman. 1999. Growth, carcass and meat quality characteristics of beef cattle with 0, 50 and 75 percent Wagyu genetic influence. Can. J. Anim. Sci. 79:129–137.

Mitsumoto, M., T. Mitsuhashi, and S. Ozawa. 1992. Influence of slaughter weight, sire, concentrate feeding and muscle on the physical and chemical characteristics in Japanese Black beef. Asian-Australas. J. Anim. Sci. 5:629–634.

Mukai, F., K. Oyama, and S. Kohno. 1995. Genetic relationships between performance test traits and field carcass traits in Japanese Black cattle. Livest. Prod. Sci. 44:199–205.

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.

Nkrumah, J. D., D. H. Crews Jr., J. A. Basarab, M. A. Price, E. K. Okine, Z. Wang, C. Li, and S. S. Moore. 2007. Genetic and phenotypic relationships of feeding behavior and temperament with performance, feed efficiency, ultrasound, and carcass merit of beef cattle. J. Anim. Sci. 85:2382–2390.

Oikawa, T., T. Sanehira, K. Sato, Y. Mizoguchi, H. Yamamoto, and M. Bada. 2000. Genetic parameters for growth and carcass traits of Japanese Black (Wagyu) cattle. Anim. Sci. 71:59–64.

Okanishi, T., M. Shojo, T. Katsuta, K. Oyama, and F. Mukai. 2008. Genetic analysis of residual feed intakes and other performance test traits of Japanese black cattle from revised protocol. Anim. Sci. J. 79:291–296.

Richardson, E. C., and R. M. Herd. 2004. Biological basis for variation in residual feed intake in beef cattle. 2. Synthesis of results following divergent selection. Aust. J. Exp. Agric. 44:431–440.

Richardson, E. C., R. M. Herd, J. A. Archer, R. T. Woodgate, and P. F. Arthur. 1998. Steers bred for improved net feed efficiency eat less for the same feedlot performance. Anim. Prod. Aust. Proc. Aust. Soc. Anim. Prod. 22:213–216.

Robinson, D. L., V. H. Oddy, and C. Smith. 1999. Preliminary genetic parameters for feed intake and efficiency in feedlot cattle. Pages 492–495 in Proc. 13th Conf. Assoc. Advancement Anim. Breeding Genetics. AAABG, Armidale, Australia.

Sasaki, Y., H. Iwaisaki, T. Mansuno, and S. Asoh. 1982. Interaction of sire × length of testing period and estimation of genetic parameters for performance testing traits of Japanese Black bulls. J. Anim. Sci. 55:771–779.

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.

Shojo, M., J. Yong, K. Anada, K. Oyama, and F. Mukai. 2005. Estimation of genetic parameters for growth and feed utilization traits in Japanese Black cattle. Anim. Sci. J. 76:115–119.

Ueda, Y., A. Watanabe, M. Higuchi, H. Shingu, S. Kushibiki, and M. Shinoda. 2007. Effects of intramuscular fat deposition on the beef traits of Japanese Black steers (Wagyu). Anim. Sci. J. 78:189–194.

Wang, Z., J. D. Nkrumah, C. Li, J. A. Basarab, L. A. Goonewardene, E. K. Okine, D. H. Crews Jr., and S. S. Moore. 2006. Test duration for growth, feed intake, and feed efficiency in beef cattle using the GrowSafe System. J. Anim. Sci. 84:2289–2298.

Yang, M., Y. Sasaki, and F. Mukai. 1985. Estimation of heritabilities for growth and carcass traits and their genetic and phenotypic correlations in Japanese Black cattle. Jpn. J. Zootech. Sci. 56:193–198.