Feed costs about 60–70% of total cost of production in bovines and improvement in feed efficiency will lead to reduction in input costs and increased profitability. Little attention has been given to improve feed efficiency and reducing feed cost while it is mainly focused on output traits (growth, milk production, fertility etc). Feed utilisation efficiency in farm animals calculated as a function of individual intake, body weight (BW) and weight gain can be appraised by several ways; one of them is gross feed efficiency. But, actions taken to improve gross feed efficiency can inadvertently lead to financial losses rather than gains (Gaines et al. 2012). This is due to the fact that single-minded actions taken to improve feed efficiency may affect other aspects of the enterprise and most important is the cost of feed. Gross feed efficiency also may reflect an animal’s energy requirement for maintenance. In growing cattle, maintenance energy costs represent approximately 70–75% of the total annual energy requirements (ICAR 2013). Measurement of RFI gives more precise way of feed conversion. RFI can be used as a tool to identify the most efficient animals. Previous research reported that RFI influenced insulin and glucose concentrations in beef heifers (Yelich et al. 1996). Yambayamba et al. (1996) reported that serum concentrations of glucose, insulin, and IGF-I in beef heifers were elevated due to increased feed intake. Richardson et al. (2004) showed that RFI was correlated with blood concentrations of insulin, glucose, urea, leptin and...
creatinine. Physiological changes can influence blood hormone and metabolite levels so the relationship of selected blood metabolites and hormones with RFI requires detailed investigation.

Accurate measurement of the RFI of cattle is time consuming, difficult and very expensive process to collect data on relatively large number of animals. By correlating with some biomarkers, we can differentiate between animal with high or low RFI within short period of time. So, it was pertinent to find out the differences in RFI in the different animals and study related biochemical parameters. This study compared the nutrient utilisation efficiency, growth performance and blood metabolites of Sahiwal calves during selection to identify individual calves with low RFI (more efficient calves) and high RFI (less efficient calves) and related biochemical parameters in male Sahiwal calves.

MATERIALS AND METHODS

The use of the animals and the experimental procedure were approved by the Institutional Animal Ethics Committee (IAEC).

Experimental site: Experiment was conducted at Livestock Research Centre, ICAR-NDRI, Karnal, Haryana, India situated at an altitude of 250 metre above mean sea level, latitude and longitude position being 29° 42′ E, respectively. The maximum ambient temperature in summer goes up to 45°C and minimum temperature in winter comes down to about 4°C with a diurnal variation to the order of 15–20°C. The average annual rainfall was 696 mm, most of which was received from early July to mid September.

Animals, management and feeding: Eighteen male Sahiwal calves of 12 months of age (average body weight =120.04 kg) were selected from Livestock Research Centre, ICAR-NDRI, Karnal, Haryana, India and housed in the experimental sheds of NDRI, Karnal with well ventilated individual pens to facilitate individual feeding. Proper cleanliness and healthy surroundings were ensured throughout the experimental period. Deworming of the animals was done before the start of feeding trial. All the animals were fed total mixed ration (TMR) comprising of green berseem (Trifolium alexandrinum) fodder, wheat straw and a concentrate mixture in a ratio of 40: 20: 40 to meet their nutrient requirements (NRC 2001). Concentrate mixture consisted of maize (Zea mays) grains 16.5%, potato (Solanum tuberosum) tubers 16.5%, soybean (Glycine max) meal 21%, mustard (Brassica compestris) oil cake 12%, wheat (Triticum aestivum) bran 20%, de-oiled rice (Oryza sativa) bran 6%, bajra 5%, mineral mixture 2% and common salt 1%. It is worth mentioning that 50% of maize grain was replaced by fresh potato on DM basis in the concentrate mixture. Refusals of feed were removed daily and weighed was replaced by fresh potato on DM basis in the concentrate mixture. Refusals of feed were removed daily and weighed was replaced by fresh potato on DM basis in the concentrate mixture. Refusals of feed were removed daily and weighed was replaced by fresh potato on DM basis in the concentrate mixture. Refusals of feed were removed daily and weighed was replaced by fresh potato on DM basis in the concentrate mixture. Refusals of feed were removed daily and weighed was replaced by fresh potato on DM basis in the concentrate mixture.

The digestibility coefficient of nutrient (DM, OM, CP, EE, and NDF and ADF) was calculated from the nutrient intake and nutrient output in faeces during metabolism trial as following:

\[
\text{Digestibility} [\%] = \left(\frac{\text{Nutrient intake} - \text{Faecal excretion}}{\text{Nutrient intake}}\right) \times 100
\]

During 60 days of experimental period, blood samples (10 mL) were collected from all the animals by jugular puncture in heparinised vacutainer thrice (at the beginning, middle and end of feeding trial) and plasma was separated by centrifugation at 3,000 rpm for 15 min. The plasma samples were stored at −20°C for further estimation of different blood metabolites and hormones. The levels of total protein, glucose and BUN were estimated in blood plasma samples using GOD-POD kits (Span Diagnostics Ltd., India). The activity of alanine aminotransferase (ALT) and aspartate aminotransferase (AST) in blood plasma samples were determined using I ELISA test kit, Endocrine Technologies, New York, USA, and IGF-I by Bovine IGF-I ELISA test kit, Endocrine Technologies, New York, USA, respectively. Nitrogen content in faeces and urine samples were estimated (AOAC 2005). The digestibility coefficient of nutrient (DM, OM, CP, EE, total CHO, NDF and ADF) was calculated from the nutrient intake and nutrient output in faeces during metabolism trial as following:

\[
\text{Digestibility} [\%] = \left(\frac{\text{Nutrient intake} - \text{Faecal excretion}}{\text{Nutrient intake}}\right) \times 100
\]

Calculation of residual feed intake: Growth of the Sahiwal calves was modelled by linear regression of body weight data against time and the regression coefficients were used to describe the growth of each animal (Archer et al. 1997).

The equation fitted was \( Y_i = b_0 + b_1x_i + e_i \) where \( Y_i \), weight of the animal at observation \( i \); \( b_0 \), intercept (weight at start of test); \( b_1 \), regression coefficient (i.e., average daily gain); \( x_i \), number of days on test at observation.
The estimates of the regression coefficients obtained were used to calculate the average daily gain during the test and the mid-test metabolic body weight. Average DMI for the 60 days feeding period was regressed on mid-test metabolic BW (BW$^{0.75}$) and ADG (Archer et al. 1997, Kelly et al. 2010). Residual feed intake was computed for each animal and was assumed to represent the residuals from a multiple regression model regressing DMI on ADG and MBW. The base model used was:

$$Y_{ij} = \beta_0 + \beta_1 MBW_j + \beta_2 ADG_j + e_j$$

where $Y_{ij}$, DMI of the $j$th animal; $\beta_0$, regression intercept; $\beta_1$, regression coefficient on MBW; $\beta_2$, regression coefficient on ADG and $e_j$, uncontrolled error of the $j$th animal (RFI).

The actual DMI minus the predicted DMI corresponded to the RFI meaning thereby that a more efficient animal had a negative RFI (observed feed intake was less than predicted feed intake) and a less efficient animal had a positive RFI (observed feed intake was greater than predicted feed intake).

Statistical analysis: The data were analyzed by general linear model procedure according to a complete randomized design using statistical software SPSS (version 16.0). Individual animals were considered as experimental units and RFI group as a fixed parameter. When ANOVA was significant (P<0.05), differences among means were examined by the Tukey ‘t’ test.

RESULTS AND DISCUSSION

Chemical composition of diets, residual feed intake and nutrient intake: The chemical composition of feed/fodders used for the animal feeding are given in Table 1. After completion of 60 days, 18 growing male Sahiwal calves were divided into two groups, i.e. low and high RFI group (Fig. 1). The dots below line (Fig. 1) indicated that 9 animals were considered as low RFI animals whereas the dots above the line indicated that 9 animals were considered as high RFI animals. RFI value was –0.20 and 0.18 kg DM/d for low and high RFI, respectively (Table 2).

The values of DMI during metabolic trial were 3.53 and 4.10 kg/d for low and high RFI groups, respectively (Table 4). It was found that low RFI group consumed 13.48% less DM than its requirement (NRC 2001) while high RFI group consumed 5.94% more DM than their expected. Also, the DMI (kg/100 kg BW/day) was lower (P<0.05) in low RFI (2.39) group compared to high RFI (2.63) group animals. The overall mean DMI during whole experimental period were 3.26±0.08 and 3.43±0.08 kg/d in low and high RFI groups, respectively (Table 2). Similar results of lower DMI in low RFI buffalo calves than that of high RFI group (1.9 kg/d vs 2.4 kg) has been reported (Sharma et al. 2016, Table 3).
respectively (Basarab et al. 2003). Carstens et al. (2002) and Basarab et al. (2003) found differences in DMI between animals of low (21%) and high (12%) RFI. Also, Richardson et al. (2004) reported that the difference of the intake between two groups of animals (less and more efficient) was lower in magnitude (6%) which could be due to high metabolizability of consumed feed and the accompanying decreased need to energy intake required for growth and maintenance (Bose et al. 2014).

Intake of CP was also significantly higher (P<0.05) in high RFI Group compared to low RFI Group (Table 4) and it was observed that low RFI group consumed 7.53% less and high RFI group consumed 1.35% more CP than expected requirements (NRC 2001). Similar was the case with TDN intake, i.e. low RFI group consumed less than expected while high RFI groups consumed more than expected intake. Total water intake (L/d) was also observed during the trial and it was found 24.88 and 24.60 in low and high RFI groups, respectively.

**Performance and efficiency measures:** The digestibility values for DM, OM, CP, total CHO, EE, NDF and ADF were 59.68 and 59.14, 61.38 and 60.61, 63.78 and 63.28, 55.95 and 55.69, 64.43 and 63.18, 55.84 and 54.62 and 44.01 and 42.46% in low and high RFI group, respectively (Table 3) and they were similar in both the groups. The digestibility of DM between high and low RFI was similar (Cruz et al. 2010). Nkrumah et al. (2006) showed that RFI tended to be negatively associated (P<0.10) with apparent digestibility of DM (r=−0.33) and CP (r=−0.34). Animal variation in RFI is associated with variation in apparent nutrient digestibility. Heifers with low RFI consumed 23% less DMI and had 20% lower feed: gain ratios than heifers with high RFI. Nkrumah et al. (2006) reported that apparent digestibility in low and high RFI group was 70.87 and 75.33% for DM, 69.76 and 74.70% for CP, 17.29, 31.49% for NDF and 3.26 and 14.67% for ADF. The low-RFI Brangus heifers fed a roughage based diet had 3% higher apparent digestibility than Brangus heifers with high RFI (Krueger et al. 2009). The low RFI Angus heifers and bulls tended to show a higher DM digestibility compared to high RFI Angus bulls and heifers (Richardson et al. 1996) and RFI was negatively correlated with DM, NDF, ADF and CP digestibility. Heifers with low RFI had higher DM, NDF, ADF and CP digestibility.

The data on intake, absorption, excretion and retention of N in low and high RFI groups have been presented in Table 3. The intake of N, N voided in faeces and urine and total N loss was lower (P<0.05) in low RFI group but N retention (% of N intake and N absorbed) was higher (P<0.05) in low RFI group than the high RFI group. Negative RFI cows would have greater apparent digestibility of N than the positive RFI animals. Intakes of N did not differ between negative RFI and positive RFI cows (Richardson et al. 1996). Negative RFI cows had a greater apparent N digestibility (77.2 vs. 75.5%) and a tendency toward greater DM and OM digestibility. The negative RFI cows had a lower faecal N output (126 vs. 138 g/d) and a lower portion of feed N to faecal N (23.1 vs. 24.7%) compared with positive RFI animals (Richardson et al. 1996). Urinary N as well as daily urine production was similar in low and high RFI animals (Nkrumah et al. 2006, Bose et al. 2014).

The ADG was 0.539 and 0.498 kg in low and high RFI groups, respectively which was similar in both the groups. Basarab et al. (2003) found that low RFI steers consumed 10.4% less and had a 9.4% lower FCR with no differences
in BW or ADG. Almeida et al. (2004) reported that animals such as Nellore heifers of 26 months of age of high RFI consumed 26% more than the most efficient cattle but the ADG was similar (1.3 kg/d). Basarab et al. (2003) reported that there was no significant relationship between RFI and ADG indicating that variation in RFI reflected animal’s maintenance requirements rather than growth, size and appetite. Kelly et al. (2010) also showed that there was no significant difference in ADG for high RFI (1.52 kg) and low-RFI (1.54 kg) groups of animals. The relationship between RFI and FCR indicated that low RFI animals consumed less feed for each kg gain in BW than the high RFI group (Fig. 2). Hegarty et al. (2007) observed no difference in ADG between low and high RFI steers although low RFI steers ate 41% less DM each day and expressed improved feed conversion efficiency relative to high RFI steers. Homm et al. (2007) reported that ADG and body weight during the test period was not correlated to RFI in crossbred steers. Nkrumah et al. (2006) observed that ADG for high RFI, medium RFI, and low-RFI groups were 1.46±0.20, 1.51±0.16 and 1.48±0.16, respectively, which was similar among all the groups. It was observed that FCR was higher for high RFI group as compared to low RFI group. The data (Table 2) clearly indicated that feed conversion efficiency of high RFI group is lower than low RFI group, i.e. high RFI group animals are less efficient as compared to low RFI group. Negesse et al. (2016) also reported lower FCR for low RFI group compared to high RFI group. Kelly et al. (2010) reported that there was significant difference (P<0.05) in FCR between high RFI (4.86) and low-RFI (4.04) groups. Nkrumah et al. (2006) also showed significant difference (P<0.05) in FCR for high and low-RFI group of animals. Arthur et al. (2001) concluded that RFI intake was genetically and phenotypically correlated with feed intake and FCR but not with ADG.

Blood metabolites: The means of all blood variables (Table 5) studied were within the normal range reported for cattle by Kaneko et al. (1997) and Dias et al. (2006). Blood glucose values similar (P>0.05) in both the groups. Sharma et al. (2014) also reported similar values of blood glucose level in low (60.48 mg/dL) and high (59.52 mg/dL) RFI growing male Sahiwal calves while Kolath et al. (2006) observed that high RFI steers had greater concentrations of glucose in their blood. Richardson et al. (2004) found that at the beginning of the RFI test period, plasma glucose concentrations were positively correlated with RFI in Angus steers. Kelly et al. (2010) observed that circulating glucose was not associated with RFI. The concentration of creatinine (mg/dL) was 1.27 and 1.78 and for BUN (mg/dL) were 15.45 and 22.22 mg/dL, respectively in low and high RFI groups and these were higher (P<0.05) in high RFI group compared to low RFI group. The concentration of total protein in blood plasma averaged 7.34 and 8.24 g/dL in low and high RFI groups, respectively and these values being higher (P<0.05) in high RFI group. Richardson et al. (1996) also demonstrated a significant increase in total plasma protein in high RFI steers compared to low RFI steers (70.05 vs. 65.20 g/L). Richardson et al. (2004) found greater blood concentrations of urea in less efficient genotypes. This may be due to greater protein intake in high-RFI animals, a greater rate of body protein degradation, or deviation in the supply of AA due in part to variation in the efficiency of microbial protein production in the rumen (Lush et al. 1991, Kahn et al. 2000). Harvey et al. (1993) observed that inefficient steers (high RFI) had greater concentrations of serum urea nitrogen compared to efficient steers (low RFI) during the finishing phase. Carstens et al. (2002) also found a higher concentration of BUN in high RFI steers.

The values for ALT activity were 25.85 and 35.72 IU/L in low and high RFI groups with corresponding values of 80.33 and 100.57 IU/L for AST. The levels of these enzymes were higher (P<0.05) in high RFI group compared to low RFI group of Sahiwal calves. The plasma insulin level was 1.37 and 1.47±0.36 and 1.11±0.003 ng/mL in low and high RFI group, respectively with corresponding values of 1.08 and 1.11 mg/mL for IGFI. The values of IGF-1 were higher (P<0.05) in calves of low RFI groups (Dudi and Chander Datt 2015). Brown et al. (2004) found a positive correlation between IGFI and RFI in which low RFI steers and bulls had 29 and 25% lower concentrations of serum IGFI compared to high RFI

### Table 5. Blood biochemical and physiological parameters in low and high RFI groups

| Parameter          | Low RFI                          | High RFI                          |
|--------------------|----------------------------------|-----------------------------------|
| Insulin (mg/mL)    | 1.37±0.27                        | 1.47±0.36                         |
| IGF-I (mg/mL)      | 1.08±0.007                       | 1.11±0.003                        |
| GH (mg/mL)         | 4.53±0.12                        | 4.24±0.12                         |
| ALT (IU/L)         | 25.85±1.21                      | 35.72±1.18                        |
| AST (IU/L)         | 80.33±2.91                       | 100.57±1.63                       |
| Blood metabolites  |                                  |                                   |
| Glucose (mg/dL)    | 60.48±0.99                       | 59.52±1.07                        |
| Creatinine (mg/dL)| 1.27±0.01                        | 1.78±0.01                         |
| Total protein (g/dL)| 7.34±0.20                    | 8.24±0.23                         |
| BUN (mg/dL)        | 15.45±1.23                       | 22.22±1.21                        |

a,bMeans bearing different superscripts in the same row differ significantly (P < 0.05).
(> 0.5 SD) steers and bulls. However, Richardson et al. (1996) found no significant differences in concentrations of IGF-I between high and low RFI cattle. Results in beef cattle showed that circulating levels of IGF-1 are genetically associated with growth and finishing performance of beef cattle and may prove useful as a genetic predictor of carcass and feed efficiency traits (Johnston et al. 2001, 2002; Herd et al. 2002). A genetic and economic evaluation of the use of IGF-1 as an indirect selection criterion in beef cattle showed that it can increase the profitability of selection decisions and would best be used as a screening test to identify animals to be placed into RFI tests in a two-stage selection program (Wood et al. 2002). The GH concentration was 4.53 and 4.24 ng/mL in the respective groups. Walker et al. (2010) documented there were no significant main effects of glucose, insulin for the low, medium, and high RFI group of cattle. 

Calves of low RFI group consumed less feed than high RFI group whereas no differences existed for the average daily gain. Therefore, selection of low RFI animals would be expected to result in reduced feed inputs without altering growth rate and daily weight gain. However, a significant association was found between some plasma biochemical parameters and RFI. Thus, it is likely that measurement of these metabolic indicators (alanine amino transferase, aspartate amino transferase, total protein, blood urea nitrogen and creatinine) will be useful in the early identification of efficient animals. Therefore, selection of animals based on RFI would be an effective tool in livestock production system.

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REFERENCES

Almeida R, Lanna D P D and Leme P R. 2004. Residual feed intake: a new trait to evaluate beef cattle efficiency. Proceedings of the 41th Annual Meeting of the Brazilian Society of Animal Science. Campo Grande, Brazil 41: 3–14. AOAC. 2005. Official Methods of Analysis. Association of Official Analytical Chemists. 18th edn. Arlington, Washington, DC, USA.

Archer J A, Arthur P F, Herd R M, Parnell P F and Pitchford W S. 1997. Optimum post-weaning test for measurement of growth rate, feed intake and feed efficiency in British breed cattle. Journal of Animal Science 75: 2024–32.

Archer J A, Richardson E C, Herd R M and Arthur P F. 1999. Potential for selection to improve efficiency of feed use in beef cattle: a review. Australian Journal of Agricultural Research 50: 147–61.

Arthur P F, Archer J A, Herd R M, Richardson E C, Exton S C, Oswin C, Dibley K C P and Burton D A. 1999. Relationship between post-weaning growth, net feed intake and cow performance. Proceedings of 13th Animal Breeding Genetics. Symposium, Mandurah, WA, Australia. pp. 484–87.

Arthur P F, Archer J A, Johnston D J, Herd R M, Richardson E C and Parnell P F. 2001. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency and other post weaning traits in Angus cattle. Journal of Animal Science 79: 2805–11.

Basarab J A, Price M A, Aalhus J L, Okine E K, Snelling W M and Lyle K L. 2003. Residual feed intake and body composition in young growing cattle. Canadian Journal of Animal Sciences 83: 189–204.

Bose B K S, Kundu S S, Tho N T B, Sharma V K and Sontakke U B. 2014. Residual feed intake as a feed efficiency selection tool and its relationship with feed intake, performance and nutrient utilization in Murrah buffalo calves. Tropical Animal Health and Production 46: 615–21.

Brown E G, Carstens G E, Fox J T, White M B, Curley K O, Bryan T M, Slay L J, Welsh T H, Randel R D, Holloway J W and Keisler D H. 2004. Physiological indicators of performance and feed efficiency traits in growing steers and bulls. Beef Cattle Res Tex. 163–66.

Carstens G E, Theis C M, White M B, Welsh T H, Warrington B G, Randel R D, Forbes T D A, Lippke H, Greene L W and Lunt D K. 2002. Residual feed intake in beef steers: I. Correlation with performance traits and ultrasound measures of body composition. Proceedings of West American Society of Animal Science 53: 552–55.

Chander Datt, Sharma V K, Dudi K, Nana B B, Sharma Ph S, Ngesse T, Kundu S S, Datta M M, Gupta R and Singh D. 2017. Residual feed intake as a tool for selecting more efficient animals: A Review. Indian Journal Animal Nutrition 34: 238–55.

Cruz G D, Rodríguez-Sánchez J A, Oljen J W and Sainz R D. 2010. Angus-Hereford steers housed in individual or group pens performance, residual feed intake, digestibility, carcass traits and profitability. Journal of Animal Science 88: 324–29.

Dias R F, Bracarense A P F R L, Marcal W S, Rocha M A and Dias R C F. 2006. Reference values and age effect on the erythrogram of bovine females of the Aquitania breed. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 58: 311–15.

Dudi K and Chander Datt. 2015. Relationship of residual feed intake with blood metabolites and hormones in Sahiwal female calves. Forage Research 41: 40–45.

Gaines A, Peterson B A and Mendoza O F. 2012. Herd management factors that influence whole herd feed efficiency. Feed Efficiency in Swine. (Ed.) Patience J F. Wageningen Academic Press, Wageningen. pp. 15–39.

Golden J W, Kerley M S and Kolath W H. 2008. The relationship of feeding behavior to residual feed intake in crossbreed Angus steers fed traditional and no roughage diets. Journal of Animal Science 86: 180–86.

Gomez R R, Bourg B M, Paddock Z D, Carstens G E, Lancaster P A, Miller R K, Tedeschi L O, Lunt D K, Moore S A and Delaney D S. 2007. Evaluation of feed efficiency in Santa Gertrudis steers and relationship with temperament and feeding behavior. Journal of Animal Science 85: 454–55.

Harvey R W, Armstrong J D, Heimer E P and Campbell R M. 1993. Feedlot performance, carcass characteristics, hormones, and metabolites in steers actively immunized against growth hormone releasing factor. Journal of Animal Science 71: 2853–59.

Hegarty R S, Goopy J P, Herd R M and Mc-Corkell B. 2007. Cattle selected for lower residual feed intake have reduced daily methane production. Journal of Animal Science 85: 1479–86.

Herd R M, Arthur P F, Archer J A and Johnston D J. 2002. IGF-I is associated with genetic variation in key production traits in young Angus cattle. Animal Production Australia 24: 313.
Homm J W, Berger L L and Rodriguez-Zas S L. 2007. Factors affecting residual feed intake in feedlot steers. Journal of Animal Science 85: 454.

ICAR. 2013. Nutrient Requirements of Cattle and Buffalo. 1st edn. Indian Council of Agricultural Research, New Delhi, India.

Johnston D J, Herd R M, Kadel M J, Graser H U, Archer P F and Archer J A. 2002. Evidence of IGF-I as a genetic predictor of feed efficiency traits in beef cattle. Proceedings of 7th World Congress Genetics Applied Livestock Production, Montpellier, France.

Johnston D J, Herd R M, Reverter A and Oddy V H. 2001. Heritability of IGF-I in beef cattle and its association with growth and carcass traits. Proceedings of Association of Advancement of Animal Breeding and Genetics, New Zealand 14: 163–66.

Kahn L P, Leng R A and Piper L R. 2000. Rumen microbial yield from sheep genetically different for fleece weight. Asian Australasian Journal of Animal Science 13: 137.

Kaneko J J, Harvey J W and Bruss M L. 1997. Clinical Biochemistry of Domestic Animals. San Diego Academy Press, USA. p. 606.

Kelly A K, Mc-Gee M, Crews Jr D H, Sweeney T, Boland T M, Krueger W K, Carstens G E, Lancaster P A, Slay L J, Miller J C, Kolath W H, Kerley M S, Golden J W and Keisler D H. 2006. Koch R M, Swiger L A, Chambers D and Gregory K E. 1963. Heritability of IGF-I in beef cattle and its association with growth and carcass traits. Proceedings of Association of Advancement of Animal Breeding and Genetics, New Zealand 14: 163–66.

Kahn L P, Leng R A and Piper L R. 2000. Rumen microbial yield from sheep genetically different for fleece weight. Asian Australasian Journal of Animal Science 13: 137.

Kanejo J J, Harvey J W and Bruss M L. 1997. Clinical Biochemistry of Domestic Animals. San Diego Academy Press, USA. p. 606.

Kelly A K, Mc-Gee M, Crews Jr D H, Sweeney T, Boland T M and Kenny D A. 2010. Repeatability of feed efficiency, carcass ultrasound, feeding behavior and blood metabolite variables in finishing heifers divergently selected for residual feed intake. Journal of Animal Science 88: 3214–25.

Koch R M, Swiger L A, Chambers D and Gregory K E. 1963. Efficiency of feed use in beef cattle. Journal of Animal Science 22: 486–94.

Kolath W H, Kerley M S, Golden J W and Keisler D H. 2006. The relationship between mitochondrial function and residual feed intake in Angus steers. Journal of Animal Science 84: 861–65.

Krueger W K, Carstens G E, Lancaster P A, Slay L J, Miller J C and Forbes T D A. 2009. Relationships between residual feed intake and apparent nutrient digestibility in growing calves. Journal of Animal Science 86: 758–63.

Lancaster P A, Carstens G E, Ribeiro F R B, Tedeschi L O and Crews DH Jr. 2009. Characterization of feed efficiency traits and relationships with feeding behavior and ultrasound carcass traits in growing bulls. Journal of Animal Science 87: 1528–39.

Lush J M, Gooden J M and Annison E F. 1991. The uptake of nitrogenous compounds from the gut of sheep genetically different in wool production. Proceedings of Nutrition Society of Australia 16: 144.

Negesse T, Chander Datt and Kundu S S. 2016. Variability in residual feed intake and nutrient utilization in Murrah buffalo heifers. Tropical Animal Health and Production 48: 1577–84.

Nkrumah J D, Basarab J A, Wang Z, Li C, Price M A, Okine E K, Crews Jr D H and Moore S S. 2007. Genetic and phenotypic relationships of feed intake and different measures of feed efficiency with growth and carcass merit of beef cattle. Journal of Animal Science 85: 2711–20.

Nkrumah J D, Okine E K, Mathison G W, Schmid K, Li C, Basarab J A, Price M A, Wang Z and Moore S S. 2006. Relationships of feedlot feed efficiency, performance, and feeding behaviour with metabolic rate, methane production and energy partitioning in beef cattle. Journal of Animal Science 84: 145–53.

NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. edn. National Research Council, National Academy Press, Washington, DC, USA.

Reitman S and Frankel S. 1957. A colorimetric method for the determination of serum glutamic oxaloacetic and glutamic pyruvic transaminases. American Journal of Clinical Pathology 28: 56–63.

Ribeiro F R B, Carstens G E, Lancaster P A, Tedeschi L O and Davis M E. 2007. Relationship of feed efficiency with carcass and non-carcass tissue composition in Angus bulls and heifers. Journal of Animal Science 85: 455–87.

Richardson E C and Herd R M. 2004. Biological basis for variation in residual feed intake in beef cattle. 2. Synthesis of results following divergent selection. Australian Journal of Experimental Agriculture 44: 431–40.

Richardson E C, Herd R M, Archer J A, Woodgate R T and Arthur P F. 1998. Steers bred for improved net feed efficiency eat less for the same feedlot performance. Proceedings of Australian Society of Animal Production 22: 213–16.

Richardson E C, Herd R M, Oddy V H, Thompson J M, Archer J A and Arthur P F. 2001. Body composition and implications for heat production of Angus steer progeny of parents selected for and against residual feed intake. Australian Journal of Experimental Agriculture 41: 1065–72.

Sharma V C, Mahesh M S, Mohini M, Chander Datt and Nampoorthiri V M. 2014. Nutrient utilization and methane emissions in Sahiwal calves differing in residual feed intake. Archives of Animal Nutrition 68: 345–57.

Sharma V K, Kundu S S, Chander Datt, Prusty S, Kumar M and Sontakke U B. 2018. Buffalo heifers selected for lower residual feed intake have lower feed intake, better dietary nitrogen utilisation and reduced enteric methane production. Journal of Animal Physiology and Animal Nutrition 102: 607–14. https://doi.org/10.1111/jpn.12802

Sharma V K, Kundu S S, Prusty S, Chander Datt and Kumar M. 2016. Nutrient utilisation, growth performance and blood metabolites in Murrah buffalo calves (Bubalus bubalis) divergently selected for residual feed intake. Archives of Animal Nutrition 70: 455–69.

SPSS. 2010. Statistical Package for Social Sciences. version 16.0., Chicago, IL, USA.

Van Soest P J, Robertson J B and Lewis B A. 1991. Methods for dietary fibre, neutral detergent fibre and non starch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74: 3583–97.

Walker D K, Tigemeyer E C, Baxa T J, Chung K Y, Johnson D E, Laudert S B and Johnson B J. 2010. Effects of ractopamine and sex on serum metabolites and skeletal muscle gene expression in finishing steers and heifers. Journal of Animal Science 88: 1349–57.

Wood B J, Archer J A and Van der Werf J H J. 2002. Genetic and economic evaluation of the use of IGF-1 as an indirect selection criterion in beef cattle. Proceedings of 7th World Congress of Genetics and Applied Livestock Production, Montpellier, France. Communication No. 02–26.

Yamabayama E S K, Price M A and Foxcroft G R. 1996. Hormonal status, metabolic changes, resting metabolic rate in beef heifers undergoing compensatory growth. Archives of Animal Nutrition 74: 57–60.

Yelich J V, Wettewann R P, Marston T T and Spencer I L. 1996. Luteinizing hormones, growth hormone, insulin-like growth factor-I, insulin and metabolites before puberty in heifers fed to rates of gain. Domestic Animal Endocrinology 13: 325–38.