

Evaluating core body temperature and lying behavior as an indicator of feed efficiency profile of beef cattle-consuming forage-based diets^{1,2}

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INTRODUCTION

Since its discovery in the 1960s (Koch et al., 1963), researchers have been looking for ways to apply residual feed intake (RFI), a measure of feed efficiency (FE) in beef cattle selection. However, assessing RFI requires an ~90-d feeding trial and individual feed intake measurement, which can lead to significant time and costs. Therefore, identifying simple and practical indicators of RFI profiles has merit. Previous studies (Montanholi et al., 2010) have demonstrated that infrared (IR) thermography of skin temperature can predict the RFI profiles of cattle but there are challenges with the application of this technology. Apart from low repeatability across days, results from IR images are affected by environmental factors such as wind speed, exposure to sunlight, and presence of debris on the skin (Montanholi et al., 2015), which would result in inaccurate assessments. This implies that

temperature data collected from areas that are less likely to be affected by ambient conditions will give more consistent temperature profiles; therefore, core body temperature (CBT) measured from the rumen (Munro et al., 2015) or rectum (Bewley et al., 2008) may provide a more practical and consistent measure than if measured from the skin under dynamic environmental conditions. Munro et al. (2015) also proposed that activity can be used as indicator of feed efficiency and health status on commercial farms. Indeed, the rumen temperature (RMT) may provide a more reliable estimate of body heat that would not be captured by IR thermography. Activity monitoring has been already applied for decades in beef research as activity changes have been associated with disease and symptoms of disease (Ito et al., 2009). Further, it is becoming easier to measure body temperature and activity with the aid of telemetric devices that could be programed to collect data at specific time intervals without affecting the behavior of the subjects. Procedures that do not alter animal behavior are less likely to bias results because handling may elevate the normal temperature of the animals.

The main focus of this study was to determine if core body temperature and activity traits can be used to determine the FE profiles of beef cattle-consuming forage-based diets. Specific objectives were to determine: 1) whether RMT or rectal temperature (RCT) could predict RFI and ii) the

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relationship between activity (measured as lying behavior) and RFI profiles of beef cattle.

MATERIALS AND METHODS

Experimental Site and Animal Management

All experimental procedures were approved by University of Saskatchewan Animal Research Ethics Board (Animal Use Protocol No. 20090107) and steers were cared for according to the guidelines of the Canadian Council on Animal Care (CCAC, 2009). The study was conducted at the Western Beef Development Centre's (WBDC) Termuende Research Ranch located near Lanigan (lat. 51°51'N, long. 105°02'W), Saskatchewan, Canada. Each year, 80 spring-born, fall-weaned Black Angus steers (average body weight [BW] = 265.4 ± 2.6 kg; average age = 209 ± 11 d) were managed in an 85-d feeding trials (year 1, November 16, 2016 to February 9, 2017; year 2, November 21, 2017 to February 14, 2018). Each steer was randomly assigned to one of two pens (50 × 120 m, each) fitted with GrowSafe feed bunks (GrowSafe Systems Ltd, Airdrie, AB, Canada) per pen to measure individual steer feed intake. The trial included a 21-d adaptation period (to acclimatize the steers to GrowSafe bunks and diet) followed by an 85-d data collection period. Water was supplied to each pen in a heated water bowl and wood chips were used as bedding during inclement extreme weather conditions.

Measurements of BW were taken over two consecutive days at the start and end of the trial and every 14 d throughout the trial. Average daily gain (ADG) was determined by a regression of BW for days on test, with six observations per animal at intervals of 14 d. Ultrasound measurements of backfat thickness (BKFT; mm) were determined at the start and end of the trial using an Aloka 500-V real-time ultrasound machine (3.5 MHz; Aloka Inc., Wallingford, CT) equipped with a 17-cm linear array transducer. The diet (11.4% CP; 57.3% TDN, on dry matter [DM] basis) consisted of 70.8% processed brome/alfalfa hay and 29.2% rolled barley. Feed was delivered ad libitum, once daily at 0800 h. The steers had free access to a commercial 2:1 mineral and cobalt iodized salt block.

Feed Intake

Feed dry matter intake (DMI) was measured with the GrowSafe (GrowSafe Systems Ltd, Airdrie, AB, Canada) automatic feeding system, which monitors individual animal feed intake as described by Durunna et al. (2011) and Damiran et al. (2018a, 2018b). Briefly, each GrowSafe bunk has a radio

frequency reader located in the top edge, which detects radio waves emitted from half-duplex radio frequency transponder button tags (Allflex USA Inc., Dallas/Fort Worth, TX) in each steer's ear when the animal comes to eat. Load bars at the base of each bunk measure weight changes (feed disappearance) every second an animal is eating at the bunk. The set up at WBDC included eight feeding troughs (or node) located in each pen (in total 16 nodes), a data logging reader panel with wireless transmission capabilities, and a computer that contains the data acquisition software. Daily feed intake (as fed) was the average feed intake for valid test days, which was multiplied by the feed DM content to derive DMI for each steer. Simultaneously, individual steer G:F value was calculated as the ratio of ADG to DMI.

Rumen and Rectal Temperature

Steers RMT was measured using San'Phone Thermobolus (Capteur San'Phone, Medria, Châteaubourg, France). Each steer was administered a reticulo-rumen temperature Thermobolus orally using a plastic balling gun. This bolus measured reticulo-rumen temperature every 5 min and wirelessly transmitted these data to a base station connected to the internet. Preprocessing of raw RMT data was conducted to eliminate the effect of water drinking using an autoregressive process of order 4 and adaptive filtering.

RCT was measured every 5 min for 4 wk using a rectal probe developed by Reuter et al. (2010). Each year, temperature probes were rectally installed in 40 randomly selected steers. Following year 1 and 2 data collection, 27 and 36 steers had usable RCT data, respectively.

Lying Behavior

To determine time spent lying (lying duration) and frequency of lying bouts, HOBO accelerometers (HOBO Pendant G acceleration data logger, Onset Corp., Pocasset, MA) were installed on all steers. These devices were programmed to record g-force on the x, y, and z-axes at 5-min intervals and were attached to the left hind leg above the fetlock, as described by Ito et al. (2009). The data loggers were removed from the steers after 56 d of data collection, and the data was downloaded using Onset HOBO ware software (Onset Corp., Pocasset, MA). These data were exported into Microsoft Excel (Microsoft Corporation, Redmond, WA), and the degree of vertical tilt (y-axis) was used to determine the lying position of the animal, such that readings <60° indicated the steer standing, whereas readings ≥60° indicated the steer lying down.

RFI Calculations and Animal Grouping

RFI was calculated as described by Durunna et al. (2011), and ADG, initial BW, and mid-test metabolic BW (MWT) were calculated from the regression coefficients of the linear growth path of each animal using the GLM procedure (SAS Inst. Inc., Cary, NC). The mid-test BW was converted to MWT by $BW^{0.75}$. Expected DMI was obtained as a regression of standardized DMI on ADG, MWT, and off-test BKFT using PROC GLM of SAS. The residuals from equation (1) were assigned as RFI,

$$Y_j = \beta_0 + \beta_1 ADG_j + \beta_2 MWT_j + \beta_3 BKFT_j + e_j, \quad [1]$$

where for each animal, Y_j is the expected DMI, β_0 is the regression intercept, β_1 is the ADG regression coefficient, β_2 is the MWT regression coefficient, β_3 is the off-test BKFT regression coefficient, and e_j indicates the residuals (RFI) (Durunna et al., 2011).

All growth curves had a coefficient of determination (r^2) greater than 95%, indicating that growth was linear and the choice of a linear regression model was appropriate. Each steer was assigned to an RFI class based on 0.5 SD greater than or less than the mean. There were three RFI classes: low-RFI (<0.5 SD), medium-RFI (± 0.5 SD), and high-RFI (>0.5 SD) from the mean.

In order to clarify if RMT, RCT, and lying duration can provide supplementary information for better predictions of steer FE, alternative models [equation (2)] for calculating expected DMI were tested using DMI, ADG, MWT, and potential FE indicator (RMT or RCT or lying duration):

$$Y_j = \beta_0 + \beta_1 ADG_j + \beta_2 MWT_j + \beta_3 Indicator_j + e_j, \quad [2]$$

where for each animal, Y_j is the expected DMI, β_0 is the regression intercept, β_1 is the ADG regression coefficient, β_2 is the MWT regression coefficient, β_3 is the potential indicator (RMT or RCT or lying duration) regression coefficient, and e_j indicates the residuals.

Statistical Analysis

Data were analyzed using the MIXED procedure of SAS 9.2 (SAS, 2003). The model used for the analysis is: $Y_{ij} = \mu + T_i + e_{ij}$, where Y_{ij} is an observation of the dependent variable ij ; μ is the population mean for the variable; T_i is the fixed effect of the animal RFI type (low-RFI, medium-RFI, and high-RFI class), and e_{ij} is the random error associated with the observation ij . When a significant difference was detected ($P < 0.05$), means were separated using the Tukey–Kramer posttest. Steer was considered an experimental unit. The Pearson correlation was also

used to determine the relationship between animal performances, CBT, activity parameters that measured in trial as affected by RFI status. For all correlation analyses, correlation coefficients were classified as strong ($r > 0.6$), moderate ($0.6 > r > 0.4$), or weak ($r < 0.4$), respectively (Damiran et al., 2018b).

RESULTS AND DISCUSSION

Steer Performance, Feed Intake, and Feed Efficiency

There was no difference ($P > 0.05$) among RFI classes for initial BW (265.4 ± 2.6 kg) (mean \pm SD), final BW (311.2 ± 3.1 kg), ADG (0.53 ± 0.02 kg/d), initial BKFT (2.5 ± 0.6 mm) as well as final BKFT (2.9 ± 0.6 mm; data not shown). The G:F values measured were lowest for ($P < 0.01$) high-RFI (0.06 ± 0.01 kg/kg), but did not differ ($P > 0.05$) between medium-RFI and low-RFI (0.06 ± 0.001 and -0.07 ± 0.01 kg/kg, respectively). However, high-RFI had the greatest ($P < 0.01$) DMI (9.3 ± 0.63 kg/d), while low-RFI had the least ($P < 0.05$) DMI (7.79 ± 0.75 kg/d). As expected, RFI was different ($P < 0.05$) among classes and was -0.78 ± 0.44 , 0.02 ± 0.19 , and 0.75 ± 0.37 kg/d for low-RFI, medium-RFI, and high-RFI classes, respectively. Moreover, residual gain was lowest for ($P < 0.01$) high-RFI (-0.06 ± 0.1 kg) but was not different ($P > 0.05$) between medium-RFI and low-RFI (0.01 ± 0.1 and 0.05 ± 0.09 kg, respectively). Steer classes did not differ ($P > 0.05$) in RCT (39.3 ± 0.15 °C), lying duration (12.9 ± 0.71 h/d), or in lying bout frequency (9.18 ± 1.35 no./d). However, low-RFI steers (39.76 ± 0.13 °C) had lower ($P < 0.05$) RMT than high-RFI (39.83 ± 0.11 °C). Medium-RFI steers were similar ($P > 0.05$) to low-RFI and high-RFI classes for RMT (39.77 ± 0.13 °C).

Relationship between Beef Steer Phenotypic Traits and RFI, CBT, and Lying Duration

When data was pooled, RFI was strongly correlated ($r = 0.78$, $P < 0.001$) with DMI; yet RMT ($r = 0.31$, $P < 0.001$), RCT ($r = 0.22$, $P = 0.079$), and lying duration ($r = 0.13$, $P = 0.106$) were weakly correlated with DMI (data not shown). Also, a weak or no correlation was observed between G:F and either RMT ($r = 0.16$; $P = 0.039$) or RCT ($r = 0.04$; $P = 0.727$). For all steer groups, RMT ($r = 0.21$, $P < 0.007$) or RCT ($r = 0.23$, $P = 0.071$) had weak and positive correlation with RFI. Results suggest that RMT or RCT, obtained using rumen boluses or rectal probes, cannot be used as an indicator of feed efficiency. Moreover, as current study results suggest, there appears to be very little or no evidence

Table 1. Descriptive statistics (SD, kg/day; minimum, Min, kg/day; and maximum, Max, kg/day), coefficient of determination (R^2), Bayesian information criterion (BIC), and regression equations of the RFI models evaluated

RFI traits ^a	SD	Min	Max	R^2	BIC	Regression equation (DMI) ^b
Rumen temperature included model ($n = 158$)						
RFI _{koch}	0.767	-1.727	2.670	0.393	186.1	$1.88 + 3.11 \times \text{ADG} + 0.063 \times \text{MBW}^{75}$
RFI _{rmt}	0.757	-1.432	2.656	0.434	184.8	$-60.18 + 2.89 \times \text{ADG} + 0.060 \times \text{MBW}^{75} + 1.569 \times \text{RMT}$
Rectal temperature included model ($n = 63$)						
RFI _{koch}	0.704	-1.917	1.436	0.278	76.9	$5.16 + 2.12 \times \text{ADG} + 0.031 \times \text{MBW}^{75}$
RFI _{ret}	0.689	-1.521	1.552	0.300	80.7	$-37.45 + 2.18 \times \text{ADG} + 0.042 \times \text{MBW}^{75} + 1.060 \times \text{RCT}$
Lying duration included model ($n = 143$)						
RFI _{koch}	0.729	-1.667	2.024	0.361	191.3	$2.92 + 3.05 \times \text{ADG} + 0.053 \times \text{MBW}^{75}$
RFI _{lyingD}	0.732	-1.707	1.893	0.361	191.3	$2.66 + 2.98 \times \text{ADG} + 0.052 \times \text{MBW}^{75} + 0.034 \times \text{LyingD}$

^aRFI_{koch}, RFI based on Koch et al. (1963) model; RFI_{rmt}, Koch model including rumen temperature; RFI_{ret}, Koch model including rectal temperature; RFI_{lyingD}, Koch model including lying duration.

^bThe error term that represents the different RFI traits, described in the first column, were not included in the equations; ADG: average daily gain, kg/d; MBW⁷⁵, mid-trial metabolic body weight, kg; RMT, rumen temperature, °C; RCT, rectal temperature, °C; LyingD, lying duration, h.

of relationships between feedlot steer feed efficiency and lying behavior (subsequently standing behavior).

Using CBT Measurement as Supplementary Data in Feed Efficiency Determination in Beef Cattle

Data were also analyzed in order to investigate if RMT, RCT, and lying duration can enable a better prediction of RFI (Table 1). The original model (Koch's model; Koch et al., 1963) for RFI (RFI_{koch}), based on a regression of DMI on MWT and ADG, had the lowest coefficient of determination (R^2 ; ranged 0.27–0.39 depending on sample sizes). This was included as the base model in all the other alternate extended models tested. In the current study, 4% of the variation in predicted DMI was explained by RMT in the alternate model. Likewise, 2.8% of the RFI_{koch} variation, also, was explained by RCT. Thus, both RMT and RCT slightly improved R^2 for DMI (therefore RFI) prediction. However, inclusion of lying duration into the original model did not improve DMI prediction.

CONCLUSIONS AND IMPLICATIONS

Using RMT and RCT or lying behavior alone may not provide an accurate prediction of RFI. However, inclusion of RMT or RCT measurements in models can allow for a more accurate prediction of RFI.

LITERATURE CITED

- Bewley, J. M., M. E. Einstein, M. W. Grott, and M. M. Schutz. 2008. Comparison of reticular and rectal core body temperatures in lactating dairy cows. *J. Dairy Sci.* 91:4661–4672. doi:10.3168/jds.2007-0835
- Canadian Council on Animal Care (CCAC). 2009. CCAC guidelines on: the care and use of farm animals in research, teaching and testing. Ottawa (Canada): CCAC. Available from https://www.ccac.ca/Documents/Standards/Guidelines/Farm_Animals.pdf. Accessed February 13, 2019.
- Damiran, D., G. B. Penner, K. Larson, F. Añez-Osuna, and H. A. Lardner. 2018a. Relationships between beef heifer feed efficiency traits and Igenity panel scores in western Canada. *Transl. Anim. Sci.* 2:S66–S70. doi:10.1093/tas/txy022
- Damiran, D., G. B. Penner, K. Larson, and H. A. Lardner. 2018b. Use of residual feed intake as a selection criterion on the performance and economics for replacement beef heifers. *Prof. Anim. Sci.* 34:156–166. doi:10.15232/pas.2017-01635
- Durunna, O. N., F. D. N. Mujibi, L. Goonewardene, E. K. Okine, Z. Wang, and S. S. Moore. 2011. Feed efficiency differences and re-ranking in beef steers fed grower and finisher diets. *J. Anim. Sci.* 89:158–167. doi: 10.2527/jas.2009–2514
- Ito, K., D. M. Weary, and M. A. von Keyserlingk. 2009. Lying behavior: assessing within- and between-herd variation in free-stall-housed dairy cows. *J. Dairy Sci.* 92:4412–4420. doi:10.3168/jds.2009-2235
- Koch, R. M., L. A. Swiger, D. Chambers, K. E. Gregory. 1963. Efficiency of feed use in beef cattle. *J. Anim. Sci.* 22:486–494.
- Montanholi, Y. R., K. C. Swanson, R. Palme, F. S. Schenkel, B. W. McBride, D. Lu, and S. P. Miller. 2010. Assessing feed efficiency in beef steers through feeding behaviour, infrared thermography and glucocorticoids. *Animal.* 4:692–701. doi:10.1017/S1751731109991522
- Montanholi, Y., S. L. Bourgon, E. Crane, and J. Munro. 2015. The biology of feed efficiency: indirect indicators and checkpoints for improving feed efficiency in beef cattle. Proceedings of the X NESPRO Meeting & II International Symposium on Beef Cattle Production Systems.
- Munro, J. C., F. C. Schenkel, S. Miller, T. Tennessen, and Y. R. Montanholi. 2015. Remote sensing of heart rate and rumen temperature in feedlot beef cattle: associations with feeding and activity patterns. *Proc. N.Z. Soc. Anim. Prod.* 75:29–33.
- Reuter, R. R., J. A. Carroll, L. E. Hulbert, J. W. Dailey, and M. L. Galyean. 2010. Technical note: development of a self-contained, indwelling rectal temperature probe for cattle research. *J. Anim. Sci.* 88:3291–3295. doi:10.2527/jas.2010-3093
- SAS. 2003. User's Guide: Statistics, 8th ed. Cary (NC): SAS Institute, Inc.