ABSTRACT: Residual feed intake (RFI) is a measure of feed efficiency defined as the difference between actual feed intake and expected feed intake required for maintenance and production. The objective of this study was to determine the relationship between RFI, feeding behavior, and other performance traits in growing heifers. Individual DMI was measured in Brangus heifers (n = 115) fed a roughage-based diet (ME = 2.0 Mcal/kg) for 70 d using Calan-gate feeders. Residual feed intake was computed as the residuals from linear regression of DMI on mid-test BW\(^{0.75}\) and ADG. Heifers with the greatest (least efficient, n = 18) and least (most efficient, n = 18) RFI were identified for quantification of feeding behavior traits. Continuous video recordings were obtained for all heifers during d 28 through d 56 of the 70-d feeding trial. Video data of 2 replications of four 24-h periods, 2 wk apart, were analyzed for the focal heifers. A head-down feeding event was defined as a heifer positioned in the feeder with her head lowered. A meal included all head-down feeding events that were separated by less than 300 s. The mean RFI for the high- and low-RFI heifers were 1.00 and −1.03 ± 0.03 kg/d, respectively. High-RFI heifers consumed 21.9% more (P < 0.0001) DM but had similar BW and ADG compared with low-RFI heifers. The high-RFI heifers spent less time in head-down feeding events per day (P < 0.0001; 124 vs. 152 ± 4.3 min/d), consumed DM at a faster rate (99.6 vs. 62.8 ± 3.3 g/min), and ate more often per day (119.1 vs. 90.5 ± 3.9 head-down feeding events/d) compared with the low-RFI heifers; however, meal duration and frequency were not related to RFI. We conclude that feeding behavior related to head-down feeding events may be more useful as an indicator of RFI than the number of meal events.

Key words: beef heifer, efficiency, feeding behavior, residual feed intake

INTRODUCTION

Feed inputs represent the largest variable cost in producing beef; however, genetic selection programs have primarily focused on output traits, such as growth and carcass quality. Selection for reduced feed inputs independent of output traits could enhance efficiency of feed utilization and substantially improve profitability of beef production systems. Traditionally, attempts to improve feed efficiency in beef cattle have selected for G:F, a ratio of BW gain to feed intake. Because G:F is related to growth traits, selection for G:F in growing cattle will likely lead to larger mature cows (Herd and Bishop, 2000), increase feed costs for the breeding herd, and not necessarily improve profitability. Residual feed intake was first proposed by Koch et al. (1963) as an alternative feed efficiency trait that was independent of growth traits. It was expressed as the difference between actual feed intake and expected feed intake based on body size and ADG. Therefore, RFI is a measure of the variation in feed intake beyond that which is needed to meet maintenance and a specified growth rate (Archer et al., 1999). Cattle identified as having low RFI have substantially less feed intake than high-RFI cattle without noticeable changes in BW or growth rates (Arthur et al., 2001a).

Recent research has shown that duration and frequency of bunk attendance may be related to feed efficiency traits. Schwartzkopf-Genswein et al. (2002) found a positive relationship between G:F and bunk attendance (meal) duration. Lancaster et al. (2009) reported a positive relationship between RFI and feeding duration and frequency in growing bulls. In the present study, head-down feeding events were used to measure feeding behavior, in addition to the conventional measurement of meals, because our informal observations indicated that some heifers spent a substantial amount of time standing at the feed bunk with the Calan gate open but with their head up and not feeding. The objective of the current study was to determine the relationship between feeding behavior, feed efficiency, and
performance in beef cattle classified as having low- or high-RFI.

**MATERIALS AND METHODS**

This study was approved by the Institutional Animal Care and Use Committee at Texas A&M University.

**Animals and Experimental Design**

One hundred fifteen Brangus heifers (236 ± 10.7 d of age) obtained from a single producer were blocked by BW and then randomly assigned to 1 of 20 pens (6 heifers/pen). The heifers had access to a continuous supply of fresh water and were individually fed a roughage-based diet (ME = 2.0 Mcal/kg) using Calan-gate feeders (American Calan Inc., Northwood, NH). The heifers were adapted to the diet and trained to eat from Calan-gate feeders for 28 d before beginning the study. Feed was delivered twice daily and feed offered was adjusted daily to target 5 to 10% feed refusals each day to minimize time when feed was unavailable. Feed refusals were measured weekly and more frequently for heifers with excessive refusals.

Cattle were moved an average of 100 m through a familiar environment from their pens to a squeeze-chute for BW measurements. Because heifers were adapted to the handling facilities before data collection began, shrink adjustments were not applied to BW. Full BW were measured weekly before the morning feed delivery, and linear regression was used to compute initial and final BW and ADG. Daily DMI was computed from weekly average feed intakes. Residual feed intake was calculated as the difference between actual DMI and the DMI predicted from multiple linear regression of DMI on mid-test BW\(^{0.75}\) and ADG using the following model:

\[
\text{DMI} = \beta_0 + \beta_1 \text{mid-test BW}^{0.75} + \beta_2 \text{ADG} + \epsilon,
\]

where \(\beta_0\) is the y-intercept, \(\beta_1\) is the partial regression coefficient of mid-test BW\(^{0.75}\), \(\beta_2\) is the partial regression coefficient of ADG, and \(\epsilon\) is the error term. At the end of the feeding trial, focal low (\(n = 18\)) and high (\(n = 18\)) RFI heifers were selected from those < or >1 SD from the mean RFI of 0.00 ± 0.68 kg/d for use in the feeding behavior portion of the project.

**Equipment**

Ten Capture 0.8-cm CCD outdoor bullet cameras (Richardson Electronics, Houston, TX) were mounted on structural beams of the barn 3.35 m above the ground using metal brackets. The cameras were placed in such a way as to record animal activity in the entire pen with particular emphasis on the feeder area. After each week, the cameras were moved laterally to record the adjacent pens. The camera data was fed to one 10-channel multiplexer recorder (GE-Interlogix Kalatel Division, Corvallis, OR), housed in the center aisle of the building, using Siamese RG-59 18/2 CCTV cable (Richardson Electronics Security Systems Division, Houston, TX) that supplied camera power and video feed. The multiplexer was housed in a cabinet that provided forced air ventilation with filtration for dust. This cabinet also contained a 12-V DC power supply to power the cameras and recorder. Direct current power was used because it is much safer for animals and people than AC power in livestock environments. A second 10-channel multiplexer was exchanged with the original multiplexer every 3 d to prevent exceeding the physical memory of the unit. The data were then transferred from the multiplexer to digital video discs (DVD). The recorded video was viewed using WaveReader 3.0 S (GE Security, Corvallis, OR) for analysis. One 150-W halogen floodlight was added to each pen to increase visibility and reduce shadows near the feeders during night.

**Feeding Behavior**

The recording of video data began on d 28 of the 70-d study and continued for 28 d (October 17 to November 23) when weather conditions were moderate. After RFI was determined and the focal heifers were identified, the recorded video was analyzed for each of the focal heifers. Continuous video data were analyzed from the first 4 d of each wk that the behavior of the focal heifer was recorded. A total of 8 d (2 × 4-d periods), 2 wk apart, were analyzed for each focal heifer. Although video recordings were only analyzed for the focal heifers, all 6 heifers remained in each of the pens. Animal was used as the experimental unit because the individual Calan gates made it reasonable to assume that head-down feeding behavior was independent of influence from other members of the group. Also, an important aspect of the study was to estimate individual variation.

Each of the heifers in this study was marked with white water-based road marking paint to facilitate identification during analysis of the video data. A series of 5 easily distinguishable markings were used, and 1 animal was not marked because there were 6 heifers in each pen. Each heifer was assigned a marking according to its designated feeder. These markings were reapplied when the heifers were in a squeeze chute for their weekly BW measurements.

A head-down feeding event (events/d) began when a heifer already in the Calan-gate feeder lowered her head to ingest feed and ended when the heifer raised her head above the feed. A new head-down feeding event was initiated each time a heifer lowered her head to feed. Head-down feeding duration (min/d) was the sum of the duration of the individual head-down feeding events. Head-down eating rate (g/min) was calculated as average daily DMI divided by head-down feeding duration, where DMI was the average daily DMI for the week of recorded behavior data. A meal event
was defined as all head-down feeding events separated by less than 300 s (Sowell et al., 1998; Schwartzkopf-Genswein et al., 1999). A new meal occurred when the time elapsed between the end of a head-down feeding event and the beginning of another head-down feeding event was greater than 300 s. Meal duration (min/d) was the sum of the duration for each individual meal event, which includes head-down duration and the time elapsed between head-down feeding events. Meal eating rate (g/min) was calculated as average daily DMI for the week of the recorded behavioral data divided by meal duration.

**Statistical Analysis**

Growth rates of individual heifers were modeled by linear regression of weekly BW against days on test using regression (SAS Institute Inc., Cary, NC). These regression coefficients were used to derive initial (d 0) and final (d 70) BW, mid-test metabolic BW (BW0.75), and ADG for each heifer for the 70-d RFI trial. Residual feed intake was the difference between actual and expected feed intake using the residuals from the linear regression of DMI on mid-test BW0.75 and ADG. Gain-to-feed ratio was calculated as kilograms of BW gain/kilogram of DM feed. Performance (BW, ADG, and DMI), feed efficiency (G:F and RFI), and feeding behavior traits were analyzed for the effect of RFI group, side of barn, pen, week of measurement, and all interactions using a general linear model (PROC GLM of SAS). All nonsignificant terms were dropped from the model. A term was considered significant if it had a P-value of less than 0.05. Correlations between feeding behavior and performance and efficiency traits were not made because focal heifers were from 2 discontinuous populations (high and low RFI), and feeding behavior was not obtained for the nonfocal heifers in the study.

The intraobserver variability (a measure of precision) of the investigator who analyzed the video was determined by reanalyzing one 30-min segment of video from each of d 1, 5, and 8 of behavior measurements. These video segments were reanalyzed at the end of the study without knowledge of the previous analysis. Periods of increased activity were used to have the greatest probability of variation. The Pearson correlation coefficient between the original and reanalyzed data was 0.99 (P < 0.001). This method was previously used to measure intraobserver variability (Lehner, 1998).

**RESULTS AND DISCUSSION**

**Feed Efficiency and Performance**

As expected, the heifers in the high-RFI and low-RFI groups had similar (P > 0.67) initial BW, final BW, and ADG because the model for measuring RFI adjusts for these traits. The high-RFI heifers consumed an average of 1.92 kg/d (22.5%) more feed than the low-RFI heifers (Table 1). The high-RFI heifers had an average daily DMI of 10.45 ± 0.19 kg/d, whereas the low-RFI heifers had an average daily DMI of 8.53 ± 0.20 kg/d. These findings are consistent with previous studies that found RFI to be positively correlated with daily DMI but independent of growth and body size (Herd and Bishop, 2000; Arthur et al., 2001a,b; Carstens et al., 2002). Carstens et al. (2002) found that low-RFI steers (<0.5 SD below the mean) consumed 21% less daily DMI than steers with high RFI (>0.5 SD above the mean) even though ADG and BW were similar between the 2 groups. Lancaster et al. (2005) reported that low-RFI calves consumed 15% less feed than high-RFI calves when calves were separated based on ±0.5 SD from the mean.

In our study, the low-RFI heifers had greater (P < 0.001) G:F than heifers with high-RFI. This difference (23.1%) was substantially larger than those found by Basarab et al. (2003) and Baker et al. (2006), who reported differences of 9.4 and 13%, respectively, between calves with divergent RFI phenotypes based on ±0.5 SD from mean RFI. These results were interpreted to suggest that low-RFI heifers gain more BW per kilogram of feed than high-RFI heifers and, hence, have greater feed efficiency.

**Feeding Behavior**

Heifers with high-RFI had head-down durations that were 22.9% less (P < 0.001) than their low-RFI counterparts (Table 2), indicating that the most-efficient animals spent more time feeding per day than the least-efficient animals. Conversely, meal duration was similar (P = 0.97) between the high- and low-RFI heifers (Ta-
These results differ from those of other researchers who used radio frequency identification (RFID) feed-intake measurement systems to calculate feeding-behavior traits. Nkrumah et al. (2007), Paddock et al. (2008), and Lancaster et al. (2009) reported that high-RFI cattle had greater meal duration than low-RFI cattle; moreover, Nkrumah et al. (2007), using an RFID-based system, reported that steers with high RFI had 40% greater head-down duration than steers with low RFI. Schwartzkopf-Genswein et al. (2002), using a similar RFID system, reported that DMI and daily meal duration were positively associated and that the most-efficient animals spent less total time at the feed bunk. Our results were interpreted to indicate that future studies should evaluate head-down feeding events in relation to RFI.

The high-RFI heifers in our study had more (P < 0.001) head-down feeding events per day (119.1 ± 3.9 vs. 90.5 ± 3.0, respectively) but no difference in the number of meal events (Table 2). No previous studies that have used RFID feed-intake systems reported head-down feeding events; moreover, previous reports on meal events have been inconsistent. Paddock et al. (2008) reported no correlation between meal frequency and RFI in Angus bulls fed corn silage-based diets. In contrast, Nkrumah et al. (2007) and Lancaster et al. (2009) reported positive correlations between meal frequency and RFI in finishing steers and growing Angus bulls, respectively.

In this study, the high-RFI heifers had greater (P < 0.001) eating rates than the low-RFI heifers, based on head-down duration and meal duration. Paddock et al. (2008) found a positive association between meal-eating rate and RFI in Angus bulls. In contrast, Lancaster et al. (2009) reported that meal-eating rate and RFI were not related.

The results of this study, particularly regarding meal duration, contrast with previous studies that have analyzed feeding-behavior traits in relation to RFI. Most studies have used RFID systems to characterize feeding-behavior traits (Schwartzkopf-Genswein et al., 2002; Nkrumah et al., 2007; Paddock et al., 2008; Lancaster et al., 2009). There were several fundamental differences between behavioral data collected in our study and data obtained through the use of RFID systems. This study visually quantified head-down feeding behavior, whereas studies that used RFID systems of measurement recorded read time (2 to 6 s) of an RFID transponder. Head-down duration, as presented in RFID studies (Lancaster et al., 2009), was calculated as the number of transponder readings multiplied by the recorded read time. It is often assumed in RFID studies that transponder readings occur when the head of the animal is within the feeder, but Schwartzkopf-Genswein et al. (1999) determined that the antenna in the feed bunk detected the transponders whenever the cattle were within 50 cm of the feed bunk.

In both methodologies, meal duration is computed in a similar manner. It is unclear how video surveillance may have affected our results compared with using RFID systems, but Sowell et al. (1998) reported that the average observed duration of a feeding event when quantified visually was 13 s different from that collected electronically by an RFID system.

The mean daily meal durations for studies using RFID systems (Schwartzkopf-Genswein et al., 2002; Nkrumah et al., 2007; Lancaster et al., 2009) ranged from 66 to 113 min/d, which were substantially less than those measured in our study (220 min/d). One key reason for these differences could be the method of housing and competition for feed. Lancaster et al. (2009) had approximately 60 bulls per pen competing for 9 feeders, whereas Schwartzkopf-Genswein et al. (2002) housed the steers and heifers in individual pens. Our study housed the heifers in groups of 6, with each heifer assigned to an individual feeder, so that all heifers could eat simultaneously. The lack of competition for feed in our study may have altered feeding behavior. De Haer and Merks (1992) reported that pigs housed in groups ate faster, spent less time eating per day, and had fewer meals per day than those in individual pens; however, Paddock et al. (2008), using an RFID system, reported

### Table 2. Head-down feeding event traits (mean ± SEM) for high residual feed intake (RFI) and low RFI growing Brangus heifers

<table>
<thead>
<tr>
<th>Trait</th>
<th>High RFI</th>
<th>Low RFI</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head-down duration, min/d</td>
<td>123.5 ± 4.2</td>
<td>151.7 ± 3.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Head-down frequency, events/d</td>
<td>119.1 ± 3.9</td>
<td>90.5 ± 3.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Head-down eating rate, g/min</td>
<td>101.6 ± 4.0</td>
<td>62.4 ± 2.0</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

### Table 3. Meal traits (mean ± SEM) for high residual feed intake (RFI) and low RFI growing Brangus heifers

<table>
<thead>
<tr>
<th>Trait</th>
<th>High RFI</th>
<th>Low RFI</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meal duration, min/d</td>
<td>219.9 ± 3.5</td>
<td>219.6 ± 5.5</td>
<td>0.97</td>
</tr>
<tr>
<td>Meal frequency, events/d</td>
<td>14.75 ± 0.34</td>
<td>15.06 ± 0.34</td>
<td>0.53</td>
</tr>
<tr>
<td>Meal eating rate, g/min</td>
<td>49.5 ± 0.94</td>
<td>41.7 ± 1.04</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
that daily meal duration was similar to that in our study (202 min/d for Angus bulls). In addition to the differences between RFID and visual quantification systems discussed previously, heifers have been reported to have longer daily feeding durations and greater feeding frequencies than steers (Schwartzkopf-Genswein et al., 2002). Furthermore, Paddock et al. (2008) reported that meal duration, frequency, and eating rate differed between Angus and Red Angus bulls.

In conclusion, cattle in our study that spent a greater amount of time feeding at a slower rate were more efficient (i.e., had lesser RFI) than cattle that ate more rapidly for a shorter period of time. Previous studies have quantified only meals instead of head-down feeding events when studying feeding behavior. We concluded that measuring the duration and frequency of head-down feeding events with greater precision could prove to be more useful as an indicator of RFI than meal data. In addition, eating-rate traits, which are less frequently reported than other measures of feeding behavior, were more strongly associated with RFI than feeding duration and frequency traits. Based on our results and those from previous studies, we concluded that feeding behavior was related to RFI; however, differences in methodology, breed type, sex, or diet may have resulted in inconsistencies among studies. Further research is necessary to elucidate the effects of these factors on the relationship between feeding behavior and RFI before feeding behavior will be useful as an early indicator of RFI.

LITERATURE CITED


