CHARACTERIZATION OF FEEDING BEHAVIOR TRAITS AND ASSOCIATIONS WITH PERFORMANCE AND FEED EFFICIENCY IN FINISHING BEEF CATTLE

A Thesis

by

EGLEU DIOMEDES MARINHO MENDES

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2010

Major Subject: Animal Science

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Approved by:

Co-Chairs of Committee,	Gordon E. Carstens
	Luis O. Tedeschi
Committee Member,	William E. Pinchak
Head of Department,	Gary R. Acuff

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ABSTRACT

Characterization of Feeding Behavior Traits and Associations with Performance and Feed Efficiency in Finishing Beef Cattle. (August 2010)

Egleu Diomedes Marinho Mendes, B.S., Universidade Federal de Minas Gerais

Co-Chairs of Advisory Committee: Dr. Gordon E. Carstens
Dr. Luis O. Tedeschi

The first objective of this study was to validate the feeding behavior measurements from a radio frequency electronic system (GrowSafe™ System Ltd., Airdrie, AB, Canada) and examine the software sensitivity to different parameter settings (MPS) to quantify feeding behavior traits. Data was continuously recorded 24 h per day using the GrowSafe™ system for 32 heifers over 81-d. Ten animals were randomly selected and evaluated over 6-d using time-lapse video recordings. Different parameter settings (MPS) from the electronic system (GrowSafe™) used to record feeding behavior data, bunk visits (BV) frequency and BV duration, were compared with the observed (video) values.

The second objective of this study was to quantify meal criterion; examine the associations between feeding behavior traits, performance, and feed efficiency; and the effects of breed type on feed efficiency (residual feed intake - RFI) and feeding behavior traits in heifers fed high-grain diets.

Results from study one demonstrated that the GrowSafe™ system 4000E could accurately predict BV and meal data compared to observed data. The 100 s, used for the maximum duration between consecutive EID recordings to end an uninterrupted BV, was the appropriate MPS to predict BV frequency and duration, and meal frequency and duration compared to observed data using the GrowSafe™ 4000E system. The system's ability to detect the animal's presence or absence at the feed bunk was 86.4 and 99.6%, respectively.

Results from the second study demonstrated that the meal criterion for heifers fed high-grain diets was 13.8 min. The 4 methods to calculate meal criterion demonstrated no differences in results of frequencies and durations of meal and the number of bunk visits per meal. Similar phenotypic correlations were found between the feeding behavior traits with RFI derived from the base model or with adjustments for final back fat. The adjustment of RFI to final back fat changed the RFI rank between breeds. The addition of feeding behavior traits to the RFI base model could accounted up to 40.4% of the variation in DMI not explained by ADG or MBW.

DEDICATION

The dedication for this thesis goes to all my family members who supported me during the time that I was at Texas A&M University, especially to my mother Irani Marinho and my father Sebastião Mendes da Silva who always dedicated their lives to the best for their children. Also a special thanks to my brothers, Aglauro and Glaucos, and to my friends Leandro Novaes, Geovana Mattos, and Samuel Boson, who I also considered part of my family.

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I would like to thank the committee co-chairs, Dr. Carstens and Dr. Tedeschi, and member, Dr. Pinchak, for the support and guidance given to accomplish this work. Also, I wish the best to my friends and co-workers, Flávio Ribeiro, André Aguiar, Aimee Hafla, Jayton Bayley, Joel Walter, and Robynne Gomez who helped and supported me during all the projects and classes at Texas A&M University. Thanks to Dr. Gale Wagner who helped me from my first steps at Texas A&M University, and my advisor during my undergraduate studies in Brazil, Dr. Ronaldo Braga Reis, who has always supported me during my undergraduate and graduate studies.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Overview

Recent increases in the costs of feed inputs have prompted considerable interest in the use of genetic selection strategies to improve feed efficiency in beef cattle. It is well known that the cost of feed is the highest variable expense associated with the production of beef (Archer et al., 1999; Arthur et al., 2001a; Basarab et al., 2007; Lancaster et al., 2009; Moore et al., 2009). Thus, breeding programs that can produce animals that require fewer feed inputs without negatively impacting performance traits will improve the profitability of integrated beef cattle production systems. Fox et al. (2001) estimated that improving feed efficiency by 10% will increase profits by 43%, whereas, improving ADG by 10% will increase profits by only 20%.

There is a worldwide research to characterize traits related to animal feed efficiency (Nkrumah et al., 2007). Studies that evaluated variations in feed efficiency traits generally were based on the analysis of outputs (e.g., weight gain or carcass traits) rather than input (e.g., feed) traits (Bingham et al., 2009; Lancaster et al., 2009). Recent studies had demonstrated the potential of the evaluation of individual feed consumption in selection for more efficient animals (Archer et al., 1999, Crews, 2005, Robinson and Oddy, 2004). Few efforts were put in research of feeding behavior traits (Weary et al., 2009) that had shown to be related to animal performance and feed efficiency traits (Basarab et al., 2007; Cammack et al., 2005; Lancaster et al., 2009; Nkrumah et al.,

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This thesis follows the style of Journal of Animal Science.

2007; Rauw et al., 2006a; Robinson and Oddy, 2004).

Feed Efficiency, Residual Feed Intake (RFI)

Numerous traits involving the ratio of inputs and outputs have been defined to measure feed efficiency in beef cattle (Carstens and Tedeschi, 2006; Crews, 2005). One of the most commonly used traits to select animals for feed efficiency is F:G, or feed conversion ratio. Previous research in beef cattle has demonstrated that considerable genetic variation exists for feed intake and F:G (Archer et al., 1999; Arthur et al., 2001a; Arthur et al., 2001b). Besides F:G, other traits can be used to evaluate animal feed efficiency: gross efficiency (inverse of F:G), maintenance efficiency, partial efficiency of growth, cow/calf efficiency, and residual feed intake (RFI; Archer et al., 1999).

Although F:G has been shown to be moderately heritable in beef cattle, it is phenotypically and genetically correlated in a negative manner with growth traits (Crews, 2005). Therefore mature size, which is associated with feed requirements of the breeding herd will be increased if F:G is used as a selection criterion for feed efficiency (Archer et al., 1999; Crews, 2005; Moore et al., 2009; Nkrumah et al., 2004). Feed to gain is a gross measurement of efficiency that does not attempt to partition feed intake into maintenance and growth requirements (Carstens and Tedeschi, 2006), therefore selection for improved F:G in growing animals will not necessarily improve feed efficiency of mature animals (Archer et al., 2002).

A desirable feed efficiency trait for use in breeding programs would account for genetic variation in feed efficiency, and would be independent of genetic variation in output traits (e.g., growth, lactation; Carstens and Tedeschi, 2006). According to these requirements, RFI would be an appropriate trait to use in breeding programs focused in improving feed efficiency.

Residual feed intake, the difference between observed and expected intake, was first proposed by Koch et al. (1963) who suggested that feed efficiency should be computed as a function of intake and gain over the time. The typical model used to calculate RFI involves linear regression of DMI on daily gain and metabolic body weight ($BW^{0.75}$) as described by Crews (2005):

$$y = \beta_0 + \beta_1 (ADG) + \beta_2 (MBW) + RFI$$

where y is feed intake, β_0 is the regression intercept, β_1 is partial regression of daily intake on average daily gain (ADG), and β_2 is the partial regression of daily intake on body weight expressed as mid-test metabolic body weight (MBW).

In the last decade, RFI has been evaluated as an alternative trait for use in selection programs to improve feed efficiency. The primary advantage of RFI as a selection trait for feed efficiency is that it is phenotypically and genetically independent of level of production (Carstens and Tedeschi, 2006; Herd and Arthur, 2009; Herd and Bishop, 2000). Consequently, selection to improve genetic merit for RFI will not increase mature cow size and consequently feed requirements (Archer et al., 1999). In beef cattle, RFI is moderately heritable ranging from 0.16 to 0.47 (Arthur et al., 2001a; Crews et al., 2003; Herd and Bishop, 2000).

To further improve accuracy of selected animals for RFI, additional research is needed to identify indicators traits that are predictive of RFI. Studies have shown that behavioral traits such as frequency and duration of feeding events are moderately correlated phenotypically (Lancaster et al., 2009) and genotypically (Nkrumah et al,

2007) with RFI. Advances in technology have reduced the time and expense of measuring feeding behavior traits (Eradus and Jansen, 1999) in animals. Thus, it is feasible to consider the use of these traits to identify more efficient animals and optimize the genetic selection for RFI.

Animal Behavior Characteristics

It has been demonstrated that cattle present various behavioral patterns in response to adaptations to various environments (Hohenboken, 1985; Stroup et al., 1987), which are often associated with variation in production traits (e.g., ADG). Scientists have been examining animal behavior characteristics and their associations with animal productivity and sickness for a long time (Weary et al., 2009). However, until the recent advances in RFID systems, it was difficult to evaluate behavioral traits in large groups of animals.

Computerized systems that use RFID-based technologies allow more animals to be evaluated at one time, and facilitate the measurement of unique animal characteristics (Eradus and Jansen, 1999). Feeding behavior data collected from computerized system have been used for early detection of respiratory diseases (González et al., 2008; Quimby et al., 2001; Sowell et al., 1998), metritis (Weary et al., 2009), evaluation of acidosis (Robles et al., 2007; Schwartzkopf-Genswein et al., 2003), and strategies to improve bunk management (Gibb and McAllister, 1999; Schwartzkopf-Genswein et al., 2002; Schwartzkopf-Genswein et al., 2004).

More recently, the associations between feeding behavior and feed intake traits have been examined to increase understanding of factors that influence inter-animal variation in feed efficiency of beef cattle (Bingham et al., 2009; Kelly et al., 2010; Lancaster et al., 2009; Nkrumah et al, 2007; Robinson and Oddy, 2004). Lancaster et al. (2009) found that variation in feeding behavior traits accounted for 35% of variation not explained by ADG, MBW ($BW^{0.75}$), and ultrasound traits. These findings reinforce the need to more fully understand how feeding behavior traits are linked to biologically relevant processes associated with efficient utilization of feed.

Feeding Behavior Evaluation

In general, there are a number of feeding behavior traits that are typically evaluated including bunk visit (BV) frequency and duration, meal frequency and duration, average length and size of meals and eating rate. BV frequency (event/d) is defined as the number of visits the animal makes to the feeding bunk on a daily basis, and BV duration (min/d) is the sum of the time the animal at the feed bunk.

Some studies use the term BV to define visits to the feed bunk with or without consumption of feed, but others studies consider BV only when the animal consumed feed. For this study, BV will be defined as a visit to the bunk with or without consumption of feed, and feeding bout defined as a visit to the feed bunk with consumption of feed. A meal is defined as a cluster of BV events, which can be distinguished from the next meal event by a non-feeding interval that exceeds a meal criterion. Meal criterion is defined as an estimate of the longest non-feeding interval that was considered to be part of a meal (Tolkamp and Kyriazakis, 1999a; Yeates et al., 2002).

The rationale for clustering bunk visits into meals is related to physiological factors that affect animal satiety such as feed digestion and stomach distention (Forbes, 1985), which are associated with the probability that an animal will initiate another feeding bout (Tolkamp and Kyriazakis, 1999a). The non-feeding interval between BV varies according to the animal satiety and this variation can be used to calculate the meal criterion (Tolkamp et al., 1998; Tolkamp and Kyriazakis, 1999a; Yeates et al., 2001; Yeates et al., 2002). The biological basis for evaluating meal events in dairy cattle has been reviewed by Tolkamp et al. (2000). In dairy cattle, DeVries et al. (2003a) reported moderate to high repeatabilities for meal-behavior traits during early (0.34 to 0.72) and late (0.22 to 0.75) lactation.

There is large variation in results across studies for feeding behavior data (Table 1.1). Some of this variation can be related to differences in the methodology applied to obtain the feeding behavior data, especially when different meal criterion is applied to the calculation of meal frequency and duration (Tolkamp et al., 2000). The frequency and duration of meal events are dependent on the value of meal criterion value used in the study. Large variations in meal criterion, ranging from 2 to 59 min have been reported (Tolkamp et al, 2000; Table 1.1). Likewise, variations in studies for meal frequency, 4 to 17.7 events d^{-1}, and meal duration, 29.4 to 333 min d^{-1}, were found (Table 1.1). Not only the differences in feeding behavior traits between studies were related to feeding behavior calculations, but breedtype, gender, diet, and feeding

Table 1.1. Differences across studies for feeding behavior traits measured as bunk visit (BV) frequency and duration and meal frequency and duration

Gender[1]	Animals	Breed	System	Meal Criteria, min	BV[1] frequency, events/d	Meal frequency, events/d	BV duration, min/d	Meal duration, min/d	Source
S	341	Angus	GrowSafe	5.0		6.9 to 8.7		85 to 118	Lancaster et al., 2009
H	115	Brangus	Calan gate	5.0		15.0		220	Bingham et al., 2009
S	234	Crossbred	GrowSafe	5		8.7 to 10.2		105 to 162	Schwartzkopf-Genswein et al., 2004
S, H	12	Charolais	GrowSafe	5		15.4 to 17.7		101 to 131	Schwartzkopf-Genswein et al., 2002
H	6	Holstein	Insentec	17.9		9.6 to 11.0		140 to 188	Devries et al., 2009
H	4	Holstein	A&D	27 to 39		9 to 10		310 to 333	Robles et al., 2007
C	142	Holstein	Merican	46.7 to 58.6		4 to 4.9		163 to 192	Bach et al., 2006
S			GrowSafe	5		8.6		87.9	Basarab et al., 2003
C	12	Holstein	GrowSafe	27.7		5 to 10		32 to 57	DeVries et al., 2003b
C	5	Holstein	Mounted[2]	20		12.1		253.6	Vasilatos and Wangsness, 1979
S	5	Holstein	Mounted	20		10.0		220.9	Chase et al., 1976
S	174	Crossbred beef	GrowSafe	-	27.7		72.4		Basarab et al., 2007
S	464	Crossbred	GrowSafe	-	29.6		66.0		Nkrumah et al., 2007
S	27	Angus x Charolais	GrowSafe	-	18 to 35		48 to 74		Nkrumah et al., 2006
S, H	1481	Tropical and Temperate	TIRIS	-	7.9 to 18.8		77 to 105		Robinson and Oddy, 2004
C	37	Holstein	Insentec	47.7	31.6 to 43.1	5.8 to 6.7	140 to 152		Tolkamp et al., 2000

[1] B = bulls; S = steer, H = heifer, C = cow; [2]Mounted = the system was mounted using a unique electronic identification systems.

management practices also influenced the feeding behavior variation (DeVries and von Keyserlingk, 2009; Gibb et al., 1998; Golden et al., 2008; Robles et al., 2007; Tolkamp et al., 2000).

Many studies have examined the relationships between feeding behavior traits and feed efficiency in poultry (Van Eerden et al., 2004), swine (de Haer et al., 1993; Rauw et al., 2006a, b; Von Felde et al., 1996), sheep (Cammack et al., 2005), dairy cattle (Veerkamp et al., 1995;), and beef cattle (Basarab et al., 2007).

A summary of phenotypic correlations between feeding behavior, feed efficiency, and performance traits are presented in Table 1.2. Differences in methodologies used to evaluate feeding behavior data contribute to some of variation in the relationships between the traits. The summary of beef cattle studies (Table 1.2) indicate that both BV and meal data are moderate to high correlated with RFI. Bunk visit duration was moderately correlated to DMI and ADG, but not with F:G (Table 1.2). Meal frequency was not correlated with F:G, DMI, or ADG, and eating rate was moderately correlated with DMI and ADG, but not related to F:G (Table 1.2). This implies that more efficient animals (low RFI) spend less time and had fewer visits at the feed bunk compared to more efficient animals.

The relationship of feeding behavior to feed efficiency and performance traits demonstrated that feeding behavior traits may be a predictor of economically desired traits. Lancaster et al, (2009), working with beef cattle, found that feeding behavior traits accounted 35% of the variation in DMI that was not explained by ADG, MBW, and ultrasound traits. Similarly, de Haer et al. (1993), working with pigs, reported that feeding behavior traits accounted for 44% of the variation in RFI.

Table 1.2. Phenotypic correlation between feeding behavior and performance and feed efficiency traits in beef cattle and other species

Trait	RFI	F:G	DMI	ADG
Beef Cattle				
Meal frequency, event/d	**0.26**[c]	-0.07[c]	0.09[h]; -0.06[c]	0.01[c]
Meal duration, min/d	**0.41**[c]	**-0.17**[h]; -0.03[c]	**0.38**[h]; **0.23**[c]	**0.14**[h]; **0.17**[c]
BV frequency, event/d	**0.18**[d]; 0.18[g]; **0.50**[a]	**-0.13**[d]; -0.08[g]	**-0.21**[d]; 0.18[g]	-0.04[d]; 0.13[g]
BV duration, min/d	**0.49**[d]; 0.16[g;]; **0.36**[a]	-0.06[d]; -0.05[g]; -0.01[c]	**0.27**[d]; 0.30[g]	**0.25**[d]; 0.23[g]
Eating rate, g/min	0.14[g]; 0.08[c]	-0.05[g]; 0.02[c]	0.26[g]; **0.53**[c]	0.18[g]; **0.32**[c]
Swine and lamb				
BV frequency, event/d	0.10[b]; 0 .13[i]; 0.17[f]; -0.01[e]	0.02[i]	0.14[b]; 0.07[i]; -0.06[f]; **-0.19**[e]	0.03[i]; **0.16**[e]
BV duration, min/d	0.10[b]; 0.37[i]; 0.08[f]; **0.15**[e]	0.14[i]	0.09[b]; 0.40[i]; **0.21**[f]; **0.28**[e]	0.20[i]; **0.19**[e]
Eating rate, g/min	0.13[i]; -0.01[e]	-0.07[i]	0.26[i]; **0.26**[e]	0.23[i]; **0.38**[e]

[a]Basarab et al., 2007; [b]Cammack et al. (2005); [c]Lancaster et al. (2009); [d]Nkrumah et al. (2007); [e]Rauw et al. (2006a); [f]Rauw et al. (2006b); [g]Robinson and Oddy (2004); [h]Schwartzkopf-Genswein et al. (2002); [i]Von Felde et al. (1996)

Bold values are correlated with $P < 0.05$

There were no specification for the P-value for the phenotypic correlation for Cammack et al. (2005), Robinson and Oddy (2004), and Von Felde et al. (1996).

Meal Criterion Calculation

Few studies have characterized meal criterion in cattle, which is an estimate of the longest non-feeding interval that is considered to be part of a meal (Tolkamp et al., 1998; Tolkamp and Kyriazakis, 1999a, b; Yeates et al., 2001; Yeates et al., 2002).

Tolkamp and Kyriazakis (1999) reviewed 5 methods to calculate meal criterion and concluded that the most appropriated method to calculate meal criterion involved fitting a log-transformed equation to non-feeding interval data with a 2-pool Gaussian distributions; with first and second pools representing the non-feeding intervals within and between meals, respectively. Using this approach, the meal criterion could be determined as the intersection of the intra-meal and inter-meal distributions of non-feeding intervals. Tolkamp and Kyriazakis (1999) also described the use of a 3-pool distribution to determined meal criterion, which was later reviewed by Yates et al. (2001) for the use of a different distribution methodology. The 3-pool distribution method of calculation for meal criterion includes non-feeding intervals with visits to the drinking trough, which may restrict the data analysis to electronic systems that measures visits to the water trough. Yates et al. (2001) also evaluated the use of the 2-pool distribution using different distribution models, but the conclusions were not clear on the biological significance of the changes in distribution models.

The 2-pool distribution method has been applied to feeding behavior data collected from dairy cattle to evaluate meal criterion (DeVries et al., 2003a), but few studies have used this methodology in beef cattle. To better evaluate variation in feeding behavior traits, it is recommended that an objective calculation for meal criterion should be used in beef cattle. This will facilitate the comparison of differences responses across studies that evaluate feeding behavior traits.

CHAPTER II

TECHNICAL NOTE: VALIDATION OF A RADIO FREQUENCY SYSTEM TO MEASURE FEEDING BEHAVIOR IN BEEF CATTLE

Introduction

The use of electronic identification systems associated to computerized technology in beef cattle may increase the accuracy and precision of the data to assess variations and relationships of feed efficiency, production, and feeding behavior traits among individuals. It may also reduce the time and labor needed to analyze the data when compared to current methods such as video and visual evaluations (Eradus and Jansen, 1999; Schwartzkopf-Genswein et al., 2002).

Radio frequency identification (RFID) systems have been used to measure intake and feeding behavior from individual animals housed in group pens. Studies that use this technology have evaluated the relationships between individual animal efficiency (e.g., residual feed intake), production (e.g., ADG) and feeding behavior data (Lancaster et al., 2009; Nkrumah et al., 2007).

Studies had shown that RFID-based systems are reliable sources to measure animal intake and feeding behavior traits (Bach et al., 2004; Chapinal et al., 2007; DeVries et al., 2003b; Schwartzkopf-Genswein et al., 1999). Until the present date, no study have evaluated the GrowSafe™ 4000E system version (GrowSafe™ System Ltd., Airdrie, AB, Canada), which measures individual feed intake and the feeding behavior data based on individual bunk visits (BV), nor the differences in the system configuration inputs that generate the feeding behavior data.

The GrowSafe™ system is being used in many research institutions and private owners in the US. Therefore, it is important to understand the influence of different configuration settings on the accuracy and precision of the calcuations for feeding behavioral data by the GrowSafe™ system. The objectives for this study was to identify if the GrowSafe™ system was able to accurately predict feeding behavior data measured as BV and meal frequencies and durations.

Material and Methods

All animal care and use procedures were in accordance with guidelines for use of Animals in Agricultural Teaching and Research and as approved by the Texas A&M University Institutional Animal Care and Use Committee.

Thirty two heifers (4 Angus, 9 Braford, 9 Brangus, and 10 Simbrah) with an initial BW of 284 ± 28 kg were used in an 81-d study. Upon arrival, heifers were fitted with passive, half-duplex, electronic identification (EID) ear tags (Allflex USA Inc., Dallas-Fort Worth, TX), and housed in a pen (12 x 28 m) equipped with 4 electronic feed bunks (GrowSafe™ 4000E; GrowSafe™ System Ltd., Airdrie, AB, Canada), at the Beef Cattle Systems Research Center (College Station, TX). Heifers were adapted to a high grain diet (3.01 Mcal ME/kg, 13% CP on DM basis) during a 28-d period using 3 step-up diets prior to the start of the study. The final experimental diet consisted of 73.7% dry-rolled corn, 6.0% hay, 6.0% cottonseed meal, 6.0% cottonseed hulls, 5.0% molasses, 2.5% mineral-vitamin premix, and 0.8% urea, and was offered ad libitum twice daily at 0830 and 1630 h.

Ten heifers were randomly selected and individually identified using an adhesive marker (Estrotec™, Spring Valley, WI) prior to the initiation of video recordings. To facilitate observational data collection, 2 groups of 5 heifers were evaluated separately for 3 consecutive d (2 blocks) on days 56-58 and 75-77 of the study. A video surveillance camera (HIKVISION model DS-2CD862, Hikvision Digital Technology, Hangzhou, China) was positioned 7 m in front of the 4 electronic feed bunks in order to record animals entering and exiting the feed bunks. Three 500-watt lights were placed above the feed bunks to facilitate collection of observational data at night. The clocks on the video recorder and the computer collecting system data were synchronized, and the video output continuously recorded using Hikvision iVMS-4000 V2.02 software (Hikvision Digital Technology, Hangzhou, China) on a separate computer. Two trained observers recorded animal ID and the start and end times for each visit to the feed bunks using Video Dub 1.5 (http://www.dvdvideosoft.com) to evaluate time-lapse video recordings.

The GrowSafe™ System

The GrowSafe™ 4000E system used for this study (Figure 2.1) consisted of 4 electronic feed bunks, with each bunk equipped with an antenna to detect animal presence at the feed bunk, load cells to measure feed disappearance, and a stanchion equipped with neck bars to allow only one animal to enter the feed bunk at a time. During the study, animals were allowed access to each of the 4 feed bunks. The GrowSafe™ system was designed to monitor feeding behavior by continuously detecting for animal presence at a feed bunk once an EID crosses through the neck bars of the

Figure 2.1. Visualization of the GrowSafe™ system used in this study.

stanchion. Concurrently, the system measures individual feed intake by continuously measuring feed disappearance during each BV. These data (EID number, bunk number, time stamp of each transponder recording, and scale weight) were continuously recorded via wireless transfer to a computer located next to the feed bunks. For the GrowSafe™ system used in this study, the EID recording rate was 2.0 s.

Data Analysis

A subroutine of the GrowSafe™ data acquisition software (DAQ; version 9.25), Process Feed Intakes (version 7.29), was used to compute feed intake and BV data. All parameter settings used to compute feed intake and feeding behavior data were default values as described in the GrowSafe™ manual (GrowSafe™, 2004, 2009) except for the parameter setting (**MPS**) to define the maximum duration between consecutive EID recordings to end uninterrupted BV. Uninterrupted BV occurs when the animal EID is not detected by the system for extended periods of time (Scenario 1; Figure 2.2). When intervals between 2 consecutive EID recordings exceed the MPS, the time of the last EID recording is used to end the BV. The MPS does not apply to interrupted BV, which occur when the animal EID is detected in another feed bunk or when another animal EID is detected at the same bunk (Scenarios 2 and 3; Figure 2.2).To evaluate the sensitivity of MPS, feeding behavior data were computed at MPS values of 30, 60, 100, 150, and 300 s (default value = 300 s), and electronic data compared to observed data from time-lapse video recordings.

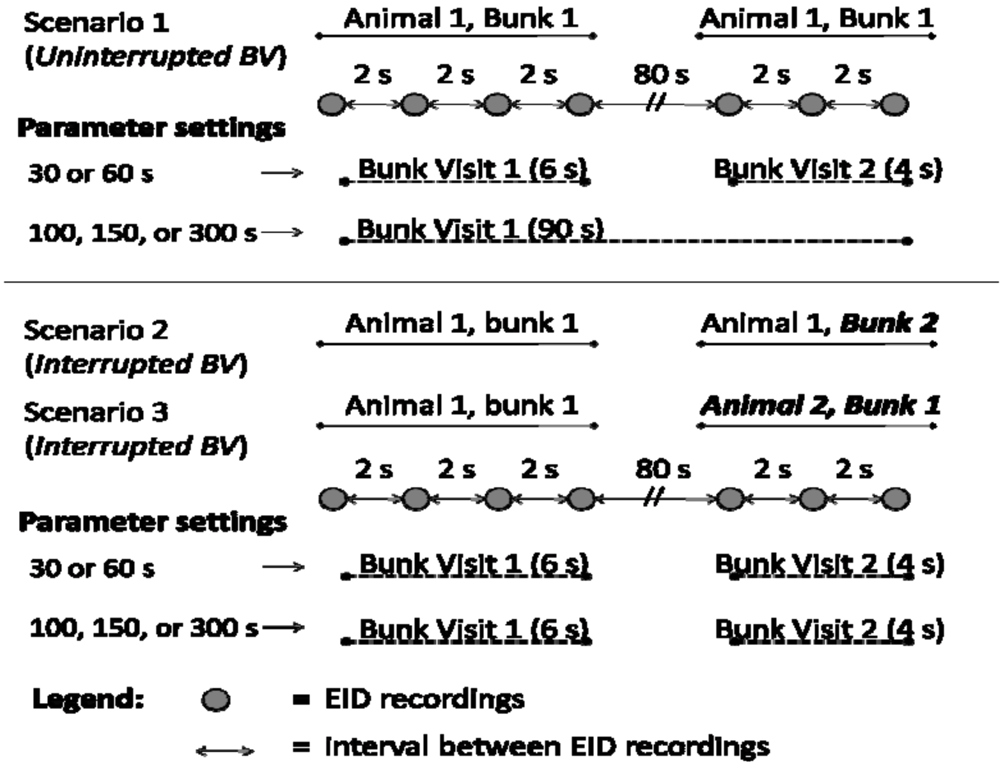

Figure 2.2. Differences in bunk visits (BV) frequency and duration using different parameter settings (MPS) for maximum duration between EID recordings; scenario 1 (uninterrupted BV): BV frequency decrease and BV duration increase if the MPS is higher than the duration between EID recordings; scenario 2 (interrupted BV): BV frequency and duration are the same for all the MPS since the animal entered to another bunk; scenario 3 (interrupted BV): BV frequency and duration are the same for all MPS since another animal entered the same bunk.

Meal-based feeding behavior traits were calculated using a predetermined meal criterion, which was defined as the minimum interval between BV before the next BV is considered part of a new meal (Tolkamp and Kyriazakis, 1999; Yeates et al., 2002; Figure 2.3). For this study, a meal criterion of 5 min was used as reported by Schwartzkopf-Genswein et al. (2002). Another subroutine from the GrowSafe™ DAQ software (version 9.25), Process Meal Events (version 1.04), was used to generate the meal data from the five MPS. In addition, the number of BV per meal was calculated for both observed and electronic. Estimates of feed intake derived from the system were calculated at MPS values of 30, 60, 100, 150 and 300 s, to determine the sensitivity of MPS on this measurement.

Data generated by the system during the 81-d trial was omitted from analyses because of system failure (power outage, equipment malfunction), system maintenance, or when the proportion of daily feed supply assigned to individual animals within a pen was less than 95%. The average feed disappearance during the study, and the first and second video recording periods were 98.2, 98.7% and 97.6%, respectively.

Statistical and Sensitivity Analyses

Animal was considered the experimental unit for all data analyzed in this study. Observed (video) and electronic (GrowSafe™ system) measurements of feeding behavior were compared using a PROC MIXED model that included treatment (30, 60, 100, 150, and 300 s MPS) as a fixed effect and block, animal within block, and day within block as random effects. Observed data were compared to electronic feeding behavior data calculated at multiple MPS values using the contrast statement of SAS

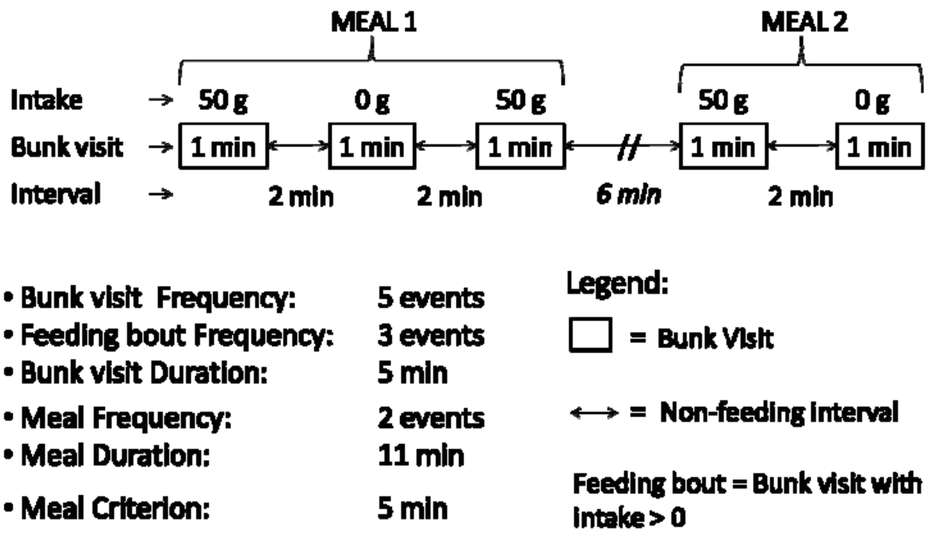

Figure 2.3. Feeding behavior definitions scheme.

(SAS Institute Inc., Cary, NC). A similar model was used to compare electronic estimates of feed intake calculated at a MPS value of 300 s (system default) to estimates of feed intake calculated at MPS values of 30, 60, 100, and 150 s.

Observed data (dependent variables) were regressed on the electronic feeding behavior data (independent variables) to obtain an estimate of precision (R^2). The mean square error of prediction (MSEP), mean bias (MB), model accuracy (Cb), and concordance correlation coefficient (CCC) were further computed to assess the accuracy of the GrowSafe™ system to predict feeding behavior traits. The Model Evaluation System (v. 3.1.8; http://nutritionmodels.tamu.edu/mes.htm) was used for these calculations (Tedeschi, 2006).

As described by DeVries et al. (2003b), sensitivity (the likelihood that an animal present at the feed bunk is detected present by the system) and specificity (the likelihood that an animal is absent from the feed bunk is detected absent by the system) were evaluated by determining feed bunk presence and absence of observed and electronic BV duration (using optimal MPS value) for each min of the day during the video recording periods.

Results

Overall means (± SE) for feeding behavior traits and DMI, using the system default value of 300 s for maximum duration between consecutive EID recordings to end an uninterrupted BV, are presented in Table 2.1. Averages for duration traits and DMI collected during the 6 observational d were numerically within ± 5% of the data collected for the same heifer during the entire 81-d trial, but the frequency traits were

Table 2.1. Feeding behavior and intake means (± SE) of GrowSafe™ data collected during the observational period (6-d), days 56 to 58 and 75 to 77 of trial, and the entire trial (81-d) for heifers (n=10) used in this study

Trait[1]	6-d Period	Entire Trial
Frequency traits, events/d		
BV frequency	46.1 ± 2.2	49.9 ± 1.9
FB frequency	42.6 ± 1.8	46.3 ± 1.8
Meal frequency	13.4 ± 0.8	12.3 ± 0.9
Duration traits, min/d		
BV duration	74.3 ± 3.7	74.9 ± 3.8
FB duration	73.4 ± 3.8	73.2 ± 5.7
Meal duration	119.3 ± 4.4	116.5 ± 4.2
Feed intake, kg/d		
DMI	9.89 ± 0.2	9.64 ± 0.2

[1] BV = bunk visit; FB = feeding bout (BV with intake > 0); the system default value of 300 s for maximum duration between consecutive EID recordings to terminate an uninterrupted BV was used to generate this data.

numerically 8.2 and 8.7% higher and FB frequencies, respectively, and 8.2% lower for meal frequency during the 81-d trial compared to the 6-d of time-lapse recordings.

Bunk Visit Calculations

The average across all the MPS values for observed and electronic BV data are presented in Table 2.2. Frequencies and durations of BV were affected by treatment (*P* < 0.05), but not block (*P* > 0.30) or day within block (*P* > 0.07). Electronic BV frequencies at MPS of 60 and 100 s did not differ (P > 0.07) from observed BV frequencies. However, electronic BV frequency at MPS of 30 s was greater (P < 0.01), and electronic BV frequencies at MPS of 150 and 300 s were less (P < 0.01) than observed BV frequencies. Similar to BV frequency, the duration of BV determined by the system at MPS of 100 s was not different (P > 0.16) than observed BV durations. Electronic BV durations were less (P < 0.01) than observed values at MPS of 30 and 60 s, but 150 and 300 s were not different (P > 0.16) than observed BV durations.

The decrease in frequencies of BV and the increase in durations of BV (Figure 2.4) determined by the system as MPS increased from 30 to 300 s can be explained by how BV is computed based on the maximum duration between consecutive EID recordings to end an uninterrupted BV (Figure 2.2). In calculating uninterrupted BV, those in-to-out BV that are separated by non-feedings intervals smaller than the MPS value are combined (Scenario 1; Figure 2.2). Consequently, BV calculated at small MPS values had greater frequency than BV calculated at large MPS. The opposite was applied to BV durations, as the non-feeding intervals were combined with the use of higher MPS, the duration was increased (Scenario 1; Figure 2.2). The purpose of the MPS, used in the BV visits calculation by the GrowSafe™ system, is to avoid overprediction of BV

Table 2.2. Means (± SE) of observed (video) and electronic (GrowSafe™) feeding behavior traits at parameter setting values of 30, 60, 100, 150, and 300 s for maximum duration between EID recordings to end uninterrupted bunk visit (BV) events[1]

Trait	Observed	30 s	60 s	100 s	150 s	300 s
BV frequency, event/d	51.2 ± 2.2^{a}	66.5 ± 3.2^{b}	50.9 ± 2.2^{a}	47.7 ± 2.0^{a}	46.4 ± 1.9^{b}	45.6 ± 1.9^{b}
BV duration, min/d	71.8 ± 3.7^{a}	53.5 ± 3.6^{b}	63.9 ± 3.6^{b}	68.0 ± 3.5^{a}	70.7 ± 3.5^{a}	73.4 ± 3.6^{a}
Meal frequency, event/d	12.9 ± 0.8^{a}	13.2 ± 0.8^{a}	13.3 ± 0.8^{a}	13.3 ± 0.8^{a}	13.3 ± 0.8^{a}	13.4 ± 0.8^{a}
Meal duration, min/d	119.3 ± 4.4^{a}	114.1 ± 4.2^{a}	114.6 ± 4.1^{a}	114.6 ± 4.1^{a}	114.4 ± 4.1^{a}	114.6 ± 4.1^{a}
BV per meal	4.4 ± 0.3^{a}	5.6 ± 0.4^{b}	4.3 ± 0.3^{a}	4.0 ± 0.3^{a}	3.9 ± 0.3^{b}	3.8 ± 0.3^{b}

[1] Meal criterion set as 5 min for meal calculations

^{ab}Values in the same row are different from observed at $P < 0.05$.

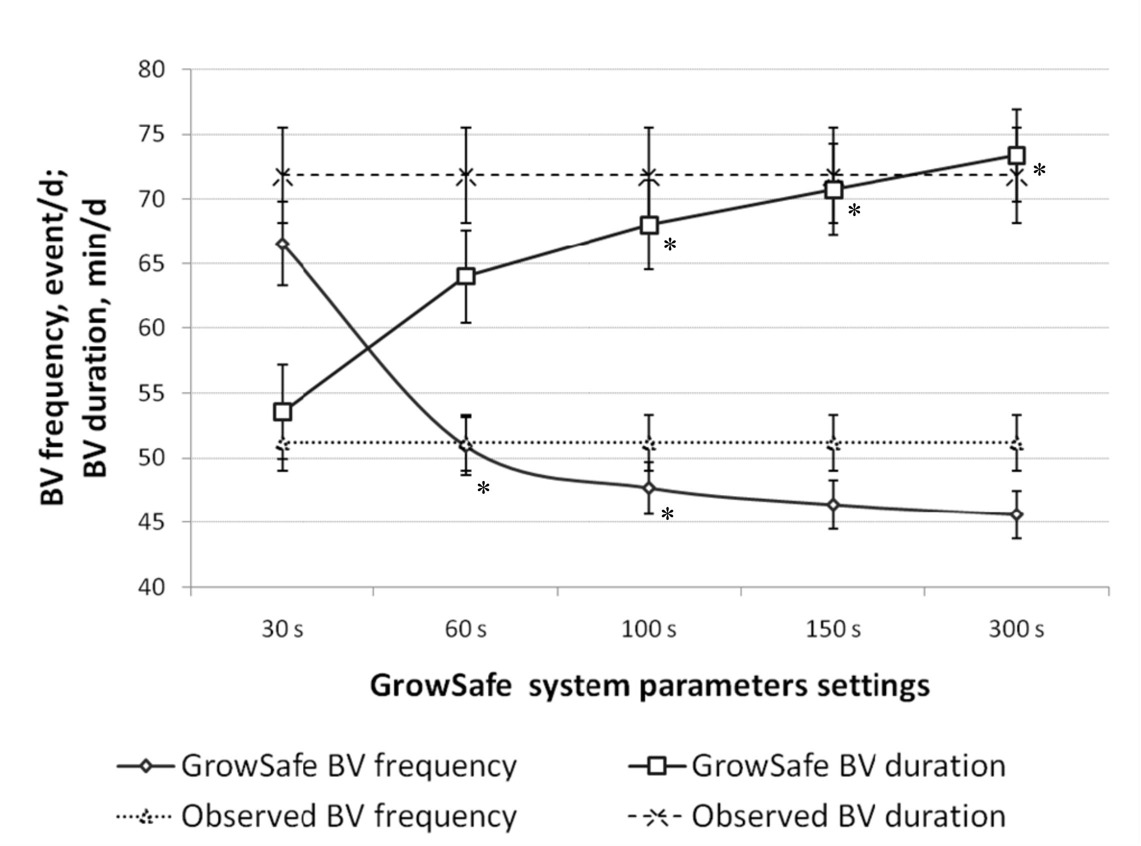

Figure 2.4. Means (± SE) of observed (video) and bunk visit (BV) frequency and duration for GrowSafe™ inputs of 30, 60, 100, 150, and 300 s; *values are not different from observed ($P > 0.05$).

frequencies that would occur when an animal lifts its head out of range of the feed antennae while consuming feed at the feed bunk.

The evaluation of goodness-of-fit of the system to predict observed frequencies and durations of BV are summarized in Table 2.3. The MPS of 60 and 100 s had better values for precision and accuracy of the system to predict BV frequencies compared to other MPS. This was determined by greater R^2 (0.68 and 0.62), less MSEP (49 and 66), less MB (0.3 and 3.5), greater Cb values (1.0 and 0.95) and CCC (0.83 and 0.75) for MPS at 60 and 100 s, respectively. The MPS of 100, 150, and 300 s had better values for precision and accuracy of the system to predict BV durations compared to other MPS. This was determined by greater R^2 (0.81, 0.82, and 0.80), less MSEP (92, 72, and 84), less MB (3.9, 1.1, and -1.6), greater Cb values (0.98, 1.0, and 1.0) and CCC (0.88, 0.90, and 0.89) for MPS at 100, 150 and 300 s, respectively. Similar to the comparison between averages, the MPS at 100 s was the only MPS that could accurately predict at the same time BV frequencies and durations.

To examine the sensitivity and specificity of the system to predict BV data, the BV duration was summarized as animal presence or absence at the feed bunk for every min of the day (1440 min total) during the 6 observational d with MPS at 100 s (Table 2.4). The values for sensitivity and specificity for BV duration were 86.4 and 99.6%, respectively.

Meal Data Calculations

The frequency and duration of meals were not affected by treatment (Table 2.2). On average, meal frequencies determined by the system were numerically 3% higher

Table 2.3. Analysis of fitness to predict observed (video) data for bunk visit (BV) frequency (event/d) and duration (min/d) using different parameters settings in the GrowSafe™ system[1]

Treatment	Mean	SD	R^2	MSEP	MB	Cb	CCC
BV frequency, events/d							
Observed	51.2	11.8					
30 s	66.5	17.7	0.63	354	-15.4	0.61	0.48
60 s	50.9	12.3	0.68	49	0.3	1.00	0.83
100 s	47.7	11.0	0.62	66	3.5	0.95	0.75
150 s	46.4	10.3	0.57	83	4.8	0.91	0.68
300 s	45.6	10.2	0.56	93	5.6	0.88	0.66
BV duration, min/d							
Observed	71.8	20.2					
30 s	53.5	20.0	0.60	511	18.3	0.71	0.55
60 s	64.0	19.7	0.77	156	7.9	0.93	0.82
100 s	68.0	19.0	0.81	92	3.9	0.98	0.88
150 s	70.7	19.1	0.82	72	1.1	1.00	0.90
300 s	73.4	19.4	0.80	84	-1.6	1.00	0.89

[1] SD = standard deviation; R^2 = coefficient of determination of a linear regression of Y on X (closer to 1 is better); MSEP = mean square error of prediction (smaller is better); MB = mean bias (closer to zero is better); Cb= model accuracy (closer to 1 is better); CCC = concordance correlation coefficient (closer to 1 is better).

Table 2.4. Means (± SE) for the records of animal detection or not detection at feed bunk using bunk visit (BV) and meal duration for every minute of the day (1440 min) for heifers (n = 10) used in the study animals that video and GrowSafe™ system were evaluated

Trait	System and observed	System only	Video only	Neither	Total
BV duration, min/d	62.8 ± 3.5	5.8 ± 0.6	9.9 ± 1.5	1361.5 ± 3.6	1440
Meal duration, min/d	112.7 ± 4.0	1.1 ± 0.6	4.9 ± 1.0	1321.3 ± 4.5	1440

[1] 100 s parameter setting was used to calculate BV and meal duration; 5 min was used as the meal criterion for meal calculation.

(P > 0.50) and meal durations were numerically 4% less (P > 0.50) than observed values. The system could predict meal data regardless of the MPS.

The evaluation of goodness-of-fit of the system to predict observed meal frequency and duration are summarized in Table 2.5. The system could predict meal data regardless of the value of MPS. Similar to the results for BV frequencies and durations, the effects of block (P > 0.30) and day within block (P > 0.08) were not found to be significant sources of variations for meal frequencies and durations.

To better differentiate the analysis between BV and meal data, the number of BV per meal was estimated by the system and was compared to observed values. The overall means (± SE) for observed and the electronic numbers of BV per meal are summarized in Table 2.2. Electronic number of BV per meal at MPS of 60 and 100 s did not differ (P > 0.07) from observed. However, electronic number of BV per meal at MPS of 30 s was greater (P < 0.01), and electronic number of BV per meal at MPS of 150 and 300 s were less (P < 0.01) than observed. These results confirmed that 100 s should be the MPS of choice.

In addition to evaluate the effects of MPS for feeding behavior traits, the estimation of the feed intake was performed between the MPS. The overall means (± SE) for 30, 60, 100, 150, and 300 s MPS measured during entire study for the 32 animals were 9.67 ± 0.2, 9.67 ± 0.2, 9.64 ± 0.2, 9.64 ± 0.2, and 9.64 ± 0.2, respectively. Compared to feed intake estimates at MPS value of 300 s (system default), similar (P > 0.50) estimates were found between the 5 MPS.

Table 2.5. Analysis of fitness to predict observed (video) data for meal frequency (event/d) and duration (min/d) using different parameters in the GrowSafe™ system[1]

Treatment	Mean	SD	R^2	MSEP	MB	Cb	CCC
Meal frequency, events/d							
Observed	12.9	4.2					
30 s	13.2	4.4	0.97	0.7	-0.30	1.00	0.98
60 s	13.3	4.4	0.97	0.7	-0.33	1.00	0.98
100 s	13.3	4.4	0.97	0.7	-0.33	1.00	0.98
150 s	13.3	4.4	0.97	0.8	-0.40	0.99	0.98
300 s	13.4	4.4	0.95	1.1	-0.53	0.99	0.97
Meal duration, min/d							
Observed	119.3	24.0					
30 s	114.1	22.8	0.93	64.7	5.20	0.98	0.94
60 s	114.6	22.4	0.94	54.7	4.77	0.98	0.95
100 s	114.6	22.4	0.94	54.7	4.77	0.98	0.95
150 s	114.4	22.2	0.95	56.0	4.97	0.98	0.95
300 s	114.6	22.2	0.94	57.0	4.77	0.98	0.95

[1] SD = standard deviation; R^2 = coefficient of determination of a linear regression of Y on X (closer to 1 is better); MSEP = mean square error of prediction (smaller is better); MB = mean bias (closer to zero is better); Cb= model accuracy (closer to 1 is better); CCC = concordance correlation coefficient (closer to 1 is better); 5 min meal criterion was applied for meal data.

Discussion

Results from this validation study found that the parameter setting used to end an uninterrupted BV affected the system ability to accurately predict the frequency and duration of observed BV. Compared to other MPS, the frequencies and durations of BV estimated using MPS of 100 s was the only MPS that was similar to observed BV frequency and duration values. Furthermore, the analyses of BV and meal frequencies and durations of 100 s MPS revealed no differences for the intercepts ($P > 0.05$) and slopes ($P > 0.05$) for linear regressions for system prediction of BV and meal frequencies and duration data of observed values.

Preview studies have validated the use of electronic RFID-based systems in cattle. DeVries et al. (2003b) and Schwartzkopf-Genswein et al. (1999) validated an earlier version of a GrowSafe™ system that was design to measure feeding behavior data, but not feed intake. Bach et al. (2004) and Chapinal et al. (2007) validated a different electronic RFID-based system that consisted of a self-locking electronic feed bunk system and an electronic feed bunk with a lock barrier that opens and closes as the animal approaches or leaves the feed bunk, respectively. Both studies reported strong coefficients of determination and no differences ($P > 0.05$) in slopes or intercepts from the regression of electronic data on observational data (Bach et al., 2004; Chapinal et al., 2007; DeVries et al., 2003b).

The sensitivity and specificity of the system to detect animal presence and absence at the feed bunk from our study were similar to results reported by DeVries et al. (2003b; 87.4 and 99.2%, respectively) but were lower than the results reported by Bach et al. (2004; 99.6 and 98.8%, respectively) and Chapinal et al. (2007; 100 and

100%, respectively). Differences in the RFID-based systems and methodology used to evaluate the data should be considered when each system's ability to detect animal presence or absence at the feed bunk. An open feed bunk assessment such as used in this study allow animals to better express their feeding behavior characteristics (DeVries et al., 2003b).

Errors may occur during the video observations related to the exact time that the animal entered the feed bunk compared to the detection of the system, which can explain part of the systems failure to detect animal presence at the feed bunk (DeVries et al.,2003; Schwartzkopf-Genswein et al.,1999). Other potential sources of variation for the detection of EID recordings by the GrowSafe™ system include the EID signal being out of the range of the feed bunk antennae (DeVries et al., 2003b), and external sources of radio frequency that interfere with signal transmission (Schwartzkopf-Genswein et al., 1999).

CHAPTER III

EVALUATION OF FEEDING BEHAVIOR CHARACTERISTICS AND THE RELATIONSHIP WITH RESIDUAL FEED INTAKE AND PERFORMANCE TRAITS IN BEEF CATTLE

Introduction

One of the ultimate goals for the beef cattle industry is the selection for more efficient animals to improve profitability (Arthur and Herd, 2008; Moore et al., 2009; Nkrumah et al., 2007). In general, genetic evaluation of beef cattle has been based on increasing output traits (e.g., daily gain), rather than reducing input traits (e.g., intake) (Carstens and Tedeschi, 2006). Some of the reasons are that compared to input traits, output traits are easily measured and can be accomplished by most of commercial cattle producers. Until recently, measurement of individual feed intake on a large scale was not practical. Advances in radio frequency identification (RFID) and computing technologies have enabled development of systems that accurately measure individual feed intake and feeding behavior (e.g., bunk visits and duration) traits in beef cattle. Selection of animals that can more efficiently utilize feed resources will have a significant economic impact on the cattle industry as feed costs are one of the highest expenses associate with beef production (Crews, 2005).

Previous studies have shown that there is considerable phenotypic variation in feed intake of beef cattle (Archer et al., 1999; Arthur et al., 2001b; Robinson and Oddy, 2004). Feed intake, growth, performance and feed conversion ratio (F:G) traits are moderately heritable in beef cattle, which provides opportunities to improve feed efficiency in beef cattle by genetic selection (Arthur and Herd, 2008; Arthur et al., 2001a). An alternative feed efficiency trait, known as residual feed intake (RFI), is the difference between the expected and the observed intake (Archer et al., 1999; Carstens and Tedeschi, 2006; Crews, 2005). Studies have demonstrated that RFI is moderately heritable (Arthur et al., 2001a; Crews et al., 2003). Unlike F:G, RFI is both phenotypically and genetically unrelated to growth, therefore selecting for improved RFI will not increase cow mature body size and consequently feed requirements to support the breeding herd (Archer et al., 1999; Crews, 2005; Nkrumah et al., 2007).

The selection for RFI requires measurements of individual feed intake, which increases the cost of evaluating animal efficiency. Studies have shown that feeding behavior traits may be useful as indicators of economically important traits such as performance and feed efficiency (Lancaster et al., 2009). Consequently, the use of these traits may facilitate selection of animals since the costs to measure behavioral traits would be lower than the costs of measuring feed intake.

Differences exist among electronic-based systems in the methodology used to record feeding behavior data that can at times make comparison of feeding behavior traits across studies difficult. It is important to validate each system and develop common methods to compute feeding behavior traits.

Most of the studies that have investigated feeding behavior have relied on meal-based traits (meal frequency and duration), to evaluate animal behavior patterns (DeVries et al., 2003b; Lancaster et al., 2009; Robles et al., 2007). The use of meal data to evaluate feeding behavior traits are well discussed in the literature (Forbes, 1985; Sibly et al., 1990; Tolkamp et al., 1998; Tolkamp and Kyriazakis, 1999b). A meal is defined as a cluster of consecutive bunk visits (BV) in which the non-feeding intervals were less than a meal criterion (Yeates et al., 2001). The meal criterion is defined as an estimate of the longest non-feeding interval that was considered to be part of a meal (Tolkamp and Kyriazakis, 1999a; Yeates et al., 2002).

Few studies have characterized meal criterion in beef cattle. Variation in meal criterion was reviewed by Tolkamp and Kyriazakis (1999a) who reported a variation of the length of meal criterion ranging from 2 to 41.8 min across different studies. Tolkamp and Kyriazakis (1999a) evaluated the use of 5 different models to calculate meal criterion and found the use of a mixture 2-pool distribution model that fit the $\log_{10}$-transformed interval lengths between BV events as the base for the meal criterion calculation.

The objectives of this study were to evaluate differences in the calculation of meal data, and its influence on performance and feed efficiency traits. In addition, to evaluate inter-animal variation in feed efficiency and feeding behavior traits both within and between breeds.

Materials and Methods

All animal care and use procedures were in accordance with guidelines for use of Animals in Agricultural Teaching and Research and as approved by the Texas A&M University Institutional Animal Care and Use Committee.

Animals and Experiment Design

One hundred twenty seven heifers (16 Angus, 34 Braford, 35 Brangus, and 42 Simbrah) with an initial BW of 286 ± 30 kg were used in an 81-d study. Upon arrival, heifers were fitted with passive, half-duplex, electronic identification (EID) ear tags (Allflex USA Inc., Dallas-Fort Worth, TX). Heifers were randomly assigned by breed to 1 of 4 pens, each equipped with 4 electronic feed bunks (GrowSafe™ 4000E; GrowSafe™ System Ltd., Airdrie, AB, Canada) at the Beef Cattle Systems Research Center (College Station, TX). Heifers were adapted to a high grain diet (Table 3.1) during a 28-d period using 3 step-up diets prior to the start of the study. The final experimental diet was offered ad libitum twice daily at 0830 and 1630 h.

The GrowSafe™ System

The GrowSafe™ 4000E system used for this study (Figure 2.1) consisted of 16 electronic feed bunks with each feed bunk equipped with an antenna to detect animal presence at the feed bunk, load cells to measure feed disappearance, and a stanchion equipped with neck bars to allow only one animal to enter the feed bunk at a time. During the study, animals were allowed access to each of the 4 feed bunks in the pen. The GrowSafe™ system was designed to measure feeding behavior by continuously detecting animal presence at a feed bunk once an EID crossed through the neck bars of the stanchion. Concurrently, the system recorded individual feed intake by continuously measuring feed bunk weight during BV. These data (EID number, bunk number, time stamp of each transponder recording, and scale weight) were continuously recorded via

Table 3.1. Heifers final diet ingredient and chemical composition summary

Item	
Ingredient	*As-fed basis %*
Dry rolled corn	79.7
Chopped costal hay	6.0
Cottonseed meal	6.0
Cottonseed hulls	6.0
Molasses	5.0
Mineral Premix[1]	2.5
Urea	0.8
Chemical Composition	*Dry matter basis*
Dry matter %	91.9
CP, % DM	13.0
NDF, % DM	20.0
ME, Mcal/kg DM	3.01

[1] Mineral Premix contained minimum 15.5% Ca, 2800 ppm Zn, 1200 ppm Mn, 12 ppm Se, 14 ppm Co, 30 ppm I, 45.4 KIU/kg Vit-A, 2.3 KIU/kg Vit-D, 726 IU/kg Vit-E, 1200 ppm Monensin, 400 ppm Tylan, and 2 ppm MGA.

wireless transfer to a computer located next to the feed bunks. For the GrowSafe™ system used in this study, the EID recording rate was 2.0 s.

Data Collection

Heifers were weighed at 14-d intervals during the study. Real-time ultrasound measurements were collected on days 0 and 81 of the study by a certified technician using an Aloka 500-V instrument with a 17-cm, 3.5-MHz transducer (Corometrics Medical Systems Inc., Wallingford, CT). Images were sent to National Centralized Ultrasound Processing laboratory (Ames, IA) for processing and estimation of 12th rib fat thickness (BF), ribeye area (REA), and percent intramuscular fat (IMF). Five animals were removed from the study due to sickness.

A total of 10-d of data generated by the GrowSafe™ system was omitted from analyses because of system failure (power outage, equipment malfunction), system maintenance, or when the proportion of daily feed supply assigned to individual animals less than 95%. The proportion of daily feed supply assigned to animals for the remaining 71-d of the study was 98.2%.

Process Feed Intakes (version 7.29), a subroutine of the GrowSafe™ data acquisition (DAQ) software was used to compute feed intake and BV data. All parameter settings used to compute feed intake and feeding behavior data were default values as described in the GrowSafe™ manual (GrowSafe ™, 2004, 2009), except for the parameter setting that defines the maximum duration between consecutive EID recordings to end an uninterrupted BV. The value of the parameter setting used for this study was 100 s.

A total of 17 feeding behavior traits were evaluated for each animal (Table 3.2). All the traits were calculated for each heifer on a daily basis and averaged over the entire study. The statistical software R (The R Foundation for Statistical Computing; http://www.r-project.org) was used to calculate the meal data. A meal was defined as a cluster of consecutive BV where the non-feeding event intervals were less than the meal criterion (Yeates et al., 2001). Meal criterion was defined as an estimate of the longest non-feeding interval that was considered to be part of a meal (Tolkamp and Kyriazakis, 1999; Yeates et al., 2002; Figure 3.1). A mixture 2-pool distribution model (R mixdist package 0.5-2) was used to fit the $\log_{10}$-transformed interval lengths between BV or feeding bout (FB) events to calculate the meal criterion (Tolkamp and Kyriazakis, 1999a). The untransformed intersection of the 2-pool distributions, which represents the intervals within and between meals, was computed as the meal criterion (Figure 3.2).

Four different methods to calculate meal criterion were evaluated: individual animal meal criterion calculated using FB; individual animal meal criterion calculated using BV; pooled (population) animal meal criterion calculated using FB; and population animal meal criterion calculated using BV. Results from the 4 methods of calculated meal criterion were then used to compute meal frequency, meal duration, BV per meal, and FB per meal for all the animals during the study. A schematic representation of the differences between meals calculated using BV and FB data are presented in Figure 3.3. The meal criterion calculated based on population and the differences between meal criterion calculated based on individuals are presented in Figure 3.2 and Figure 3.4, respectively.

Table 3.2. Feeding behavior traits definition

Trait name	Definition	Unit
Number of daily bunk visits (BV)	A BV began when the transponder of an animal was first detected and ended when the time between the last 2 EID readings was greater than 100 s, the same EID was detected at another bunk, or when a different EID number was encountered	event/d
Number of daily feeding bouts (FB)	The BV frequency when intake is > 0	events/d
Number of daily meals	Cluster of BV which the non-feeding event interval was shorter than the meal criterion	events/d
Daily bunk visit duration	Sum of daily BV time	min/d
Daily feeding bout duration	Sum of daily FB time	min/d
Daily meal duration	Sum of meal frequency time	min/d
Length of bunk visits	Average duration of BV event	min/event
Length of feeding bouts	Average duration of FB event	min/event
Length of meals	Average duration of meal event	min/event
Feeding bout size	Average DMI per FB event	kg/event
Meal size	Average DMI per meal event	kg/event
Eating rate of feeding bouts	Average DMI consumed per min for FB	g/min
Eating rate of meals	Average DMI consumed per min for meals	g/min
Number of bunk visits per meal event	Ratio of daily number of BV frequency per daily number of meal frequency	
Number of feeding bouts per meal event	Ratio of daily number of FB frequency per daily number of meal frequency	
Bunk visit duration per length of meal	Ratio of daily BV duration per daily number of meal duration	
EID hits per length of meal	Ratio of number of EID recordings per daily meal duration	

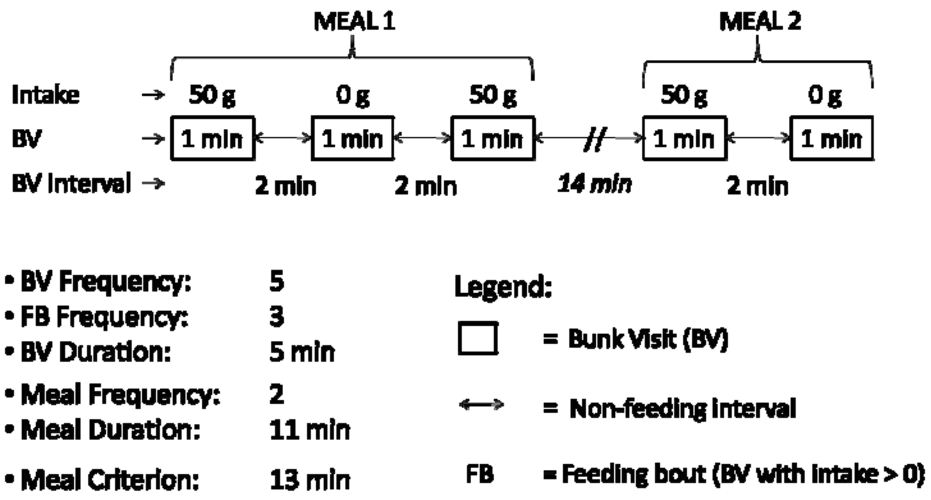

Figure 3.1. Feeding behavior definitions scheme.

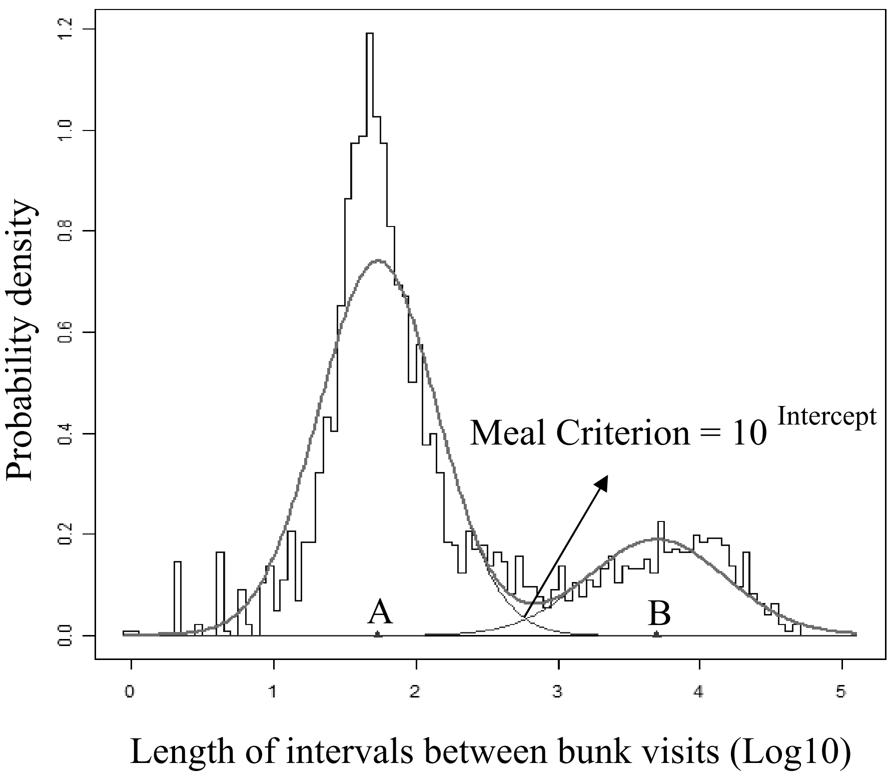

Figure 3.2. Graphical representation of a 2-pool Gaussian distribution of nonfeeding intervals between bunk visits to calculate a meal criterion values; A = the distribution of intervals within meal; B = the distribution of intervals between meals.

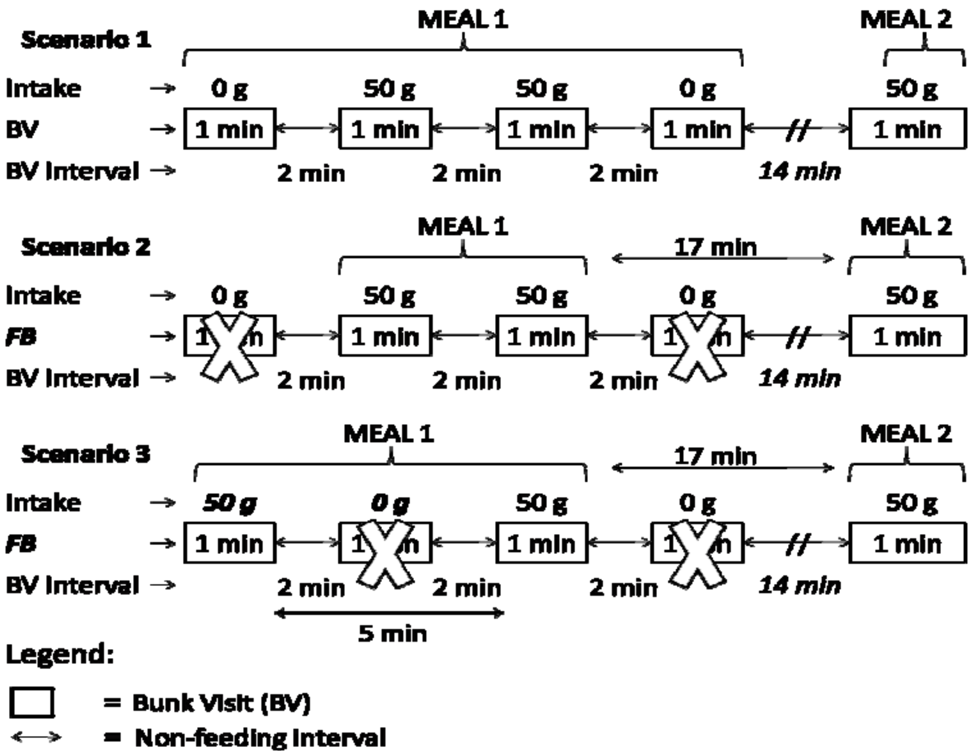

Figure 3.3. Meal calculation using bunk visit (BV) and feeding bout (FB); meal criterion = 13 min; scenario 1: meal calculation using BV; scenarios 2 and 3: meal calculation using FB.

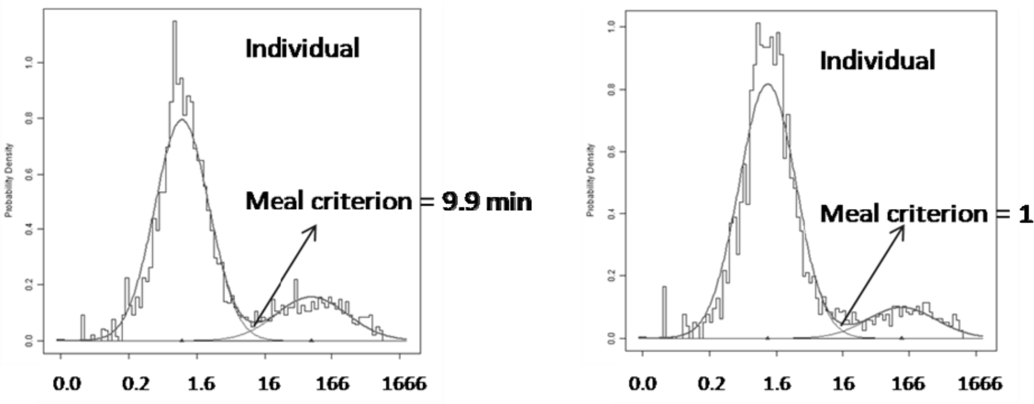

Figure 3.4. Different representations of a Graphical 2-pool Gaussian distribution of nonfeeding intervals between bunk visits to calculate a meal criterion values using individual values.

Diet ingredient samples were collected weekly and composited by weight at the end of the trial. Moisture analysis was conducted by drying in a forced-air oven for 48 h at 105°C (AOAC, 1995), and chemical analyses of composite feed ingredient samples conducted by an independent laboratory (Cumberland Valley Analytical Services Inc., Hagerstown, MD). Metabolizable energy concentration of the experimental diet was computed using the ingredients' chemical analysis and Large Ruminant Nutrition system (Fox et al. 2004, http://nutritionmodels.tamu.edu/lrns.htm).

Statistical Analysis

Animal was considered as the experimental unit for this study. Estimates for missing feed intake data were derived from linear regression of the feed intake on the day of the trial according to Hebart et al. (2004). The dry matter was obtained from the analysis of the ingredients and was used to compute average DMI over the 81-d.

The PROC GLM (SAS Inst. Inc., Cary, NC) was used to calculate the growth rates of individual heifers using linear regression of 14-d BW on the day of the trial. The regression coefficients were used to calculate the initial and final BW, ADG, and metabolic BW (MBW; mid-test $BW^{.75}$).

Residual feed intake (RFI_p) was calculated as the difference between actual and expected DMI from linear regression of DMI and ADG and mid-test $BW^{.75}$ (Arthur et al., 2001a). Residual feed intake was also calculated with adjustment for ultrasound trait (RFI_c) based on the increase or R^2 using step-wise regression from the RFI base model with the inclusion of different ultrasound traits. To further characterize RFI, heifers were ranked into 3 groups: low RFI (< 0.5 SD), medium RFI (± 0.5 SD), and high RFI (> 0.5 SD) groups derived from the mean RFI base model (Lancaster et al., 2009).

To examine the effects of RFI group and breed on feed efficiency, performance, and feeding behavior data, a two way analysis of variance using PROC GLM (SAS Inst. Inc., Cary, NC) was performed for breed, RFI group and breed x RFI group interaction. The terms that were nonsignificant ($P > 0.10$) in the model were removed from statistical analysis. Correlation coefficients were calculated for feed efficiency, performance, and feeding behavior data using the MANOVA (multivariate ANOVA), an option of PROC GLM (SAS Inst. Inc., Cary, NC).

To test the difference between the 4 different calculations for meal criterion, a contrast statement in PROC MIXED (SAS Inst. Inc., Cary, NC) was performed with treatment (4 calculation methods) as fixed effects and pen and breed as random effects.

To evaluate the diurnal variation between low and high RFI animals, the BV duration for all the animals was averaged by hour (0 to 23 h) during the entire study. Differences between the RFI groups were analyzed using SAS PROC MIXED (SAS Inst. Inc., Cary, NC) model with treatments (low and high RFI) as fixed effects and pen and breed as random effects.

Results

Overall means (± SD) for performance, feed efficiency, ultrasound, and feeding behavior traits are summarized in Table 3.3. For our study, the RFI base model (RFI_p) was adjusted for final back fat (RFI_c), which was the ultrasound trait that had the greatest increase in the R^2 from the base model (0.48 to 0.53; Table 3.4). Inclusion of final back

Table 3.3. Overall summary of performance, feed efficiency, and ultrasound traits for heifers (n =122) fed a high-grain diet

Variable[1]	Mean	SD	Min	Max
Performance traits				
Initial BW, kg	286	30	216	377
Final BW, kg	393	40	295	502
ADG, kg/d	1.52	0.3	0.98	2.36
DMI, kg/d	9.7	1.4	6.3	13.7
Feed efficiency traits				
G:F	0.16	0.02	0.11	0.22
RFI_p, kg/d	0.00	0.99	-2.81	2.29
RFI_c, kg/d	0.00	0.95	-2.59	2.33
Ultrasound traits				
Initial REA, cm^2	48.4	6.3	34.8	67.1
Final REA, cm^2	68.4	7.8	53.5	98.1
Initial BF, cm	0.30	0.1	0.13	0.56
Final BF, cm	0.70	0.3	0.23	1.52
Initial IMF, %	2.4	0.5	1.2	3.9
Final IMF, %	3.2	0.8	1.7	5.4
Feeding behavior traits				
BV frequency, events/d	51.1	8.7	27.8	78.1
BV duration, min/d	61.1	16.9	28.8	105.6
Length of BV, min/event	1.3	0.3	0.6	2.6
FB frequency, event/d	47.7	8.1	26.4	72.6
FB duration, min/d	60.0	16.5	28.5	104.3
Length of FB, min/event	1.3	0.4	0.7	2.7
FB size, kg/event	0.241	0.04	0.145	0.349
FB eating rate, g/min	170	38	97	290
Meal frequency, events/d	8.39	1.4	4.2	12.5
Meal duration, min/d	137	27.2	71.9	231.5
Length of meal, min/event	17.4	3.2	10.5	24.8
Meal size, kg/event	1.40	0.30	0.81	2.30
Meal eating rate, g/min	73	13	43	112
Ratio traits				
BV per meal	6.6	1.2	3.9	9.6
FB per meal	6.1	1.2	3.6	9.1
BV duration per length of meal	0.44	0.09	0.27	0.66
EID hits per length of meal	11.3	4.0	3.7	24.6

[1] RFI_p = residual feed intake from base model; RFI_c = residual feed intake from adjusted model; REA = rib-eyea area; BF = 12th-rib fat thickness; IMF = intramuscular fat; BV = bunk visits; FB = feeding bout (BV > 0); meal data was derived from meal criterion calculated as the population 2-pool distribution with BV data.

Table 3.4. Variation in residual feed intake (RFI) base model (BM) R^2 with the additional of ultrasound and feeding behavior traits for heifers fed-high grain diets

Trait	R^2	Additional Increase
RFI BM	0.48	
Ultrasound		
RFI BM + Final REA	0.48	0.2%
RFI BM + Final BF	0.53	9.7%
RFI BM + Final IMF	0.48	0.0%
Feeding Behavior		
RFI BM + Meal duration	0.58	19.3%
RFI BM + Meal frequency	0.48	0.0%
RFI BM + BV duration	0.64	30.8%
RFI BM + BV frequency	0.58	19.3%
RFI BM + BV per meal	0.52	7.7%
RFI BM + BV duration per meal duration	0.56	15.4%
RFI BM + EID hits per length of meal	0.62	27.0%
RFI BM + BV duration + BV frequency	0.67	36.6%
RFI BM + BV duration + BV frequency + Final BF	0.70	42.3%
RFI BM + EID hits per length of meal + BV frequency	0.69	40.4%
RFI BM + EID hits per length of meal + BV frequency + Final BF	0.73	48.1%

[1] REA = rib-eyea area; BF = 12th-rib fat thickness; IMF = intramuscular fat; BV = bunk visits; meal data was derived from meal criterion calculated as the population 2-pool distribution with BV data.

fat in the model explained 9.7% of the variation in DMI that was not explained by variation in DMI accounted for ADG and MBW.

Meal Criterion Calculation

The overall results for the analysis of the 4 different methods to calculate meal criterion are presented in Table 3.5. The use of BV compared to FB in calculated meal criterion did not affect ($P > 0.05$) frequency and duration of meals and the number of BV or FB per meal. Likewise the computation of meal criterion based on individual or population had no impact ($P > 0.05$) on frequency and duration of meals and the number of BV or FB per meal. This demonstrated that meal criterion calculated as the population or individual 2-pool Gaussian distribution with BV or FB does not affect feeding behavior traits derived from the meal criterion. For further analysis of meal data reported in this study, meal criterion was calculated using the population 2-pool Gaussian distribution with BV data.

Phenotypic Correlation and RFI Group Evaluation

The correlations between feed efficiency and performance traits are presented in Table 3.6. High correlations ($P < 0.05$) were found between ADG, DMI, and G:F. Residual feed intake calculated from base model and adjusted for final back fat were highly ($P < 0.01$) correlated to DMI and G:F, but were not correlated ($P > 0.05$) with initial BW and ADG. The RFI_c and RFI_p were highly correlated to each other ($P < 0.01$; Table 3.6).

Table 3.5. Overall means (± SE) for meal data using four different calculations for meal criterion based on a 2-pool distribution

Trait[1]	Meal criterion from individual		Meal criterion from population		SE	P-value	
	FB base	BV base	FB base	BV base		Population v s. Individual	BV vs. FB
No. of heifers	122	122	122	122			
Meal frequency, events/d	8.75	8.76	8.38	8.39	0.4	0.05	0.95
Meal duration, min/d	132	136	133	137	4.7	0.94	0.15
BV per meal, events/meal	6.50	6.49	6.57	6.55	0.2	0.62	0.92
FB per meal, events/meal	6.08	6.07	6.13	6.12	0.2	0.62	0.94

[1] BV = bunk visit; FB = feeding bout

[ab] Means within row without a common superscript differ ($P < 0.05$).

Table 3.6. Phenotypic Pearson correlations between performance and feed efficiency traits in heifers (n =122) fed high-grain diet[1]

Item	ADG	DMI	G:F	RFI_p	RFI_c
Initial BW	0.36[a]	0.52[a]	-0.13	0.07	0.04
ADG		0.65[a]	0.53[a]	0.03	0.04
DMI			-0.30[a]	0.74[a]	0.71[a]
G:F				-0.76[a]	-0.73[a]
RFI_p					0.97[a]

[1] BW = body weight; ADG = average daily gain; DMI = dry matter intake; G:F = gain to feed; RFI_p = residual feed intake from base model; RFI_c = residual feed intake from composition-adjusted model

[a] Correlations are different from zero at $P < 0.05$.

To better quantify the magnitude of the differences between animal performance and feeding behavior data, the animals were classified by RFI groups: low, medium and high RFI (Table 3.7). No differences were found between the RFI groups for initial BW ($P = 0.37$), final BW ($P = 0.64$), and ADG ($P = 0.94$), but differences ($P < 0.01$) were found for DMI and G:F between the RFI groups. Heifers with low RFI phenotypes consumed on average 20% less feed and gained 28% more per kg of feed consumed compared to high RFI heifers.

The correlations between performance, feed efficiency, and feeding behavior traits are summarized in Table 3.8. Similar correlations were found for frequency, duration and length of visits calculated as BV or FB with performance and feed efficiency traits. Both RFI_p and RFI_c had similar correlations with the feeding behavior traits (Table 3.8).

Positive correlations ($P < 0.05$) were found for length of BV, length of meal, and meal size with ADG, DMI and RFI_p. Positive relationships ($P < 0.05$) were found between meal eating rate and the ratio traits with DMI and RFI_p, but no relationship ($P > 0.05$) were found for ADG and G:F. The length of BV was not related ($P > 0.05$) to ADG, but was negatively correlated ($P < 0.05$) to G:F. Length of meal was not related ($P > 0.05$) to G:F, but meal eating rate was negatively correlated ($P < 0.05$) to G:F. Initial and final BW had similar correlations with feeding behavior data, excepted for BV duration and number of EID hits per length of meal. The feeding behavior traits that had the highest correlations with RFI_p were the number of EID hits per length of meal (0.51) followed by the number of BV per meal (0.39).

Table 3.7. Effects of RFI classification on performance and feed efficiency traits in heifers fed a high-grain diet

Item[1]	Low RFI	Medium RFI	High RFI	SE	P-value
No. of heifers	37	52	33		
Performance trait					
Initial BW, kg	281	286	283	5.83	0.37
Final BW, kg	389	394	390	7.64	0.64
ADG, kg/d	1.54	1.54	1.52	0.05	0.94
DMI, kg/d	8.6^{c}	9.8^{b}	10.7^{a}	0.20	0.01
Feed Efficiency trait					
G:F	0.18^{b}	0.16^{a}	0.14^{c}	0.01	0.01
RFI_p, kg/d	-1.111^{c}	0.034^{b}	1.064^{a}	0.09	0.01
RFI_c, kg/d	-1.069^{c}	0.001^{b}	0.939^{a}	0.08	0.01

[1] RFI_p = residual feed intake from base model; RFI_c = residual feed intake from adjusted model; low RFI (< 0.5 SD), medium (± 0.5 SD), and high RFI (> 0.5 SD) derived from mean ± SD of RFI_p

[ab] Means within row without a common superscript differ ($P < 0.05$).

Table 3.8. Phenotypic correlations between performance, feed efficiency, and feeding behavior traits in heifers (n = 122) fed a high-grain diet[1]

Item[2]	Initial BW	Final BW	ADG	DMI	G:F	RFI_p	RFI_c
BV traits							
BV frequency	-0.15	-0.02	0.21[a]	0.33[a]	-0.11	0.38[a]	0.42[a]
BV duration	0.15	0.25[a]	0.31[a]	0.57[a]	-0.25[a]	0.53[a]	0.53[a]
Length of BV	0.23[a]	0.24[a]	0.15	0.35[a]	-0.22[a]	0.31[a]	0.27[a]
FB traits							
FB frequency	-0.12	0.01	0.23[a]	0.39[a]	-0.14	0.43[a]	0.46[a]
FB duration	0.15	0.26[a]	0.31[a]	0.58[a]	-0.26[a]	0.54[a]	0.53[a]
Length of FB	0.22[a]	0.22[a]	0.14	0.33[a]	-0.20[a]	0.28[a]	0.25[a]
FB size	0.50[a]	0.49[a]	0.26[a]	0.40[a]	-0.12	0.17[b]	0.12
FB eating rate	0.16	0.13	0.01	-0.08	0.11	-0.20[a]	-0.23[a]
Meal traits							
Meal frequency	-0.06	0.02	0.13	0.05	0.12	-0.01	-0.01
Meal duration	-0.05	0.12	0.36[a]	0.42[a]	-0.02	0.36[a]	0.35[a]
Length of meal	0.04	0.15	0.27[a]	0.41[a]	-0.12	0.36[a]	0.36[a]
Meal size	0.41[a]	0.46[a]	0.33[a]	0.60[a]	-0.26[a]	0.45[a]	0.44[a]
Meal eating rate	0.43[a]	0.36[a]	0.09	0.30[a]	-0.22[a]	0.18[a]	0.16[b]
Ratio traits							
BV per meal	-0.06	-0.01	0.08	0.27[a]	-0.22[a]	0.36[a]	0.39[a]
FB per meal	-0.03	0.02	0.09	0.30[a]	-0.24[a]	0.38[a]	0.41[a]
BV duration per length of meal	0.23[a]	0.20[a]	0.07	0.37[a]	-0.33[a]	0.39[a]	0.40[a]
EID hits per length of meal	0.15	0.16[b]	0.12	0.45[a]	-0.35[a]	0.51[a]	0.54[a]

[1] RFI_p = residual feed intake from base model; RFI_c = residual feed intake from adjusted model

[2] BV = bunk visits; FB = feeding bout (BV > 0); meal data was derived from meal criterion calculated as the population 2-pool distribution with BV data.

[ab] Correlations are different from zero at $P < 0.05$ and $P < 0.08$, respectively.

The evaluation of the effects of RFI group on feeding behavior traits are summarized in Table 3.9. The longest differences between heifers with divergent RFI phenotypes were found for the number of EID hits per length of meal, BV duration, meal size, and the BV duration per length of meal, with high RFI heifers being 61, 38, 26, and 23%, respectively, higher than low RFI heifers.

The diurnal variation in BV duration between low and high RFI heifers is presented in Figure 3.5. The results demonstrate that BV duration was higher in heifers with high RFI at both feeding times (0830 and 1630 h), with a decrease of divergent RFI groups at night (1900 h). The greatest difference between low (165 s) and high RFI heifers (286 s) in BV duration occurred at 0900 h, right after the morning feeding. These results demonstrated that the overall 37% difference in BV duration between low and high RFI heifers is related to the hour of the day that the animal consumed feed.

Variation in the RFI Base Model

The use of feeding behavior traits in the RFI base model (Table 3.4) demonstrated that BV duration followed by the ratio of number of EID hits per meal duration were the two feeding behavior traits that accounted for most of the variation in DMI that was not explained by ADG and MBW (30.8 and 27.0%, respectively). Inclusion of these traits in the RFI base model increased R^2 from 0.48 to 0.64 and 0.48 to 0.62, respectively.

The inclusion of the number of EID hits per meal duration along with BV frequency increased the R^2 from 0.48 to 0.69, and accounted for 40.4% of the variation in DMI not explained by ADG and MBW. The number of EID hits per meal duration

Table 3.9. Effects of RFI classification on feeding behavior traits in heifers fed a high-grain diet[1]

Item	Low RFI	Medium RFI	High RFI	SE	P-value
No. of heifers	37	52	33		
BV traits					
BV frequency, events/d	48.0^{b}	50.7^{b}	54.7^{a}	1.49	0.01
BV duration, min/d	50.8^{b}	65.1^{ab}	69.9^{a}	2.74	0.01
Length of BV, min/event	1.12^{b}	1.39^{a}	1.37^{a}	0.05	0.01
FB traits					
FB frequency, event/d	44.3^{b}	47.6^{b}	51.2^{a}	1.36	0.01
FB duration, min/d	49.8^{b}	64.0^{a}	68.7^{a}	2.67	0.01
Length of FB, min/event	1.20^{b}	1.47^{a}	1.44^{a}	0.06	0.01
FB size, kg/event	0.230	0.246	0.247	0.01	0.16
FB eating rate, g/min	179^{b}	161^{a}	160^{a}	5.90	0.03
Meal traits					
Meal frequency, event/d	8.4	8.2	8.3	0.25	0.21
Meal duration, min/d	128^{b}	136^{ab}	146^{a}	4.49	0.01
Length of meal, min/event	16.3^{b}	17.7^{ab}	18.8^{a}	0.51	0.01
Meal size, kg/event	1.24^{b}	1.45^{ab}	1.56^{a}	0.05	0.01
Meal eating rate, g/min	69	73	75	2.40	0.08
Ratio traits					
BV per meal	6.1^{b}	6.6^{a}	7.1^{a}	0.19	0.01
FB per meal	5.6^{b}	6.2^{a}	6.6^{a}	0.18	0.01
BV duration per length of meal	0.39^{b}	0.48^{a}	0.48^{a}	0.01	0.01
EID hits per length of meal	8.2^{b}	12.5^{a}	13.2^{a}	0.80	0.01

[1] BV = bunk visits; FB = feeding bout (BV > 0); meal data was derived from meal criterion calculated as the population 2-pool distribution with BV data

[abc] Means within row without a common superscript differ ($P < 0.05$).

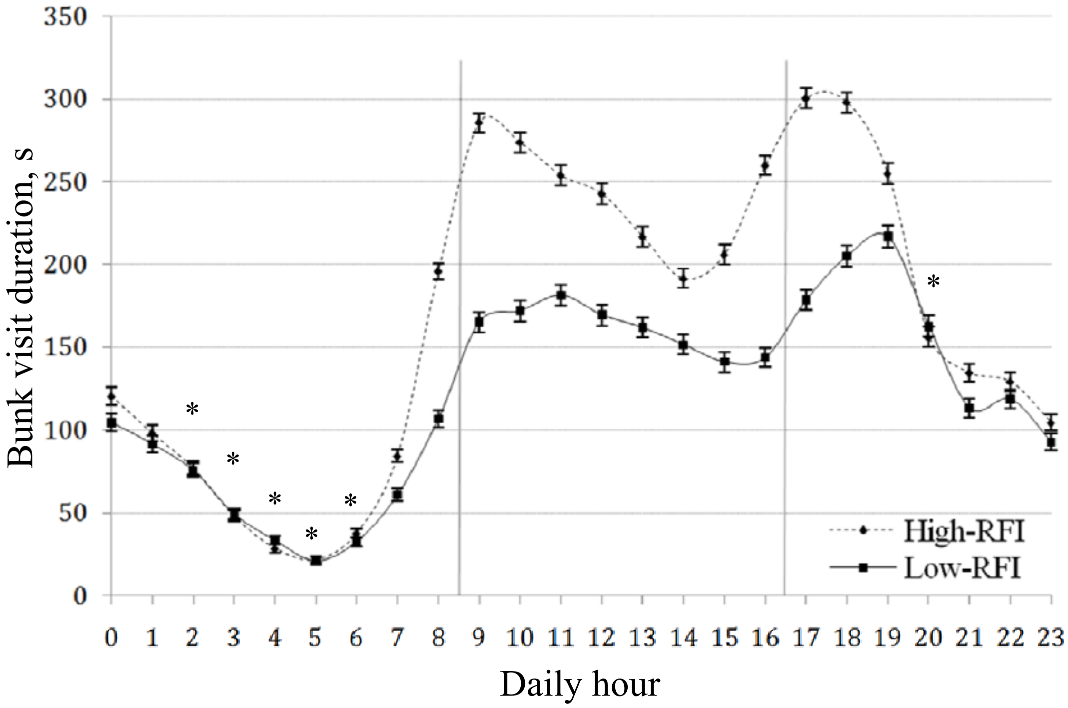

Figure 3.5. Means (±SE) for bunk visit (BV) duration over 24h for high and low RFI animals for 81-d period; *values are not different ($P > 0.05$); feeding times are vertical lines, 0830 and 1630 h.

was moderate to high correlated with BV duration and meal duration (0.76 and 0.26, respectively; $P < 0.01$), but it was not correlated to BV frequency (0.11; $P = 0.21$). Thus, BV frequency was selected to be evaluated together to the number of EID hits per meal duration rather than BV duration.

Breed Evaluation

The performance and feed efficiency differences across the four breeds are summarized in Table 3.10. Breed differences ($P < 0.01$) were found for initial and final BW, G:F, RFI_p and RFI_c. Simbrah and Angus heifers had higher ($P < 0.01$) G:F compared with Braford and Brangus. Simbrah heifers were more efficient ($P < 0.01$) than Angus, Braford and Brangus heifers based on RFI_p. Based on RFI_c, both Simbrah and Angus heifers were more efficient than Braford and Brangus. This was related to the final back fat of Angus (0.95 cm) being higher ($P < 0.01$) than Simbrah (0.59 cm) with Braford (0.73 cm) and Brangus (0.73 cm) being intermediate.

The breed differences in feeding behavior data are summarized in Table 3.11. The BV frequencies were similar ($P = 0.35$) for all breeds, but BV durations were higher ($P < 0.01$) for Angus and Brangus compared to Simbrah, with Braford being intermediate. Unlike BV frequency, meal frequency was different between breeds. Angus and Simbrah heifers had lower meal frequencies ($P < 0.01$) than Braford and Brangus heifers. Simbrah heifers had the lowest ($P = 0.02$) meal duration compared to other breeds. The length and eating rate of FB were different ($P < 0.02$), but FB size was similar ($P = 0.74$) between breeds. Different from FB, meal size was different ($P = 0.03$) and length and meal eating rate were similar ($P > 0.07$) between breeds. Besides the ratio

Table 3.10. Effects of breed on performance and feed efficiency traits in heifers fed a high-grain diet

Item[1]	Angus	Braford	Brangus	Simbrah	SE	P-value
No. of heifers	15	34	34	39		
Performance traits						
Initial BW, kg	276^{b}	277^{b}	283^{b}	299^{a}	5.39	0.01
Final BW, kg	391^{ab}	379^{b}	389^{ab}	406^{a}	9.58	0.04
ADG, kg/d	1.63	1.42	1.53	1.53	0.08	0.09
DMI, kg/d	9.92	9.55	9.86	9.47	0.34	0.33
Feed Efficiency traits						
G:F	0.167^{a}	0.153^{b}	0.155^{b}	0.162^{a}	0.01	0.01
RFI_p, kg/d	-0.007^{b}	0.173^{b}	0.226^{b}	-0.409^{a}	0.28	0.01
RFI_c, kg/d	-0.242^{a}	0.094^{b}	0.200^{b}	-0.225^{a}	0.25	0.01

[1] RFI_p = residual feed intake from base model; RFI_c = residual feed intake from adjusted model

[ab] Means within row without a common superscript differ ($P < 0.05$).

Table 3.11. Effects of breed on feeding behavior traits in heifers fed a high-grain diet

Item[1]	Angus	Braford	Brangus	Simbrah	SE	P-value
No. of heifers	15	34	34	39		
BV traits						
BV frequency, events/d	51.0	52.0	52.4	49.2	2.38	0.35
BV duration, min/d	67.9^{a}	60.0^{ab}	66.4^{a}	53.6^{b}	3.64	0.01
Length of BV, min/event	1.44^{a}	1.24^{bc}	1.33^{ab}	1.16^{c}	0.07	0.02
FB traits						
FB frequency, event/d	47.6	48.2	48.6	46.3	2.19	0.58
FB duration, min/d	66.7^{a}	58.9^{ab}	65.1^{a}	52.8^{b}	3.50	0.01
Length of FB, min/event	1.52^{a}	1.31^{ab}	1.41^{a}	1.22^{ab}	0.08	0.02
FB size, kg/event	0.249	0.235	0.238	0.241	0.01	0.74
FB eating rate, g/min	151^{b}	171^{b}	158^{b}	188^{a}	6.8	0.01
Meal traits						
Meal frequency, event/d	7.8^{b}	8.6^{a}	9.0^{a}	7.8^{b}	0.26	0.01
Meal duration, min/d	138^{ab}	139^{a}	146^{a}	126^{b}	5.88	0.02
Length of meal, min/event	18.8	17.1	17.2	17.2	0.79	0.45
Meal size, kg/event	1.53^{a}	1.33^{b}	1.32^{b}	1.46^{a}	0.07	0.03
Meal eating rate, g/min	73	70	69	77	2.53	0.07
Ratio traits						
BV per meal	7.0^{a}	6.4^{ab}	6.2^{b}	6.8^{a}	0.36	0.03
FB per meal	6.5^{a}	5.9^{ab}	5.7^{b}	6.4^{a}	0.34	0.01
BV duration per length of meal	0.49^{a}	0.43^{b}	0.45^{ab}	0.42^{b}	0.02	0.02
EID hits per length of meal	11.9	11.0	11.6	10.8	0.95	0.65

[1] BV = bunk visits; FB = feeding bout (BV > 0); meal data was derived from meal criterion calculated as the population 2-pool distribution with BV data

[abc] Means within row without a common superscript differ ($P < 0.05$).

of EID hits per meal duration, the ratio traits were different ($P < 0.05$) between breeds (Table 3.11).

Discussion

On average, the frequency of BV in this study (51.1 events d^{-1}) was higher compared to other studies (Table 1.1). The duration of BV (61.1 min d^{-1}) was similar to results reported by Basarab et al. (2007), Nkrumah et al. (2007) and Nkrumah et al. (2006), but it was lower than values reported by Robinson and Oddy (2004) and Tolkamp et al (2000; Table 1.1). On average, 93% of BV were determined to be FB, which include visits to the feed bunk where feed was consumed.

The differences in methods used to calculate meal criterion make comparisons of meal data between studies difficult. The meal frequency from our study ranged from 4.2 to 12.5 events d^{-1} and was closely related to the results reported in other studies compared to meal duration (Table 1.1). Meal duration from our study ranged from 71.9 to 231 min d^{-1} and other studies ranged from 32 to 333 min d^{-1} (Table 1.1)

Differences in methodologies and electronic systems to measure and calculate behavioral traits affects how the feeding behavior values were obtained (Tolkamp et al., 2000), therefore, increasing the range of results for behavior related traits. Meal frequencies and durations are dependent on the meal criterion value. Consequently, a large variation in meal criterion such as 2 to 58.6 min (Tolkamp et al, 2000; Table 1.1) could explain the large differences for meal frequency, 4 to 17.7 events d^{-1}, and meal duration, 29.4 to 333 min d^{-1} (Table 1.1). The use of an objective method to calculate meal criterion can minimize differences between studies. However, the use of different types of cattle, diet, and bunk management, will also influence the results (Table 1.1).

Bach et al. (2006), DeVries et al. (2003a) and Tolkamp et al (2000), working with dairy cattle, calculated the meal criterion using a 2 or 3-pool Gaussian distribution and their results for meal criterion ranged from 27.7 to 58.6 min. The meal criterion from our study, which used a 2-pool Gaussian distribution, was 13.8 min and was lower than reported by the dairy cattle studies (Table 1.1). Physiological factors that affects animal satiety such as feed digestion and stomach distention (Forbes, 1985), which are associated with the probability that an animal will initiate another feeding bout (Tolkamp and Kyriazakis, 1999a), may explain differences in meal criterion between beef and dairy cattle. In addition, the differences in meal criterion from our study and dairy studies are related to differences in diet.

Besides eating rate, studies that evaluated feeding behavior traits rather than BV frequency and duration and meal frequency and duration are scarce in the literature. Our findings of 170 g min^{-1} for FB eating rate agree with results from Robinson and Oddy (2004), who reported a range of 131 to 158 g min^{-1} on the comparison of different breeds. Our findings for meal eating rate, 73 g min^{-1}, is consistent with results found by Lancaster et al. (2009) and Bach et al. (2006; 97.1 and 88.8 to 91.2 g min^{-1}, respectively), but it was higher than the findings reported by Bingham et al. (2009), DeVries et al. (2009), Robles et al. (2007), and Chase et al. (1976; 41.7 to 49.5, 45 to 57, 32.7 to 37.7 and 27.9 g min^{-1}, respectively) and lower than findings reported by Schwartzkopf-Genswein et al. (2002), Tolkamp et al. (2000), and Vasilatos and Wangsness (1979; 203.0 to 242.4, 269 to 340, and 175 g min^{-1}, respectively).

The length of BV (1.3 min event^{-1}) and length of meal (17.4 min event^{-1}) were both lower than reported by other studies. Tolkamp et al. (2000) reported length of BV and length of meal within a range of 4.3 to 5.2, and 24.1 to 26.4 min event^{-1}, respectively. DeVries et al. (2009) and Robles et al. (2007) reported length of meal with a range from 26 to 32.8 and 32.2 to 37.4 min event^{-1}, respectively. For the FB size, our finding (0.241 kg event^{-1}) was lower than Tolkmap et al. (2000; 1.74 kg event^{-1}), and for meal size (1.40 kg event^{-1}) our findings was also lower than other studies as reported by Bach et al. (2006), Tolkamp et al. (2000), and Vasilatos and Wangsness (1979; 3.45 to 4.20, 6.4 to 8.3, and 3.6 kg event^{-1}, respectively). FB size from our study was higher than results reported by DeVries et al. (2009) and Robles et al. (2007; 0.52 to 0.59 and 0.95 to 1.02 kg event^{-1}, respectively).

The associations between feeding behavior and feed intake traits have been examined to increase the understanding of factors that influence inter-animal variation in feed efficiency (Bingham et al., 2009; Lancaster et al., 2009). Our findings demonstrated that the addition of feeding behavior traits in the RFI base model could explain the variation in DMI not accounted by ADG and MBW 40.4% , which is consistent with other studies. Lancaster et al. (2009) incorporated meal frequency and duration and number of EID hits in the RFI base model and found that feeding behavior traits accounted for 35% of variation in DMI not explained by ADG, MBW, and ultrasound traits. de Haer et al. (1993), working with pigs, evaluated the BV frequency and BV duration in the RFI base model and these feeding behavior traits associated to the RFI base model accounted for 44% of the variation in DMI not explained by ADG, MBW.

These findings reinforce the need to more fully understand how feeding behavior traits are linked to biologically relevant processes associated with efficient utilization of feed.

Studies had evaluated different methodologies to calculate meal criterion (Tolkamp et al., 1998; Tolkamp and Kyriazakis, 1999a, b; Yeates et al., 2001; Yeates et al., 2002), but currently no studies have determined if differences in meal criterion calculations affects meal criterion values, meal frequency, meal duration, or the ratio of BV or FB per meal. Our findings demonstrate that there were no differences ($P > 0.05$) between the four different methods (population and individual with BV or FB) to calculate meal criterion.

Meal criterion calculated using the individual 2-pool distribution (data not shown) with BV demonstrated that there was a tendency ($P < 0.08$) for meal criterion to be correlated to RFI_p and RFI_c. This suggests that meal criterion may be a trait that can explain part of the differences between RFI groups.

The correlations of feeding behavior traits, feed efficiency and performance traits (Table 3.8) were similar to other studies (Table 1.2), which demonstrated positive correlation of BV duration with ADG and DMI; positive correlations between BV frequency and duration with RFI_p; positive correlations of meal duration with ADG, DMI, and RFI_p; and no relationship of meal frequency with ADG, DMI and G:F (Table 1.2; Table 3.8). Different from other studies (Table 1.2), our findings demonstrated that BV frequency was positive correlated ($P < 0.05$) with ADG and DMI; BV duration was negatively correlated ($P < 0.05$) with G:F; and meal frequency was not related ($P > 0.05$) to RFI_p (Table 3.8). Our findings demonstrated that BV frequency was negatively correlated with G:F (-0.25), which agrees with findings by Nkrumah et al. (2007;

-0.13), but differ from findings by Robinson and Oddy (2004; -0.08). Our results for meal duration found that no correlation ($P > 0.05$) with G:F (-0.02), which is consistent with findings by Lancaster et al. (2009; -0.03), but differ from Schwartzkopf-Genswein et al. (2002; -0.17).

The comparison of BV duration and meal duration data between heifers with divergent RFI groups demonstrate that low RFI animals spent 27 and 12% less time ($P < 0.05$), respectively, at the feed bunk compared to high RFI animals. Lancaster et al. (2009) found a difference of 15% ($P < 0.05$) between low RFI and high RFI animals for meal duration, and Nkrumah et al. (2006) and Nkrumah et al. (2007) reported that low RFI animals spent 54 and 32%, respectively, less time at the feeding bunk compared to high RFI animals.

The correlation of BV frequency with RFI_p (0.38) was consistent with findings from Basarab et al. (2007), Lancaster et al. (2009), and Robinson and Oddy (2004; Table 1.2). Our findings demonstrated a difference ($P < 0.05$) of 14% between high and low RFI groups for BV frequency (Table 3.9), which was consistent with Nkrumah et al. (2007; 16%) but it was lower than Nkrumah et al. (2006; 65%).

The results from eating rate, which demonstrate how fast the animal consumed feed, demonstrated differences from other studies (Table 1.2; Table 3.8). Lancaster et al. (2009) reported that eating rate was not correlated to RFI_p (0.08) and F:G (0.02) and also that ADG was moderately correlated with eating rate (0.32; Table 1.2). Our study found that meal eating rate was moderately to highly correlate to G:F (-0.22) and RFI_p (0.18), but not correlated to ADG (0.09; Table 3.8). Robinson and Oddy (2004) also evaluated the correlation of eating rate with performance and feed efficiencies, but BV rather than

FB was used to examine eating rate, which may explain some of the differences with this study (Table 1.2; Table 3.8).

The feeding behavior ratio traits were found to be moderately to highly correlate to RFI_p and RFI_c. Similar to de Haer et al. (1993), who reported that the ratio of number of visits to the number of meals was negatively correlated (-0.33) to RFI in pigs, our results found a moderate ($P < 0.05$) correlation of number of BV per meal (0.39). Low RFI animals had 5 fewer visit ($P < 0.05$) per meal compared to high RFI animals (Table 3.9). The higher correlation of the number of EID hits per meal duration with RFI_p (0.51), and the difference of 61% from high and low RFI for this trait associated with the highest increase in the R^2 from the RFI base model, and suggests that future research should consider this trait in the evaluation of the variation in RFI. DeVries et al. (2003a) had demonstrated that the number of EID hits per meal duration had high repeatability in dairy cows from early to peak lactation.

Few studies had evaluated the differences in breed for feeding behavior traits. A study by Robinson and Oddy (2004) reported an influence of breed type on meal frequency. Brahmans cattle had higher meal frequency compared to Belmont Reds and Santa Gertrudis, and temperate breeds had less frequency to the feed bunks compared to tropically adapted breeds (Robinson and Oddy, 2004). In our study the Simbrah and Angus Breeds had the lowest meal frequency ($P < 0.01$) compared to Braford and Brangus (Table 3.11).

CHAPTER IV

SUMMARY AND CONCLUSIONS

Results from study one demonstrated that the GrowSafe™ system 4000E could accurately predict BV and meal data compared to observed data. The 100 s, used for the maximum duration between consecutive EID recordings to end an uninterrupted BV, was the appropriate MPS to predicted BV frequency and duration, and meal frequency and duration compared to observed data using the GrowSafe™ 4000E system. The system ability to detect the animal present or not present at the bunk were 86.4 and 99.6%, respectively.

Results from the second study demonstrated that the meal criterion for heifers fed high-grain diets was 13.8 min. The 4 methods to calculate meal criterion demonstrated no differences in results for frequencies and durations of meal and the number of bunk visits per meal. Similar phenotypic correlations were found between the feeding behavior traits with RFI derived from the base model or with adjustments for final back fat. The adjustment of RFI to final back fat changed the RFI rank between breeds. The addition of feeding behavior traits to the RFI base model could explain up to 40.4% of the variation in DMI not explained by ADG or MBW.

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