FEED INTAKE AND FEEDING BEHAVIOR ASSOCIATIONS WITH PERFORMANCE AND FEED EFFICIENCY OF FEEDLOT CATTLE FED A CORN-BASED DIET

A Thesis

by

JAYTON CARL BAILEY

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

December 2011

Major Subject: Animal Science

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Approved by:

Chair of Committee,	Gordon E. Carstens
Committee Members,	Luis O. Tedeschi
	Jason E. Sawyer
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ABSTRACT

Feed Intake and Feeding Behavior Associations with Performance and
Feed Efficiency of Feedlot Cattle Fed a Corn-based Diet. (December 2011)
Jayton Carl Bailey, B.S., Texas A&M University
Chair of Advisory Committee: Dr. Gordon E. Carstens

The objective of the first study was to determine which combination of bimodal (2-population) distribution models best fit non-feeding interval data to distinguish intervals within (1st population) and between (2nd population) meals in beef cattle fed a corn-based diet. Feeding behavior traits were measured in 119 heifers fed a corn-based diet using a GrowSafe system. Bimodal distribution models were fitted to the $\log_{10}$-transformed interval lengths between bunk visit (BV) events for each animal using Gaussian (G); Weibull (W); Log-Normal; Gamma and Gumbel statistical functions. Goodness of statistical fit of each model was assessed by using Akaike's Information Criterion (AIC) and likelihood probability estimates.

Objectives of the second study were to quantify individual meal criterion and examine the associations between feeding behavior traits, performance, and feed efficiency traits in heifers fed a corn-based diet.

Results from study one indicate that the G-W bimodal distribution model is a statistically better fitting and likely a more appropriate model to define meal criterion compared to the standard G-G model used in previous literature.

Results from the second study suggest that the meal criterion for heifers fed a corn-based diet is 11.48 min when applying the G-W bimodal model to log-transformed interval lengths between BV events. Moderate phenotypic correlations between feed efficiency (residual feed intake- RFI) and several feeding behavior traits were found. Inclusion of these feeding behavior traits to the base model for RFI accounted for an additional 25% of the variation in DMI not explained by ADG or mid-test $BW^{0.75}$. Significant ($P < 0.05$) differences in 11 observed feeding behavior traits between RFI classification groups were also found suggesting that differences in feeding behaviors may contribute to the variation in RFI due to differences in energetic costs related to feeding activities.

DEDICATION

I would like to dedicate this thesis to my wife, Roxanne, who sacrificed many hours of “together time” very early in our marriage, but always loved and supported me through this work and in many times of frustration. I would also like to dedicate this work to my parents who taught me to rely on God no matter what life brings you and to never quit; which gives me the confidence to complete anything I set my mind to. To God be all the glory for the many amazing things he has created, and the mysteries of biology he left for us to study.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Overview

The main goal of beef production is to meet consumer demand for high-quality beef in an economically and environmentally sustainable manner. Profitability in the beef industry greatly depends on reducing costs of inputs relative to the value of outputs for the production system. Historically, the output traits have received the most focus in breeding programs for beef cattle. Attention has recently focused on traits for selection programs that improve the utilization of feed inputs without negatively impacting growth or other economically relevant traits. Feed costs represent the largest variable expense associated with producing beef, which emphasizes the necessity of selecting animals that are more efficient at using feed resources. Improving feed efficiency by just 10% will increase profits by 43% as estimated by Fox et al. (2001). Therefore, increasing efficiency of feed utilization would aid producers to have a more economically sustainable business while maintaining low beef costs for consumers. Approximately 50% of the total feed energy used to produce beef is needed to support the maintenance energy requirements of the breeding herd, and Montano-Bermudez et al. (1990) demonstrated that considerable between-animal variation exists in energy requirements for maintenance of beef cows. Maintenance energy requirements have been reported to be moderately heritable (Carstens et al., 1989; Bishop, 1992) suggesting that it is

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possible to select for more efficient beef cows. Therefore, it is important to fully understand the biological, physiological and genetic factors that contribute to feed efficiency in order to develop cost-effective strategies to select cattle that are more efficient at utilizing feed resources to enhance the economic sustainability of the beef industry.

Approaches Used to Measure Efficiency of Feed Utilization

Feed efficiency in growing cattle has traditionally been measured as a ratio of feed consumed per unit of weight gain (F:G or feed conversion ratio; FCR), or its inverse (G:F), which is commonly referred to as gross efficiency. Feed conversion ratio has been shown to be inversely related to average daily gain (ADG) and mature body size such that selection for a decreased FCR will result in an increase in ADG and mature body size (Herd and Bishop, 2000; Arthur et al., 2001b; Nkrumah et al., 2004; Lancaster et al., 2009). Koots et al. (1994b) reported estimates of genetic correlations between FCR, and body weight and gain that ranged from -0.24 to -0.95, clearly indicating that increased genetic potential for performance and size is negatively correlated with FCR. This relationship is undesirable for producers because cows with larger mature size have increased maintenance energy requirements, thus reducing overall efficiency in certain environments (Archer et al., 1999; Herd and Bishop, 2000; Crews, 2005).

Feed conversion ratio has been shown to be moderately heritable in beef cattle (Koots et al., 1994a; Arthur et al., 2001a,b; Schenkel et al., 2004; Crews, 2005).

However, Herd (1990) reported that selection for improved growth rate in beef cattle resulted in progeny that had similar post-weaning FCR as progeny produced by parents selected for low growth rates. Similarly, post-weaning FCR selection does not guarantee improvement in feed efficiency as Archer et al. (2002) reported a low genetic correlation between FCR measured in post-weaning heifers and FCR of open mature cows. Additionally, selection based on ratio traits like FCR can sometimes result in divergent and unpredictable genetic responses of the component traits (ADG, DMI) if genetic variances of the components are different (Gunsett, 1984; Crews, 2005). Although FCR may be a relevant feed efficiency trait in certain industry segments devoted primarily to production of growing animals, it has limited utility in breeding programs for replacement heifers as an increase in feed requirements through an increase in cow size counteracts the gains in efficiency of feedlot progeny (Archer et al., 1999). As a consequence, alternative measures of feed efficiency that are minimally affected by output traits such as ADG and mature body size are needed to evaluate efficiency of feed utilization of cow-calf production systems.

Several other traits have been used to assess efficiency of feed utilization such as the Kleiber ratio, relative growth rate and partial efficiency of growth. The Kleiber ratio is defined as weight gain per unit of metabolic body weight and is phenotypically and genetically correlated with relative growth rate, which is growth relative to size (Arthur et al., 2001b). Partial efficiency of growth is defined as the ratio of weight gain to feed after the expected requirements for maintenance have been subtracted (Archer et al., 1999). All three of these efficiency traits have been shown to be strongly related to growth (Arthur et al., 2001b; Nkrumah et al., 2004), suggesting that favorable selection for efficiency using these traits would increase mature cow size and feed requirements for the cow herd.

The concept of residual feed intake (RFI) was first introduced in beef cattle by Koch et al. (1963) as an alternative efficiency trait that was independent of body size and performance traits (e.g., growth). Residual feed intake is defined as the difference between actual intake and the animal's expected feed intake based on body size and gain over time. Animals that consume less feed than expected would then be considered more efficient (low RFI). The model used to calculate RFI involves linear regression of DMI on daily gain and metabolic body weight ($BW^{0.75}$):

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

where y is feed intake, β_0 is the regression intercept, β_1 is the 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 metabolic body weight (MBW; Koch et al., 1963). Residual feed intake has been found to be moderately heritable (Archer et al., 1997; Herd and Bishop, 2000; Arthur et al., 2001a,b; Crews et al., 2005), and responds to selection (Archer et al., 2002). Using RFI as a selection trait for feed efficiency is advantageous because it is phenotypically and genetically independent of level of production (Herd and Bishop, 2000; Carstens and Tedeschi, 2006; Herd and Arthur, 2009). Several studies (Herd and Bishop, 2000; Arthur et al., 2001a; Schenkel et al., 2004; Nkrumah et al., 2007) have reported that RFI is not genetically or phenotypically related to growth or body size like FCR, but is positively related to feed intake. However, studies have shown that RFI is not always unrelated (0.32 and -0.21) with body size (Arthur et al., 2001b and Archer et al., 2002, respectively). Thus, selection to improve genetic merit for RFI would be expected to have minimal effects on cow mature size, and subsequent feed requirements for the breeding herd (Archer et al., 1999).

While selection programs that focus on reducing feed inputs relative to level of production (e.g., RFI) can be used to improve economic efficiency of beef production systems, the cost of measuring feed intake remains a barrier to wide spread adoption. Additional research is needed to identify indicator traits for RFI such as feeding behavior traits that may be used to predict genetic merit for feed efficiency.

Behavioral Patterns Associated with Feeding Activities

Advancements in radio frequency identification (RFID) based technologies have made it easier to objectively measure feeding behavior traits in large groups of animals. Feeding behavior traits typically evaluated include frequency and duration of relatively short bunk visit (BV) events, and frequency and duration of longer meal events. Bunk visit frequency (events/d) is defined as the number of visits an animal makes to the feedbunk with or without consuming feed, and bunk visit duration (min/d) is the summation of time the animal spends each day at the feedbunk. A meal is defined as a cluster of bunk visit events which can be distinguished from the next meal by a meal criterion, which is the longest non-feeding interval still considered part of a meal (Tolkamp and Kyriazakis, 1999a; Yeates et al., 2001). Therefore, meal frequency (events/d) is defined as the total number of meals per day and meal duration (min/d) is the sum of time within each meal throughout the day. In addition, meal length (min/event), meal size (kg/event) and eating rate (g/min) traits can also be quantified after meal events have been defined by a meal criterion.

The concept for clustering bunk visits into separate meals is related to physiological factors that affect animal satiety with the probability that an animal will begin another feeding bout (Forbes, 1985; Tolkamp et al., 2000). Tolkamp et al. (2000) concluded that grouping of feeding bouts into meals is the most biologically relevant method to examine feeding behavior compared to using the total number of bunk visits per animal which can be sensitive and subject to social hierarchy, feeding pressures, diurnal and environmental changes. Repeatability for meal-behavior traits in dairy cattle was found by DeVries et al. (2003) to be moderate to high in early (0.34 to 0.72) and late (0.22 to 0.75) lactation periods.

The challenge to assessing feeding behavior data is that diverse technologies are used to collect behavioral data associated with feeding activities. Visual observations, video-taped observations, jaw movements and computerized systems can have an effect on the number of feeding events that are recorded (Tolkamp et al., 2000). There is large variation in behavior traits measured across multiple studies (Table 1.1). In addition, there are multiple methods of quantifying a meal criterion resulting in divergence in the length of meal criterion and subsequently, meal traits. Meal criterion ranges from 2 to 59 min (Tolkamp et al. 2000; Table 1.1). Likewise, large variations in meal frequency (4 to

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

Gender[1]	Number of Animals	Breed and Diet[2]	System	Meal Criteria, min	BV[3] frequency, events/d	Meal frequency, events/d	BV[3] duration, min/d	Meal duration, min/d	Source
S	341	Angus[C]	GrowSafe	5	--	7 to 9	--	85 to 118	Lancaster et al. (2009)
H	115	Brangus[F]	Calan Gate	5	--	15	--	219	Bingham et al. (2009)
H	6	Holstein[F]	Insentec	17	--	10 to 11	--	140 to 188	DeVries et al. (2009)
H	4	Holstein[C]	A&D	27 to 39	--	9 to 10	--	310 to 333	Robles et al. (2007)
C	142	Holstein[F]	Merican	47 to 59	--	4 to 5	35 to 51	163 to 192	Bach et al. (2006)
S	234	Crossbreed[C]	GrowSafe	5	--	9 to 10	--	105 to 162	Schwartzkopf - Genswein et al. (2004)
C	12	Holstein[F]	GrowSafe	28	--	5 to 10	--	32 to 57	DeVries et al. (2003)
S,H	12	Charolais[F]	GrowSafe	5	--	15 to 18	--	101 to 131	Schwartzkopf - Genswein et al. (2002)
C	37	Holstein[F]	Insentec	48	--	6 to 7	--	34 to 40	Tolkamp et al. (2000)
S	464	Crossbreed[C]	GrowSafe	--	30	--	66	--	Nkrumah et al. (2007)
S	174	Crossbred[C]	GrowSafe	--	28	--	72	--	Basarab et al. (2007)
S	27	Angus x Charolais[C]	GrowSafe	--	18 to 35	--	48 to 74	--	Nkrumah et al. (2006)
C	40	Holstein[F]	Insentec	--	12	--	170	--	Shabi et al. (2005)
S,H	1481	Tropical &Temperate[C]	Insentec	--	8 to 19	--	77 to 105	--	Robinson and Oddy (2004)
H	86	Limousin x Holstein[C]	Insentec	--	53 to 68	--	116 to 117	--	Kelly et al. (2010)

[1] S = steer, H = heifer, C = cow; [2] C= high concentrate diet, F = high forage diet; [3] BV = bunk visit event

17.7 min/d) and meal duration (33.8 to 333 min/d) have been reported in the literature emphasizing the obvious disparities in both feeding behavior evaluations and meal criterion calculation techniques. These differences in the range of feeding behavior traits are related to the multiple calculation methods used to assess meal criterion, and these differences are also influenced by breed type, gender, diet, and feeding management practices.

Several studies (Schwartzkopf-Genswein et al., 2002; Golden et al., 2008; Basarab et al., 2007; Nkrumah et al., 2007; Bingham et al., 2009) have evaluated the relationships between feeding behavior traits, and feed intake and feed efficiency in beef cattle. Robinson and Oddy (2004) found that RFI was phenotypically and genetically correlated with BV duration reported as feeding time (0.16 and 0.35, respectively) and BV frequency reported as the number of feeding sessions per day (0.18 and 0.43, respectively). Kelly et al. (2010) found positive correlations between RFI and BV frequency (which consisted of visits when feed was consumed; 0.45), visits to the bunk without consuming feed (0.23), and eating rate (0.26) in growing beef heifers. Likewise, Montanholi et al. (2009) reported positive correlations between RFI and BV duration (0.24), BV frequency (0.35), eating rate (0.44), and meal size (0.41) in growing steers. Lancaster et al. (2009) reported that meal duration was positively correlated with RFI (0.41), ADG (0.17), and DMI (0.23). In this study, RFI was weakly correlated with meal frequency (0.26), but was not correlated with meal eating rate, which is in contrast with results presented by Kelly et al. (2010) and Montanholi et al. (2009).

The relationship between feeding behavior traits and feed efficiency has been examined in other species including swine, sheep, and poultry. In growing Duroc barrows, Rauw et al. (2006) reported moderate correlations (0.21, 0.31, and 0.34) between BV duration and RFI during 3 different feeding periods in which RFI was calculated. De Haer et al. (1993) found that pigs with low RFI phenotypes visited the feeder less frequently, ate more per visit and spent less time eating compared to high-RFI pigs. Bunk visit duration, frequency and feed intake per BV traits were all found to have moderate to high heritabilities in Landrace and Large White boars of 0.43, 0.43, and 0.51, respectively (Von Felde et al., 1996). Similarly, BV duration and frequency were found to be moderately heritable in composite ram lambs (0.36 and 0.35, respectively) by Cammack et al. (2005). In a review of poultry literature, Morrison and Leeson (1978) reported that more efficient laying hens (based on feed to egg mass ratio) spent more time resting, less time standing and less time feeding compared to less efficient hens. Katle et al. (1984) also observed that more efficient hens (based on RFI) were less active and less sensitive to disturbances than the less efficient contemporaries.

In beef cattle, Lancaster et al. (2009) found that feeding behavior traits accounted for 35% of the variation in DMI not explained by ADG, MBW and ultrasound traits. Similarly, in pigs, de Haer et al. (1993) reported 44% of the variation in RFI was explained by feeding behavior traits. Identifying feeding behavior parameters that are predictors of feed efficiency could prove to be a cost-effective approach for selection programs.

Determination of Meal Criterion

Many studies have characterized meal criterion in dairy cattle (Tolkamp and Kyriazakis, 1999a; Yeates et al., 2002; DeVries et al., 2003), but there are few studies that have evaluated meal criterion in beef breeds. By definition, a meal criterion is the longest interval between bunk visit events that is still considered part of a meal. Tolkamp and Kyriazakis, (1999b) concluded that determination of meal-event data was useful in understanding the relationships between feeding behaviors and long-term feed intake patterns.

Numerous methodologies have been used to derive meal criterion in order to evaluate meal patterns in animals. One of the earliest methods, first used by Forbes et al. (1986) and later used by Rook and Huckle (1997) to evaluate grazing cow data involved a frequency analysis of non-feeding interval lengths (the time between bunk visit events) plotted against the duration of these intervals. Piecewise linear regressions, referred to as the ‘broken-stick’ model, were plotted on the non-feeding interval data. The breakpoint of the best-fitting broken-stick was visually selected as the meal criterion (Rook and Huckle, 1997). Tolkamp and Kyriazakis (1999a) applied this method to dairy cattle data and found that the residuals of the model were not randomly distributed and that it overestimated the middle and outer ranges of non-feeding intervals. Moreover, Tolkamp and Kyriazakis, (1999a) reported that a meal criterion based on this method was only 1.9 min. Therefore, frequency-type analyses are considered irrelevant due to the models predicting negative frequencies and a small meal criterion, both of which cannot be biologically interpreted (Tolkamp and Kyriazakis, 1999a).

The log-survivorship analysis, which also uses the broken stick technique, is another method of assessing meal criterion. The log-survivorship model is very similar to the frequency model in that the frequency of non-feeding intervals are transformed logarithmically and plotted against the linearly scaled duration of these intervals. Accumulation of gap lengths in the log-survivorship model begins with the longest gap, not the shortest gap as in the frequency model which is the defining difference between the two techniques (Sibly et al., 1990). The broken-stick model is applied, and the meal criterion, selected by visual assessment, is considered to be the interval where the two lines meet. The log-survivorship model is based on the assumption that the probability of an animal initiating a meal event or a feeding bout (within a meal) is independent of the preceding non-feeding interval length (Langton et al., 1995). Based on this assumption, two separate groups of intervals, within meals and between meals will be formed, resulting in negative exponential distributions. Similar to the broken-stick model, a clear biological explanation for the resulting negative exponential distributions has yet to be presented in the literature, which has negated the reliability of the log-survivorship technique for evaluation of meal criterion.

Use of the log-survivorship model has been scrutinized by Sibly et al. (1990) and Langton et al. (1995) because cumulative frequencies are not independent events. Therefore, a log-frequency model which does not accumulate non-feeding interval gap lengths and instead incorporates log-transformed intervals was reviewed and tested by Tolkamp and Kyriazakis (1999a). The broken-stick technique was applied to the non-feeding intervals that were grouped into classes by obtaining maximum likelihood estimates and deleting some selected intervals in order to obtain a meal criterion. However, due to the close similarities to the log-survivorship method, the log-frequency model resulted in similar residuals that had unclear biological explanations and conflict with the satiety concept.

A fourth approach that has been used to evaluated meal criterion involves the application of a bimodal Gaussian distribution model. Non-feeding interval lengths between BV events are log-transformed and fitted to a 2-population distribution model, with the 1st population representing non-feeding intervals within a meal and the 2nd population representing non-feeding intervals between meals. Using this method, two Gaussian statistical functions are fitted to both populations and the meal criterion is defined by the intersection of the two Gaussian curves. This approach provides a more objective method of computing meal criterion. Furthermore, Tolkamp and Kyriazakis (1999a) found that this method, which is based on the principles of satiety, was more biologically correct and provided a superior statistical fit to the non-feeding interval data compared to previous meal criterion techniques. Similarly, Allcroft et al. (2004) concluded that the use of the bimodal Gaussian model not only improved statistical fit, but allowed for the effect of 'short-term memory' which biologically describes feeding behavior better than log-survivorship models used by Slater and Lester (1982), Sibly et al. (1990), and Langton et al. (1995).

The satiety concept states that as time since the last meal increases, the probability of the next meal starting also increases, indicating that feeding events are not randomly distributed throughout the day (Tolkamp et al., 1998). Applying Gaussian distributions, which have a symmetrical nature, to non-feeding interval data may not statistically fit the non-symmetrical frequency data. The Weibull distribution has been used previously to examine the tendency of locusts to start a meal (Simpson and Ludlow, 1986), to describe the herd life of Holstein cows (Dǖrr et al., 1999), and describe licking behavior of rats (Davis, 1996). The Weibull distribution can take a two-parameter form with a fixed origin, or a three-parameter form that allows the starting point of the distribution to move from the origin to another point on the x-axis (Yeates et al., 2001). This property enables the Weibull distribution to be used on data sets that do not encompass an origin, i.e. the population of non-feeding intervals between meals. Yeates et al. (2001) and Melin et al. (2005) considered a Weibull function in 2 and 3-population distribution models in evaluating non-feeding interval data from dairy cows. The Weibull distribution was found to fit the 2nd population (between-meal intervals) of non-feeding intervals statistically better than the Gaussian distribution. The biological significance of the better statistical fit of the Weibull distribution is not entirely evident. However, when model parameters are used to calculate starting probabilities that the animal will begin a meal within a designated time after the last meal, the Weibull distribution predicted starting probabilities more accurately than the Gaussian distribution, which better supported the satiety concept (Yeates et al., 2001).

Three-population Gaussian distribution models have also been fit to non-feeding intervals (Tolkamp and Kyriazakis, 1999a; Yeates et al., 2001) with the 1st and 3rd populations representing non-feeding intervals within and between meals, respectively, and the 2nd population representing extended intervals related to drinking bouts. The 3-

population model was less consistent in supporting the satiety concept compared to the 2-population model. The 3-population model initially predicted that meal starting probabilities would first increase, but then decrease as the time from the last meal increased, whereas the 2-population model predicted that meal starting probabilities would continually increase as time from the last meal increased (Tolkamp and Kyriazakis, 1999a; Yeates et al. 2001; Melin et al., 2005).

Similar to the 2-population method, use of a Weibull function in the 3-population model to describe the between-meal intervals was in better agreement with the satiety concept than 3-population models that used G functions to fit between-meal intervals (Yeates et al., 2001; Melin et al., 2005). As with the 2-population models, the statistical fit of 3-population models with the Weibull function were better than models with G functions. However, both studies reported evidence that not all individual cows show a distinct third population of non-feeding intervals, thus disqualifying those animals from application of the 3-population distribution model. Due to the fact that the 3-population model cannot be used on every animal, the benefits of implementing the third population have not been well described in the literature.

The use of the 2-population distribution model in dairy cattle to evaluate meal criterion (Tolkamp and Kyriazakis, 1999a,b; Yeates et al., 2001; Melin et al., 2005) has proven to be the most useful, biologically sound, and consistent technique compared to other methods. However, few studies have used this methodology to evaluate meal criterion in beef cattle. Further research is warranted to establish objective and repeatable methods to quantify meal criterion in livestock species.

Dietary Effect on Feeding Patterns

Analysis of short-term feeding behavior patterns can provide relevant biological insight into long term regulation of feed intake (Forbes et al., 1985), and further, increase our understanding of the mechanisms involved in long-term diet selection. Frequently, animals select a consistent long-term diet (Forbes and Kyriazakis, 1995) and this consistency in diet selection is a result of short-term feeding behaviors (Gill and Romney, 1994). Physical properties, nutrient composition and palatability of a ration can have a large effect on the daily dry matter intake of the animal consuming the given feed and thereby affecting the short-term feeding behavior of animals (Allen, 2000). As a result of these ration characteristics, initiation and termination of meals occurs from information received in the satiety centers of the brain via feedback mechanisms from visceral organs such as distension and hypertonicity in the reticulo-rumen, chemical and osmotic receptors in the digestive tract wall, and metabolite receptors in the liver (Forbes, 1985). Intake is a function of meal frequency and meal size as determined by individual animal maintenance energy requirements and dietary factors that affect hunger and satiety (Allen, 2000).

Feeds with a rapid rate of ruminal fermentation drastically change the volatile fatty acid profile and osmolality in the reticulo-rumen, which stimulates receptors in the rumen wall signaling the satiety centers in the brain to temporarily satisfy the animal’s appetite. This satiety mechanism could potentially influence short-term feeding behaviors by increasing or decreasing meal lengths and sizes. Rapid rates of fermentation also increase the passage rate of the digesta through the rumen, which then stimulates the animal to eat again, shortening the time between meals. High concentrate diets are typically small in particle size allowing the animal to spend less time chewing and consuming more feed per minute. However, as particle size of the diet decreases, the potential for acidosis increases as ruminal fermentation rates increase and less saliva is being introduced into the rumen. DeVries et al. (2009) examined short-term behaviors such as feeding, ruminating, and lying behaviors in lactating dairy cows that were classified as low or high risk for subacute ruminal acidosis (SARA). Overall, cows with high risk for SARA were found to spend less time ruminating than cows at low risk for SARA. Upon an acidosis challenge, lying time decreased, but feeding and rumination time increased in both groups 24 h after the challenge, suggesting that acute bouts of acidosis possibly alter short-term behavioral patterns. SARA involves a complex interaction between the microbial population in the rumen, intake and diet composition, but reasoning for why some animals develop the problem and some do not is unclear in current literature (Schwarzkopf-Genswein et al., 2003).

The physical characteristics between forage and concentrate diets and their affects on short-term feeding behaviors are well known. Golden et al. (2008) found that efficient animals consuming a concentrate diet without forage ate more times a day (14.5 vs. 11.0 events/d) and had greater eating rates (149 vs. 98 g/min) than steers fed a traditional feedlot diet with forage.

Differences in fermentation rates of concentrate diets on feeding behaviors were examined by Rotger et al. (2006) using a 2 × 2 factorial arrangement of diets consisting of corn, barley, soybean meal, and sunflower meal. The barley-sunflower rapid fermentation diet resulted in reduced intake, shorter meal lengths, meal size (g/meal) and meal criterion, but more frequent meals and a greater eating rate (g/min) compared to the other diets. Rumination and chewing time was greater ($P < 0.005$) in the barley based diets per kilogram of dry matter but total eating time per kilogram of dry matter was not affected by any diet combination.

Animals consuming a diet with a greater proportion of forage are expected to chew more and ruminate longer, but chewing time per unit of forage intake decreases as intake increases due to an increase in rumination efficiency (Yang et al., 2001). Large particle size and increased saliva production could likely be the cause for the increase in microbial digestion and rumination efficiency (Beauchemin, 1991). It could then be expected that meal length and meal criterion linearly increase with the additional increase of forage in a diet. As animals spend more time chewing, non-feeding intervals would increase in length of time, thereby increasing the meal criterion. A greater meal criterion decreases meal frequencies but increases meal length, which incorporates the additional chewing time observed in a high forage diet. Meal criterion has been found to be longer in studies with greater amounts of forage in the diet than studies examining cattle fed high-concentrate rations (Table 1.1). However, studies that have examined feeding patterns in animals fed high-concentrate diets have typically arbitrarily selected a meal criterion based on previous literature (Schwartzkopf-Genswein et al., 2004; Lancaster et al., 2009; Montanholi et al., 2009).

Few studies have directly examined the effects of diet composition on meal criterion and meal patterns in cattle. There is limited research available on individually calculated meal criterion of animals fed a high-concentrate diet and in addition, multiple methodologies to calculate meal traits have been used in previous literature. A robust methodology to analyze short-term feeding behaviors that generates biologically useful information is needed in order to compare studies. This method should assist in the understanding of long-term diet choice and grant researchers the ability to estimate relevant feeding behavior traits that could be implemented in breeding programs as selection traits for feed efficiency.

CHAPTER II

TECHNICAL NOTE: EVALUATION OF BIMODAL DISTRIBUTION MODELS TO DETERMINE MEAL CRITERION IN HEIFERS FED A HIGH-GRAIN DIET

Introduction

Behavioral patterns associated with feeding activities provide biological insight into long-term regulation of feed intake (Forbes et al., 1985), diet preferences (Yeates et al., 2002), and health status of animals (Gonzalez et al., 2008). Multiple technologies have been used to collect frequency and duration of feedbunk event (BV) data to examine feeding behavior traits in cattle (Tolkamp et al., 2000). In addition, various analytical techniques have been used to evaluate meal patterns (e.g., meal size, frequency, duration) from feedbunk event data. Meal events represent clusters of BV events separated by short intervals that are differentiated from the next meal by a non-feeding interval that is long compared to the non-feeding intervals within a meal. The longest non-feeding interval considered to be part of a meal is defined as the meal criterion.

Tolkamp and Kyriazakis (1999) examined multiple techniques to objectively quantify meal criterion in dairy cattle. They concluded that use of a bimodal model to define meal criterion as the intersection of 2 distributions that described within and between-meal non-feeding intervals provided the most biologically appropriate estimate of meal criterion. The bimodal distribution method has been applied to the analysis of feeding behavior data of dairy cattle (Tolkamp et al., 2000; Yeates et al., 2001; DeVries et al., 2003), but this method has not yet been evaluated in beef cattle. The establishment of a robust methodology to objectively quantify meal criterion is essential for studies that aim to determine how feeding behavior patterns regulate appetite and feeding efficiency in beef cattle. Therefore, the objective of this study was to determine the best bimodal distribution model to describe non-feeding intervals within (1^{st} population) and between (2^{nd} population) meals in beef heifers fed a high-grain diet.

Materials and Methods

Animals and Experimental Design

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

Feeding behavior traits were measured in 119 heifers of four breeds (23 Angus, 29 Braford, 43 Brangus, and 24 Simbrah) with an initial BW of 252 ± 32 kg. Upon arrival, heifers were fitted with passive, half-duplex, electronic identification (EID) transponder ear tags (Allflex USA Inc., Dallas, TX) and placed into 1 of 4 pens (12 × 28 m) each equipped with 4 electronic feedbunks (GrowSafe DAQ 4000E; GrowSafe System Ltd., Airdrie, AB, Canada) at the Beef Cattle Systems Research Center in College Station, TX. Heifers were adapted to a high-grain diet (3.08 Mcal ME/kg, 13% CP on DM basis) for 28-d using 3 step-up diets prior to the start of the 70-d 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 which was offered ad libitum twice daily at 0830 and 1630 h.

The GrowSafe System

The GrowSafe system (DAQ 4000E) used in this study consisted of feedbunks equipped with load bars to measure feed disappearance, stanchions with neck bars to allow only one animal access to a feedbunk at once, and antenna to detect animal presence at the feedbunk. The GrowSafe system was designed to monitor feeding behavior by continuously recording presence of an animal at the feedbunk once an electronic identification (EID) transponder tag transverses the neck bars of the stanchion. The electronic system measures individual feed intake by continuously weighing feed disappearance during each BV event. These data (EID number, feedbunk number, time stamp of each EID recording, and scale weight) were recorded via wireless transfer to a data-acquisition computer. The EID scanning rate of the GrowSafe system used in this study was 2 s.

Feeding Behavior Data Collection

A subroutine of the GrowSafe 4000E software, Process Feed Intakes was used to compute feed intake and BV data. All default settings as previously defined (GrowSafe, 2009) were used in this study, with the exception of the parameter setting for maximum duration of time between consecutive EID recordings to end an uninterrupted BV event. For this study, the parameter setting of 100 s was used as recommended by Mendes et al.

(2011). Feeding behavior data from 4 d of the 70-d study period were omitted due to system failure (power outage, equipment malfunction), or when the proportion of daily feed supply assigned to individual animals (e.g., feed disappearance) was less than 95%. The average proportion of feed disappearance assigned to animals for the remaining 66 d of data used for this study was 99.3%.

Model Fitting and Testing

Feedbunk visit frequency was defined as the number of daily BV events recorded regardless of whether or not feed was consumed during the event, and BV duration as the length summation of all BV events during a 24 h period (Figure 2.1). Animals consumed feed in approximately 9 out of 10 BV events; 572,627 total BV events were recorded during the 66 d period. The interval lengths between BV events when an animal was not at the feedbunk were defined as non-feeding intervals. The EID scanning interval of the GrowSafe system used in this study resulted in a natural periodicity of non-feeding intervals at 2 s. Therefore, non-feeding intervals less than 0.3 $\log_{10}$s (2 s) were removed prior to data analysis, which was similar to the approach used by DeVries et al. (2003).

Non-feeding intervals were $\log_{10}$-transformed and plotted in a frequency distribution graph using the Meal Criterion Calculation software (MCC; http://nutritionmodels.tamu.edu), which uses the statistical software R (ver. 2.13; R Foundation for Statistical Computing; http://r-project.org), and the mixdist package (R Foundation for Statistical Computing). Within MCC, a total of 25 bimodal distribution

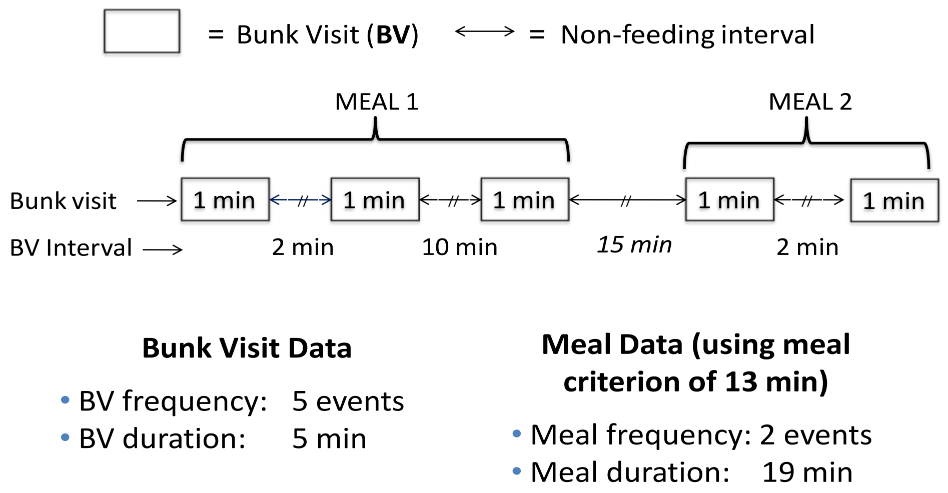

Figure 2.1. Feeding behavior definitions scheme.

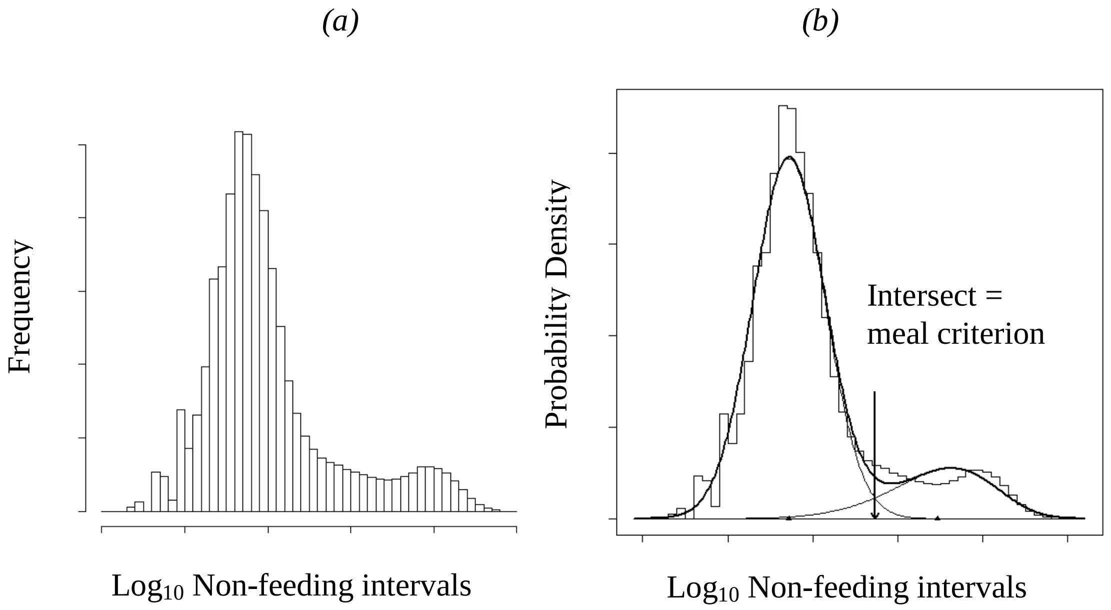

Figure 2.2. *a)* Histogram of $\log_{10}$-transformed non-feeding intervals. Intervals less than 2 s have been removed *b)* Graphical representation of the G-W combination with a bin width of 0.1 $\log_{10}$ units. Intervals less than 2 s have been removed.

models comprised of Gaussian (G), Weibull (W), Log-Normal (Ln), Gamma (Gam), and Gumbel (Gum) probability density functions (PDF; see Appendix A) were fitted to each individual animal's $\log_{10}$-transformed non-feeding intervals (Figure 2.2), and the intersection of the 2 PDF defined the meal criterion.

Three methods were used to evaluate the statistical fit of the 25 bimodal PDF models. First, the Akaike Information Criterion (AIC, Akaike, 1974) was used to determine goodness of fit for each bimodal PDF model within each animal. The bimodal model with the least AIC value was considered the best fitting combination for that animal. The PROC FREQ command of SAS (SAS Inst. Inc., Cary, NC) was used to evaluate the frequency distribution of the best fitting models across animals and to examine the effect of breed on the frequency distribution of the selected best fitting bimodal model.

Second, the change in AIC for each of the 25 models within an individual animal was compared to the G-G combination using the equation:

$$\Delta\ \mathrm{AIC} = \mathrm{AIC}_{\mathrm{Combination\ A}} - \mathrm{AIC}_{\mathrm{G\text{-}G}}$$

whereas a negative Δ AIC signifies that distribution combination A has a lower AIC value than G-G and thus a better statistical fit and vice versa. The number of non-feeding interval observations used in fitting the PDF influences the AIC value computed for each bimodal distribution model, and each animal possesses its own unique number of BV events and non-feeding intervals. Therefore, direct comparison of AIC values for a given model across animals is not a robust method to assess the overall best model, which formed the rationale for computing delta AIC values to compare distribution models across animals. Use of this method eliminated the influence of between-animal variation of BV frequency on AIC values to provide a more reliable approach in evaluating the best overall distribution model.

Third, probability likelihood estimates were generated for each of the 25 model within individual animals using the equation (Motulsky and Christopoulos, 2003):

$$P = (e^{-0.5\Delta AIC}) / (1 + e^{-0.5\Delta AIC})$$

The GLIMMIX procedure in SAS was used to test the probabilities for each combination against the G-G model with breed as a fixed effect. Distribution combinations with a probability greater than 0.50 were considered as having a greater likelihood to be a statistically better fitting model compared to the G-G model.

Results and Discussion

The G-W and W-W distribution models were selected as the best fitting models for 52 and 41 individual animals, respectively, or 78.2% of the total number of animals (Table 2.1). Breed type had no affect ($P > 0.7$) on the best fitting model that was selected. The summary statistics in Table 2.2 reveal that there was substantial variation in the frequency and duration of BV events measured in this study. Although mean BV frequency was numerically higher than in previous studies with beef cattle fed high-grain diets, the coefficient of variation for BV frequency in this study (0.194) is comparable to values reported by Nkrumah et al. (2006; 0.130) and Kelly et al. (2010; 0.274) who reported ranges in BV frequency of 18.0 to 35.0, and 53.4 to 68.1 events/d, respectively.

Table 2.1. Frequency distribution of 2-population distribution models that were selected as the best fit based on AIC value (n = 119).

Distribution[1]	Frequency
Gaussian – Weibull	52
Weibull – Weibull	41
Gamma – Weibull	10
Gumbel – Weibull	9
Log-Normal – Weibull	6
Weibull – Gaussian	1

[1] All other model combinations were not selected as the best fit for any animal.

$\chi 2 = 113.54$; $P < 0.01$.

Table 2.2. Summary statistics of feeding behavior traits for heifers fed a high-grain diet (n = 119).

Item[1]	Mean	SD	Minimum	Maximum
DMI, kg/d	7.91	1.39	6.61	14.52
Bunk visit frequency, events/d	74.7	14.5	49.6	117.1
Bunk visit duration, min/d	73.0	22.3	20.7	134.7
Meal frequency, events/d	12.0	4.0	5.0	25.0
Meal duration, min/d	155.2	35.3	78.2	262.0
Meal criterion, min	8.06	0.03	2.11	30.64

[1] Meal data calculated from applying the Gaussian-Weibull distribution model to log-transformed non-feeding interval data.

Table 2.3. Average Δ AIC values ± SD and likelihood probability estimates for each mixed distribution model compared to the Gaussian-Gaussian model.

2-population distribution model[1]	Gaussian	Weibull	Log-Normal
Gaussian	0 (0.500)^{c}	-34.54 ± 42.9 (0.997)^{a}	39.64 ± 32.6 (0.000)^{f}
Weibull	-12.36 ± 111.8 (0.443)^{c}	-52.48 ± 119.4 (0.727)^{b}	22.24 ± 138.1 (0.204)^{d}
Log-Normal	394.83 ± 282.1 (0.045)^{f}	318.83 ± 316.4 (0.131)^{e}	409.58 ± 278.6 (0.040)^{f}

^{a,b,c,d,e,f} Means without a common superscript differ ($P < 0.05$).

[1] Functions in the first column represent first population; Functions in the first row represent second population.

Delta AIC values and likelihood probability estimates for nine bimodal distribution models compared to the G-G model are presented in Table 2.3. The distribution models that incorporated a Gam or Gum function had high delta AIC values and very low or zero likelihood probabilities and therefore are not presented. Bimodal models for which the Ln function represented either the first or second population also had relatively large delta AIC values and low likelihood probability estimates, suggesting that these models were not statistically better fitting than the standard G-G model. The G-G model was selected as the standard distribution model based on previous modeling work by Tolkamp et al. (2000) who pioneered the bimodal distribution modeling technique based on the concepts of satiety. The G-W, W-G, and W-W combinations were the only models with negative delta AIC values suggesting that these bimodal distribution models statistically fit the $\log_{10}$-transformed non-feeding intervals better than the G-G model.

The G-W and W-W models were both found to be more likely (0.997 and 0.727, respectively) correct compared to the standard (0.500) G-G model. The W-W model had a lower delta AIC value than the G-W model; however, the SD was larger for the W-W model (119.4 vs. 42.9), suggesting that the G-W model was more consistent in describing non-feeding interval data across animals. In addition, the G-W model had the highest ($P < 0.05$) likelihood probability suggesting it is the most likely to be the best statistical fitting model compared to the G-G model.

Model parameters for the 4 bimodal models that incorporated the G and W functions are presented in Table 2.4. Use of the G-G and G-W distribution models

Table 2.4. Model parameters for mixed model distributions using Gaussian (G) and Weibull (W) functions.

Parameter	G-G	G-W	W-G	W-W
Proportion of intervals in first population	0.842	0.835	0.806	0.810
Proportion of intervals in second population	0.158	0.165	0.194	0.190
Median of first population, min	0.880	0.872	0.813	0.813
Variance of first population, min	0.044	0.044	0.041	0.042
Median of second population, min	54.98	48.88	35.11	32.36
Variance of second population, min	0.062	0.068	0.079	0.083
Meal criterion, min	9.3	9.0	5.9	5.9
Meal frequency, events/d	11.8	12.0	13.7	14.0
Meal duration, min/d	156.9	155.2	143.3	144.2

resulted in a numerically higher proportion of the non-feeding intervals defined as within-meal intervals compared to the used of the W-W and W-G models. Likewise, Yeates et al. (2001) found that a higher proportion of non-feeding intervals were defined as within-meal intervals when a G distribution was used to describe the 1st population of intervals rather than the W distribution. When a W distribution was used to described the non-feeding intervals between meals instead of the G distribution, Yeates et al. (2001) and Melin et al. (2005) found that the models had better statistical fit, and a higher proportion of intervals were defined as between-meal intervals. Similarly, the G-W model in the current study accounted for a higher numerical proportion of between-meal intervals and had better statistical fit than the G-G model.

In addition, Yeates et al. (2001) and Melin et al. (2005) found that distribution models that used the W distribution to describe between-meal intervals predicted increasing starting probabilities of a meal as time since the last meal increased, which conformed to the satiety concept. In contrast, both of these studies found that use of the G distribution to describe between-meal intervals predicted decreasing starting probabilities of a meal as time since the last meal increased.

The meal criterion derived from the G-W model in this study was less than the values of 21.2 and 41.7 min reported by Yeates et al. (2001) and Melin et al. (2005), respectively, in dairy cows. Meal frequency is dependent upon meal criterion such that a small meal criterion will result in higher meal frequency and in contrast, a larger meal criterion results in less frequent meals. Therefore, meal frequency was higher for the G-

W model in this study than previous research (Yeates et al., 2001; Melin et al., 2005) in dairy cattle.

Differences in bunk management, genetics, and diet could all be potential sources of variation when comparing feeding behaviors and meal traits between beef and dairy cattle. Despite these differences, results from this study are in agreement with Yeates et al. (2001) and Melin et al. (2005) who suggested the use of the G-W combination to better statistically describe feeding behavior in dairy cattle.

In summary, our analysis indicated that application of the G-W bimodal distribution model to non-feeding interval data was the best choice to evaluate meal pattern behavioral traits in beef heifers fed high-grain diets. Application of the G-W model to individual-animal feeding behavior data to quantify meal patterns has considerable potential to allow further investigation of mechanisms regulating feed intake and feed efficiency in cattle. Consequently, this method could be used to identify inter-animal variation in feeding behavior and meal traits in beef cattle leading to enhanced management strategies in the feedlot to improve profitability.

CHAPTER III

FEED INTAKE AND FEEDING BEHAVIOR ASSOCIATIONS WITH PERFORMANCE AND FEED EFFICIENCY OF FEEDLOT CATTLE FED A CORN-BASED DIET

Introduction

Profitability in the beef industry greatly depends on reducing costs of inputs relative to the value of outputs for the production system. Historically, the output traits have received the most focus in breeding programs for beef cattle. Attention has recently focused on traits for selection programs that improve the utilization of feed inputs without negatively impacting growth or other economically relevant traits. Feed costs represent the largest variable expense associated with producing beef, which emphasizes the necessity of selecting animals that are more efficient at using feed resources.

Several studies (Schwartzkopf-Genswein et al., 2002; Golden et al., 2005; Basarab et al., 2007; Nkrumah et al., 2007; Bingham et al., 2009) have evaluated the relationships between feeding behavior traits, and feed intake and feed efficiency in beef cattle. Residual feed intake (RFI) was first proposed as an alternative efficiency trait by Koch et al. (1963) and is the difference between actual DMI and expected DMI calculated by the linear regression of DMI on growth and body size. Using RFI as a selection trait for feed efficiency is advantageous because unlike FCR, RFI is phenotypically and genetically independent of production traits (Herd and Bishop, 2000;

Carstens and Tedeschi, 2006; Herd and Arthur, 2009). Studies in beef cattle have found that RFI is moderately heritable (Archer et al., 1997; Herd and Bishop, 2000; Arthur et al. 2001a,b; Crews et al., 2003). Therefore, selection to improve genetic merit for RFI will have minimal effects on cow mature size and feed requirements (Archer et al., 1999).

Advancements in radio frequency identification (RFID) based technologies have made it easier to objectively measure feeding behavior traits in large groups of animals. Feeding behavior traits (e.g., bunk visits and duration) have been found to be weakly to moderately correlated with RFI (Nkrumah et al., 2007; Lancaster et al., 2009; Montanholi et al., 2009; Kelly et al., 2010) and account for 44% and 35% of the variation in feed intake that was not accounted for by ADG, MBW (de Haer et al., 1993 and Lancaster et al., 2009, respectively). Use of these traits as an indicator of efficiency could provide knowledge into the biological basis for variation in RFI as well as decrease the costs associated with measuring feed efficiency. Therefore, the objective of this study was to evaluate feed intake and feeding behavior associations with performance and feed efficiency traits in cattle fed a corn-based diet.

Materials and Methods

Animals and Experimental Design

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

Eight-hundred-seventy-five heifers (182 Angus, 238 Braford, 264 Brangus, and 191 Simbrah) from the Deseret Ranch (St. Cloud, FL) were used in this study. Data was collected during 6 trials, with one trial conducted during the spring (n = 464) and fall (n = 411) for 3 consecutive years. Upon arrival cattle were fitted with passive, half-duplex transponder ear tags (Allflex USA Inc., Dallas, TX) and placed into pens equipped with electronic feedbunks (GrowSafe System Ltd., Airdrie, AB, Canada). Two trials (n = 241) were conducted at the Beef Research Unit (College Station, TX) in 4 pens, each with 4 GrowSafe bunks while the remaining 4 trials (n = 634) were conducted in 2 pens, each with 10 GrowSafe bunks at the McGregor Research Center (McGregor, TX). For each trial, calves were adapted to a high grain diet (Table 3.1) for 28 days and allowed to become accustom to the GrowSafe system. Thereafter, heifers were fed ad libitum for approximately 70 d, and individual feed intake and feeding behavior data was collected.

The GrowSafe System

The GrowSafe system (DAQ 4000E) used in this study consisted of feedbunks equipped with load bars to measure feed disappearance, and stanchions with neck bars to prevent more than one animal from eating from the feedbunk at a given time. Antenna within each feedbunk detected animal presence by recording the radio-frequency identification tags upon entry to a feedbunk. Feed intake is allocated to each individual animal based on continuous recordings of feed disappearance during each BV event. Along with individual feed intake data, the system also recorded each bunk visit, the EID number, scale number and time stamp, which was logged in the data-acquisition

Table 3.1. Heifers’ final diet ingredient and chemical composition summary.

Item	
Ingredient	*As-fed basis %*
Dry rolled corn	79.7
Chopped coastal 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	3.0

[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.

computer. The GrowSafe systems used in this study have scanning rate frequencies of 2 s (Beef Research Unit, Texas Agrilife Research, College Station, TX) and 3 s (McGregor Research Center, Texas Agrilife Research, McGregor, TX).

Data Collection

A subroutine of the GrowSafe 4000E software, Process Feed Intakes was used to compute feed intake and BV data. All default settings as previously defined (GrowSafe, 2009) were used in this study, with the exception of the parameter setting for maximum duration of time between consecutive EID recordings to end an uninterrupted BV event. For this study, the parameter setting of 100 s was used as recommended by Mendes et al. (2011). Feeding behavior data from a total of 6, 3, 4, 2, 0, and 2 d for trials 1, 2, 3, 4, 5, and 6, respectively were omitted from all analyses due to system failure (power outage, equipment malfunction), system maintenance, or when the proportion of daily feed supply assigned to individual animals (average feed disappearance) was less than 95%. Average feed disappearance for the six trials was 97.1%, 98.2%, 99.3%, 97.8%, 98.4%, and 97.5%, respectively.

Cattle were weighed at 14-d intervals and ultrasound measurements of subcutaneous fat depth and longissimus muscle area were collected on days 0 and 70 of the trial by a certified technician who used an Aloka 500-V instrument with a 17-cm, 3.5-MHz transducer (Corometrics Medical Systems Inc., Wallingford, CT). Images were then sent to the National Centralized Ultrasound Processing laboratory (Ames, IA) for estimation of 12th rib fat thickness (BF), ribeye area (REA) and percent intramuscular fat (IMF).

Diet samples were collected weekly and composited by weight at the end of each trial. Moisture analysis was conducted by drying in a forced-air oven for 48 h at 105°C and chemical analysis was conducted by an independent laboratory (Cumberland Valley Analytical Services Inc., Hagerstown, MD). Metabolizable energy concentration of the experimental diet was computed using the Large Ruminant Nutrition System (http://nutritionmodels.tamu.edu/lrns.htm) which is based on the Cornell Net Carbohydrate and Protein System.

A total of 14 feeding behavior traits (Table 3.2) were evaluated for each individual animal on a daily basis and averaged within each trial. BV frequency (Figure 3.1) was calculated as the number of visits each animal makes to the feedbunk with, or without consuming feed and BV duration as the summation of time the animal spends each day at the feedbunk. Non-feeding intervals for each individual animal were calculated from GrowSafe bunk visit data using the Meal Criterion Calculation software (MCC; http://nutritionmodels.tamu.edu), which relies on the statistical software R (ver. 2.13.0; The R Foundation for Statistical Computing; http://www.r-project.org).

Within MCC, non-feeding intervals were $\log_{10}$-transformed and plotted in a frequency distribution graph (Figure 3.2). The intersection of the 2-population distributions, which represents intervals within and between meals, was computed as the meal criterion (Figure 3.2). Differences in meal criterion between 2 individual animals are presented in Figure 3.3. Individually calculated meal criterion was used to determine

Table 3.2. Definition of feeding behavior traits measured in this study.

Trait	Definition	Unit
BV frequency	A BV began when the transponder of an animal was first detected and the BV ended when the time between the last two readings was greater than 100s, the same EID detected at another bunk, or when a different EID was detected in the original bunk	events/d
BV duration	Sum of total daily BV time	min/d
NFI frequency	Cumulative intervals between BV events	events/d
NFI duration	Sum of daily time not spent at a feedbunk	min/d
Meal frequency	Sum of independent meal events as determined by meal criterion	events/d
Meal duration	Sum of meal frequency time	min/d
Meal criterion	The longest interval between bunk visits that is still considered part of a meal	min/d
Meal length	Average duration of a meal event	min/event
Meal size	Average DMI consumed per meal event	g/min
Eating rate	Average DMI consumed per min within a meal	g/min
BV per meal	BV frequency per meal event	events/meal
Head down duration	EID recordings multiplied by the reading rate of the system during each recorded bunk visit	min/d
Head down duration per bunk visit duration	Ratio of head down duration per bunk visit duration	-
Head down duration per meal duration	Ratio of head down duration per meal duration	-

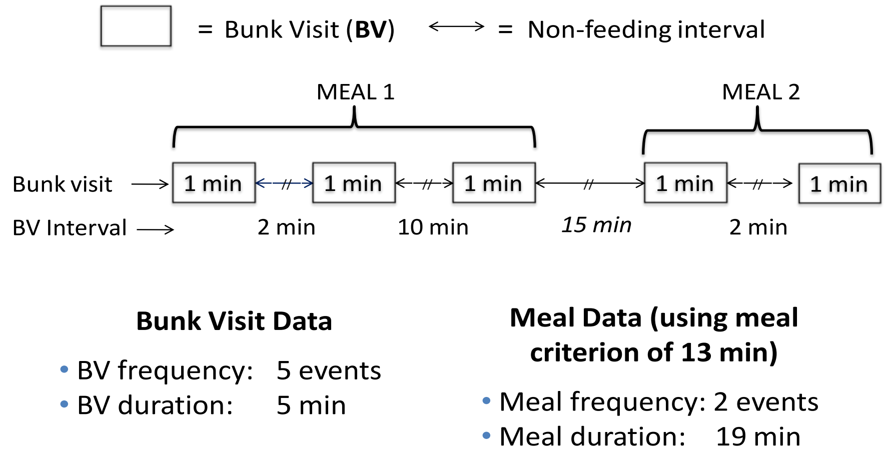

Figure 3.1. Schematic of measured feeding behaviors.

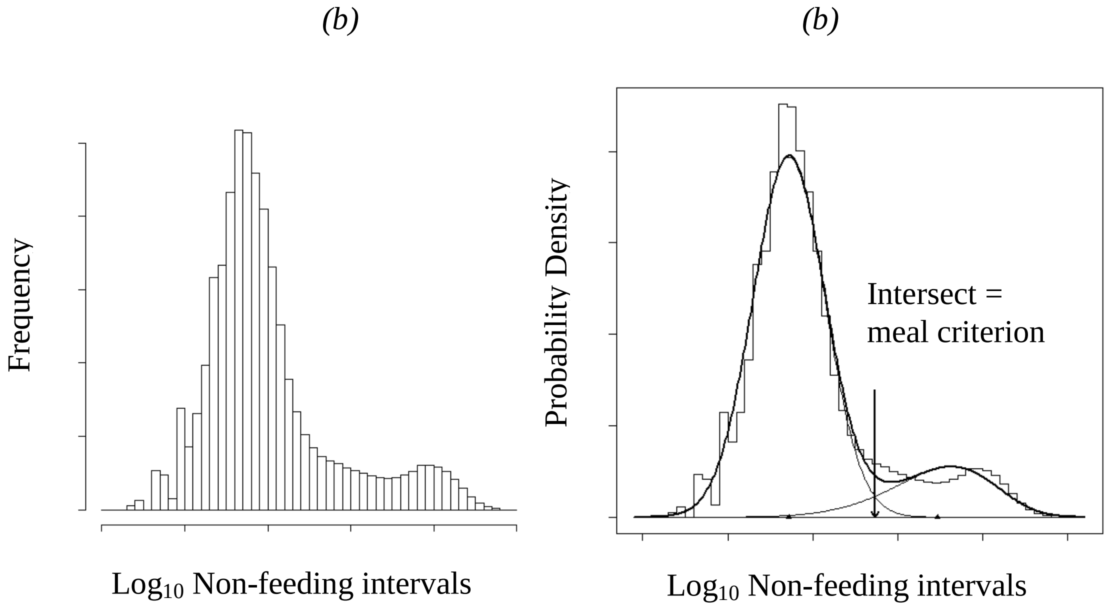

Figure 3.2. *a)* Frequency histogram of log$_{10}$-transformed non-feeding intervals. Intervals less than 2 s have been removed *b)* Graphical representation of the Gaussian-Weibull combination with a bin width of 0.1 log$_{10}$ units. Intervals less than 2 s have been removed.

meal traits. Meal frequency was defined as the number of independent meal events recorded per day as determined by the calculated individual meal criterion; meal duration was computed as the sum of all daily individual meal events (Table 3.2).

Statistical Analysis

Each animal was considered the experimental unit for all the data analyzed in this study. The PROC GLM procedure in SAS (SAS Inst. Inc. Cary, NC.) was used to model growth rates of individual animals using linear regression of 14-d BW on the day of the trial. The regression coefficients were then used to calculate the initial and final BW, ADG, and metabolic BW (mid-test BW$^{0.75}$). Moisture analysis of the diet ingredients was used to compute average daily DMI from feed intake data for each animal. The SAS PROC GLM procedure was used to derive individual feed intake over the entire trial period. Any missing intake data was estimated using linear regression of the feed intake.

Residual feed intake was calculated as the difference between actual and expected DMI from linear regression of DMI, ADG and mid-test BW$^{0.75}$ (Koch et al., 1963). Residual gain efficiency (RGE) was calculated from linear regression of ADG on DMI and mid-test BW$^{0.75}$ (Koch et al., 1963). Stepwise regression (PROC REG; SAS Inst. Inc.) was used to determine the order of inclusion of ultrasound carcass composition traits in the base model which includes ADG and MBW. Feed conversion ratio was computed as the ratio of daily DMI to ADG. To evaluate the relationship between feeding behavior traits and RFI, all feeding behavior traits were added to the carcass-adjusted regression that included ADG, MBW and ultrasound traits.

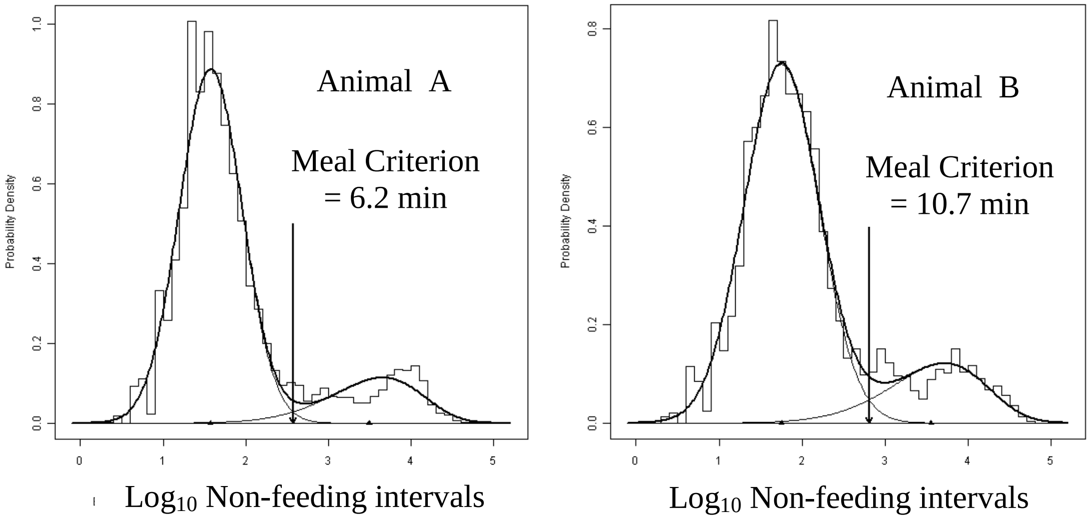

Figure 3.3. Different individual animal representations of a Gaussian-Weibull mixed distribution model of non-feeding intervals between bunk visits.

To characterize RFI, heifers were ranked into three classification groups: low-RFI (< 0.5 SD), medium-RFI (± 0.5 SD), and high-RFI (> 0.5 SD). Data were analyzed using the PROC MIXED command in SAS (SAS Inst. Inc.) which included fixed effects of RFI group, age and breed with all possible interactions; random effects of trial and pen within trial. Interaction terms that were not significant ($P > 0.10$) for a trait were removed from the final model. Although there were no RFI group × breed interactions on any of the traits, the RFI group × age interaction was significant ($P < 0.05$) for RGE, initial and final back fat. An age × breed interaction was found to be significant for several performance and feeding behavior traits in addition to a three way interaction between RFI group × age × breed for DMI.

Least squares means comparisons between RFI groups were generated using the Tukey post hoc test. All performance, feed efficiency, ultrasound measurements, and feeding behavior traits were then adjusted to remove the random effect of trial by using the mixed procedure in SAS. Dependent variables were analyzed using a one-way random-effect treatment structure with breed as a fixed effect, trial as a random effect and an adjusted variable computed as the overall mean plus the residual. Phenotypic Pearson correlation coefficients using the PROC CORR command of SAS were generated among the adjusted performance, feed efficiency, ultrasound measurements and feeding behavior traits.

Results and Discussion

Means for the six performance trials are presented in Table 3.3. Trials 1, 3, and 5 were conducted in the fall/winter (September to February), whereas trials 2, 4 and 6

Table 3.3. Summary statistics (±SD) of performance, feed efficiency, ultrasound composition, and feeding behavior traits for heifers in the 6 trials.

Trait[1]	Trial 1	Trial 2	Trial 3
No. of heifers	170	161	117
Performance traits			
Initial BW, kg	296.2 ± 30.3	302.8 ± 29.4	253.1 ± 31.9
ADG, kg/d	1.63 ± 0.33	1.31 ± 0.28	1.40 ± 0.30
DMI, kg/d	9.99 ± 1.36	10.64 ± 1.17	7.91 ± 1.39
Feed efficiency traits			
F:G	6.2 ± 1.0	8.4 ± 1.7	5.78 ± 1.04
RFI_p, kg/d	0.00 ± 1.02	0.00 ± 0.86	0.00 ± 0.87
RFI_c, kg/d	0.00 ± 0.98	0.00 ± 0.85	0.00 ± 0.82
RGE, kg/d	0.00 ± 0.24	0.00 ± 0.22	0.00 ± 0.22
Carcass ultrasound traits			
Initial REA, cm^2	45.83 ± 6.2	63.04 ± 9.01	37.46 ± 5.14
Initial BF, cm	0.38 ± 0.10	0.48 ± 0.12	0.26 ± 0.06
Initial IMF, %	3.41 ± 0.79	3.62 ± 0.80	3.94 ± 0.74
Final REA, cm^2	65.31 ± 7.0	74.39 ± 8.46	59.65 ± 7.78
Final BF, cm	0.71 ± 0.23	0.83 ± 0.23	0.52 ± 0.16
Final IMF, %	3.97 ± 0.88	4.02 ± 0.85	4.09 ± 1.06
Bunk Visit traits			
BV frequency, events/d	59.1 ± 20.5	49.9 ± 15.4	74.72 ± 14.35
BV duration, min/d	56.4 ± 20.6	43.5 ± 14.9	73.15 ± 22.54
NFI frequency, events/d	55.4 ± 19.3	47.7 ± 14.8	72.3 ± 13.7
NFI duration, min/d	1345.8 ± 23.9	1344.8 ± 30.0	1354.4 ± 22.9
Meal traits			
Meal frequency, events/d	5.96 ± 2.98	5.90 ± 1.86	11.94 ± 4.02
Meal duration, min/d	136.7 ± 44.2	102.8 ± 36.1	155.68 ± 35.32
Meal criterion, min	15.94 ± 11.55	11.24 ± 9.33	8.06 ± 4.65
Meal length, min/event	26.11 ± 11.5	19.3 ± 9.4	14.6 ± 6.4
Meal size, kg/event	1.93 ± 0.73	1.96 ± 0.61	0.74 ± 0.27
Eating rate, g/min	82.9 ± 36.5	120.4 ± 57.8	52.7 ± 12.4
Ratio traits			
BV per meal, events/meal	10.8 ± 4.1	9.0 ± 3.4	6.8 ± 2.2
Intensity traits			
HD, min/d	29.5 ± 11.9	21.2 ± 8.2	44.01 ± 19.5
HD:BV duration	0.52 ± 0.06	0.49 ± 0.12	0.62 ± 0.26
HD:Meal duration	0.22 ± 0.08	0.21 ± 0.07	0.29 ± 0.13

[1] RFIp = residual feed intake from base model; RFIc = residual feed intake from adjusted model; RGE = residual gain efficiency; REA = rib eye area; BF = 12th-rib fat thickness; IMF = intramuscular fat; BV = bunk visit; NFI = non-feeding interval; HD = head down duration; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.

Table 3.3 cont'd.

Trait[1]	Trial 4	Trial 5	Trial 6
No. of heifers	144	124	159
Performance traits			
Initial BW, kg	356.5 ± 32.24	286.6 ± 30.07	331.8 ± 32.7
ADG, kg/d	1.07 ± 0.23	1.52 ± 0.25	1.38 ± 0.26
DMI, kg/d	10.0 ± 1.33	9.66 ± 1.42	11.79 ± 1.31
Feed efficiency traits			
F:G	9.6 ± 1.8	6.5 ± 0.91	8.8 ± 2.01
RFI_p, kg/d1	0.00 ± 1.01	0.00 ± 1.04	0.00 ± 1.20
RFI_c, kg/d	0.00 ± 0.99	0.00 ± 0.99	0.00 ± 1.19
RGE, kg/d	0.00 ± 0.18	0.00 ± 0.19	0.00 ± 0.25
Carcass ultrasound traits			
Initial REA, cm^2	52.57 ± 6.64	48.48 ± 6.28	51.04 ± 6.84
Initial BF, cm	0.44 ± 0.09	0.29 ± 0.09	0.30 ± 0.09
Initial IMF, %	4.24 ± 0.89	2.36 ± 0.50	2.84 ± 0.63
Final REA, cm^2	69.17 ± 8.47	68.43 ± 7.77	74.14 ± 7.21
Final BF, cm	0.79 ± 0.26	0.70 ± 0.26	1.08 ± 0.29
Final IMF, %	4.21 ± 1.07	3.17 ± 0.77	3.56 ± 1.02
Bunk Visit traits			
BV frequency, events/d	62.90 ± 9.47	51.09 ± 8.72	61.84 ± 10.01
BV duration, min/d	44.3 ± 14.4	60.91 ± 17.4	60.61 ± 16.4
NFI frequency, events/d	58.72 ± 9.15	49.54 ± 8.47	57.78 ± 9.44
NFI duration, min/d	1378.7 ± 13.8	1331.6 ± 19.9	1307.8 ± 20.8
Meal traits			
Meal frequency, events/d	6.76 ± 2.64	9.90 ± 4.62	6.67 ± 2.06
Meal duration, min/d	123.01 ± 30.24	124.9 ± 32.29	150.2 ± 35.50
Meal criterion, min	10.72 ± 7.33	9.39 ± 2.82	13.7 ± 7.59
Meal length, min/event	20.92 ± 9.04	14.73 ± 6.78	24.87 ± 10.07
Meal size, kg/event	1.64 ± 0.53	1.22 ± 0.73	1.91 ± 0.5
Eating rate, g/min	85.9 ± 22.8	80.7 ± 17.6	82.8 ± 21.0
Ratio traits			
BV per meal, events/meal	10.3 ± 3.2	6.5 ± 4.1	9.9 ± 2.7
Intensity traits			
HD, min/d	31.33 ± 12.2	25.73 ± 11.66	40.15 ± 14.39
HD:BV duration	0.69 ± 0.08	0.41 ± 0.10	0.65 ± 0.09
HD:Meal duration	0.26 ± 0.09	0.20 ± 0.07	0.27 ± 0.09

[1] RFIp = residual feed intake from base model; RFIc = residual feed intake from adjusted model; RGE = residual gain efficiency; REA = rib eye area; BF = 12th-rib fat thickness; IMF = intramuscular fat; BV = bunk visit; NFI = non-feeding interval; HD = head down duration; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.

were conducted in the spring/summer (May to July). Initial body weights were 278 vs. 347 ± 31 kg and initial ages were 341 vs. 507 ± 21 d for heifers used in the fall/winter (younger) and spring/summer (older) trials. Overall summary statistics for performance, feed efficiency, ultrasound and feeding behavior traits are presented in Table 3.4.

Step-wise regression analysis determined the order of inclusion of ultrasound carcass composition traits which includes final BF, final REA and final IMF. In this study, the RFI base model (RFIp) was adjusted for final BF carcass ultrasound trait (RFIc) which accounted for the largest increase in variation in DMI beyond ADG and MBW (0.43 to 0.45; Table 3.5). Inclusion of carcass fat traits as independent variables has been reported to account for more variation in DMI by Arthur et al. (2003), Basarab et al. (2003) and Lancaster et al. (2009). The additional increase in the R^2 in these studies range from 2 to 4%, similar to our study which found an increase of 3.5%. The reduction in SD of RFI after inclusion of the ultrasound traits in this study (1.01 vs. 0.98 kg/d for RFI_p and RFI_c, respectively) was similar to previous studies by Basarab et al. (2003; 0.66 vs. 0.62 kg/d) in growing steers and Schenkel et al. (2004; 1.47 vs. 1.45 kg/d) in growing bulls. Lancaster et al. (2009) also reported a reduction in SD of RFI but the difference was larger (0.78 vs. 0.72 kg/d) than what was observed in this study.

Pearson (0.98) and Spearman (0.97) rank correlations coefficients between RFIp and RFIc were strong, similar to Basarab et al. (2003) and Lancaster et al. (2005) who also reported rank correlations of 0.87 and 0.92, respectively between the phenotypic

Table 3.4. Summary statistics for performance, efficiency, ultrasound and feeding behavior traits in heifers (n = 875) fed a high-grain diet.

Trait[1]	Mean	SD	Min	Max
Performance traits				
Initial BW, kg	315	48	166	462
Final BW, kg	419	53	253	584
ADG, kg/d	1.39	0.33	0.25	2.66
DMI, kg/d	10.1	1.8	3.3	14.5
Feed efficiency traits				
F:G	7.65	2.09	3.33	14.48
RFI_p, kg/d	0.00	1.01	-3.45	3.3
RFI_c, kg/d	0.00	0.98	-3.61	3.22
RGE, kg/d	0.00	0.22	-0.756	0.783
Carcass ultrasound traits				
Initial REA, cm^2	50.26	10.22	9.03	85.81
Initial BF, cm	0.37	0.13	0.13	0.89
Initial IMF, %	3.4	0.96	1.19	7.37
Final REA, cm^2	68.72	9.28	36.77	100.64
Final BF, cm	0.78	0.29	0.23	1.98
Final IMF, %	3.85	1.01	1.35	7.18
Bunk Visit traits				
BV frequency, events/d	59.6	16	13.29	126.84
BV duration, min/d	55.7	20.3	11.43	134.67
NFI frequency, events/d	56.45	15.3	12.42	119.76
NFI duration, min/d	1343.5	31.3	1173	1414.3
Meal traits				
Meal frequency, events/d	7.6	3.76	2.07	32.98
Meal duration, min/d	131.4	40.2	22.77	285.7
Meal criterion, min	11.48	0.03	1.02	64.36
Meal length, min/event	20.59	10.21	2.16	73.79
Meal size, kg/event	1.62	0.73	0.22	4.52
Eating rate, g/min	86.03	38.5	27.4	392.2
Ratio traits				
BV per meal, events/meal	9.05	3.74	1.22	26.99
Intensity traits				
HD, min/d	28.9	13.1	3.52	98.07
HD:BV duration	0.536	0.128	0.085	1.769
HD:Meal duration	0.242	0.095	0.049	0.764

[1] RFI_p = residual feed intake from base model; RFI_c = residual feed intake from adjusted model; RGE = residual gain efficiency; REA = rib eye area; BF = 12th-rib fat thickness; IMF = intramuscular fat; BV = bunk visit; NFI = non-feeding interval; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.

Table 3.5. Variation in residual feed intake (RFI) base model (BM) R^2 with additional ultrasound and feeding behavior traits for heifers fed a high-grain diet.

Trait[1]	R^2	Additional Increase
RFI_p Base Model (BM; ADG and MBW)	0.43	
Ultrasound		
RFI BM + Final REA	0.43	0.00%
RFI BM + Final IMF	0.43	0.00%
RFI BM + Final BF	0.45	3.51%
Feeding Behavior		
RFI BM + BV frequency	0.48	8.77%
RFI BM + BV duration	0.55	21.05%
RFI BM + HD	0.56	22.81%
RFI BM + BV frequency, duration, HD	0.57	24.56%

[1] RFI_p = residual feed intake from base model; RFI_c = residual feed intake from adjusted model; REA = rib eye area; BF = 12th-rib fat thickness; IMF = intramuscular fat; BV = bunk visit; HD = head down duration; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.

RFI base model (ADG, MBW) and the base RFI model adjusted for carcass traits in finishing steers. Likewise, Lancaster et al. (2009) found rank correlations of 0.92 and 0.91 between the phenotypic RFI base model and a carcass-fat adjusted RFI model in growing Angus bulls.

Phenotypic Correlations between Performance, Feed Intake, and Feed Efficiency Traits

The phenotypic correlations between growth and feed efficiency traits are presented in Table 3.6. Dry matter intake was strongly ($P < 0.05$) correlated with ADG (0.52), initial BW (0.44), and final BW (0.62), although the magnitude of these correlations were numerically lower compared with previous studies (Carstens et al., 2002; Nkrumah et al., 2007; Lancaster et al. 2009). Moderate to strong correlations among all 4 measured efficiency traits were found in this study. The RFIp and RFIc traits were both strongly correlated with DMI, but were independent of ADG and initial BW such that heifers with a lower RFIp consumed 20% less ($P > 0.01$) DMI than heifers with higher RFIp, even though ADG is similar across RFI classification groups (Table 3.7). This result is expected due to the use of linear regression to compute RFI which forces the trait to be phenotypically independent of the component traits. These findings are consistent with previous studies that found RFI to be positively correlated with DMI but independent of growth and body size (Herd and Bishop, 2000; Arthur et al., 2001a,b; Nkrumah et al., 2007; Lancaster et al., 2009). Carstens et al. (2002) reported low-RFI steers consumed 21% less DMI than high-RFI steers similar to Lancaster et al. (2005) who found that low-RFI calves consumed 15% less feed than high-RFI calves. Both

Table 3.6. Phenotypic Pearson correlations among growth, feed intake, and feed efficiency traits in heifers (n = 875) fed a high-grain diet[1].

Trait	ADG	DMI	F:G	RGE	RFI_p	RFI_c
Initial BW	0.16[a]	0.44[a]	0.14[a]	-0.23[a]	-0.02	-0.02
ADG		0.52[a]	-0.74[a]	0.79[a]	0.00	0.00
DMI			0.14	-0.03	0.74[a]	0.72[a]
F:G				-0.91[a]	0.54[a]	0.54[a]
RGE					-0.37[a]	-0.37[a]
RFI_p						0.98[a]

[1] BW = body weight; ADG = average daily gain; DMI = dry matter intake; F:G feed to gain; RGE = residual gain efficiency; RFIp; residual feed intake from base model; RFIc = residual feed intake from carcass adjusted model.

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

Table 3.7. Effects of RFI classification on performance, feed efficiency, and ultrasound traits in heifers (n = 875) fed a high-grain diet.

Item[1]	Low RFI	Medium RFI	High RFI	SE	P-value
No. of heifers	250	369	256	-	-
Performance traits					
Initial BW, kg	314.0	310.6	312.9	31.3	0.44
Final BW, kg	418.2	412.9	418.1	39.1	0.16
ADG, kg/d[*]	1.43	1.38	1.41	0.27	0.16
DMI, kg/d[#]	8.98^{a}	9.97^{b}	11.13^{c}	0.93	0.01
Feed efficiency traits					
F:G[*]	6.57^{a}	7.63^{b}	8.35^{c}	1.32	0.01
RFI$_p$, kg/d	-1.14^{a}	0.00^{b}	1.07^{c}	0.46	0.01
RFI$_c$, kg/d	-1.13^{a}	0.01^{b}	1.11^{c}	0.49	0.01
RGE, kg/d[*Ŧ]	0.125^{a}	0.003^{b}	-0.093^{c}	0.19	0.01
Carcass ultrasound traits					
Initial REA, cm^2	49.01	49.78	50.16	6.64	0.14
Initial BF, cm[*Ŧ]	0.35^{a}	0.36^{ab}	0.37^{b}	0.09	0.03
Initial IMF, %	3.45	3.43	3.39	0.65	0.69
Final REA, cm^2	67.98	68.30	69.08	7.46	0.25
Final BF, cm[Ŧ]	0.73^{a}	0.76^{a}	0.81^{b}	0.22	0.01
Final IMF, %	3.79	3.89	3.89	0.75	0.23

[1] RFIp = residual feed intake from base model; RFI$_c$ = residual feed intake from carcass adjusted model; Low RFI (< 0.5 SD), Medium RFI (± 0.5 SD), and High RFI (> 0.5 SD) derived from mean ± SD of RFI$_p$.

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

[*] Age x Breed interaction ($P < 0.05$).

[Ŧ] RFI x Age interaction ($P < 0.05$).

[#] RFI x Age x Breed interaction ($P < 0.05$).

RFIp and RFIc were moderately correlated in a negative manner with RGE (-0.37 and -0.37, respectively) such that heifers with lower RFIp had greater (P > 0.01) residual gain compared to heifers with a higher RFIp. A strong negative correlation between ADG and F:G (-0.74) was also observed in this study, which is consistent with correlations reported previously (Arthur et al., 2001a; Nkrumah et al., 2004; Lancaster et al., 2009). This suggests that applying selection pressure against F:G will increase growth rate and mature body size which increases feed requirements.

Both RFI traits were moderately correlated with F:G such that low-RFI animals had a 21.3% less F:G ratio than high-RFI animals, similar to Lancaster et al. (2009) who reported correlations of 0.49 and 0.45 for RFIp and RFIc, respectively and an 18.1% difference in F:G between low and high RFI animals. In growing bulls and steers, Arthur et al. (2001b) and Nkrumah et al. (2004) found stronger correlations (0.53 and 0.62, respectively) between RFIp and F:G. RGE was strongly correlated with F:G such that selection against both RFI traits and RGE would be beneficial to improving feed efficiency and residual gain of animals with little effect on growth traits.

Feeding Behavior Phenotypic Correlations and RFI Classification Evaluation

Phenotypic correlations between performance, feed efficiency, and feeding behavior traits are summarized in Table 3.8 and differences in feeding behavior traits between heifers with divergent RFI phenotypes are presented in Table 3.9.

RFIp and RFIc were both similarly correlated with bunk visit frequency and duration such that heifers classified as low RFI visited the feedbunk 14.7% less

Table 3.8. Phenotypic correlations between performance, feed efficiency, and feeding behavior traits in heifers (n = 875) fed a high-grain diet[1].

Trait	ADG	DMI	F:G	RGE	RFI_p	RFI_c
Bunk Visit traits						
BV frequency, events/d	0.06	0.21[a]	0.08[a]	0.01	0.31[a]	0.31[a]
BV duration, min/d	0.11[a]	0.39[a]	0.17[a]	-0.07	0.43[a]	0.43[a]
NFI frequency, events/d	0.07	0.21[a]	0.08[a]	0.01	0.30[a]	0.31[a]
NFI duration, min/d	0.01	-0.25[a]	-0.20[a]	0.13[a]	-0.28[a]	-0.28[a]
Meal traits						
Meal frequency, events/d	0.03	0.00	-0.03	0.04	0.01	0.01
Meal duration, min/d	0.13[a]	0.26[a]	0.05	0.03	0.27[a]	0.27[a]
Meal criterion, min/d	0.01	-0.01	-0.02	0.02	-0.03	-0.02
Meal length, min/event	0.00	0.07[a]	0.08[a]	-0.04	0.09[a]	0.09[a]
Meal size, kg/event	0.01	0.09[a]	0.08[a]	-0.05	0.10[a]	0.10[a]
Eating rate, g/min	0.08[a]	0.14[a]	0.00	-0.04	0.03	0.01
Ratio traits						
BV per meal, events/meal	0.04	0.16[a]	0.07[a]	-0.02	0.19[a]	0.19[a]
Intensity traits						
Head down duration, min/d	0.08[a]	0.39[a]	0.20[a]	-0.08[a]	0.44[a]	0.46[a]
HD:BV duration	0.00	0.16[a]	0.13[a]	-0.07[a]	0.20[a]	0.21[a]
HD:Meal duration	0.00	0.27[a]	0.20[a]	-0.13[a]	0.31[a]	0.32[a]

[1] RFIp = residual feed intake from base model; RFIc = residual feed intake from adjusted model; BV = bunk visit; NFI = non-feeding intervals; HD = head down duration; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.

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

Table 3.9. Effects of RFI classification on feeding behavior traits in heifers (n = 875) fed a high-grain diet[1].

Trait	Low RFI	Medium RFI	High RFI	SE	P-value
No. of heifers	250	369	256		
Bunk Visit traits					
BV frequency, events/d	55.19^a	59.62^b	64.71^c	11.18	0.01
BV duration, min/d*	47.95^a	56.50^b	65.83^c	14.40	0.01
NFI frequency, events/d	52.40^a	56.75^b	61.45^c	10.62	0.01
NFI duration, min/d	1351.3^a	1343.4^b	1336.2^c	21.05	0.01
Meal traits					
Meal frequency, events/d*	7.78	7.78	7.81	3.05	0.99
Meal duration, min/d	121.31^a	129.75^b	144.04^c	32.02	0.01
Meal criterion, min	11.63	10.88	11.38	0.25	0.37
Meal length, min/event*	17.94^a	20.08^b	22.17^c	8.83	0.01
Meal size, kg/event	1.38^a	1.59^b	1.75^c	0.56	0.01
Eating rate, g/min*	83.2	85.8	83.9	0.03	0.54
Ratio traits					
BV per meal, events/meal	7.93^a	8.89^b	9.51^c	3.09	0.01
Intensity traits					
Head down duration, min/d	25.46^a	31.84^b	39.00^c	11.15	0.01
HD:BV duration	0.53^a	0.56^b	0.59^c	0.13	0.01
HD:Meal duration	0.21^a	0.25^b	0.27^c	0.08	0.01

[1] BV = bunk visit; NFI = non-feeding intervals; HD = head down duration; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.

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

[*] Age x Breed interaction ($P < 0.05$).

frequently and spent 27.2% less time at the bunk than heifers who were phenotyped as high RFI. Nkrumah et al. (2006, 2007) also found that more efficient animals spent (35 and 24%, respectively) less time at the feedbunk and visited the feedbunk (49 and 14%, respectively) less than their less efficient counterparts.

The relationship between bunk visit frequency and RFIp and RFIc in this study (0.31) is larger than Nkrumah et al. (2007; 0.18), but similar to Montanholi et al. (2009) and Kelly et al. (2010) who reported correlations of 0.35 and 0.45, respectively. Bunk visit duration was phenotypically correlated to both RFI traits (0.43), higher than Montanholi et al. (2009; 0.24) but complementary to Nkrumah et al. (2007; 0.49). In growing pigs Rauw et al. (2006) reported moderate correlations between bunk visit duration and RFI during 3 different feeding periods in which RFI was calculated (0.21, 0.31, and 0.34 respectively) similar to de Haer et al. (1993) who found that low RFI pigs visited the feeder less frequently than high RFI pigs. Bunk visit frequency was correlated with DMI in this study (0.21) which is less than previously reported (0.57) by Gibb et al. (1998). However, bunk visit duration was found to be more strongly correlated with DMI (0.39), similar to Schwartzkopf-Genswein et al. (2002) who found duration to be correlated (0.38) with DMI.

Although not examined in this study, Nkrumah et al. (2006) found bunk visit frequency to be related with daily heat production, NDF and ADF digestibility, and bunk visit duration to be related to daily fecal output and methane production. Bunk visit frequency in this study (59.5 events/d) was higher than previous studies (Robinson et al., 2004; Nkrumah et al., 2006; Basarab et al., 2007), but similar to Kelly et al. (2010) and

Montanholi et al. (2009) who reported a ranges of 53.4 to 68.1 and 53.0 to 13.5 bunk visits per day, respectively. Duration of bunk visits (55.7 min/d) was consistent with Nkrumah et al. (2006, 2007), but much lower than results found by Shabi et al. (2005), Robinson and Oddy (2004) and Kelly et al. (2010). These results suggest that bunk visit duration is a better indicator of individual animal intake than bunk visit frequency.

Evaluation of Meal Traits and RFI Classification

Differences in electronic systems and methodologies to calculate behavioral traits and meal data make comparisons between studies difficult (Tolkamp et al. 2000). Meal frequencies and durations are highly dependent on the meal criterion value, therefore a large variation in meal criterion as described by Tolkamp et al. (2000) of 2 to 58.6 min could explain the wide variation in meal frequencies and durations found throughout literature (DeVries et al., 2003; Schwartzkopf-Genswein et al., 2002, 2004; Bach et al., 2006; Robles et al., 2007; Bingham et al., 2009). Differences in breed types of cattle, diet, and bunk management could also influence the variation in behavioral traits.

Previous meal criterion work in dairy cattle (Tolkamp et al., 2000; DeVries et al., 2003; Bach et al., 2006) applied a 2-population Gaussian distribution model to the non-feeding interval data and reported meal criterion ranging from 27.7 to 58.6 min. In this study, a Gaussian-Weibull mixed bimodal distribution model was chosen to fit the non-feeding interval data based on previous recommendation by Yeates et al. (2001) in dairy cattle and as a result of the first study. Meal criterion averaged 11.8 min, which is lower than studies in dairy cattle which have used the Gaussian-Weibull methodology to calculate meal criterion. Physical properties, nutrient composition and palatability of a ration can have a large effect on intake of the animal and also affect the short-term feeding behavior of animals (Allen, 2000), which may explain the observed differences in meal criterion between beef and dairy cattle.

Meal frequency (7.6 ± 3.7 events/d) was similar to previous literature (Tolkamp et al., 2000; DeVries et al., 2003; Schwartzkopf-Genswein et al., 2004; Lancaster et al., 2009), and meal duration (131.4 ± 40.2 min/d) was consistent with earlier findings (Schwartzkopf-Genswein et al., 2002, 2004; DeVries et al., 2009; Lancaster et al., 2009). Meal frequency was not correlated with ADG or DMI, however, meal duration, head down duration and eating rate were weak to moderately correlated with both of these traits similar to Lancaster et al. (2009). This relationship indicates that better performing heifers with increased ADG and DMI, spent more time at the feedbunk and consumed feed faster.

Both phenotypic and genetic correlations have been reported between meal duration and feed intake and gain in cattle fed high-grain diets (Schwartzkopf-Genswein et al., 2002; Robinson and Oddy, 2004; Nkrumah et al., 2007), growing lambs (Cammack et al., 2005) and swine (de Haer et al., 1993; Von Felde et al., 1996; Rauw et al., 2006). Similar to this study, phenotypic correlations between eating rate and DMI and ADG have been found in cattle (Robinson and Oddy, 2004) and in swine (de Haer et al., 1993; Rauw et al., 2006). However, reported correlations between meal frequency and growth and performance traits have been less consistent. Von Felde et al. (1996) and

Schwartzkopf-Genswein et al. (2002) did not find meal frequency to be phenotypically related to intake or gain in pigs and cattle, respectively.

Meal eating rate in this study (86 g/min) was similar to previous values of 97.1 g/min reported by Lancaster et al. (2009) and a range of 88.8 to 91.2 g/min reported by Bach et al. (2006), but higher than results found by Chase et al. (1976; 27.9 g/min), Robles et al. (2007; 32.7 to 37.7 g/min), DeVries et al. (2009; 45 to 57 g/min), and Bingham et al. (2009; 41.7 to 49.5 g/min). Our findings were lower than other studies (Vasilatos and Wangsness, 1979; Tolkamp et al., 2000; Schwartzkopf-Genswein et al., 2002) who reported values of 175, 269 to 340, and 203.0 to 242.4 g/min, respectively. Differences in diet composition and animal breedtype could explain the variation in eating rates between studies. Heifers with low-RFI phenotypes in this study consumed the same amount of feed per minute as heifers with high-RFI phenotypes (Table 3.9) which agrees with Lancaster et al. (2009) but differs from others (Bingham et al., 2009; Montanholi et al., 2009; Kelly et al., 2010) who found a significant ($P < 0.01$) differences in eating rate between low and high RFI phenotypes.

Meal frequency, meal duration, and meal eating rate were not significantly correlated with F:G (Table 3.7), although head down duration was weakly related which differs from Lancaster et al. (2009) who did not find a relationship between head down duration and F:G. In addition, meal duration was moderately correlated with RFIp and RFIc whereas meal frequency, meal size and meal eating rate were not. Although no significant relationships between feeding behavior traits and RGE were found, heifers ith a low RFIp phenotype spent 16% less ($P < 0.01$) time consuming meals and consumed

21% smaller ($P < 0.01$) meals, but had similar meal frequency, meal criterion, and meal eating rates compared to heifers with high RFIp phenotypes.

In agreement with this study, meal eating rate was not phenotypically correlated with RFI in cattle (Golden et al., 2008) or pigs (de Haer et al., 1993; Rauw et al., 2006). However, Montanholi et al. (2009) reported a moderate correlation of 0.44 between eating rate and RFI in crossbreed steers. Weaker relationships between meal eating rate and ADG and DMI (0.11 and 0.18, respectively) were found in this study compared to Lancaster et al. (2009) who reported correlations of 0.32 and 0.53, respectively. In calves fed a high-grain diet, meal duration was positively correlated with RFI (0.29) as well as in dams fed high-roughage rations (0.36; Basarab et al., 2007). Genetic and phenotypic correlations between RFI and eating time (0.35 and 0.16, respectively), eating rate (-0.07 and 0.14, respectively), and feeding frequency (0.43 and 0.18, respectively) were reported by Robinson and Oddy (2004). In addition, correlations have been found in cattle (Nkrumah et al., 2007; Lancaster et al., 2009) and swine (de Haer et al., 1993) between RFI and meal duration (0.49, 0.41 and 0.64, respectively) and meal frequency (0.18, 0.26 and 0.45, respectively). These relationships were larger than the corresponding correlations between these feeding behavior traits and ADG and DMI suggesting that between-animal variation in feed intake is more associated with RFI than growth and performance traits, and conversely that, eating rate is more associated with growth and performance traits than RFI.

The bunk visit per meal ratio was found to be correlated with RFIp and RFIc (0.19) such that low RFI heifers had 16.6% fewer ($P < 0.01$) bunk visits per meal compared to high RFI heifers (Table 3.9). This finding differs from de Haer et al (1993) who reported that bunk visit per meal was negatively (-0.33) correlated with RFI in pigs which indicates that animals with increased RFI would visit the bunk less times per meal than animals with decreased RFI. Head down duration was moderately correlated with RFIp and RFIc (0.44 and 0.49, respectively) which is similar to Lancaster et al. (2009) who reported correlations of 0.38 and 0.37, respectively. In growing steers Nkrumah et al. (2007) also found head down duration to be correlated to both phenotypic and genetic RFI (0.50 and 0.45, respectively). Heifers with low RFI phenotypes had head down durations that were 34.7% less ($P < 0.01$) than their high-RFI counterparts (Table 3.9) indicating that the less efficient animals spent more time feeding per day than the more efficient animals. These results agree with Nkrumah et al. (2007) and Lancaster et al. (2009) who reported high-RFI cattle had greater head down duration time compared to low-RFI cattle. When added as a single trait to the RFI base model, head down duration accounted for the largest percent of variation in DMI not explained by MBW and ADG (Table 3.5) suggesting that future research of feeding behavior traits should consider this trait. DeVries et al. (2003) found that non-derived measures of feeding behavior (e.g. head down duration) had high repeatability in dairy cows from early to peak lactation periods and recommended further research on this trait.

Variation in the RFI Base Model

Energy expenditures associated with consuming feed are strongly related to time spent eating and are minimally affected by ingestion or eating rates (Susenbeth et al., 1998). Therefore, differences in time spent eating and the frequency of meals may contribute to the variation in RFI due to differences in energetic costs related to feeding activities. In pigs, 44% of the variation in feed intake that was not accounted for by ADG, MBW, and carcass lean percentage was associated with time spent eating and bunk visit frequency (de Haer et al., 1993). Lancaster et al. (2009) incorporated meal frequency and duration and head down duration in the carcass-adjusted RFI model (RFIc) and found an increase in the R^2 value from 0.777 to 0.856 explaining 35% of variation in DMI not explained by the base RFI model. In this study, inclusion of bunk visit frequency and duration and head down duration in the base RFI model accounted for 25% of the variation in DMI not associated with ADG and MBW increasing the R^2 value from 0.43 to 0.58 (Table 3.5).

Residual feed intake has great potential for use in selection programs due to the lack of association with production traits, but high costs are currently associated with measuring the trait. Therefore, feeding behaviors are more cost-effective traits to quantify that may be valid indicators of activity and other physiological processes contributing to the variation in RFI. Results from this study indicate relationships between RFI and feeding behavior traits further suggesting that these feeding behavior traits may be related to biological signals that control hunger and satiety. In this study, cattle that came to the bunk less often, spent lesser amounts of time at the bunk, had shorter meal durations and lengths as well as smaller meal sizes were more efficient (low-RFI) than cattle with a high-RFI phenotype. Short-term feeding behaviors may be the result of the overall energy status of the animal which provides a basis for further research to better characterize feeding behaviors and examine their associations with feed efficiency in beef cattle.

Breed Evaluation

Differences in performance, feed efficiency and carcass ultrasound traits across the four breeds are summarized in Table 3.10. Breed differences ($P < 0.01$) were found for initial and final BW. Angus heifers gained more ($P < 0.01$) than Braford and Brangus with Simbrah heifers being intermediate. Braford cattle ate less DMI and had a higher F:G ratio than the Angus, Brangus, and Simbrah cattle. Simbrah heifers were more efficient ($P < 0.01$) than Angus, Brangus, and Braford heifers based on RFIp, however, RFIc was not affected by breedtype. The difference in RFI between the Simbrah (*B. indicus* influenced) and Angus heifers in this study coincides with Elzo et al. (2009) who reported that feed efficiency improved (decreased RFI) as the genetic fraction of *B. indicus* increased. Although significance values were not reported, Schenkel et al. (2004) found differences in RFI between *B.* taurus breeds: Limousin, Angus, Simmental, Hereford, and Blonde d'Aquitaine and Charolais bulls. However, Nkrumah et al. (2004) found nonsignificant differences in RFI among *B. taurus* crossbred cattle sired by Angus, Charolais, and University of Alberta crossbred bulls. The results in this study support Elzo et al. (2009) suggestions that breed differences in RFI between *B. indicus* and *B. taurus* breeds are greater than among *B. taurus* breeds.

Angus and Braford heifers in this study had smaller ($P < 0.01$) initial REA, but more initial BF compared to Brangus and Simbrah. Braford heifers had the smallest (P <

Table 3.10. Effects of breedtype on performance, feed efficiency, and carcass ultrasound traits in heifers (n = 875) fed a high-grain diet[1].

Item	Angus	Braford	Brangus	Simbrah	SE	P-value
No. of heifers	182	238	264	191	-	-
Performance traits						
Initial BW, kg	312.0^{a}	304.9^{a}	313.9^{ab}	320.0^{b}	31.3	0.01
Final BW, kg/d	422.5^{a}	398.1^{b}	418.8^{a}	426.1^{a}	39.1	0.01
ADG, kg/d[*]	1.49^{a}	1.26^{b}	1.41^{c}	1.43^{ac}	0.27	0.01
DMI, kg/d[#]	10.30^{a}	9.52^{b}	10.10^{a}	10.12^{a}	0.93	0.01
Feed efficiency traits						
F:G[*]	7.29^{a}	7.81^{b}	7.54^{a}	7.41^{a}	1.32	0.01
RFIp, kg/d	0.05^{a}	-0.02^{a}	-0.01^{a}	-0.11^{b}	0.46	0.01
RFIc, kg/d	-0.01	-0.06	-0.03	0.03	0.49	0.28
RGE, kg/d[*Ŧ]	0.071^{a}	-0.050^{b}	0.012^{c}	0.013^{ac}	0.19	0.01
Carcass ultrasound traits						
Initial REA, cm^2	48.29^{a}	48.09^{a}	50.95^{b}	51.29^{b}	6.64	0.01
Initial BF, cm[*Ŧ]	0.38^{a}	0.38^{a}	0.36^{a}	0.31^{b}	0.09	0.01
Initial IMF, %	4.07^{a}	3.28^{b}	3.42^{b}	2.93^{c}	0.65	0.01
Final REA, cm^2	68.21^{a}	65.21^{b}	70.79^{c}	69.60^{ac}	7.46	0.01
Final BF, cm[Ŧ]	0.86^{a}	0.82^{ab}	0.80^{b}	0.59^{c}	0.22	0.01
Final IMF, %	4.85^{a}	3.62^{b}	3.87^{c}	3.08^{d}	0.75	0.01

[1] RFIp = residual feed intake from base model; RFIc = residual feed intake from carcass adjusted model; Low RFI (< 0.5 SD), Medium RFI (± 0.5 SD), and High RFI (> 0.5SD) derived from mean ± SD of RFIp.

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

[*] Age x Breed interaction ($P < 0.05$).

[#] RFI x Age x Breed interaction ($P < 0.05$).

[Ŧ] RFI x Age interaction ($P < 0.05$).

0.01) final REA upon completion of the 70-d trial, but along with Angus and Brangus, had more (P < 0.01) final BF than the Simbrah heifers.

Few studies have evaluated differences between breeds for feeding behavior traits. In this study, Angus heifers visited the bunk fewer times (P < 0.01) than the other breeds, but along with Brangus, spent more time at the bunk than Braford or Simbrah heifers (Table 3.11). Although the meal criterion, meal length, BV per meal, and HD:BV duration traits were not affected by breed type, Angus had fewer (P < 0.01) daily meals than Braford with Brangus and Simbrah being intermediate. Robinson and Oddy (2004) reported that Brahman cattle had higher meal frequency compared to Belmont Reds and Santa Gertrudis, which in turn ate more meals than Angus, Hereford, Murray Grey and Shorthorn cattle. Angus and Simbrah heifers in this study had lower (P < 0.01) meal durations and larger meal eating rates than Braford and Brangus. Braford heifers ate smaller (P < 0.01) meals compared to Angus, Brangus and Simbrah heifers. Angus and Brangus heifers had longer head-down duration time than Braford and Simbrah heifers.

Age Evaluation

The effects of age on performance, feed efficiency, and carcass ultrasound traits are presented in Table 3.12. As expected, young heifers had lighter (P < 0.01) initial and final BW, greater (P < 0.01) ADG and lower (P < 0.01) F:G than the old heifers. No significant differences were found in DMI, both RFI traits and RGE. Initial and final REA were smaller for the young heifers compared to the old heifers. Although age did not affect initial BF, initial IMF and final IMF, final BF was lower (P < 0.01) in the

Table 3.11. Effects of breedtype on feeding behavior traits in heifers (n = 875) fed a high-grain diet[1].

Trait	Angus	Braford	Brangus	Simbrah	SE	P-value
No. of heifers	182	238	264	191	-	-
Bunk Visit traits						
BV frequency, events/d	57.03^{a}	60.83^{b}	60.13^{b}	61.37^{b}	11.18	0.01
BV duration, min/d*	61.53^{a}	53.96^{b}	58.79^{a}	52.76^{b}	14.4	0.01
Meal traits						
Meal criterion, min	10.87	11.01	12.02	11.31	0.25	0.28
Meal frequency, events/d*	7.2^{a}	8.3^{b}	7.9^{ab}	7.8^{ab}	3.05	0.01
Meal duration, min/d	124.8^{a}	133.3^{b}	138.8^{b}	130.0^{a}	32.02	0.01
Meal length, min/event*	19.3	19.85	20.59	20.27	8.83	0.67
Meal size, kg/event	1.68^{a}	1.45^{b}	1.57^{a}	1.61^{a}	0.56	0.01
Eating rate, g/min*	93.3^{a}	78.2^{b}	80.4^{b}	85.5^{a}	0.03	0.01
Ratio traits						
BV per meal, events/meal	8.47	8.72	8.65	9.31	3.09	0.06
Intensity traits						
Head down duration, min/d	35.58^{a}	30.32^{b}	33.45^{a}	29.15^{b}	11.15	0.01
HD:BV duration	0.56	0.57	0.57	0.54	0.13	0.12
HD:Meal duration	0.27^{a}	0.23^{b}	0.24^{b}	0.22^{b}	0.08	0.01

[1] BV = bunk visit; NFI = non-feeding intervals; HD = head down duration; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.

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

*Age x Breed Interaction ($P < 0.05$).

Table 3.12. Effects of age classification on performance, feed efficiency, and carcass ultrasound traits in heifers (n = 875) fed a high-grain diet[1].

Item	Young	Old	SE	P-value
No. of heifers	411	464	-	-
Performance				
Initial BW, kg	278.1[a]	346.9[b]	31.3	0.01
Final BW, kg	386.2[a]	446.6[b]	39.1	0.01
ADG, kg/d[*]	1.54[a]	1.26[b]	0.27	0.03
DMI, kg/d[#]	9.23	10.79	0.93	0.07
Feed efficiency traits				
F:G[*]	6.13[a]	8.90[b]	1.32	0.01
RFI$_p$, kg/d	-0.01	-0.05	0.46	0.34
RFI$_c$, kg/d	-0.01	-0.02	0.49	0.66
RGE, kg/d[*Ŧ]	0.019	0.005	0.19	0.45
Carcass ultrasound traits				
Initial REA, cm^2	43.71[a]	55.59[b]	6.64	0.02
Initial BF, cm[*Ŧ]	0.31	0.40	0.09	0.19
Initial IMF, %	3.31	3.53	0.65	0.72
Final REA, cm^2	64.34[a]	72.57[b]	7.46	0.01
Final BF, cm[Ŧ]	0.65[a]	0.89[b]	0.22	0.04
Final IMF, %	3.85	3.87	0.75	0.95

[1] RFIp = residual feed intake from base model; RFIc = residual feed intake from carcass adjusted model; Low RFI (< 0.5 SD), Medium RFI (± 0.5 SD), and High RFI (> 0.5SD) derived from mean ± SD of RFIp.

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

[*] Age x Breed interaction ($P < 0.05$).

[#] RFI x Age x Breed interaction ($P < 0.05$).

[Ŧ] RFI x Age interaction ($P < 0.05$).

young animals compared to old (0.65 vs. 0.89 cm).

Young heifers spent more ($P < 0.02$) time at the bunk compared to old animals (64.4 vs. 49.1 min/d), however, no other differences across feeding behavior traits were found to be significant (Table 3.13). Results from this study indicate that feeding behavior traits, with the exception of BV duration, were not affected by age and can therefore be characterized in animals regardless of age.

Effects of Interactions

Although significant RFI group x breed interactions were not evident, RFI group × age interactions were significant for final BF thickness and RGE (Figure 3.4). In older heifers, final BF thickness was similar between low and high RFI heifers, whereas in younger heifers, those with low RFI had less ($P < 0.04$) final BF thickness than those with high RFI. Heifers with low RFI had higher RGE than high-RFI heifers for both age classifications, but the magnitude of difference in RGE was much greater in younger heifers than older heifers.

The age × breed interactions were significant ($P < 0.05$) for ADG, F:G, RGE, BV duration, meal frequency, meal length, and meal eating rate. Angus heifers gained more ($P < 0.01$) than Braford, Brangus, and Simbrah heifers classified as young, whereas in the older heifers, Simbrah gained more than Braford with Angus and Brangus being intermediate (Figure 3.5).

Table 3.13. Effects of age classification on feeding behavior traits in heifers (n = 875) fed a high-grain diet[1].

Trait	Young	Old	SE	P-value
No. of heifers	411	464	-	-
Bunk Visit traits				
BV frequency, events/d	61.49	58.19	11.18	0.70
BV duration, min/d*	64.43^{a}	49.09^{b}	14.40	0.02
Meal traits				
Meal criterion, min	10.79	11.81	0.25	0.68
Meal frequency, events/d*	7.8	9.8	3.1	0.19
Meal duration, min/d	138.5	124.9	32.02	0.39
Meal length, min/event*	18.44	21.68	8.83	0.44
Meal size, kg/event	1.31	1.84	0.56	0.15
Eating rate, g/min*	71.8	96.8	0.03	0.09
Ratio traits				
BV per meal, events/meal	9.14	6.44	3.09	0.14
Intensity traits				
Head down duration, min/d	33.58	30.62	11.15	0.69
HD:BV duration	0.51	0.61	0.13	0.25
HD:Meal duration	0.24	0.25	0.08	0.84

[1] BV = bunk visit; NFI = non-feeding intervals; HD = head down duration; Meal data was derived from meal criterion calculated from individual data and applying a Gaussian-Weibull bimodal model.

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

*Age x Breed interaction ($P < 0.05$).

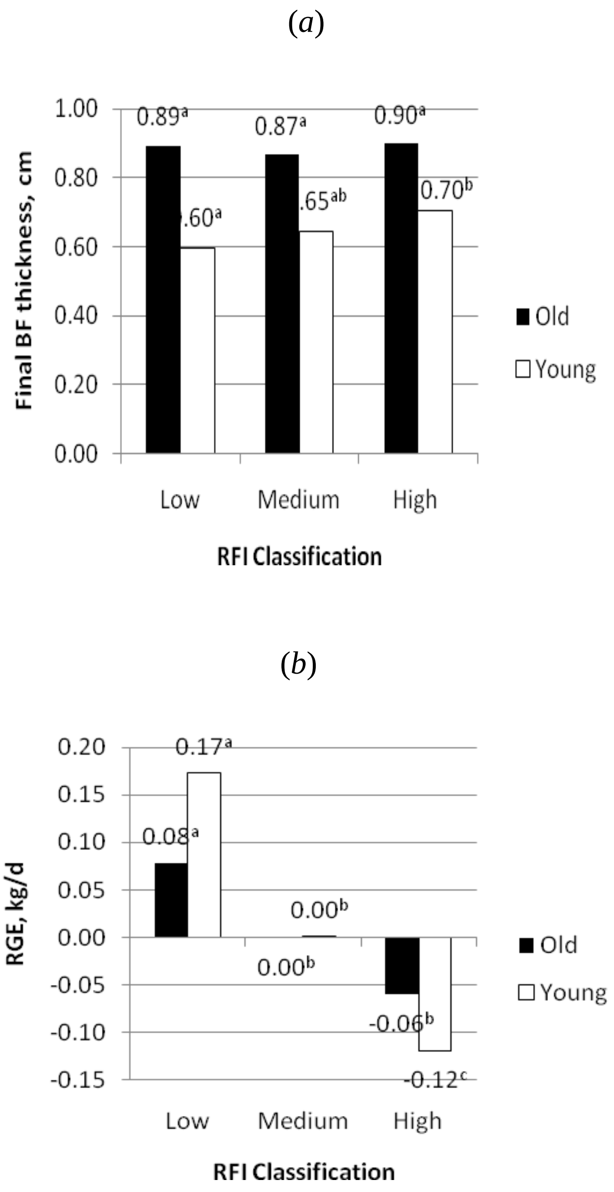

Figure 3.4. Interactions (P < 0.04) of RFI classification and age on final BF thickness (a), and residual gain efficiency (RGE;b) in heifers (n = 875) fed a high-grain diet.

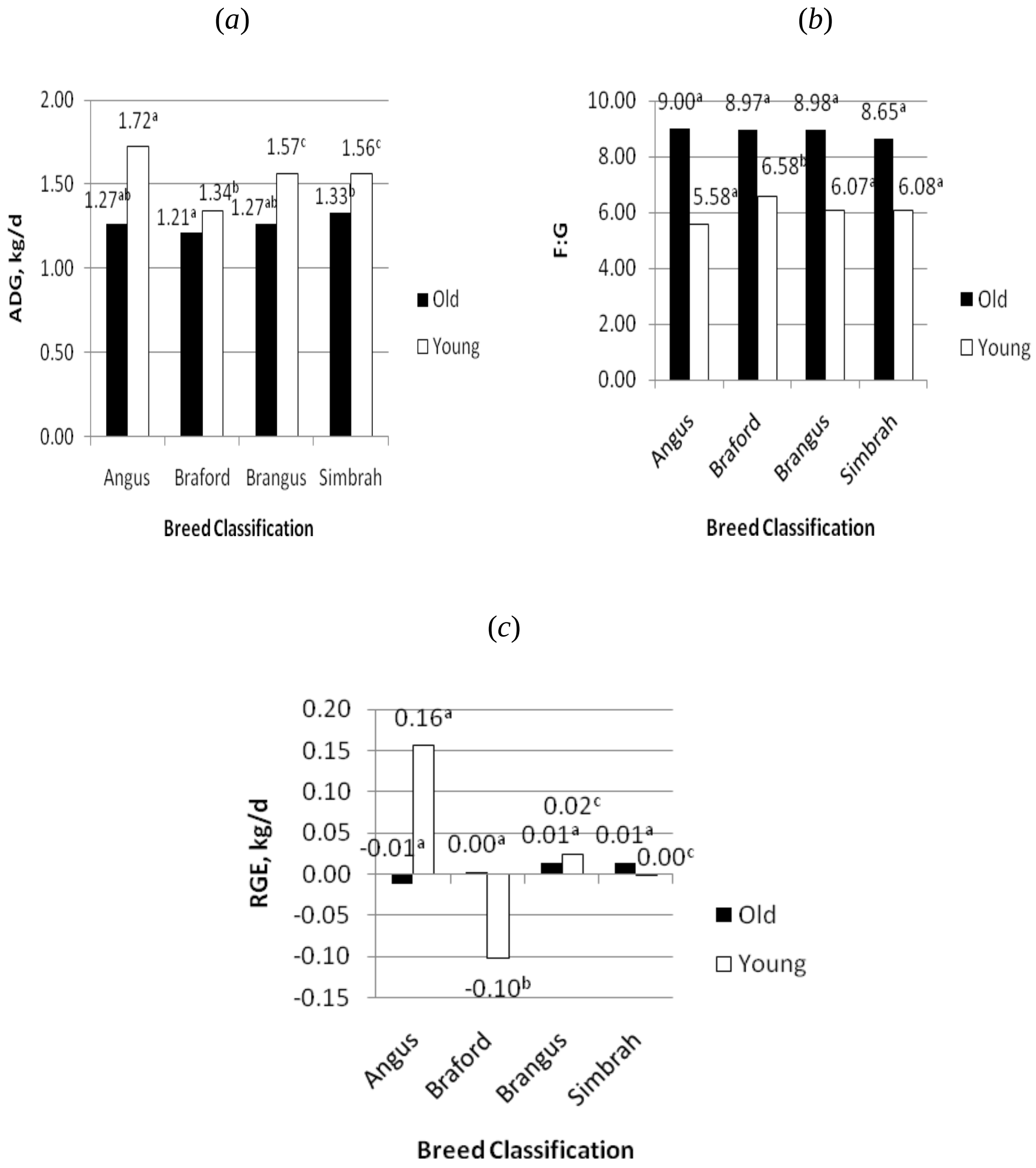

Figure 3.5. Interactions ($P < 0.01$) of age classification and breedtype on ADG (a), F:G (b), residual gain efficiency (RGE; c) in heifers ($n = 875$) fed a high-grain diet.

A similar age classification x breed interaction was found in F:G, such that young Braford heifers had the least favorable F:G compared to the other 3 breeds, but breed had no effect on F:G in the older heifers (Figure 3.5). Young Angus heifers had greater ($P < 0.01$) RGE than Braford, Brangus and Simbrah heifers; however there were no differences between breeds in the older heifers. Angus and Brangus heifers classified as young spent more ($P < 0.01$) time at the bunk each day (BV duration) than the younger Braford and Simbrah heifers; old Angus heifers had greater BV durations than the other breeds (Figure 3.6). Young Braford, Brangus, and Simbrah heifers had higher ($P < 0.02$) meal frequencies than young Angus, however, these breed differences were not found in the older heifers (Figure 3.6). The older Angus heifers had smaller ($P < 0.03$) meal lengths and larger meal eating rates compared to the other 3 breeds, whereas no differences in meal length or meal eating rates between breeds were found in the younger heifers (Figure 3.6).

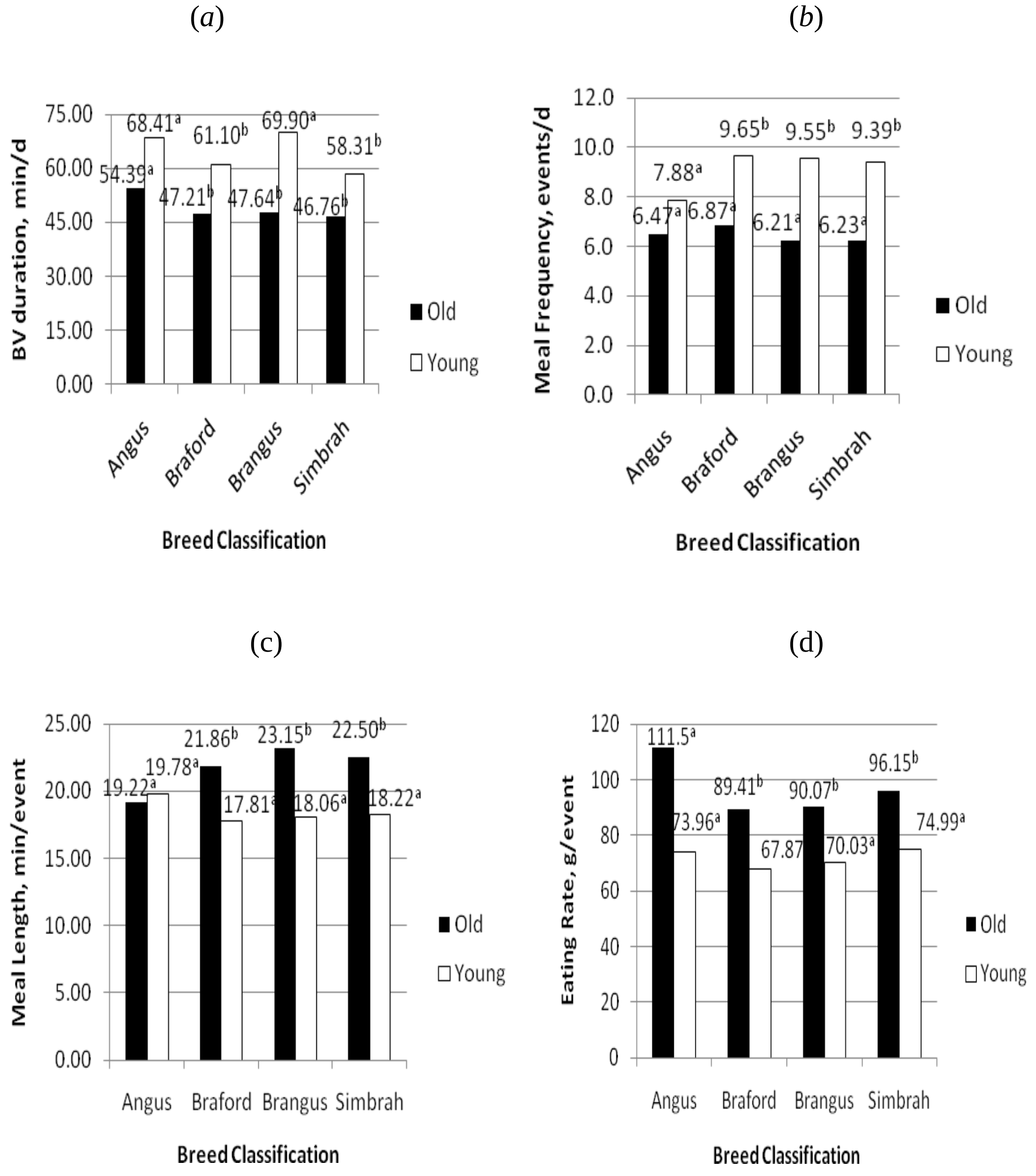

Figure 3.6. Interaction ($P < 0.03$) of age classification and breedtype on feedbunk visit duration (a), meal frequency (b), meal length (c), and eating rate (d) in heifers ($n = 875$) fed a high-grain diet.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Establishing a robust methodology to quantify biologically appropriate estimates of meal criterion is essential for critical examination of the relationships between feeding behavioral traits and feed intake and efficiency. Results from the first study demonstrated that the application of the Gaussian-Weibull bimodal distribution model to non-feeding interval data was the best approach to evaluate meal criterion in beef cattle fed corn-based diets compared to the standard Gaussian-Gaussian model originally proposed. Application of the Gaussian-Weibull method should provide a more biologically and statistically appropriate estimate of meal criterion calculation in order to evaluate between-animal variation in meal patterns. Consequently, meal pattern data derived from this bimodal modeling approach should yield valuable insights into genetic variation of behavioral attributes associated with feeding activities in beef cattle.

Meal criterion derived from the Gaussian-Weibull distribution model in the second study with heifers fed high-grain diets was determined to be 11.5 min. Moderate phenotypic correlations between RFI and behavioral traits associated with BV and meal patterns were found in this study. A total of 11 feeding behavior traits were found to be different between heifers with divergent phenotypes (± 0.50 SD) for RFI, suggesting that differences in feeding behaviors may contribute to the variation in RFI. In general, heifers with low RFI phenotypes came to the feedbunk less often, spent less time at the feedbunk, had shorter meal durations and lengths as well as smaller meal sizes compared to heifers with high-RFI phenotypes. Inclusion of BV frequency, BV duration, head-down duration in the base model used to compute RFI accounted for an additional 25% of the variation in DMI not explained by ADG or mid-test BW$^{0.75}$. Results from this study demonstrate that behavioral traits associated with feeding activities may be effective indicator traits for RFI. Future development of technologies to cost-effectively measure feeding behavior traits may support genetic evaluation for efficiency of feed utilization in animals lacking intake records.

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APPENDIX A

PROBABILITY DENSITY FUNCTIONS

Gaussian (G):

$f(x) = (e\hat{}(x - \mu)^2/(2\sigma^2)) / (\sigma\surd 2\pi)$

Weibull (W):

$f(x) = (\gamma/\alpha)((x - \mu) / \alpha)\hat{}(\gamma - 1)\ \exp(- ((x - \mu)/\alpha)\hat{}\gamma);\ x \geq \mu;\ \gamma, \alpha > 0$

Log-Normal (Ln):

$f(x) = (e\hat{}((\ln((x-\theta)/m))^2/(2\sigma^2))) / ((x - 0)\sigma\surd 2\pi);\ x \geq \theta;\ m, \sigma > 0$

Gamma (Gam):

$f(x) = (((x-\mu)/\beta)\hat{}(\gamma-1)\exp(-(x-\mu)/\beta)) / (\beta\Gamma(\gamma);\ x \geq \mu;\ \gamma, \beta > 0$

Gumbel (Gum):

$f(x) = (e\hat{}(x-\mu)/\beta)\ (e\hat{}(-e\hat{}(x-\mu)/\beta)) / \beta$

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