EFFECTS OF RFI CLASSIFICATION ON GROWTH EFFICIENCY, FEEDING BEHAVIOR PATTERNS, AND SEMEN QUALITY TRAITS IN GROWING BULLS

A Thesis

by

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ABSTRACT

The objectives of this study were to evaluate the effects of residual feed intake (RFI) classification on growth efficiency, feeding behavior patterns, carcass ultrasound and fertility traits in growing bulls. In study 1, feed intake and feeding behavior traits were measured in 395 Beefmaster bulls (3 trials) using the GrowSafe System. For each trial, bulls were sorted by RFI were classified into low, medium, and high RFI groups based on ± 0.5 SD from mean RFI. Low-RFI bulls consumed 17% less ($P < 0.001$) feed compared to high-RFI bulls even though ADG and BW were similar. Low-RFI bulls had fewer ($P < 0.005$) bunk visit (BV) events, shorter BV and meal events, shorter head-down (HD) durations, a higher HD duration per meal duration, and took 27 min longer ($P < 0.005$) to approach the feed bunk following feed delivery (Time to bunk; TTB) compared to high-RFI bulls. Although day-to-day variation in DMI was not affected by RFI classification, low-RFI bulls had less ($P < 0.05$) day-to-day variation in BV and HD duration, but more ($P < 0.01$) variation in maximal NFI and TTB compared to high-RFI bulls. In study 2, performance, feed intake, feeding behavior, carcass ultrasound, and fertility traits were measured in 625 Angus, SimAngus and Simmental bulls (8 trials). Low-RFI bulls consumed 20% less ($P < 0.01$) feed compared to high-RFI bulls. Low-RFI bulls had fewer ($P < 0.005$) BV events, shorter BV and meal events, shorter HD durations, and a reduced HD duration per meal duration. There was less ($P < 0.01$) daily variation in feed intake in low-RFI vs high-RFI bulls. Additionally, there was less ($P < 0.05$) day-to-day variation in BV and HD duration in low-RFI vs high-RFI bulls. Backfat (BF) depth was 10% less ($P < 0.01$) in low-RFI bulls compared to high-RFI bulls,

however loin muscle area (LMA) and intramuscular fat (IMF) were not affected by RFI classification. There were no significant differences observed in semen quality traits as assessed by motility and morphology between bulls with divergent RFI phenotypes. Additionally, scrotal circumference was not affected by RFI classification. Results from these studies demonstrate that growing bulls with divergent phenotypes for RFI have distinctively different feeding behavior patterns. In general, bulls with low-RFI phenotypes have fewer BV and meal events that are shorter in duration then high-RFI bulls. Additionally, low-RFI bulls appear to have less daily variation in feed intake and feeding behavior traits then high-RFI bulls. Furthermore, results from these studies indicate that semen quality traits and scrotal circumference was not associated with RFI, suggesting that selection for RFI would not be negatively associated with fertility traits in growing bulls.

DEDICATION

I would like to dedicate this thesis to my grandfather, Alton Newberry. I would not have become this passionate about working with livestock and the agriculture industry, had it not been for the early experiences he provided me at his ranch. The work ethic and discipline he instilled into me, at a young age, has carried me through my education and will remain with me forever.

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NOMENCLATURE

ADG	Average daily gain
AFD	Assigned feed disappearance
BCS	Body composition score
BF	Backfat
BSE	Breeding soundness exam
BV	Bunk visit
BW	Body weight
DMI	Dry matter intake
FB	Feeding behavior
HD	Head down
IMF	Intramuscular fat
LMA	Loin muscle area
MBW	Metabolic BW
NFI	Non-feeding interval
RFI	Residual feed intake
RG	Residual gain
SC	Scrotal circumference
TTB	Time to bunk

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

In order for the agricultural industry to meet the increased demand for food and surpass current production levels, production practices must become intensified. Human population growth, income growth and urbanization are driving forces behind the growing demand for livestock products. Future livestock production will be affected more than ever by the competition for natural resources, such as land and water, competition between food and feed and the need to operate in a carbon constrained economy (Thornton, 2010). With the existing and future challenges of the agricultural industry, developments in animal health, breeding and nutrition must take responsibility to support the needed increase in production parameters.

In order to improve the efficiency of beef cattle production systems, inputs must be reduced per unit of output (Herd et al., 2003). The largest variable cost related to beef production is feed cost. In many beef production systems, roughly 65-80% of the total feed used by an operation is for the management and maintenance of the cow breeding herd. Thus, the feed cost an operation experiences serves as a major determinant of its profitability (Arthur et al., 2004; Van der Westhuizen et al., 2004). Selection for efficiency of feed utilization could have noticeable impacts pertaining to increasing the overall efficiency of beef production.

Traditionally, the most commonly used trait to select cattle for feed efficiency is feed to gain (F:G), or feed conversion ratio (FCR). Even though F:G has been shown to be moderately heritable in beef cattle, it is phenotypically and genetically correlated in a negative manner with growth traits (Crews, 2005). The push for increased gain and more output per head, in most production systems, has resulted in cattle which have the ability to grow faster and to heavier weights. Since the 1960s, global livestock production has increased substantially and beef production has more than doubled, due to improved productivity. This increase in productivity reflects an increase in carcass beef produced per beef cow inventory. In fact, over the past 2 decades, beef carcass weights have increased an approximately 30% (Thornton, 2010). The use of traits such as F:G to select for improved feed efficiency would result in continued increases in carcass weight as F:G is highly corrected with ADG in a negative manner. Due to the strong genetic associations with growth, selection for favorable F:G has been questioned in regards to efficiency and profitability of ruminant production systems, because of the resulting larger mature cow sizes (Herd and Bishop, 2000). When F:G becomes a focal point of an operation, bigger mature cow sizes are a concern, as this relates to greater maintenance requirements for the breeding herd. Feed to gain (F:G) is considered a gross measurement of efficiency that does not partition feed intake into maintenance and growth requirements (Carstens and Tedeschi, 2006). As a result, intensified selection for F:G in growing animals will not necessarily improve feed efficiency of mature animals, who are present in the breeding herd (Archer et al., 2002).

Identifying a feed efficiency trait which accounts for genetic variation in feed efficiency, and is independent of genetic variation in output traits, such as growth and lactation, would be ideal for use in breeding programs (Carstens and Tedeschi, 2006).

These requirements allow residual feed intake (RFI) to be considered the preferred selection trait for genetic improvement of feed efficiency. This measure of feed efficiency is independent of growth traits (Herd and Arthur, 2009) and is moderately heritable, ranging from 0.16 to 0.47 (Herd et al., 2003; Herd and Bishop, 2000). Koch et al. (1963) were the first to introduce RFI as an alternative way to measure the feed efficiency (Arthur et al.2001). Residual feed intake is calculated as the difference between an animal's actual feed intake and its expected feed intake; which is needed to meet its requirements for maintenance and growth based on actual body size and average daily gain (ADG). This trait has the ability to measure the variations of intake that occur for animals of the same type (breed, age, sex) consuming similar diets. The model used to calculate RFI utilizes a liner regression of dry matter intake (DMI) on daily gain and metabolic body weight ($MBW^{0.75}$) as described by Crews (2005):

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

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

Due to linear regression, RFI is independent of traits, such as BW and ADG, which are used in the calculation of expected DMI. This allows RFI to be a feed efficiency trait that accounts for inter-animal variance in daily feed intake which is not explained by variation BW and ADG.

The challenge of measuring residual feed intake on individual animals is the collection of daily feed intake of each animal, which can be time consuming and expensive. A Canadian company, Growsafe, developed a feed-intake measurement system that uses radio frequency identification (RFID) to record individual animal's feeding behavior and intake data. One animal is allowed into the feed bunk to eat at a given time, and the feed disappearance is measured as RFID tags are recorded during each feed bunk visit.

The expected intake is subtracted from the actual intake measured by the Growsafe System to calculate residual feed intake. Predicted intake is determined by the regression of feed intake on mid-test body weight ($MBW^{0.75}$) and ADG (Crews et al., 2006). Animals that eat more than expected and are below average for feed efficiency will have positive RFI values (high RFI). Negative RFI values (low RFI) represent animals that eat less than expected and therefore are above average for feed efficiency. Selection for low RFI animals would permit for a reduction in feed intake without increasing genetic merit on growth performance or mature cow size.

Seedstock operations have begun utilizing GrowSafe technology to measure daily intake, with the mission to determine which growing animals are feed efficient. Selection for more efficient cattle will have a great impact on an operation's profitability. Due to the expenses of advanced technology such as GrowSafe, commercial programs will have a difficult time measuring individual animal's intake on a large proportion of seedstock cattle. However, inclusion of RFI in selection indexes would let commercial cattlemen invest in progressive purebred cattle, with the goal of improving profitability. Investing in a low RFI, feed efficient bull, could have positive effects on an operation for ensuing generations.

Arthur et al. (2001), conducted a study utilizing Charolais bulls to examine the impacts of feed efficient sires on future generations and discovered that progeny from parents resulting from 1.5 generations of selection for low-RFI consume 11.3% less feed while possessing yearling BW and ADG that were comparable to cattle selected for high-RFI. This work exemplifies that selection for low RFI cattle will result in the improvement of feed efficiency in later generations (Arthur et al., 2001). In order for selection of more efficient cattle to be truly beneficial, it is vital to fully understand the physiological and genetic factors which are responsible for variations in feed efficiency and how it relates to other economically relevant traits, such as carcass quality and fertility.

Biological Sources of Variation in Residual Feed Intake

Numerous studies have examined the biological basis for variation in RFI for beef cattle, with results indicating that several physiological mechanisms are responsible for differing RFI values (Herd and Arthur, 2009). A study conducted by Richardson and Herd (2004) utilizing Angus calves resulting from a generation of divergent selection for RFI, specified several factors that attributed to the biological variation. The Angus progeny provided the following percentages reflecting biological variations: digestion for 10%, heat increment for 9%, activity for 10%, body composition for 5%, feeding patterns for 2%, metabolism and stress for 37%, and 27% was accounted by other processes, including ion transport (Richardson and Herd, 2004).

Digestibility differences have been recorded amongst low and high RFI cattle. A trend present, is the negative correlation between RFI and dry matter digestibility (DMD). This correlation exemplifies that as RFI increases, their DMD decreases. This may be partly explained by work indicating that intake causes a decline in digestibility (Nkrumah et al., 2006; Krueger et al., 2009; McDonald et al., 2010). McDonnell et al. (2016) examined the effects of diet type and RFI class on DMD. Grass silage during period one, pasture during period 2 and a 30:70 corn silage: concentrate diet during period 3, were the diets consumed. It was discovered that diet type was a variable playing a role in the DMD of the heifers. Low RFI heifers had a higher DMD compared to high RFI animals on grass silage, but not the other two diets. Richardson et al. (1996) conducted work with steers, showing that low RFI cattle had 1% higher DMD, than the high RFI cattle. Studies such as these, suggest minor differences in digestibility is a possible factor affecting feed efficiency of cattle.

The variation of energy expenditures associated with activity, result in animals having differing levels of heat production, and energy accessible for maintenance and growth (Herd and Arthur, 2009). Activity has been held accountable for variations in RFI in species such as pigs and chickens (de Haer et al., 1993; Luiting et al., 1991). In pigs, the number of visits to a feeding station and total daily feeding time were positively correlated with RFI (de Haer et al., 1993). In the poultry industry, Luiting et al. (1991) concluded that approximately 80% of the genetic difference in RFI between lines of chickens divergently selected for RFI could be linked to an alteration in the bird's daily physical activity. Studies have been done with cattle to examine heat production of differing RFI classifications. Basarab et al. (2003) calculated heat production using the comparative slaughter method, and found that low RFI steers produced 10% less heat when compared to their high RFI counterparts. Indirect calorimetry chambers were utilized by Nkrumah et al. (2006) to investigate heat production differences in low and high RFI cattle. Similar to the Basarab et al. (2003) study with comparative slaughter method, low RFI cattle had 21% less heat production compared to cattle with high RFI (Nkrumah et al, 2006). Pedometers were used by Richardson et al. (1999) to measure daily step counts. They reported a phenotypic correlation of 0.32 between physical activity and RFI. The variances in physical activity present in cattle may serve as a biological factor responsible for differing energy expenditures related to differences in RFI. In the future, with the aid of advanced technology, cattle's physical activity could possibly be an indicator trait for predicting RFI classes.

Heart rate measurements would be another potential indicator trait as it is associated with energy expenditure in cattle. Herd and Bishop (2000) stated that the genetic variation in maintenance energy requirements was associated with variation in RFI of beef cattle. In cattle operations, fulfilling the breeding herds maintenance energy requirements can become costly, as it represents up to 75% of an animal's overall energy needs (Archer et al., 1999). Research pertaining to heart rate measurements has been conducted in cattle in different environmental conditions, to validate this approach as an accurate way to estimate expected energy expenditures in beef cattle (Brosh et al., 1998). In a study conducted by Brosh et al. (1998), six Hereford heifers were implanted with heart rate radio transmitters, kept in individual pens, and fed diets differing in energy.

Every half hour their heart rate was measured. From the findings, it was concluded that consumption of low energy diets resulted in heifers having a lower average heart rate and daily energy expenditure, when compared to measurements taken from heifers consuming a high energy diet. Heart rate measurements proved as an easy reading to attain, and provided a precise approximation of the individual heifer's daily energy expenditure.

Body composition has been found to be related to in RFI of growing cattle (Lancaster et al., 2009a; Nkrumah et al., 2004). In general, positive genetic and phenotypic correlations between RFI and subcutaneous fat depth has been reported. Arthur et al. (2003) found that including backfat depth in the model used to compute RFI increased the variation in DMI, up to 4 percentage units, when compared to the existing model that only included ADG and $MBW^{0.75}$ (Arthur et al., 2003).

In livestock, feeding behavior patterns have been shown to be related to feed intake and feed efficiency. Research in pigs, found that daily feeding patterns were responsible for 44% of variation in RFI (de Haer et al., 1993). Research conducted with beef cattle (Lancaster et al., 2009b) found that feeding behavior traits accounted for approximately 35% of the variation in DMI, which was not explained by ADG, $MBW^{0.75}$, and ultrasound traits. With the diversity present in the biological mechanisms responsible for variance in individual animal's RFI values, it is vital to fully understand how they affect the profitability of livestock operations (Herd and Arthur, 2009). Additional research needs to be done to further validate how these factors positively or negatively influence RFI and other traits significant to long term productivity.

Feeding Behavior Patterns

Fully understanding the feeding behavior patterns of cattle can assist in dictating individual-animal feed intake, feed efficiency, and health status (Quimby et al., 2001; Lancaster et al., 2009b; Nkrumah et al., 2006; Kelly et al., 2010). With the assistance from advancements in technology, having the ability to fully analyze and recognize an animal's feeding behavior will help predict altering feed intake and feed efficiency, as well as ill animals.

Usually, feeding behavior patterns are determined by an animal's bunk visit events (BV). Bunk visits consist of both the frequencey and duration of these events, which begin when the animal enters a feed bunk and ends when the animal exists. Bunk visit (BV) fequency is the number of visits an animal has during a 24-h period, and is measured by events/d. Bunk visit (BV) duration can be defined as the total amount of time an animal spends at the feed bunk during a 24-h period, and is measured by min/d. Feeding behavior can be seen by evaluating these traits, however these traits have the susceptibility to be altered by other factors. Social hierarchy ranks have been seen to cause animals to be involuntarily removed from a feed bunk (Tolkamp et al., 1999). These observations typically occur during periods of peak intake, such as directly after feed delivery. Tolkamp et al., (1999) proposed that it is perplexing to make assumptions based on feeding behavior patterns and traits such as: feed intake, feed efficiency and illness across trials due to BV events being affected by random occurrences and the social hierarchy setting. These issues can be resolved by utilizing the feeding behavior traits defined as meal events. Meals are clusters of BV events, which are disconnected by short intervals. According to Bailey (2012), meals are less subjected to factors including feed bunk space, environmental situations and social hierarchy. Therefore, a meal is considered to be the most biologically relevant trait when evaluating an animal's feeding behavior patterns. Yet, the determination of differences in individual animals depends on the approximation of a meal criterion for each animal. This can be defined as the longest non-feeding interval, which is part of a meal (Yeates et al., 2001). Bailey et al. (2012) reported that the analysis of non-feeding interval (NFI) was best fit by applying the Gaussian-Weibull bimodal distribution function. Therefore, meal criterion can be predicted by fitting a 2-pool, bimodal probability density function to the log-transformed non-feeding intervals of each animal using the Meal Criterion Calculation Software (MCC; http://nutritionmodels.tamu.edu), with meal criterion being the intersection of the 2 probability density functions. Miller (2016) explains that meal criterion is then used to cluster BV events into meals. These meals are organized into feeding behavior traits known as: meal frequency, length and duration. The use of these feeding behavior traits can be applied in the discovery of mechanisms influencing feed intake and feed efficiency.

Implications of Bull Selection Based on Residual Feed Intake

Breeding soundness examinations (BSE) are conducted to identify bulls that are clearly abnormal in their semen quality (Kastelic and Thundathil, 2008). In beef cattle operations, sub-fertile bulls can diminish productivity and profitability by delaying conception, prolonging calving seasons, reducing calf weaning weights and increasing female cull numbers. When selecting potential breeding stock, their BSE is important to consider. Increased scrotal circumference (SC) has been shown to be positively correlated with testes weight, sperm production in bulls, and earlier onset of puberty in heifer progeny (Kastelic and Thundathil, 2008; Hahn et al., 1969). Bourdon and Brinks (1986) reported that the heritability of weight-adjusted SC in beef cattle was 0.46. Previous research has found that a growing bull's SC is phenotypically and genetically independent of RFI (Arthur et al., 2001; Schenkel et al., 2004).

Factors such as breed, age of bull, and environmental conditions, can affect sperm motility. Fertilization of the ovum may be compromised by abnormalities associated with morphology, including knobbed acrosomes or bent tails. Barber and Almquist (1975) conducted research utilizing Charolais bulls to examine the relationships between growth and feed efficiency with pubertal traits. Using a single pubertal ejaculation, bulls that grew faster, had reduced sperm motility, and less live sperm per ejaculate compared to slower growing bulls. The body composition of growing bulls has also been shown to impact their SC, sperm motility, and sperm morphology (Barth and Waldner, 2002). Bulls with a body condition score (BCS) of 2.0 (scale of 1-9) were seen to be less likely to produce semen characterized as satisfactory. The likelihood of the satisfactory status (minimum sperm motility of 30%, and minimum sperm morphology of 70% normal cells) being achieved, was much greater in bulls who had a BCS of 3.0 to 3.5 (Barth and Waldner, 2002). However, bulls with higher BCS, carrying excess body fat, have demonstrated lower sperm production and poor semen quality (Mwansa and Makarechian, 1991; Coulter et al., 1997). Schenkel et al. (2004) and Nkrumah et al. (2007) reported positive genetic and phenotypic associations between subcutaneous fat depth and RFI. These implications imply that low RFI animals are leaner than their high RFI contemporaries.

The diet growing bulls consumes can also affect semen quality. Coulter et al. (1997) examined the effects of dietary energy on bull fertility, and found that high dietary energy can have negative consequences on scrotal or testicular thermoregulation, due to reduced amounts of heat radiated from the scrotal neck. Bulls consuming moderate energy diets were seen to have higher sperm motility and a higher proportion of normal sperm than bulls consuming high energy diets.

Breeding soundness exams (BSE) are vital to insure a sire's ability to breed cows. Menegassi et al. (2011) evaluated the bio-economic impact of BSE scores in beef production systems. Two cow herds were evaluated over a 4-year period, with findings suggesting that 23% of bulls were categorized as being unsound during their first exam. Calf production increased by 31%, with an increase of 14 calves/bull/year and 24 kg of calves/cow/year due to use of sound vs unsound bulls based on BSE. The increase in beef production during this period of time suggests that the low cost management practice of conducting a BSE is valuable and provides more profit for the producer. Breeding soundness exams (BSE) have three classifications: Satisfactory Potential Breeder, Classification Deferred, and Unsatisfactory Potential Breeder. Bulls who are considered healthy, sound, exhibit acceptable SC, > 70 % morphologically normal sperm, and >30% progressive motility are considered to be Satisfactory Potential Breeders (Kastelic and Thundathil, 2008). Temporary conditions such as: injury, lameness (likely to resolve), and testicular degeneration, can be reasons a sire is considered Deferred. Unsatisfactory Potential Breeders possess unwanted heritable defects, inadequate SC, injury, disease and permeant testicular degeneration (Kastelic and Thundathil, 2008).

Crews et al. (2006) developed a multiple trait selection index including RFI, with the main objective to improve the net feedlot revenue of market cattle from tested bulls. The traits used in this index were RFI, ADG and 365-d yearling BW, with the index being positively correlated with RFI, DMI, and ADG. However, this index was not correlated with yearling BW, resulting in high indexing animals who consumed less dry matter daily, gained at more rapid rates and had similar yearling BW, when compared to animals with low index values. More importantly, the selection index yielded a positive correlation with SC (0.16), this correlation likely exhibits the positive association between ADG and SC. Crews et al. (2006) concluded that the use of multiple trait indexes that contain RFI would not be expected to indirectly select for bulls with smaller SC.

Age and timing of puberty may perhaps have an effect on RFI classification in growing bulls. When feeding groups of bulls of different ages and breeds, sexual maturity is an imperative item to consider while the cattle are on feed. Past studies suggest measuring phenotypic RFI of a group of heifers which included pre-pubertal and post-pubertal females lead to later maturing heifers being more efficient. Early maturing heifers, due to energy demands stemmed from sexual development and activity, did not demonstrate equivalent feed efficiencies (Basarab et al. 2011). The same occurrence in bulls possibly exists, nevertheless more research needs to be conducted to further examine the relationship between RFI and growing bull fertility traits and performance.

Associations Between Residual Feed Intake and Cow Efficiency

Historically, cattle operations have focused on selection for output characteristics, such as ADG and yearling BW to improve overall beef productivity. Traits that model feed consumed per unit of weight gain (F:G or FCR) are genetically correlated with mature body size and growth, inherently producing cows with larger mature body size and higher energy requirements at maintenance, when making breeding selections and genetic improvements based on these traits (Herd and Bishop, 2000; Arthur et al 2001). Feed costs are the primary expense of beef cattle production, and are important to consider when managing a breeding herd. Accordingly, a significant fraction of the input costs may be reduced if lowering feed intake while sustaining production can be achieved. As previously mentioned, the correlated response between F:G ratio and mature cow size (Herd and Bishop, 2000; Arthur et al 2001) yields larger mature cows, which ultimately costs more to feed and maintain, due to higher requirements.

Residual feed intake is by definition, independent of BW and ADG and is determined by the difference in actual feed intake and expected feed requirements at maintenance (Basarab et al., 2007). In a study conducted by DiCostanzo et al. (1991) Angus cows were placed into phenotypical categories contingent on efficiency. In order to label cows efficient, average or inefficient, their individual performance was assessed by calculating the difference between actual ADG and expected ADG, which was based on BW and DMI. Measurements were taken at maintenance and ad libitum levels of intake. Upon evaluation, when fed ad libitum, cows across all categories held the same level of energy. However, the less efficient group of cows had a higher level of intake than the other two performance groups (efficient, average). A negative association was established between ADG and metabolizable energy requirements for maintenance (MEm) when cows were fed at maintenance level, due to cows with a lower MEm requirement gained more weight than anticipated (DiCostanzo et al., 1991). This assessment implies that efficient, low MEm cows would be expected to uphold their BW when forage access is restricted.

A study done by Meyer et al. (2008), evaluated the RFI of grazing beef cows with consideration to forage intake. Residual feed intake was calculated by feeding forage utilizing the GrowSafe Systems. Cows were grouped into 1 of 3 categories, low-RFI, medium-RFI and high-RFI. However, this method potentially contributed to error of the measurements due to the design of GrowSafe Systems being ideal for measuring pelleted feed intake. Two experiments were completed; one using mid to late gestation cows and the second using cow-calf pairs, all grazing pasture. A measurement of DMI was collected by using grazing exclosures, weekly rising plate meter readings, and forage harvests every 21 d during each trial. Initially, no difference was determined between low and high RFI groups for initial BW, as well as average daily gain between low and high RFI groups.

The relationships between progeny residual feed intake and dam productivity traits were examined by Basarab et al. (2007). This work was conducted over a span of

10 production cycles and utilized 222 yearling calves and their dams, with intentions of understanding the phenotypic relationships between maternal productivity and progeny performance. Over this period of time, cows and calves that were deemed efficient, consumed less feed, had less time spent feeding, and had more favorable F:G than the cattle who were inefficient. Basarab et al. (2007) reported that dams that produced low RFI offspring also had less calf death loss, lower twinning rates, maintained a higher BCS throughout production, and produced an equivalent weight of calf weaned per cow exposed. However, these same cows were also seen to calve later as first calf heifers and this trend continued, as mature cows, on average they calved later (5-6 days) in the year when compared to their high RFI counterparts.

Improvements in feed efficiency starting at the cow-calf sector has the ability to reduce the feed cost associated with the breeding herd. Developing selection practices with feed utilization and maintenance energy requirements as a priority can help combat the challenging financial burden. Yet, the implications of selection for RFI on reproductive performance and long term cow productivity needs to be examined more to know the full effects.

Effect of Breed on RFI, Feeding Behavior, and Carcass Ultrasound Traits

The diversity of settings where beef cattle production exists, demands utilization of different breeds and breed types to ensure adaptability and efficiency in varying environmental conditions. Breeds of cattle have the ability to optimally cater to certain operations, however in a different location, their performance could be altered. Past studies have been conducted to analyze how breeds contrast pertaining to RFI classification, feeding behavior patterns, and carcass ultrasound traits.

Previous work utilizing heifers, bulls, and progeny form divergent sire breeds has been evaluated to distinguish to what extent breeds are affected by RFI classification. A study conducted using Angus, Braford, Brangus, and Simbrah heifers in a feedlot setting concluded that there was no effect of breed type on RFI classification (Olson et al., 2019). Nkrumah et al. (2004), reported similar findings suggesting that sire breed does not affect progeny RFI classification. In contrast, Crowley et al. (2010) reported that Limousin and Charolais sired bulls had lower RFI than Angus, Hereford, and Simmental bulls. In a study using numerous breeds of bulls it was established that Blonde d'Aquitaine, Limousin, Charolais, and Simmental bulls were more efficient, based on RFI classification, when compared to Angus and Hereford bulls.

Kayser and Hill (2013) examined the effect of breed on feeding behavior patterns in Hereford and Angus bulls. They reported that differences were seen throughout this study, and stated that Angus cattle exemplified a longer head down (HD) duration. Olson et al. (2019) stated that Braford heifers spent less time at the feed bunk daily, when compared to Angus, Brangus, and Simbrah heifers. As well, from this work it was stated that the Angus heifers possessed more backfat (BF) depth, than did the other breeds of heifers.

From preceding studies conclusions have been made involving the breeds directly compared within test. However, more research needs to be done to truly define the breed effects present in beef cattle production and how they relate to feed efficiency, feeding behavior, and carcass ultrasound traits.

Summary

The increasing production costs associated with beef cattle systems and the demand for greater outputs, has increased the demand for the beef industry to become more efficient. As an industry, it is vital to focus on both the quantity and quality of the product produced. Existing methods of determining efficiency in cattle, such as F:G, have shown to cause an increase mature cow size. Larger mature cow sizes have the consequence of minimizing the enhancement in efficiency needed for current and future sustainability. Adopting the use of RFI, a feed efficiency trait that is independent of body size and productivity, could result in selection for cattle who will be more feed efficient in all phases of production. However, measuring feed intake throughout production and in different settings has proved to be a challenge in the determination of cattle's RFI in commercial operations. Variations in RFI in cattle are due to numerous physiological, biological and genetic mechanisms, which need to be further studied. In addition, the impacts of selecting for RFI on economically relevant traits, such as bull fertility, cow productivity and carcass composition, are not fully understood and need to be thoroughly examined.

CHAPTER II

EFFECTS OF RFI ON PERFORMANCE, FEED EFFICIENCY, AND FEEDING BEHAVIOR TRAITS IN GROWING BEEFMASTER BULLS

Introduction

Increasing the efficiency of beef production, by reducing input costs, will increase overall profitability. The largest input cost associated with managing a beef cattle operation is feed cost (Arthur et al., 2004; Van der Westhuizen et al., 2004). Historically, beef cattle selection and genetic improvements have focused on increasing output traits, rather than attempting to decrease input traits (Carstens and Tedeschi, 2006). Output traits have been utilized as a selection criteria to improve overall efficiency of commercial cattle operations as these traits are easier to evaluate and record. Feed to gain (F:G), or feed conversion ratio (FCR), have commonly been used to select cattle who are more feed efficient. However, the use of F:G as a selection trait has been observed to increase mature cow sizes, and therefore causing a larger feed cost related to maintaining the breeding herd (Herd and Bishop, 2000).

Residual feed intake (RFI) has recently become an alternative trait to measure of feed efficiency, which is the difference between an individual animal's expected and actual intake (Carstens and Tedeschi, 2006; Crews, 2005). Past studies have shown that RFI is independent of growth traits and is moderately heritable (Herd et al., 2003; Herd and Arthur, 2009). Selection for RFI will not result in an increase in mature cow sizes, or greater input costs, because it is phenotypically and genetically independent of growth (Archer et al., 1999; Crews, 2005).

Relationships between feeding behavior traits and feed efficiency have been evaluated with the assistance of advanced technology. Radio frequency identification (RFID) technology has allow for feeding behavior traits to be more easily recorded. RFI has been proven to be weakly to moderately correlated to feeding behavior traits (Lancaster et al., 2009b; Nkrumah et al., 2007). Feeding behavior traits have also proven to account for variation in dry matter intake that was not accounted for by body weight or gain (Lancaster et al., 2009b). Having the ability to monitor feeding behavior patterns of individual animals could assist in a better assessment of the relationships between these traits and differing RFI classifications and help further the understandings of biological variations in RFI.

The objective of this study was to evaluate the effects of RFI on performance, feed efficiency, and feeding behavior traits in growing Beefmaster bulls.

Materials and Methods

Experimental animals and design

The data used for this analysis was previously collected by the Beefmaster Association. Data collected from 3 consecutive trials utilizing 395 Beefmaster bulls were used for this study (n = 130 trial 1, n = 174 trial 2, n = 91 trial 3). These trials were conducted at the Central Texas Bull Testing Center (Evant, TX). The bulls were placed in pens that were equipped with GrowSafe feed bunks (GrowSafe Systems Ltd., AB, Canada). Following a short adaptation period, daily feed intake, performance and feeding behavior traits were measured for 48 d, 49 d, and 53 d, respectively.

Data collection

For each trial, BW were measured for individual bulls at the beginning, middle and end of the feeding period.

Computation of traits

Individual animal feed intake was computed as described by Parsons et al. (2019) using a subroutine of the GrowSafe 4000E software (Process feed intakes). For each trial, when the assigned feed disappearance (AFD) of an individual bunk in a pen was below 85% or the average AFD of the pen was less than 90%, data was deleted for a pen. Daily intake values were determined by linear regression of DMI on day of trial using the Standard Least Squares procedure of JMP (SAS Inst. Inc., Cary, NC), when system failure resulted in the deletion of data.

Linear regression of serial BW data on day of trial using the Standard Least Squares procedure of JMP (SAS Inst. Inc., Cary, NC) was used to determine mid-test $MBW^{0.75}$ and ADG. Residual feed intake was computed within trial, as described by Koch et al. (1963), by using the difference between actual and expected DMI from the linear regression of mean DMI on MBW and ADG. Within each trial, bulls were ranked by RFI and classified into 1 of 3 RFI phenotypic groups; low (< 0.5 SD), medium (± 0.5 SD) or high (> 0.5 SD).

Feeding behavior traits were computed as described by Parsons et al. (2019) based on the frequency and duration of individual animal bunk visits (BV) and meal events. Bunk visit events were initiated when an animal's electronic identification (EID) tag was detected by a feed bunk and ended when the period of the time between the last

2 consecutive EID readings exceeded 100-s, the EID tag was distinguished in another feed bunk, or the EID of another animal was identified at the same feed bunk (Mendes et al., 2011). Bunk visit frequency and duration were then defined as the number and the sum of duration of BV events recorded during a 24-h period, regardless of whether feed was consumed. The interval between BV events was defined as the non-feeding interval (NFI), with maximum NFI being defined as the longest NFI during a 24-h period. Head down (HD) duration was computed as the sum of EID tag readings detected each day, multiplied by the scan rate of the GrowSafe System, which was 1.0 reading per second (Jackson et al., 2016). Lastly, daily time to bunk (TTB) was calculated as the interval between feed delivery and each animals' first BV event each day.

Meals were defined as the clusters of BV events in which NFIs were no longer than the meal criterion, which is the longest NFI considered to be part of a meal (Bailey et al., 2012). Meal criterion was evaluated by fitting a 2-pool, Gaussian-Weibull bimodal probability density function to the $\log_{10}$-transformed NFI of each animal using the Meal Criterion Calculation Software (MCC; ver. 1.7.6836.33854; http://nutrition models.tamu.edu). This software uses the statistical software R (ver. 3.5.1; R Foundation for Statistical Computing; http://r-project.org), with meal criterion being defined as the intersection of the 2 probability density functions (Bailey et al., 2012). Meal criterion was used to group bunk visit events into meals, with meal frequency, length, and duration being defined as the number of meal events, average meal event length, and sum of length of meal events recorded each day (Miller, 2016).

Day-to-day variation of FB traits were calculated as the SD of the residuals of actual vs. predicted values based on linear regression of FB traits on day of trial using the Standard Least Squares procedure of JMP (SAS Inst. Inc., Cary, NC). Day-to-day variation was calculated for BV frequency and duration, HD duration, maximum NFI, TTB, meal frequency, meal duration, and meal length. In addition, 3 ratio traits were computed; BV frequency per meal event, HD duration per meal event, and HD duration per BV event.

Overall, 19 FB traits were evaluated, including frequency and duration of BV and meal events, HD duration, meal length, maximum non-feeding interval, TTB, corresponding day-to-day variation (SD) of these traits, and ratios of HD duration per BV duration, HD duration per meal duration, and BV events per meal event.

Statistical Analysis

To evaluate the effect of RFI classification on performance, feed efficiency, and FB traits, a mixed model (JMP; SAS Inst. Inc., Cary, NC) was used that included the fixed effect of RFI classification, the random effect of trial and all other significant interactions. Student's t- Test was used to evaluate the difference among means, which had a $P < 0.05$.

Pearson correlations were generated based on adjusting each trait or variable for the random effect of trial and then used these adjustments in a multivariate platform (JMP; SAS Inst. Inc., Cary, NC).

Results and Discussion

Performance and feed efficiency traits

Summary statistics for performance and feed efficiency traits for Beefmaster bulls from 3 trails are presented in Table 2.2. The initial age of the bulls averaged 353 d (SD = 21) for Trial 1and 414 d (SD = 20) for Trial 2. The initial age of bulls in Trial 3 was not available. Trial 1 represented the lightest bulls, having an average initial BW of 411 kg (SD = 52) and bulls in Trial 3 were the heaviest cohort with an average initial BW of 556 kg (SD = 69). Bulls in Trial 1 had the lowest mean ADG and DMI, 1.90 kg/d (SD = 0.33) and 11.2 kg/d (SD = 1.6), respectively. Bulls in Trial 3 had the highest mean ADG and DMI, 2.06 kg/d (SD = 0.34) and 13.9 kg/d (SD = 1.5). Gain to feed (G:F) ranged from 0.149, for Trial 2 and 3, to 1.70 for Trial 1. Residual gain across the 3 trials ranged from -0.130 kg/d to 0.133 kg/d. For the more efficient bulls (0.133 kg/d), residual gain was higher ($P < 0.001$), compared to the less efficient bulls (-0.130), which matches conclusions from previous studies (Crowley et al., 2010; Hafla et al., 2013). The SD for RFI for the 3 trials were 1.29, 1.38, and 1.44, respectively.

The effects of RFI classification on performance and feed efficiency traits is presented in Table 2.3, reporting that low-RFI animals had a lower DMI (11.3 kg/d) and higher G:F (0.170), when compared to their high-RFI counterparts, with minimal differences in BW and ADG. Low-RFI animals consumed less, having a 17% less DMI (13.6 kg/d), and had the lowest G:F (0.143). Earlier studies have provided similar results for reduction in feed intake in low-RFI cattle (Baldassini et al., 2018; Hafla et al., 2013). Hafla et al. (2013) stated a 20% reduction in DMI, when comparing growing bulls in low-RFI and high-RFI classifications.

Feeding behavior traits

The effect of RFI classification on feeding behavior traits in Beefmaster bulls is presented in Table 2.4. From these findings, it is shown that low-RFI bulls had fewer BV events ($P < 0.001$) each day and did not spend as long at the feed bunk during these events, due to having a lower BV duration ($P < 0.001$). Low-RFI animals approached the feed bunk an average of 38 times a day, which is 15% fewer BV events than high-RFI animals. The more efficient animals also spent 16% less time at the feed bunk, compared to the less efficient animals. Accordingly, the lower BV duration exhibited by the low-RFI bulls is paired with the longest max non-feeding interval ($P < 0.001$), having an average of 500 min, compared to only 461 min in high-RFI bulls. A study using heifers reported that less efficient, high-RFI cattle spent 24 % more time at the bunk per day and had 14% more BV events daily, compared to low-RFI bulls (Nkrumah et al. 2007). However, literature utilizing differing breeds (Nellore, Angus, and Hereford) of cattle specified there to be small differences in BV events and BV duration (Gomes et al., 2013; Kayser and Hill 2013). Low-RFI animals had a 16% shorter HD duration ($P < 0.001$), than the high-RFI animals, having a HD duration averaging 71.1 min a day. Past research agrees with the elevated HD duration recorded in high-RFI Beefmaster bulls across this study. The high-RFI Beefmaster bulls in these three trials underwent equal and less change in HD duration, when compared to high-RFI Angus and Hereford bulls, 16% and 31%, respectively (Kayser and Hill 2013). However, in contrast to reported HD duration decreases for more efficient bulls, both in the current study and work done by Kayser and Hill (2013), heifer trials have provided opposing conclusions, reporting low-RFI heifers experiencing increases in HD duration (Bingham et al., 2009).

Time to bunk (TTB), the number of minutes it takes an individual animal to approach the feed bunk after feed delivery, was longer for low-RFI bulls ($P < 0.001$). Less efficient cattle in prior work conducted, have been proven to approach the feed bunk more rapidly once feed has been delivered. In this study it was observed that the less efficient cattle approached the feed bunk 27 min sooner, compared to more efficient cattle. Meal duration was reduced by 13% ($P < 0.001$) for low-RFI animals, and meal frequency exhibited a tendency to be lower ($P = 0.066$). In agreeance, Lancaster et al. (2009b), concluded from a study analyzing feeding behavior in growing bulls, that meal duration declined ($P < 0.01$) 13% and also stated an 11% decrease in meal frequency. Past heifer trials have not established matching commonalities. Across differing RFI classifications, Bingham et al. (2009) found meal duration and meal frequency to be altered minimally. However, it was noted by Ramirez (2014), heifers represented by the low-RFI classification had a shorter meal duration, yet no changes in meal frequency were observed.

Feeding behavior traits, that displayed a significant difference in day-to-day variation include: BV and HD duration, max NFI and TTB. Low-RFI bulls had less day-to-day variation in BV and HD duration then high-RFI bulls. However, low-RFI bulls had more day-to-day variation in max NFI and TTB. High RFI bulls exhibited a greater ($P < 0.058$) day-to-day variance for DMI, when compared to low-RFI bulls.

Conclusion

Results from this study suggest that RFI classification is a determinant for the number of events and amount of time individual bulls spent eating each day. The length of time taken by each bull to approach the feed bunk after feed delivery could potentially be a characteristic to further examine in differing RFI classifications. Day-to-day variation traits propose that more variation in time to bunk and less variation in bunk visit duration identifies more efficient bulls. Further research is needed to fully understand the effect of RFI classification on feeding behavior patterns in growing bulls.

CHAPTER III

EFFECTS OF RFI AND BREED ON PERFORMANCE, FEED EFFICIENCY, FEEDING BEHAVIOR, CARCASS ULTRASOUND, SCROTAL CIRCUMFERENCE, AND SEMEN QUALITY TRAITS IN GROWING BULLS

Introduction

The profitability of beef cattle operations is dependent on the feed efficiency, carcass premiums and fertility traits that the animals possess in their specific sector of the industry. However, all sectors of the industry must utilize feed for either maintenance or to promote growth. Feed is considered the highest cost, in regards to beef production (Arthur et al., 2004; Van der Westhuizen et al., 2004). The pressures of increasing the amount of beef produced, with fewer cow numbers, has resulted in selection and genetic improvements focusing on increasing output traits, rather than attempting to decrease input traits (Carstens and Tedeschi, 2006). Feed to gain (F:G), or feed conversion ratio (FCR), have commonly been used to select cattle, which were considered to more efficiency convert feed into product. Using F:G as a selection trait has shown to increase carcass weights nearly 30 percent (Thornton, 2010). Heavier carcass weights can be perceived as a positive change, however repercussions in the breeding herd, pertaining to larger mature cow sizes are proving to be more concerning. Selection for favorable F:G has been questioned, because of its strong genetic associations with growth (Herd and Bishop, 2000). Feed to gain (F:G) does not partition feed intake into maintenance and growth requirements, therefore it is considered a gross measurement of efficiency (Carstens and Tedeschi, 2006). Utilizing

F:G in growing animals will not directly improve feed efficiency of animals who are retained in the breeding herd (Archer et al., 2002).

Residual feed intake (RFI), which was introduced by Koch et al. (1963), as an alternative measure of feed efficiency, is the difference between an individual animal's expected and actual intake (Carstens and Tedeschi, 2006; Crews, 2005). The model used to calculate RFI is best explained as a linear regress of DMI on ADG and $MBW^{0.75}$. Commercial operations have a difficult time using RFI as a selection trait due to it being expensive and time consuming to record individual animal's intake. However, seedstock operations with the capability of owning technology that can record daily intakes, can provide commercial cliental with a calculated RFI value or classification on their tested heifers and bulls. The addition of RFI in selection indexes will allow for the selection of feed efficient animals, without hindering performance and growth traits.

Radio frequency identification (RFID) technology allows for large studies to accurately evaluate feeding behavior patterns. RFI has been proven to be weakly to moderately correlated to feeding behavior traits (Lancaster et al., 2009b; Nkrumah et al., 2007). Feeding behavior patterns, that individual animals possess, could provide information pertaining to how differing RFI classes of animals visit the feed bunk daily.

Previous research has been conducted to evaluate the effect of RFI classification on carcass ultrasound traits in growing cattle (Arthur et al., 2001; Lancaster et al., 2009a; Nkrumah et al., 2004). It was concluded that RFI was slightly correlated (0.14 to 0.25) with 12^{th} rib fat thickness. However, RFI was not correlated with LMA or intramuscular fat ultrasound measurements.

In the past, studies have been done to analyze the effect of RFI classification on age of puberty in growing heifers (Arthur et al., 2005; Basarab et al., 2007; Shaffer et al., 2011; Basarab et al., 2011). From this research, it was concluded that low-RFI heifers, more efficient, have a later onset of puberty, when compared to their high-RFI, less efficient counterparts. The reason for this occurrence, as stated by Basarab et al. (2001), could be due to measuring RFI in heifers results in selection of later maturing females who reach puberty at an older age. This is explained by these heifers having lower energy expenditures as a result of slower sexual maturity and less daily activity. With this implication known for heifer development, it is very important to evaluate the effects of RFI classification bull on fertility traits.

Adequate scrotal circumference is vital for young, growing bulls to pass a breeding soundness exam and is correlated to sperm production (Lunstra and Echternkamp, 1982; Gipson et al., 1985). RFI classification has been reported as not being correlated to scrotal circumference in young bulls, however, minimal work has been done to evaluate the associations between RFI classification and semen quality traits (Schenkel et al., 2004; Arthur et al., 2001).

The objective of this study was to evaluate the effects of RFI on growth efficiency, feeding behavior, carcass ultrasound, scrotal circumference, and semen quality traits in growing Angus, SimAngus and Simmental bulls.

Materials and Methods

Experimental animals and design

The data used for this analysis was previously collected by the University of Florida at their Feed Efficiency Center (Marianna, FL). Data collected from 8 consecutive trials utilizing 625 bulls (Angus, SimAngus, and Simmental) were used in this study (n = 54 year 1, n = 76 year 2, n = 81 year 3, n = 72 year 4, n = 82 year 5, n = 108 year 6, n = 79 year 7, n = 66 year 8). The bulls were weighed and randomly assigned to pens (108 m^2/pen at a stocking rate of 16.9 bulls/pen), which were equipped with 2 GrowSafe feed bunks (GrowSafe Systems Ltd., AB, Canada). Following a short adaptation period, daily feed intake, performance and FB traits were measured for 56, 56, 57, 63, 56, 56, 61, and 56 d, respectively. A total of 682 bulls (Angus, SimAngus, and Simmental) were enrolled in these 8 trials. However, only 625 bulls had accurate and high quality intake records and from these bulls n = 607 for reported carcass ultrasound records, n = 580 for reported scrotal circumference record and n = 586 for reported breeding soundness exam records.

Data collection

For each trial, BW was measured on days 0, 28, and 56, and hip height (HH) measurements were collected on 0 d and 112 d. Ultrasound measurements of 12th rib-fat backfat (BF) depth, LM area, and intramuscular fat percentage (IMF) were collected at the conclusion of the 112 d feeding phase. At this time, each bull had a BSE conducted and repeated approximately 30 d after, if classified as Deferred or Unsatisfactory. For this analysis, only data collected from the initial BSE was used.

Computation of traits

Individual animal feed intake was computed as described by Parsons et al. (2019) using a subroutine of the GrowSafe 4000E software (Process feed intakes). For each trial, when the assigned feed disappearance (AFD) of an individual bunk in a pen was below 85% or the average AFD of the pen was less than 90%, data was deleted for a pen. Daily intake values were determined by linear regression of DMI on day of trial using the Standard Least Squares procedure of JMP (SAS Inst. Inc., Cary, NC), when system failure resulted in the deletion of data.

Linear regression of serial BW data on day of trial using the Standard Least Squares procedure of JMP (SAS Inst. Inc., Cary, NC) was used to determine mid-test $MBW^{0.75}$ and ADG. Residual feed intake was computed within trial, as described by Koch et al. (1963), by using the difference between actual and expected DMI from the linear regression of mean DMI on MBW and ADG. Within each trial, bulls were ranked by RFI and classified into one of three RFI phenotypic groups; low (< 0.5 SD), medium (± 0.5 SD) or high (> 0.5 SD).

RFIc represents residual feed intake from a composition-adjusted model including backfat depth. The current model is represented by a linear regression of mean DMI on ADG, MBW and additionally BF ($P < 0.001$) using JMP (SAS Inst. Inc., Cary, NC). When including LMA and IMF into the model, they proved to be non-significant ($P > 0.05$). Therefore, the composition-adjusted model for RFIc only included backfat depth.

Feeding behavior traits were computed as described by Parsons et al. (2019), based on the frequency and duration of individual animal bunk visits (BV) and meal events. Bunk visit events were initiated when an animals' electronic identification (EID) tag was detected by a feed bunk and ended when the period of the time between the last 2 consecutive EID readings exceeded 100-s, the EID tag was distinguished in another feed bunk, or the EID of another animal was identified at the same feed bunk (Mendes et al., 2011). Bunk visit frequency and duration were then defined as the number and the sum of duration of BV events documented during a 24-h period, regardless of whether feed was consumed. The interval between BV events was defined as the non-feeding interval (NFI), with maximum NFI being defined as the longest NFI during a 24-h period. Head down (HD) duration was computed as the sum of EID tag readings detected each day, multiplied by the scan rate of the GrowSafe System, which was 1.0 reading per second (Jackson et al., 2016). Lastly, daily time to bunk (TTB) was calculated as the interval between feed delivery and each animals' first BV event each day.

Meals were defined as the clusters of BV events in which NFIs were no longer than the meal criterion, which is the longest NFI considered to be part of a meal (Bailey et al., 2012). Meal criterion was evaluated by fitting a 2-pool, Gaussian-Weibull bimodal probability density function to the $\log_{10}$-transformed NFI of each animal using the Meal Criterion Calculation Software (MCC; ver. 1.7.6836.33854; http://nutritionmodels.tamu.edu). This software uses the statistical software R (ver. 3.5.1; R Foundation for Statistical Computing; http://r-project.org), with meal criterion being defined as the intersection of the 2 probability density functions (Bailey et al., 2012). Meal criterion was used to group bunk visit events into meals, with meal frequency, length, and duration being defined as the number of meal events, average meal event length, and sum of length of meal events recorded each day (Miller, 2016).

Day-to-day variation of FB traits were calculated as the SD of the residuals of actual vs. predicted values based on linear regression of FB traits on day of trial using the Standard Least Squares procedure of JMP (SAS Inst. Inc., Cary, NC). Day-to-day variation was calculated for BV frequency and duration, HD duration, maximum NFI, TTB, meal frequency, meal duration, and meal length. In addition, 3 ratio traits were computed; BV frequency per meal event, HD duration per meal event, and HD duration per BV event.

Overall, 19 FB traits were evaluated, including frequency and duration of BV and meal events, HD duration, meal length, maximum non-feeding interval, TTB, corresponding day-to-day variation (SD) of these traits, and ratios of HD duration per BV duration, HD duration per meal duration, and BV events per meal event.

Statistical Analysis

To evaluate the effect of RFI classification on performance, feed efficiency, ultrasound, SC, fertility and FB traits, a mixed model (JMP; SAS Inst. Inc., Cary, NC) was used that included the fixed effect of RFI classification, fixed effect of breed, the random effect of trial and all other significant interactions. Student's t- Test was used to evaluate the difference among means, which had a $P < 0.05$.

Pearson correlations were generated based on adjusting each trait or variable for the random effect of trial and then used these adjustments in a multivariate platform (JMP; SAS Inst. Inc., Cary, NC).

Results and Discussion

Summary Statistics

Performance, feed efficiency, carcass ultrasound and fertility traits

Summary statistics for performance, feed efficiency, carcass ultrasound, and fertility traits for Angus, SimAngus, and Simmental bulls are presented in Table 3.6 and 3.7. The initial age of the bulls averaged 315 d across the 8 trials, and ranged from 304 d in Trial 1 to 323 d in Trial 3. In this study, SimAngus bulls from Trial 7 represented the oldest group of bulls, and the SimAngus bulls from Trial 1 were the youngest. Initial BW averaged 411 kg, and ranged from 393 kg in Trial 1 to 424 kg in Trial 8. The heaviest cohorts were the SimAngus bulls from Trial 6 and 7, weighing an average of 447 kg. The lightest cohort were the Angus bulls from 2011, weighing an average of 379 kg. Bulls in Trial 4 had the lowest ADG (1.13 kg/d) and DMI (9.67 kg/d), while bulls in Trial 8 had the highest ADG (1.56 kg/d) and DMI (11.02 kg/d). Gain to feed (G:F) ranged from 0.117 during Trial 4 to 0.150 during Trial 5. Residual gain for trials varied from -0.107 kg/d to 0.131 kg/d, and was higher ($P < 0.001$), in more efficient bulls (0.125 kg/d), when compared to less efficient bulls (-0.111). RFI values for the bulls were the lowest, more efficient cattle, in Trial 4 (-0.112 kg/d) and the highest, less efficient cattle, in Trial 5 (0.085 kg/d). The SD for RFI ranged from 0.840 to 1.50, which compares similarly to SD ranges previously stated (Schenkel et al., 2004; Basarab et al., 2003).

Backfat depth averaged 0.605 cm in this study ranged from 0.541 cm in Trial 4 to 0.739 cm in Trial 1. Across differing RFI classifications, backfat depth ranged from 0.566 cm to 0.632. The average IMF percentage was 2.64% in this study, and ranged from 2.21% to 3.28%. LMA averaged 87.07 cm^2, bulls from Trial 7 had the smallest LMA (81.84 $cm^{2)}$ and bulls from Trial 3 had the largest (91.72 cm^2).

Mean scrotal circumferences ranged from 36.3 to 39.9 cm. The Angus bulls from Trial 8 had the lowest average SC (35.1 cm) and the Simmental bulls from Trial 6 had the highest average SC (40.8 cm). The Angus bulls from Trial 8 were amongst the youngest and lightest cohorts. The Simmental bulls from Trial 6 were nearly the oldest and heaviest bulls in the study. The proportion of normal sperm cells viewed during breeding soundness exams ranged from 71.4% in Angus bulls from Trial 4 to 85.0% in Simmental bulls from Trial 1. Literature exists addressing the effect of age and BW of bulls on morphology, explaining older bulls typically have increased normal sperm cell counts (Fields et al., 1982).

RFI Effects

Performance, feed efficiency, carcass ultrasound and fertility traits

The effect of RFI classification on performance, feed efficiency, carcass ultrasound, and fertility traits are presented in Table 3.8. The low-RFI bulls consumed 20% less ($P < 0.001$) DMI and had higher ($P < 0.001$) G:F compared to their less efficient counterparts, with no differences in BW and ADG. This agrees with previous studies that reported a reduction in feed intake in low-RFI cattle (Baldassini et al., 2018; Hafla et al., 2013). Hafla et al. (2013) reported a 20% difference in DMI when comparing growing bulls divergent in RFI.

Low-RFI bulls were the leanest group of bulls ($P < 0.05$), matching findings from preceding research (Shaffer et. al., 2011; Hafla et al., 2013). However, LM area and IMF were not affected by RFI classification.

Table 3.9 presents the Pearson correlations between performance and feed efficiency traits, showing positive correlations ($P < 0.05$) between DMI and RFI (0.68), and RFIc (0.67). These positive correlations of this study are similar to findings by Lancaster et al. (2009a), who reported positive correlations of 0.70 and 0.67, respectively. Past research has shown RFI to be independent of ADG (Arthur et al., 2001; Herd and Bishop 2000; Schenkel et al., 2004).

Feeding behavior traits

The effect of RFI classification on feeding behavior traits in growing Angus, SimAngus and Simmental bulls is presented in Table 3.11. From these findings, it is shown that low-RFI bulls had fewer ($P < 0.001$) bunk visit (BV) events each day and did not spend as long at the feed bunk during these events. Low-RFI animals approached the feed bunk an average of 27.8 times a day, which is 10% fewer BV events than high-RFI animals. The more efficient bulls also spent 19% less time at the feed bunk, compared to the less efficient bulls, which is comparable to the 24% reduction in BV duration recorded in previous studies (Nkrumah et al., 2007). Low-RFI animals had a 28% less ($P < 0.001$) HD duration than the high-RFI animals. Prior studies using bulls have specified an increase in HD duration by 31% in high-RFI bulls (Kayser and Hill 2013). Low-RFI cattle had a HD duration per BV duration of 0.464 and HD duration per meal duration of 0.328, as compared to high-RFI cattle which had a HD duration per BV duration of 0.529 and HD duration per meal duration of 0.397.

There were fewer meal events recorded and fewer (P < 0.001) minutes a day recorded for meal duration in the low-RFI compared to high-RFI bulls. A 11% reduction in meal frequency events was seen for these low-RFI animals and meal duration was reduced by approximately 21 min a day in this group of bulls. High-RFI bulls had a greater (P < 0.001) meal size and consumed more feed per minute, denoted by an elevated (P = 0.015) meal eating rate. Similar feeding behavior traits were found by Lancaster et al. (2009), who concluded from a study utilizing growing bulls that meal duration was lower in more efficient cattle.

Presented in Figure 3.4, low-RFI bulls have less (P < 0.001) day-to-day variation for DMI, BV duration (P = 0.025), max non-feeding interval (P < 0.001) and HD duration (P < 0.001). These traits experience less daily fluctuation in efficient bulls, as compared to less efficient bulls. However, time to bunk was the only feeding behavior trait that had greater variation for low-RFI compared to high-RFI bulls in this study.

Table 3.10 presents Pearson correlations between performance, feed efficiency, and feeding behavior in growing Angus, SimAngus, and Simmental bulls. From this table it can be observed that RFI is more highly correlated to feeding behavior traits (BV frequency, BV duration, meal duration, meal length, HD duration, BV frequency SD, BV duration SD, and HD duration SD) than DMI.

Breed effects

Performance, feed efficiency, carcass ultrasound and fertility traits

The effect of breed on performance, feed efficiency, carcass ultrasound, and fertility traits in growing Angus, SimAngus, and Simmental bulls is presented in Table 3.11. Performance traits differed across the 3 breeds for the following traits: initial age, initial BW, final BW, ADG, initial hip height, and final hip height. On average, Simmental bulls were the oldest at the beginning of each trial (326 d) compared to Angus (314 d) and SimAngus (315 d). In regards to BW, initially the SimAngus bulls were the heaviest (427 kg), followed by Simmental (413 kg) and Angus (402). These breeds were ordered heaviest to lightest in the same sequence, in regards to final BW, at the end of the feeding period with the resulting weights, SimAngus (512 kg), Simmental (494 kg), and Angus (476 kg). Simmental and SimAngus bulls had equal initial (124 cm) and final (133 cm) hip heights. Whereas, Angus bulls were more moderate, averaging 2 cm shorter initially and 3 cm at the end of the testing period.

Dry matter intake, RG, RFI, and RFIc were significantly affected by breed ($P < 0.05$). Based on RFI, Simmental bulls (-0.050 kg/d) were more efficient than SimAngus (0.112 kg/d) and Angus (0.078 kg/d) bulls. Simmental cattle being more feed efficient, was also reported by Crowley (2010). Based on RG, Angus bulls (-0.052 kg/d) were less ($P < 0.05$) efficient then SimAngus and Simmental bulls.

Carcass ultrasound traits that were affected by breed included backfat depth, LMA and IMF. Angus bulls were the heaviest conditioned (0.649 cm), lightest muscled (83.8 cm^2) and had the greatest IMF percentage (2.96%). SimAngus bulls were the heaviest muscled scanning a LMA of 92.20 cm^2. Simmental bulls were the leanest (0.517 cm), and accordingly possessed the lowest IMF percentage (2.15%). With Simmental cattle representing the lowest RFI cohort, based on breed, it is understood from previous literature that this group would also be the leanest (Crowley et al., 2010; Shaffer et al., 2011).

Fertility and semen quality traits were collected from breeding soundness exams performed at the end of each feeding period. All fertility and semen quality traits were affected by breed. Angus bulls had the smallest SC (37.3 cm), lowest percentage of normal cells (74.3%), accordingly the highest percentage of primary abnormalities (16.3%), lowest motility (2.58), yet had the highest numeric value for their BSE score (1.52). This may be the result that there were a higher proportion of Angus bulls in this study. In accordance, Schenkel et al. (2004) reported that Simmental bulls had lager SC than Angus bulls. SimAngus bulls recorded the largest SC (38.6 cm). Simmental bulls had the highest percentage of normal cells (79.9%), the most ideal motility (2.88), however they had the lowest numeric value for their BSE score (1.29). This breed had the smallest number of bulls (n = 108) in the study.

Feeding behavior traits

The effects of breed on feeding behavior traits in growing Angus, SimAngus and Simmental bulls are presented in Table 3.11. From these findings, it is shown that Simmental and SimAngus bulls had fewer ($P < 0.001$) BV events each day, and Angus bulls spent the longest time at the feed bunk each day, due to having a significantly higher ($P < 0.001$) BV duration. Simmental bulls approached the feed bunk an average of 27.4 times a day, which is 16% fewer BV events than Angus bulls (31.9 BV events/d). When analyzing data from Table 3.8 and Table 3.11 it is notable that SimAngus and Simmental have a greater DMI, compared to Angus. Combining the understanding of this feed efficiency trait (DMI) with recorded feeding behavior traits (BV frequency and BV duration), as would be expected, these breeds have a higher BV eating rate. Similarly, meal duration was shorter ($P < 0.001$) for SimAngus and Simmental bulls, being on average 20 and 24 min/d, respectively, less than Angus bulls. Accordingly, Angus bulls had a longer HD duration (58.0 min/d) compared to SimAngus bulls (52.2 min/d). Time to bunk, the number of minutes it takes an individual animal to approach the feed bunk after feed delivery, was longer ($P = 0.003$) for Simmental bulls than for Angus and SimAngus bulls.

Angus bulls had more ($P < 0.001$) day-to-day variation in BV frequency, BV duration ($P < 0.001$), meal duration ($P < 0.001$), meal length ($P < 0.001$) and HD duration ($P < 0.001$) than SimAngus and Simmental bulls.

RFI x breed effects

Performance and feed efficiency traits

Residual feed intake x Breed interactions for feed efficiency traits are presented in Figure 3.1. For more efficient cattle (low-RFI), Angus bulls had lower ADG than Simmental bulls, whereas in the less efficient cattle (high-RFI), Simmental bulls had lower ADG than Angus and SimAngus bulls. Significant RFI x breed interactions were also observed for G:F ($P < 0.05$), RFIc ($P < 0.05$), and RG ($P < 0.05$). The RFI x breed interaction for RFIc was due to the fact that the magnitude of the difference between low and high RFI groups were greater ($P < 0.05$) for Angus then SimAngus bulls.

Fertility traits

There were tendencies for RFI x breed interactions for semen quality traits (Figure 3.2). For percentage of primary abnormalities, the medium-RFI Angus bulls had numerically higher primary abnormalities then low- and high-RFI bulls, whereas low-RFI Simmental bulls had numerically higher primary abnormalities then medium- and high-RFI Simmental bulls. Medium-RFI Angus bulls had numerically lower sperm motility then low- and high-RFI Angus bulls, whereas, low-RFI Simmental bulls had lower sperm motility then medium- and high-RFI Simmental bulls.

Feeding behavior

Residual feed intake x breed interactions for feeding behavior and day-to-day variance traits are presented in Figure 3.3. The RFI x breed interaction for BV frequency was due to the fact that there was a larger difference between low- vs high-RFI in Angus compared to Simmental bulls, whereas there was no difference in BV frequency due to RFI classification in SimAngus bulls. For day-to-day variance of DMI, low-RFI bulls had lower ($P < 0.05$) daily variation in DMI then high-RFI bulls for all 3 breeds, however, the RFI x breed interaction was due to the fact that daily variation for DMI of medium-RFI bulls was lowest in Simmental and intermediate in Angus and SimAngus bulls. similar high-RFI Angus bulls had greater daily variation in DMI then low- and medium-RFI Angus bulls, whereas However, when comparing low-RFI and high-RFI cattle, the trend was consistent (low-RFI vs. high-RFI), implying more efficient bulls had less day-to-day variation for this feeding behavior trait, than did less efficient bulls.

Conclusion

Results from this study suggest that RFI classification was associated with the number of events and amount of time individual bulls spend eating each day. Day-to-day variation traits exemplify less variation in bunk visit duration identifies more efficient bulls. From this study conducted with 625 bulls, there were no significant differences in fertility traits between bulls with divergent RFI, suggesting no reproductive consequences would be evident due to selection of low-RFI sires. Further research is warranted to fully understand the effect of RFI classification on feeding behavior patterns and fertility traits in growing bulls.

CHAPTER IV

CONCLUSION

Efficiency and profitability of beef cattle production systems relies on inputs being reduced per unit of output (Herd et al., 2003). Feed costs are the largest variable cost a beef cattle producer will experience and decreasing this expense will help sustain and progress an operation (Arthur et al., 2004).

These two studies, utilizing growing beef bulls, reported effects of RFI classification on growth efficiency and feeding behavior traits. Bulls classified as efficient (low-RFI) consumed 17% and 20% less feed than less efficient (high-RFI) bulls, but were similar in age, BW and ADG. Bulls with low-RFI phenotypes had 15% and 10% fewer daily bunk visits (BV), 16% and 19% shorter BV durations, 16% and 28% shorter head down (HD) durations, compared to high-RFI bulls. Meal frequency tended to be less in low-RFI bulls than high-RFI bulls. Less day-to-day variation was seen for BV duration and HD duration in low-RFI bulls.

The second study, using Angus, SimAngus, and Simmental bulls, reported effects of RFI classification on carcass ultrasound and fertility traits. From these trials it was shown that low-RFI bulls were compositionally leaner, due to having 10% less backfat (BF) depth, compared to their high-RFI counterparts. This study also provide effects pertaining to scrotal circumference and semen quality. The data suggests that selection based on RFI classification does not have a negative impact on reproductive soundness and no undesirable effects were seen on scrotal circumference (SC) measurements, semen quality estimates, and breeding soundness exam (BSE) satisfactory rates. Additional research is still needed to fully understand the effect of RFI classification on feeding behavior patterns and fertility traits in growing bulls. However, from these studies it is suggested that feeding behavior patterns have potential to be an indicator trait for RFI classification and no fertility trait antagonisms were seen based on RFI classification.

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APPENDIX FIGURES AND TABLES

Chapter 2 Figures and Tables

Table 2.1. Composition and analyzed nutrient content of the diets used in the Beefmaster trials.

Item	**Value**
Ingredient composition	
Chemical composition (DM basis)[1]	
DM, %	49.9
NEM, Mcal/lb	0.76
NEG, Mcal/lb	0.49
TDN, %	70.9
CP, %	18.0
ADF, %	20.3

[1]Chemical analysis was conducted by an independent laboratory (Dairy One Inc., Ithaca New York).

Table 2.2. Summary statistics of performance and feed efficiency traits for Beefmaster bulls from three trials.

	Trial 1	Trial 2	Trial 3
No. of bulls	130	174	91
Performance Traits[1]			
Initial age, d	353 ± (21)	414 ± (20)	--
Initial BW, kg	411 ± (52)	496 ± (50)	556 ± (69)
Final BW, kg	502 ± (58)	588 ± (54)	664 ± (75)
ADG, kg/d	1.90 ± (0.33)	1.90 ± (0.31)	2.06 ± (0.34)
Feed Efficiency Traits			
DMI, kg/d	11.2 ± (1.6)	12.7 ± (1.4)	13.9 ± (1.5)
G:F	0.170 ± (0.024)	0.149 ± (0.021)	0.149 ± (0.025)
RG, kg/d	0.038 ± (0.251)	-0.056 ± (0.267)	0.054 ± (0.326)
RFI, kg/d	0.062 ± (1.29)	0.000 ± (1.38)	0.000 ± (1.44)

[1]Initial age = age at start of trials; RFI = residual feed intake; RG = residual gain.

Table 2.3. Effects of RFI on performance and feed efficiency traits in growing Beefmaster bulls.

	RFI Classification				RFI
Trait	Low	Medium	High	SE	P-value
No. of bulls	114	164	117		
Performance Traits					
Initial age, d	388	386	392	4	0.316
Initial BW, kg	486	478	483	5	0.489
Final BW, kg	582	574	579	6	0.546
ADG, kg/d	1.92	1.93	1.95	0.03	0.851
Feed Efficiency Traits					
DMI, kg/d	11.3[a]	12.5[b]	13.6[c]	0.1	<0.001
G:F	0.170[a]	0.155[b]	0.143[c]	0.002	<0.001
RG, kg/d	0.133[a]	-0.005[b]	-0.130[c]	0.025	<0.001
RFI, kg/d	-1.71[a]	0.047[b]	1.92[c]	0.09	<0.001

[1]Initial age = age at start of trials; RFI = residual feed intake;
RG = residual gain.

Table 2.4. Effects of RFI on feeding behavior traits in growing Beefmaster bulls.

Item	RFI Classification			SE	RFI
	Low	Medium	High		P-value
No. animals	114	164	117		
Bunk visit traits:					
Bunk visit (BV) frequency, events/d	37.7[a]	40.7[b]	44.2[c]	0.9	<0.001
BV duration, min/d	90[a]	96[b]	107[c]	1.7	<0.001
Max non-feeding interval, min	500[a]	464[b]	461[b]	7	<0.001
BV eating rate, g/min	132	135	132	3	0.552
Meal traits:					
Meal criterion, min	9.87	9.42	8.79	0.49	0.285
Meal frequency, events/d	9.79	10.1	10.6	0.25	0.066
Meal duration, min/d	139[a]	147[b]	160[c]	3	<0.001
Meal length, min/event	16.5	16.6	17.3	0.6	0.594
Meal size, g/event	1257	1318	1376	37	0.080
Meal eating rate, g/min	820	867	923	32	0.076
Intensity traits:					
Head down (HD) duration, min/d	71.1[a]	76.2[b]	84.9[c]	1.7	<0.001
HD duration per BV duration	0.782	0.792	0.790	0.008	0.673
HD duration per meal duration	0.241[a]	0.223[ab]	0.209[b]	0.009	0.046
BV events per meal event	4.06	4.24	4.41	0.12	0.143
Time to bunk, min	158[a]	138[b]	131[b]	5	<0.001
Day-to-day variation traits†:					
DMI SD, kg/d	3.22	3.20	3.32	0.06	0.248
BV frequency SD, events/d	11.4	11.6	12.4	0.4	0.123
BV duration SD, min/d	17.0[a]	17.1[a]	18.7[b]	0.5	0.027
Max non-feeding interval SD, min	131[a]	124[b]	118[b]	2	<0.001
Meal frequency SD, events/d	2.30	2.39	2.42	0.07	0.399
Meal duration SD, min/d	4.62	4.57	4.57	0.86	0.985
Meal length SD, min/event	27.9	27.7	29.2	0.2	0.380
HD duration SD, min/d	13.8[a]	13.8[a]	15.2[b]	0.5	0.053
Time to bunk SD, min	167[a]	150[b]	146[b]	5	0.008

†Day-to-day variation traits = day-to-day standard deviation for each trait.

[a,b,c]Means within row with different superscripts differ ($P < 0.05$).

Chapter 3 Figures and Tables

Table 3.5. Composition and analyzed nutrient content of the diets used in the Beefmaster trials.

Item	**Value**
Ingredient composition, % (DM basis)	
Corn gluten feed, pelleted	43.0
Soybean hulls, pelleted	42.0
Cottonseed hulls	5.0
Ground bermudagrass hay (T85)	5.0
Supplement[1]	5.0
Chemical composition (DM basis)[2]	
DM, %	90.9
NEm, Mcal/kg	0.32
NEg, Mcal/kg	0.20
TDN, %	69.0
Crude Protein, %	16.0
ADF, %	29.9
Ca, %	0.75
P, %	0.58
K, %	1.51
Cu, ppm	12.0
Zn, ppm	57.0

[1]Pelleted supplement to provide vitamins (A, D, E), micro and macro-minerals, and to supply 35 mg of monensin and 10 mg of thiamine per kg of diet DM (Furst-McNess Company, Freeport, IL).
[2]Chemical analysis was conducted by an independent laboratory (Dairy One Inc., Ithaca New York).

Table 3.6. Summary statistics of performance, feed efficiency, carcass ultrasound, and fertility traits in growing bulls from 2011-2014.

	2011			2012			2013			2014		
	Breed[1]			Breed			Breed			Breed		
	AN	SA	SM	AN	SA	SM	AN	SA	SM	AN	SA	SM
Performance traits[2]												
Initial age, d	302	297	313	325	304	307	324	322	326	317	314	329
Initial BW, kg	379	400	413	398	409	396	387	415	388	407	430	395
Final BW, kg	549	571	588	577	597	577	561	591	550	575	605	564
ADG, kg/d	1.25	1.42	1.47	1.40	1.56	1.44	1.20	1.40	1.25	1.12	1.13	1.15
Initial hip height, cm	118	122	122	122	122	122	122	124	123	122	125	124
Final hip height, cm	128	132	132	130	132	131	129	132	130	131	132	132
Feed efficiency traits												
DMI, kg/d	10.7	11.3	11.3	10.3	10.9	9.89	10.3	10.1	9.68	9.64	9.93	9.50
G:F	0.116	0.125	0.130	0.137	0.144	0.147	0.128	0.139	0.124	0.117	0.114	0.122
RG, kg/d	-0.050	0.032	0.103	-0.061	0.065	0.052	0.008	0.048	-0.092	-0.004	-0.005	0.015
RFI, kg/d	0.079	0.069	-0.292	0.110	-0.014	-0.458	0.279	-0.385	0.039	-0.079	-0.186	-0.131
RFIc, kg/d	0.014	0.071	-0.142	0.116	0.018	-0.416	0.255	-0.411	-0.003	-0.017	0.036	0.013
Carcass ultrasound traits												
Backfat depth, cm	0.778	0.764	0.531	0.600	0.575	0.399	0.585	0.547	0.549	0.588	0.535	0.427
LMA, cm^2	82.8	85.9	91.2	87.6	97.8	89.7	84.3	96.0	98.6	85.0	91.9	83.1
IMF, %	3.14	2.29	2.07	2.74	2.18	2.15	2.54	2.04	1.66	2.59	1.91	1.98
Fertility traits												
Scrotal circumference, cm	37.0	38.5	37.8	37.4	38.0	37.6	37.3	37.8	36.9	37.3	38.2	37.1
Erection, (1=Y; 2=N)	1.06	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ejaculation, (1=Y; 2=N)	1.09	1.00	1.00	1.00	1.00	1.00	1.03	1.00	1.00	1.00	1.00	1.00
Protrusion, (1=Y; 2=N)	1.09	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Motility†	2.36	2.91	3.22	2.73	2.71	2.75	2.74	2.74	2.85	2.44	2.44	2.94
Normal cells, %	70.8	81.1	85.0	73.3	76.1	78.7	75.9	76.2	77.3	71.4	76.4	78.0
Primary abnormalities, %	14.3	9.50	7.89	18.6	16.5	15.0	14.3	13.9	12.5	19.8	17.1	16.2
Secondary abnormalities, %	13.5	9.42	7.11	8.56	7.38	6.43	9.78	9.87	9.42	9.26	6.56	5.24
BSE‡	1.52	1.17	1.00	1.48	1.18	1.50	1.39	1.48	1.31	1.52	1.50	1.35

[1]Angus (AN), SimAngus (SA), Simmental (SM). [2]Initial age = age at start of trials; RFI = residual feed intake; RFIc = carcass fat adjusted RFI; RG = residual gain; LMA = LM area; IMF = intramuscular fat.
†Motility, (1= Poor; 2= Fair; 3= Good; 4= Very Good). ‡BSE, (1= Satisfactory; 2= Unsatisfactory; 3= Deferred).

Table 3.7. Summary statistics of performance, feed efficiency, carcass ultrasound, and fertility traits in growing bulls from 2015-2018.

	2015			2016			2017			2018		
	Breed[1]			Breed			Breed			Breed		
	AN	SA	SM	AN	SA	SM	AN	SA	SM	AN	SA	SM
Performance traits[2]												
Initial age, d	311	315	327	306	323	333	313	335	311	302	304	328
Initial BW, kg	385	423	426	402	447	431	405	447	414	388	402	424
Final BW, kg	540	584	583	557	626	606	560	625	579	559	579	591
ADG, kg/d	1.38	1.47	1.55	1.35	1.52	1.53	1.20	1.56	1.42	1.50	1.51	1.4
Initial hip height, cm	122	124	125	120	124	127	121	126	124	123	124	123
Final hip height, cm	129	132	134	129	133	135	129	134	132	132	132	132
Feed efficiency traits												
DMI, kg/d	8.87	10.3	10.1	10.4	11.1	10.8	9.59	10.4	9.63	11.3	10.9	10.6
G:F	0.157	0.142	0.155	0.133	0.138	0.142	0.122	0.147	0.152	0.131	0.151	0.152
RG, kg/d	0.021	-0.039	0.055	-0.057	0.056	0.092	-0.107	0.127	0.131	-0.049	0.032	0.103
RFI, kg/d	-0.222	0.386	-0.095	0.249	-0.104	-0.176	0.176	-0.082	-0.447	0.283	-0.207	-0.317
RFIc, kg/d	-0.368	0.332	-0.123	0.126	-0.121	-0.176	0.158	-0.027	-0.328	0.349	-0.344	-0.611
Carcass ultrasound traits												
Backfat depth, cm	0.555	0.509	0.507	0.673	0.61	0.543	0.712	0.558	0.462	0.766	0.695	0.68
LMA, cm^2	80.8	87.6	90.9	83.3	90.7	86.9	78.2	89.1	84.1	90.7	94.0	95.0
IMF, %	2.65	2.17	2.15	3.46	2.51	2.34	3.82	2.86	2.54	3.07	2.37	2.20
Fertility traits												
Scrotal circumference, cm	36.8	37.6	37.6	39.3	40.7	40.8	37.3	40.3	37.7	35.1	37.6	38.1
Erection, (1=Y; 2=N)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	--	--	--
Ejaculation, (1=Y; 2=N)	1.00	1.00	1.00	1.04	1.00	1.00	1.00	1.00	1.00	--	--	--
Protrusion, (1=Y; 2=N)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	--	--	--
Motility†	2.44	2.56	3.00	3.15	3.24	3.18	1.97	2.61	2.23	--	--	--
Normal cells, %	75.0	80.4	79.4	77.5	80.8	80.7	71.1	79.0	79.1	--	--	--
Primary abnormalities, %	16.9	13.0	12.0	10.9	8.3	9.2	22.7	13.8	14.9	--	--	--
Secondary abnormalities, %	8.07	6.59	8.55	11.6	11.2	10.3	6.24	6.96	6.00	--	--	--
BSE‡	1.45	1.27	1.27	1.54	1.31	1.11	1.86	1.34	1.15	1.47	1.32	1.38

[1]Angus (AN), SimAngus (SA), Simmental (SM). [2]Initial age = age at start of trials; RFI = residual feed intake; RFIc = carcass fat adjusted RFI; RG = residual gain; LMA = LM area; IMF = intramuscular fat.
†Motility, (1= Poor; 2= Fair; 3= Good; 4= Very Good). ‡BSE, (1= Satisfactory; 2= Unsatisfactory; 3= Deferred).

Table 3.8. Effects of RFI and breed on performance, carcass ultrasound, and fertility traits in growing bulls.

	RFI Classification		Breed[2]				P-values		
Trait	Low	High	AN	SA	SM	SE	RFI	Breed	RFI x Breed
No. of bulls	206	180	317	200	108				
Performance traits[1]									
Initial age, d	318	317	314[a]	315[a]	326[b]	3	0.965	<0.001	0.350
Initial BW, kg	414	402	402[a]	427[b]	413[ab]	6	0.436	<0.001	0.960
Final BW, kg	494	499	476[a]	512[b]	494[c]	7	0.388	<0.001	0.941
ADG, kg/d	1.39	1.41	1.30[a]	1.49[b]	1.41[b]	0.05	0.836	<0.001	0.006
Initial hip height, cm	124	123	122[a]	124[b]	124[b]	1	0.110	<0.001	0.814
Final hip height, cm	132.0	131.7	129.8[a]	132.5[b]	132.5[b]	0.4	0.149	<0.001	0.979
Feed efficiency traits									
DMI, kg/d	9.32[a]	11.7[b]	10.1[a]	10.9[b]	10.3[a]	0.24	<0.001	<0.001	0.323
G:F	0.148[a]	0.124[b]	0.134	0.136	0.137	0.005	<0.001	0.417	0.036
RG, kg/d	0.125[a]	-0.111[c]	-0.052[a]	0.051[b]	0.0267[b]	0.019	<0.001	<0.001	0.030
RFI, kg/d	-1.15[a]	1.30[c]	0.078[a]	0.112[a]	-0.050[b]	0.05	<0.001	0.044	0.443
RFIc, kg/d	-1.02[a]	1.16[c]	0.052	0.061	-0.012	0.05	<0.001	0.536	0.013
Ultrasound traits									
Backfat depth, cm	0.566[a]	0.632[b]	0.649[a]	0.619[a]	0.517[b]	0.033	0.054	<0.001	0.078
LMA, cm^2	89.2	88.4	83.8[a]	92.2[b]	89.2[c]	0.7	0.537	<0.001	0.710
IMF, %	2.45	2.49	2.96[a]	2.30[b]	2.15[b]	0.14	0.894	<0.001	0.937
Fertility traits									
Scrotal circumference, cm	38.3	37.9	37.3[a]	38.6[b]	38.1[ab]	0.5	0.376	<0.001	0.650
Normal cells, %	78.1	79.4	74.3[a]	78.9[b]	79.9[b]	1.6	0.202	<0.001	0.086
Primary abnormalities, %	13.9	12.1	16.3[a]	13.0[b]	12.3[b]	1.8	0.164	0.026	0.083
Secondary abnormalities, %	8.12	8.62	9.40[a]	8.14[ab]	7.72[b]	0.84	0.779	0.047	0.829
Motility†	2.69	2.81	2.58[a]	2.74[ab]	2.88[b]	0.14	0.535	0.013	0.093
BSE‡	1.31	1.31	1.52[a]	1.27[b]	1.29[b]	0.08	0.165	<0.001	0.457

[1]Initial age = age at start of trials; RFI = residual feed intake; RFIc = carcass fat adjusted RFI; RG= residual gain; LMA = LM area; IMF = intramuscular fat. [2]Angus (AN), SimAngus (SA), Simmental (SM).†Motility, (1= Poor; 2= Fair; 3= Good; 4= Very Good). ‡BSE, (1= Satisfactory; 2= Unsatisfactory; 3= Deferred).[a,b,c]Means within row with different superscripts differ ($P < 0.05$).

Table 3.9. Pearson correlations between performance and feed efficiency traits in growing bulls.

Item	ADG, kg/d	DMI, kg/d	G:F	RG, kg/d	RFI, kg/d	RFIc kg/d
Initial BW, kg	**0.15**	**0.57**	**-0.28**	**-0.13**	0.03	0.00
ADG, kg/d		**0.53**	**0.73**	**0.83**	0.03	0.00
DMI, kg/d			**-0.17**	0.03	**0.68**	**0.67**
G:F				**0.93**	**-0.50**	**0.51**
RG, kg/d					**-0.38**	**0.39**
RFI, kg/d						**0.95**

RFI = residual feed intake; RFIc = carcass fat adjusted RFI; RG= residual gain.

Correlations in **BOLD** significant at P < 0.05.

Table 3.10. Pearson correlations between performance, feed efficiency, and feeding behavior traits in growing bulls.

Item	ADG, kg/d	DMI, kg/d	G:F	RG, kg/d	RFI, kg/d	RFIc, kg/d
Bunk visit traits:						
Bunk visit (BV) frequency, events/d	**0.11**	**0.17**	-0.01	0.01	**0.28**	**0.27**
BV duration, min/d	-0.03	**0.18**	**-0.17**	**-0.16**	**0.40**	**0.37**
Max non-feeding interval, min	-0.01	**-0.09**	0.07	0.05	**-0.15**	**-0.19**
BV eating rate, g/min	**0.36**	**0.48**	0.03	**0.14**	**0.10**	**0.13**
Meal traits:						
Meal criterion, min	**-0.12**	**-0.21**	0.03	-0.01	**-0.11**	**-0.11**
Meal frequency, events/d	**0.11**	**0.19**	-0.02	0.01	**0.15**	**0.16**
Meal duration, min/d	-0.05	0.03	-0.08	**-0.10**	**0.25**	**0.23**
Meal length, min/event	**-0.09**	-0.07	-0.04	-0.08	**0.11**	0.07
Meal size, kg/event	**0.25**	**0.50**	**-0.10**	0.00	**0.34**	**0.30**
Meal eating rate, g/min	**0.32**	**0.50**	-0.03	**0.08**	**0.16**	**0.18**
Intensity traits:						
Head down (HD) duration, min/d	-0.08	**0.13**	**-0.20**	**-0.21**	**0.31**	**0.27**
HD duration per BV duration	-0.08	**0.09**	**-0.18**	**-0.19**	**0.19**	**0.15**
HD duration per meal duration	-0.05	**0.14**	**-0.18**	**-0.18**	**0.20**	**0.16**
BV events per meal event	0.00	0.01	0.00	-0.01	**0.15**	**0.12**
Time to bunk, min	**-0.16**	**-0.25**	0.01	-0.03	**-0.14**	**-0.09**
Day-to-day variation traits†:						
BV frequency SD, events/d	-0.01	0.06	-0.06	-0.06	**0.19**	**0.17**
BV duration SD, min/d	**-0.20**	-0.08	**-0.15**	**-0.19**	**0.12**	**0.10**
Max non-feeding interval SD, min	**-0.08**	**-0.17**	0.05	0.02	**-0.19**	**-0.19**
Meal frequency SD, events/d	0.05	**0.14**	-0.06	-0.01	0.08	**0.08**
Meal duration SD, min/d	**-0.15**	**-0.15**	-0.05	**-0.11**	0.03	0.02
Meal length SD, min/event	**-0.08**	**-0.11**	0.00	-0.03	0.01	-0.02
HD duration SD, min/d	**-0.16**	0.03	**-0.22**	**-0.25**	**0.22**	**0.19**
Time to bunk SD, min	**-0.09**	**-0.12**	-0.01	-0.03	**-0.10**	-0.08

RFI = residual feed intake; RFIc = carcass fat adjusted RFI; RG= residual gain.

†Day-to-day variation traits = day-to-day standard deviation for each trait.

Correlations in **BOLD** significant at $P < 0.05$.

Table 3.11. Effects of RFI and breed on feeding behavior (FB) traits in growing bulls.

	RFI Classification		Breed[1]				P-values		
Item	Low	High	AN	SA	SM	SE	RFI	Breed	RFI x Breed
No. of bulls	206	180	317	200	108				
Bunk visit traits:									
Bunk visit (BV) frequency, events/d	27.8[a]	31.0[b]	31.9[a]	28.6[b]	27.4[b]	1.9	<0.001	<0.001	0.046
BV duration, min/d	94[a]	116[c]	112[a]	102[b]	101[b]	7	<0.001	<0.001	0.541
Max non-feeding interval, min	320[a]	299[b]	316[a]	303[b]	309[ab]	5	<0.001	0.009	0.775
BV eating rate, g/min	105	108	94[a]	114[b]	110[b]	8	0.543	<0.001	0.695
Meal traits:									
Meal criterion, min	13.4	12.0	13.9[a]	12.5[b]	12.2[b]	1.2	0.138	0.040	0.558
Meal frequency, events/d	11.5[a]	12.9[b]	11.5[a]	12.5[b]	12.5[b]	0.4	<0.001	<0.001	0.698
Meal duration, min/d	139[a]	160[c]	164[a]	144[b]	140[b]	8	<0.001	<0.001	0.584
Meal length, min/event	12.9	13.9	15.5[a]	12.5[b]	12.3[b]	0.70	0.301	<0.001	0.742
Meal size, kg/event	0.836[a]	0.966[c]	0.909	0.909	0.87	0.026	<0.001	0.201	0.650
Meal eating rate, g/min	71.5[a]	78.6[b]	64.4[a]	80.2[b]	80.0[b]	4.1	0.015	<0.001	0.867
Intensity traits:									
Head down (HD) duration, min/d	45.8[a]	63.7[c]	58.0[a]	52.2[b]	53.9[ab]	6.6	<0.001	0.013	0.255
HD duration per BV duration	0.464[a]	0.529[b]	0.504	0.484	0.509	0.034	<0.001	0.398	0.558
HD duration per meal duration	0.328[a]	0.397[b]	0.358	0.357	0.378	0.031	<0.001	<0.001	0.222
BV events per meal event	2.44	2.51	2.84[a]	2.33[b]	2.25[b]	0.13	0.676	<0.001	0.046
Time to bunk, min	34.3	31.1	30.6[a]	31.1[a]	36.1[b]	2.6	0.147	0.003	0.362
Day-to-day variation traits†:									
DMI SD, kg/d	1.54[a]	1.69[b]	1.62	1.61	1.55	0.057	<0.001	0.184	0.018
BV frequency SD, events/d	7.20	7.80	8.50[a]	7.15[b]	6.83[b]	0.66	0.076	<0.001	0.065
BV duration SD, min/d	18.4[a]	19.5[b]	20.6[a]	17.7[b]	17.8[b]	1.1	0.025	<0.001	0.515
Max non-feeding interval SD, min	82.1[a]	71.9[b]	78.2[a]	73.2[b]	78.2[ab]	2.3	<0.001	0.024	0.147
Meal frequency SD, events/d	2.14	2.32	2.10[a]	2.24[b]	2.30[b]	0.09	0.057	0.007	0.587
Meal duration SD, min/d	29.9	30.4	33.6[a]	28.6[b]	28.3[b]	1.4	0.906	<0.001	0.856
Meal length SD, min/event	3.37	3.26	3.85[a]	3.09[b]	2.99[b]	0.18	0.784	<0.001	0.910
HD duration SD, min/d	11.4[a]	13.3[b]	13.6[a]	11.4[b]	11.7[b]	1.0	<0.001	<0.001	0.816
Time to bunk SD, min	40.0	37.4	37.6[a]	37.4[a]	41.2[b]	2.3	0.268	0.055	0.426

[1]Angus (AN), SimAngus (SA), Simmental (SM).
†Day-to-day variation traits = day-to-day standard deviation for each trait.
[a,b,c]Means within row with different superscripts differ ($P < 0.05$).

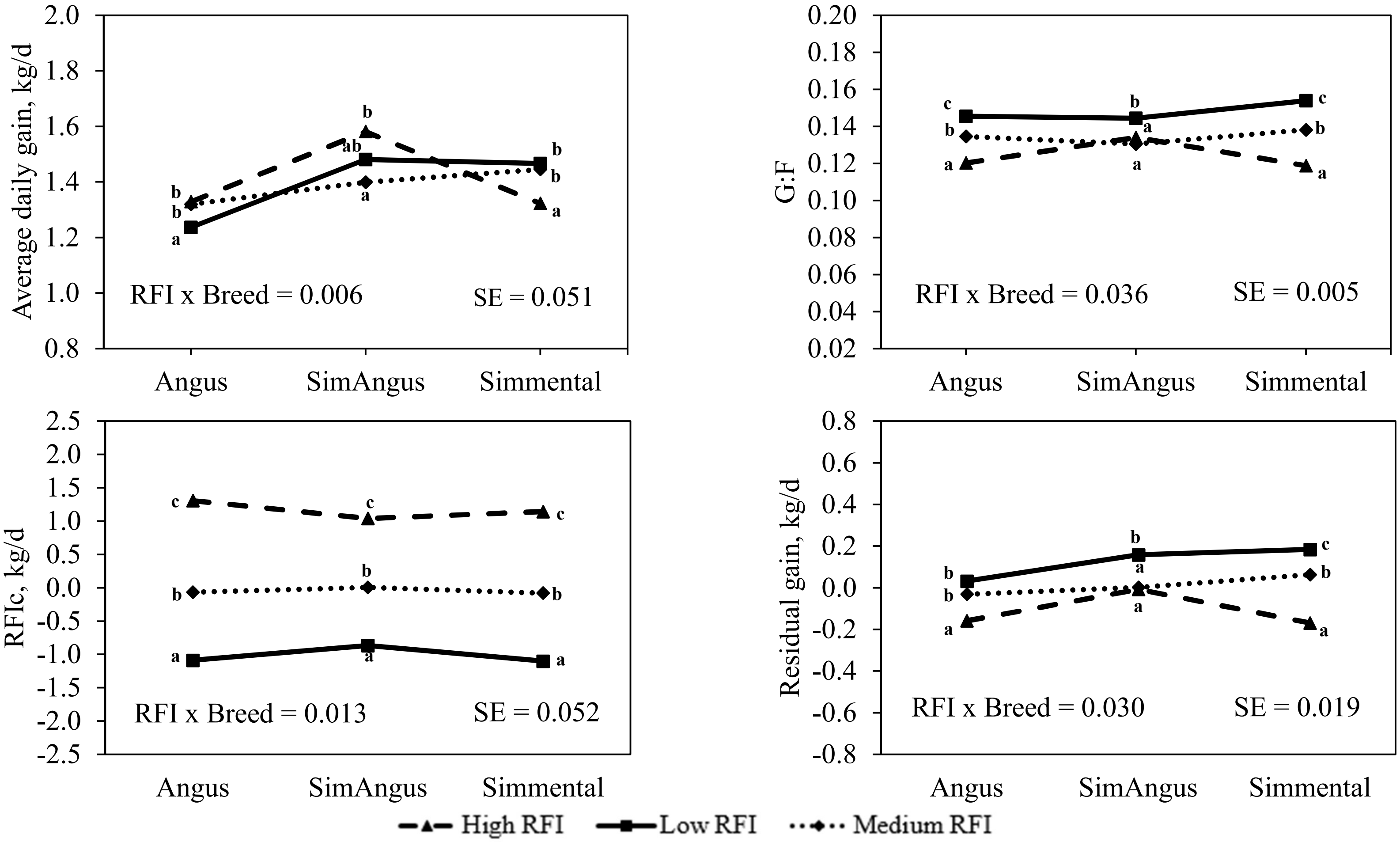

Figure 3.1. Least squares means of ADG, G:F, RFIc, and RG by breed for high, medium and low RFI classifications.

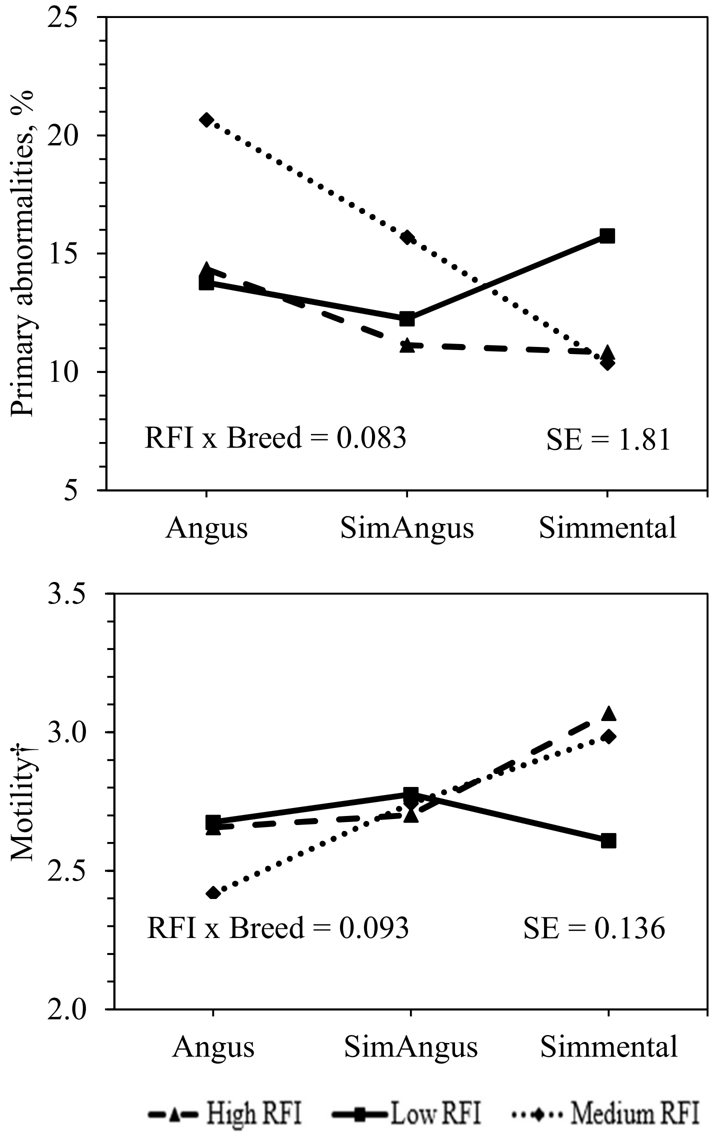

Figure 3.2. Least squares means of Primary abnormalities and Motility† by breed for high, medium and low RFI classifications.

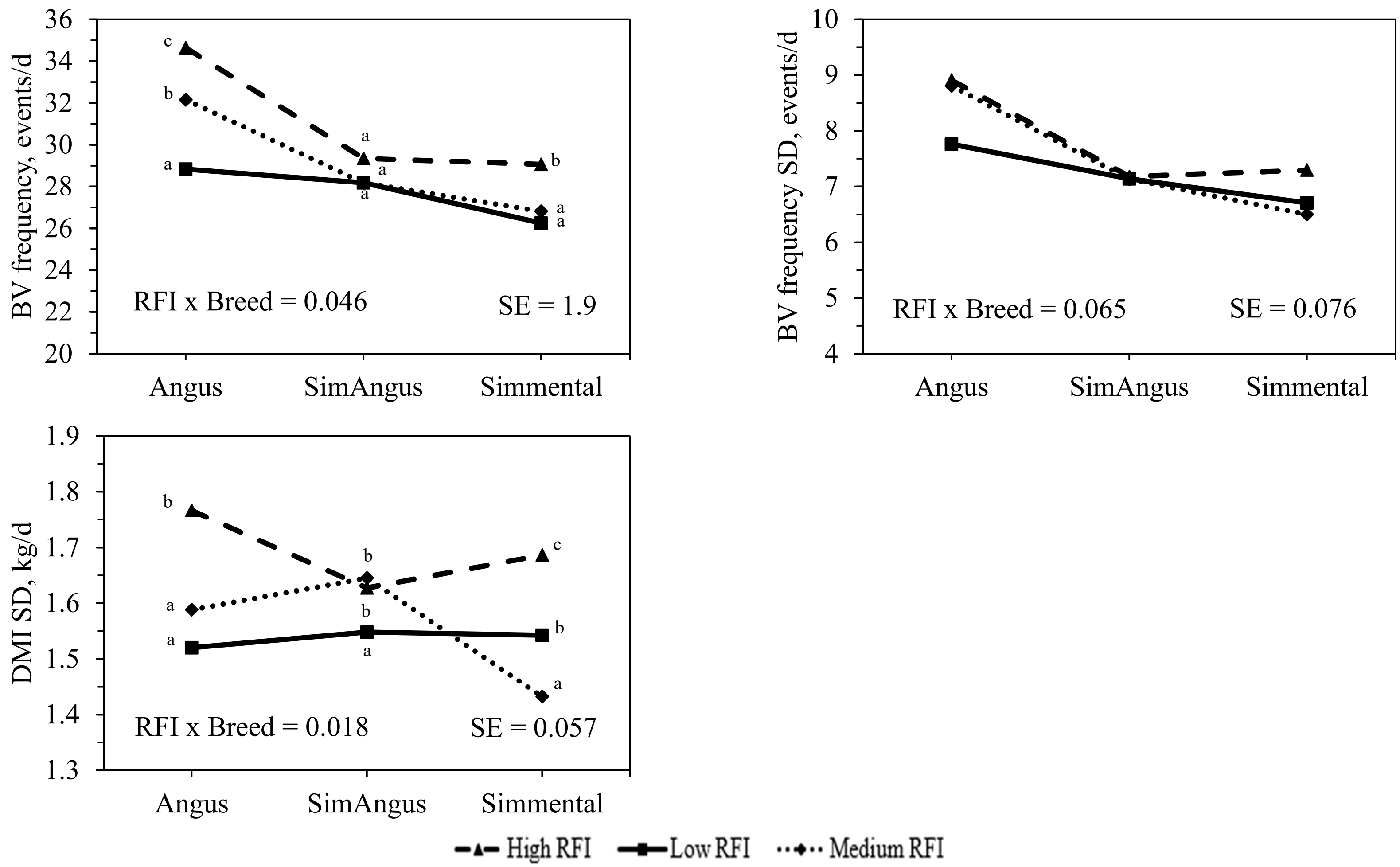

Figure 3.4. Least squares means of Bunk visit (BV) frequency, BV frequency SD, and DMI SD by breed for high, medium and low RFI classifications.

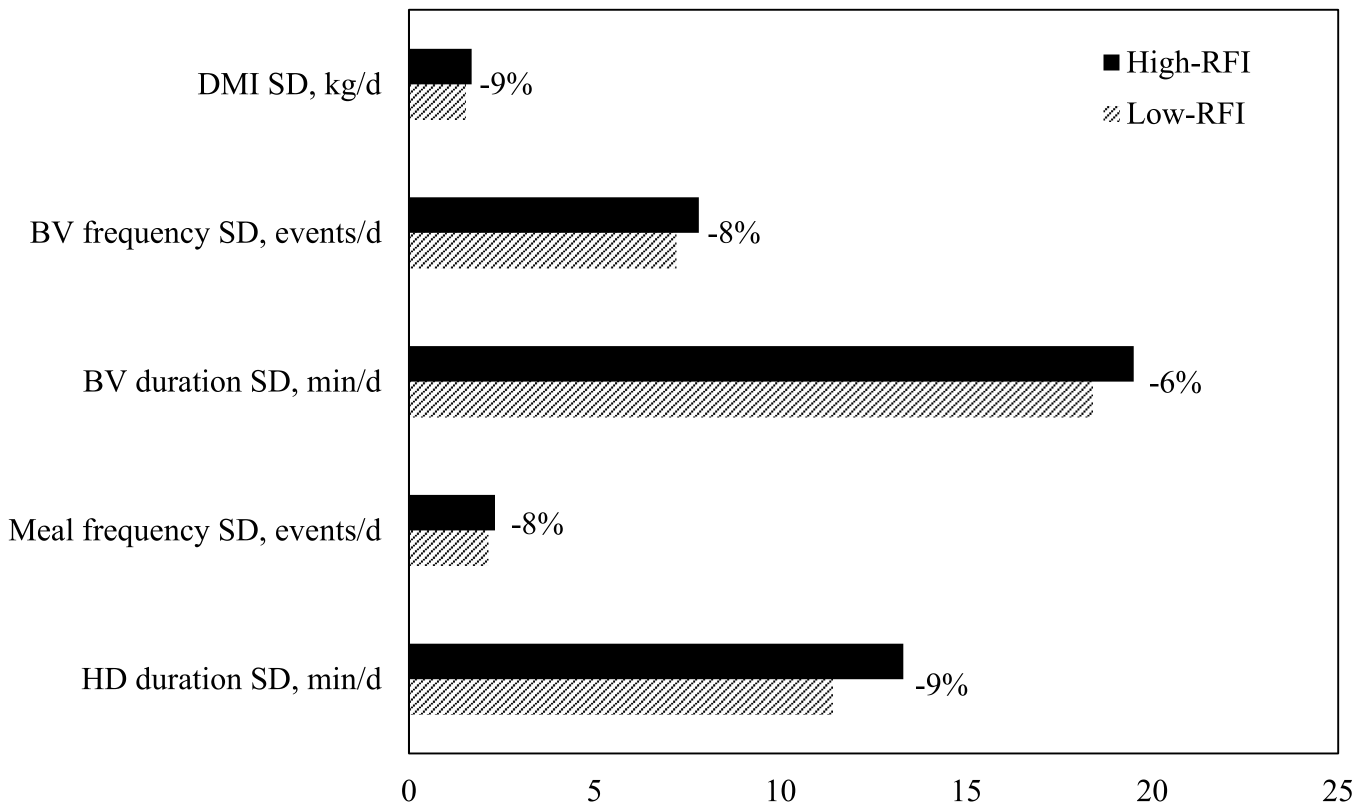

Figure 3.5. Effects of RFI classification on day-to-day variation of DMI and feeding behavior traits (P < 0.10) in growing bulls.