THE IMPACT OF SELECTION USING RESIDUAL AVERGAE DAILY GAIN AND MARBLING EPDS ON GROWTH PERFORMANCE AND CARCASS TRAITS IN ANGUS CATTLE

by

RACHAEL A. DETWEILER

(Under the Direction of T. Dean Pringle)

ABSTRACT

The objective of this study is to compare growth performance, feed efficiency, body composition, and carcass characteristics in steers, and to compare growth, body composition, and reproductive performance in heifers from bulls divergently selected for feed efficiency. Angus sires were selected with high and low residual average daily gain (RADG) EPDs and high and average marbling (MARB) EPDs. This resulted in a 2x2 factorial arrangement with four treatment combinations: high RADG, high MARB (Hi/Hi); high RADG, average MARB (Hi/Avg); low RADG, high MARB (Lo/Hi); and low RADG, average MARB (Lo/Avg). The overall goal of this research program is to develop lines of cattle using RADG EPD so that a better understanding of the biological and physiological basis of efficiency in beef cattle can be ascertained. Selection using RADG EPD resulted in improved feed efficiency in steer progeny; however additional research is needed in heifer progeny.

INDEX WORDS: ANGUS, RESIDUAL FEED INTAKE, RESIDUAL AVERAGE DAILY GAIN, MARBLING, EXPECTED PROGENY DIFFERENCE, HEIFER, STEER

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DEDICATION

First, I would like to dedicate this work to God. I have been so grateful for this opportunity that He has given me to grow. Second, I would like to dedicate this work to my entire family. To my parents, Mark and Regina, thank you for teaching me to work diligently to the Lord, and not unto man. Thanks for always being there for the late night calls, prayers, encouragement, for talking me through the break-downs (car and emotional), to work through the tough times and reminding me that God doesn't give us anything we can't handle. I wouldn't be the woman I am today without the values and morals you have taught me over these years. To Rebekah, Matthew, and Rhesa, thank you for always calming me down with humor when I was extremely stressed with school, thanks for showing me life is too short to be stressed; I can't imagine my childhood without you three in it. To my grandparents Papa and GranGran, Grandma and Grandpa, thank you teaching me to be kind, supporting me, and helping me over these years. Many people my age aren't as blessed with the wisdom you have given me about life, work, and dedication. To the Dunaways W.C., Dorothy, Jenn, Ashley, Hollis, Jess, and Michael, thank you for always supporting me and encouraging me to finish strong. And last, to my fiancé L.A., thank you so much for all the time you spent helping me complete this chapter in my life. From your off-days turning into helping me in the lab, to the late night dinners, to the phone calls of frustration, to always taking care of me, thank you for being my best friend. I am so grateful God made you for me. All I can amount to is that I am beyond blessed. Thank you all for helping me accomplish my goals. I love you all more than words could ever explain and I dedicate this work to you all.

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# CHAPTER 1

# INTRODUCTION

Approximately 65% of the total farm expenditures for beef cattle operations are associated with feed cost (Lancaster et al., 2009). Anderson et al. (2005), reported that feed costs alone, represent the largest variable cost in beef cattle production, totaling approximately two-thirds of the cost in US beef cattle production systems. The mature cow herd alone, uses an estimated 72% of all feed sources consumed (Ferrell and Jenkins, 1985). Balancing output (growth) with input costs (feed) is needed in practicing selection (Rolf et al., 2011). Feed efficiency is thus recognized as one of the most important factors in determining overall profitability in the cow-calf herd; however minimum information exists on the growth and reproductive performance in replacement females selected for feed efficiency (Shaffer et al., 2011).

Residual feed intake is a feed efficiency measure, which is reportedly independent of the component production traits such as DMI,  BW, and milk production; and is defined as the difference between actual and predicted intake (RFI= Actual intake – Predicted intake) of a beef animal with a given rate of gain (Berry and Crowley, 2013). Residual feed intake (RFI) is determined using the linear regression of midpoint metabolic body weight and average daily gain during a feed trial where daily dry matter intake was recorded for individual animals over a period of time (Koch et al., 1963).The resulting RFI values can be interpreted as higher (+) values indicating less efficient animals since they ate more than predicted, and lower (-) values indicating more efficient animals since they ate less than predicted over a feed trial yet still maintained the same or similar ADG to their less efficient, higher RFI contemporaries (Arthur and Herd, 2008). The heritability for RFI has been reported to be similar to other growth traits (such as average daily gain (ADG), relative growth rate) so selection for low RFI values in cattle should result in more pounds of carcass produced per unit of feed consumed. Residual feed intake offers selection of the portion of feed intake, which is not utilized by the requirements for maintenance and production (Arthur and Herd, 2005).

However in heifers and the mature cow herd, the following two potentially negative effects could result from selection for increased efficiency using feed conversion ratios: indirect selection for increased average daily gain and increased mature size (Basarab et al., 2003). Increased mature size of animals generally correlates to increased feed required by the mature animal in order to fulfill maintenance requirements (Ferrell and Jenkins, 1985; Montano-Bermudez et al., 1990; Ferrell and Jenkins, 1998). Over time, this can result in additional cow costs for cow-calf operations, which can be directly attributed to elevated maintenance requirements of the larger mature females (Montano-Bermudez et al., 1990). Additionally, prolonged calving season can result from reduced first service conception rate when selecting for efficiency (Donoghue et al., 2011). This decrease in early breeding season conception will result in a delay in calving that could negatively impact the reproductive efficiency of females for the remainder of their lives by delaying rebreeding in subsequent years (Basarab et al., 2007). One possible explanation, is high RFI heifers tended to reach puberty earlier than low RFI heifers (Shaffer et al., 2011). This could be due to fat deposition being energetically more expensive than lean tissue (Pullar and Webster, 1977). High RFI females will have a greater feed intake compared to the low RFI females, which could be the reason for increased fat deposition.

One of the primary challenges when selecting for improved efficiency in beef cattle is the lack of feed intake data that is readily available for use in developing genetic values for efficiency (Basarab et al., 2003). Producers and researchers have worked for many years to gather individual animal intake data to allow for genetic selection for efficiency. Unfortunately, this trait is relatively difficult and costly to measure because of the labor and expense associated with feeding systems that measure individual intake (Herd and Arthur, 2009). The GrowSafe™ Beef system enables producers to more accurately measure feed intake in growing cattle through an electronic recording system that greatly reduces the time and money associated with recording feed intake (Wang et al., 2006), resulting in greater availability of feed intake data from test facilities across the country.

The increasing availability of feed intake data along with development of genomic predictors of feed intake led the American Angus Association to develop the Residual Average Daily Gain (RADG) expected progeny difference (EPD) in 2010 (Northcutt, 2010). Calculation of this relatively new efficiency EPD utilizes calf weaning weight, postweaning gain, ultrasound subcutaneous fat thickness, and genomic or actual dry-matter intake (Northcutt, 2010). Since this index included BW gain and feed intake, it produced the best economic outcome for producers (Rolf et al., 2011) The RADG EPD is a genetic value for an animal's average daily gain given a constant amount of feed in the postweaning period. It is expressed in pounds per day, therefore a higher value of RADG EPD is more favorable suggesting a more feed efficient (low RFI) animal and a lower value of RADG EPD predicts that an animal is not as feed efficient (high RFI). Zeng et al. (2012) reported that residual feed intake and carcass merit are complex traits that are critical in determining the profitability of beef producers and they suggested that genome-wide selection, using DNA markers, may have potential for replacing the costly measurement of these traits. However, since the RADG EPD is a relatively new tool for potential genetic improvement in efficiency, investigation is needed to verify its potential and to determine the full utility of this EPD. Thus, the objective of this study was to compare feed efficiency, growth performance, and carcass traits in steers and heifers from Angus sires that were selected for improved feed efficiency using RADG EPD.

CHAPTER 2

LITERATURE REVIEW

**The Need for Efficiency**

By the year 2050, the global population is predicted to be 9.5 billion people (US Census Bureau, 2008). The Food and Agriculture Organization of the United Nations (FAO, 2009) suggests that food production will have to increase by 70% to fulfill the caloric and nutritional needs of the human population at that time. The question then arises how the global agriculture and food industries provide food for this increasing population with the limited resources at hand.

One solution is to increase production from the current land base through increased efficiency of production (Berry and Crowley, 2013). For beef production, it has been estimated that the mature cow herd uses 72% of all feed sources consumed, resulting in a large monetary cost to cow-calf producers (Ferrell and Jenkins, 1985). Anderson et al. (2005), reported that feed costs alone, represent the largest variable cost in beef cattle production, totaling approximately two-thirds of the production costs to US beef cattle producers. If animal efficiency can be improved, there is a potential for decreased land use for livestock production or more likely increased livestock production on a fixed area of productive land.

In the typical cow-calf operation alone, approximately 65% of the total farm expenditures are associated with feed cost (Lancaster et al., 2009). Balancing output (growth) with input costs (feed) is needed in selection of breeding animals (Rolf et al., 2011). Basarab et al. (2003) reported that only 5% of the total life cycle dietary energy consumption of beef cattle is used for protein deposition, compared to 14 and 22 % in pork and poultry, respectively. This is evidence of the energetic inefficiency of the beef animal in comparison to monogastric livestock species. United States livestock producers face the challenge of producing sufficient, safe, affordable beef to meet consumer demand, using a finite resource base (Capper et al., 2011). One approach to meeting these consumer demands is the genetic selection for improved feed efficiency in the beef animal.

**Feed Efficiency**

Feed efficiency is measured as a function of gain in body weight and feed consumed (Koch et al., 1963). Traditionally, feed efficiency has been measured by feed conversion ratios (FCR), which have been defined as units of dry matter intake (DMI), required per unit of body weight gain (Berry and Crowley, 2013).

Average daily gain is defined as the change in the animal's weight over a period of time. Calculation of this performance trait only requires a scale (Archer et al., 1999). According to Rolf et al. (2011), feed conversion ratio (FCR) is the inverse of gross feed efficiency and is the ratio of DMI and ADG. However, in the study by Berry and Crowley (2013), FCR and RFI were positively genetically correlated with feed intake (0.39 and 0.72, respectively), but only FCR was genetically correlated with ADG (−0.62), indicating that improved FCR was associated with greater ADG. The genetic correlation between FCR and RFI was 0.75, with a range in correlations from −0.21 to 0.93. However, neither FCR nor RFI was genetically correlated with midtest BW, although considerable variation in the genetic correlations existed, especially for FCR. Furthermore, a delayed onset of puberty and reduced productivity of the cow has been observed in selection for RFI (Shaffer et al., 2011). One possible explanation, is high RFI heifers tended to reach puberty earlier than low RFI heifers (Shaffer et al., 2011). This could be due to fat deposition being energetically more expensive than lean tissue (Pullar and Webster, 1977). High RFI females will have a greater feed intake compared to the low RFI females, which could be the reason for increased fat deposition.

Two potentially negative effects that could result from selection for increased efficiency using feed conversion ratio are the indirect selection for increased average daily gain and increased mature size (Basarab et al., 2003). Increased mature size of animals generally correlates to increased feed required by the mature animal in order to fulfill maintenance requirements (Ferrell and Jenkins, 1985; Montano-Bermudez et al., 1990; Ferrell and Jenkins, 1998). Over time, this can result in additional costs for cow-calf operations, as it is estimated that over 50% of the total feed consumed can be directly attributed to maintenance requirements of the mature females (Montano-Bermudez et al., 1990). Furthermore, a delayed onset of puberty and reduced productivity of the cow has been observed (Shaffer et al., 2011). Although increased ADG directly translates to increased growth, if the animal is eating more feed than the value of the additional gain then this additional growth might not be economical gain to the beef operation (Montano-Bermudez et al., 1990; Archer et al., 1999; Arthur et al., 2001; Herd et al., 2003; Arthur and Herd, 2008). Thus animal selection on the basis of FCR may improve efficiency during the growth and finishing stages of beef production; however, it may not improve the efficiency or profitability of the whole production system (Archer et al., 1999).

**Measuring Feed Efficiency**

Feed intake and its utilization by the animal involve a complex of biological processes, pathways, and interactions with the environment (Herd et al., 2003). Three measures can be computed to assist with determining feed efficiency: (1) feed consumption adjusted for differences in gain; (2) gain adjusted for differences in feed consumption; and (3) the ratio of gain to feed consumed. With all three measures collected, one can take a midweight, yearling weight etc., and calculate feed efficiency by the removal of differences in maintenance requirements (Koch et al., 1963) by: actual intake – predicted intake.

Traditionally, measurement of feed intake occurs in central test stations, or on-farm, and uniform guidelines are required to ensure that standardized and accurate data are generated (Herd et al., 2003). “However, measuring individual animal feed intake is difficult and expensive, and this constraint has been responsible for the paucity of scientific information required to develop comprehensive strategies for genetic improvement in feed intake and efficiency” (Arthur and Herd, 2005). Not only is feed intake difficult and costly to measure for individual animals, but feed intake is highly correlated with body size and level of production. However, feedlot diets are ideal for evaluating the feed efficiency potential of cattle for profitability (Durunna et al., 2010). All animals are in the same contemporary group, which means they are exposed to the same environment, receiving the same ration, thus managed the same way.

In order to fully characterize the efficiency of gain within the beef cattle production system, the dry matter intake of individual animals must be accounted for and the level of resulting performance measured, whether it is milk production, lean muscle gain, or fat deposition.  There is considerable individual animal variation in feed intake above and below that expected or predicted on the basis of size and growth rate. This difference in intake is calculated as residual (or net) feed intake (Herd et al., 2003). The resulting measure of net feed efficiency, or residual feed intake (RFI), has become the primary method of measuring feed efficiency since it was first proposed in 1963 by Koch and coworkers.

**Residual Feed Intake**

Residual feed intake is a feed efficiency measurement, which is, by definition, independent of the component production traits. Residual feed intake may be defined as the difference between actual and predicted intake (Berry and Crowley 2013). It offers the possibility to select on the portion of feed intake, which is not explained by the requirements for maintenance and production. Therefore, RFI accounts for just actual feed intake compared to predicted feed intake. Traditionally, feed efficiency is dependent on production traits like FCR, but RFI allows selection without effecting growth or performance selection. It is therefore, a useful trait for studying the physiological mechanisms underlying variation in feed efficiency, without the complication of change in production (Arthur and Herd 2005).

Sherman et al. (2010) calculated residual feed intake by the difference between actual DMI of an animal and the expected DMI based on its BW and growth rate. Alternatively, RFI may be generated using standard feed tables (e.g., NRC, 2001) or other information sources to allocate the energy demand for each of the energy sinks (growth, lactation, gestation, maintenance) and subtract the total from the energy intake; this measure of RFI is sometimes termed “nutritional RFI”.

Traditionally, predicted intake for use in determining RFI has been determined using the linear regression of midpoint metabolic body weight and average daily gain during a feed trial where daily dry matter intake was recorded for individual animals over a period of time (Koch et al., 1963). The resulting RFI values can be interpreted as higher (+) values indicating less efficient animals since they ate more than predicted based on their bodyweight gain, and lower (-) values indicating more efficient animals since they ate less than predicted over a feed trial yet still maintained the same or similar ADG to their less efficient, higher RFI contemporaries (Arthur and Herd, 2008)

Describing the relationship between RFI and the traditional feed conversion ratio, Arthur et al. (2001), reported that feed conversion ratio was genetically (r(g) = 0.66 ) and phenotypically (r(p) = 0.53) correlated with residual feed intake and that feed conversion ratio was correlated (r(g) = -0.62, r(p) = -0.74) with ADG, whereas residual feed intake was not (r(g) = -0.04, r(p) = -0.06). In contrast to feed conversion ratio, RFI acts independently of DMI and ADG and accounts for maintenance requirements and growth without indirectly selecting for increased body size (Koch et al., 1963). This means that RFI could be used as a selection tool within herds without the direct risk of increasing mature size of cows and increasing maintenance requirements of the cow herd (Montano-Bermudez et al., 1990; Basarab et al., 2007; Hafla et al., 2013).

Unlike feed conversion ratios that are dependent upon growth rate, RFI is independent of growth rate and can be utilized to improve efficiency independently of other growth traits (Koch et al., 1963; Basarab et al., 2003). Furthermore, RFI is not influenced by mature weight (Lancaster et al., 2009; Shaffer et al., 2011; Herd et al., 2014). As a result, when selecting for improved efficiency using RFI, the potentially negative effects associated with selection using feed conversion ratios alone are avoided, like increased matures size (Basarab et al., 2007).

**Measuring Residual Feed Intake**

One of the challenges of incorporating RFI data collection into genetic evaluations by breed associations is the additional time, equipment, and labor required to measure dry matter intake on the individual animal basis (Arthur and Herd, 2005; Tedeschi et al., 2006; Wang et al., 2006; Comerford et al., 2007; Arthur and Herd, 2008; Lancaster et al., 2009; Shaffer et al., 2011). The process of manually measuring individual feed intake is rigorous and time consuming. Today, individual feed intake can be recorded for any contemporary group via the GrowSafe™ feed intake system. This information can then be used to calculate residual feed intake for possible use in genetic evaluations and development of breeding values for efficiency (Kolath et al., 2005). Berry and Crowley (2013) evaluated the length of time required during a feed intake trial to obtain accurate estimates of feed efficiency and concluded that a 70-d test period (after acclimatization), with animals weighed at least every 2 week, was sufficient.

In the past, group fed studies were utilized in order to determine efficiency, but ultimately group feeding does not account for the variability in feed intake between animals and is not a good intake determination practice (Archer et al., 1997; Archer and Bergh, 2000; Wang et al., 2006). It was not until 1970 when the Calan Gate (American Calan, Northwood, NH) was developed that cattle could be group housed, yet have individual feed intake data recorded accurately (Broadbent et al., 1970). The Calan Gate system is comprised of individual feeding bunks with electronic gates that limit access to a single individual. Each gate can be unlocked by a transducer worn around the neck of an animal and opens only for the animal wearing the correct transducer. A training period, typically seven to fourteen days, is required before collecting accurate feed intake and some animals never learn to successfully use their assigned Calan gate with their key (Broadbent et al., 1970). Feed intake in this system is defined as the difference between the feed offered to the animal and the feed refusal (feed left in the bunk) which should be weighed at least weekly.

Common problems with the Calan gate feeding system include the following: trouble with animals opening their gate; if electrical problems occur, transducers will not read the key and animals will be unable to eat; errors in feed intake measurement by inaccurate weight measurements by feedlot personal; and potential stealing of feed by other animals reaching past their individual bunks. Although the Calan gate still requires labor inputs to record feed intake, it greatly reduces the work of recording feed intake and allows for individual intake to be measured while animals are housed in groups (Stock, 1986).

In early 2001, a computerized intake data collection system, called the GrowSafe™ system (GrowSafe Systems Ltd, Airdrie, AB, Canada), became available for beef cattle intake measurement,. The GrowSafe™ system utilizes RFID tags for animal identification and enables producers to more accurately measure feed intake in growing cattle through an electronic recording system that greatly reduces the time and money associated with recording feed intake (Wang et al., 2006). The system automatically records when an animal eats; how much the animal eats; and how many times per day the animal visits the feeding unit. The computer processor analyzes the intake data and produces an intake data file complete with average DMI over the course of the feed test period (Wang et al., 2006).

Barasab et al. (2003) found that metabolic mid-point weight, ADG, gain in empty body fat and gain in empty body water accounted for 67.9, 8.6, 3.9 and 1.1%, respectively, of the variation in actual feed intake. Similarly, metabolic mid-point weight, ADG, gain in ultrasound backfat thickness, gain in ultrasound marbling score and year accounted for 80.9% of the variation in actual feed intake (Barasab et al., 2003).

Furthermore, Kolath et al. (2005) found that mitochondrial function is not different between high and low RFI groups but rather the rate of mitochondrial respiration is increased in low RFI steers compared with high RFI steers. Average daily feed intake by the high RFI animals was 1.54 kg/d greater than for the low RFI animals. Low RFI steers exhibited a greater rate of state 2 and 3 respiration, respiratory control ratio, and hydrogen peroxide production than high RFI steers when provided with glutamate or succinate as a respiratory substrate. Kolath et al. (2003) also found increased plasma glucose concentrations 1 wk prior to slaughter in high RFI steers compared to their low RFI counterparts. This was presumed to be the result of a greater feed intake by these animals.

**Selecting for Efficiency**

Koch and coworkers (1963) suggested that selection for gain should be effective and lead to both increased feed efficiency and increased feed consumption, while selecting for feed efficiency would increase feed efficiency and result in increased daily gain without affecting feed consumption. They further suggested that selection for feed consumption would increase feed consumption and daily gain, but would lead to no improvement in feed efficiency other than that attributable to a smaller portion of the intake being used for body maintenance. Thus, they proposed that direct selection for feed efficiency was needed in the beef industry.

Genetic correlations between postweaning RFI and other economically important traits have been determined in Angus progeny (Arthur et al., 2001). Feed intake had a genetic correlation of 0.66 with RFI, while ADG had a correlation of 0.04, suggesting that feed intake can be reduced without negatively impacting ADG. Furthermore feed efficiency, feed intake and other post weaning traits, had a 12$^{th}$ rib fat genetic correlation of 0.17 and ribeye area was reported at 0.09. In a study by Donoghue et al. (2011), feed intake data was collected on bulls and used to identify high and low RFI sires. The high and low RFI sires were then used to create lines of cattle that differed based on phenotypic selection for RFI. Performance of the cattle from the lines were compared and the results indicated that five generations is adequate time to observe a clear divergence in RFI using phenotypic selection alone. This suggests that selection for animal efficiency using phenotypic RFI measures is possible and may be beneficial to the beef producer.

Selection for increased efficiency in beef cattle may provide benefits beyond just production traits. Based solely on the fact that feed intake would be lower, higher efficiency cattle should produce less greenhouse gas emissions and less waste per unit of live weight produced, without compromising growth performance (Herd et al., 2003). Feed intake and its utilization by the animal involve a complex of biological processes and pathways, and interactions with the environment (Arthur and Herd, 2005). Which is essential, considering that 70 to 75% of the total energy requirement for beef production is used for maintenance functions (Montano-Bermudez et al., 1990). In grass-based systems, calf-to-weanling and calf-to-beef, Lawrence et al. (2012) reported that the cow herd consumed, 0.85 and 0.50 of total feed inputs, respectively. This confirms that maintenance of the cow herd is a considerable proportion of total costs in beef production systems (Ferrell and Jenkins, 1985; Montano-Bermudez and Nielsen, 1990). It is important to note also, that there are currently very few published studies that show how RFI measures in young females correlate with mature cow production (Archer, 2002; Basarab et al., 2007; Donoghue et al., 2011).

An index including BW gain and RFI produced the best economic outcome for producers (Rolf et al., 2011). To calculate this index, individual performance ratios would need to rank bulls within their contemporary groups (Parish et al., 2008). An estimated breeding value (EBV) for feed intake after a phenotypic adjustment for growth performance (growth rate and BW) seems most practical. Such an EBV would best be used in an economic selection index to account for genetic correlations with other traits in the breeding objective, including feed intake of the breeding herd, and the economic value of feed in relation to other traits (Herd et al., 2003).

**Heritability**

Efficiency, expressed as gain adjusted for differences in feed consumption (i.e., ± deviation from the regression of gain on consumption), was considered the most accurate mathematical description of the cause and effect relationships with feed consumption adjusted for: differences in gain; gain adjusted for differences in feed consumption and the ratio of gain to feed consumed. Additionally, efficiency expressed as gain adjusted for differences in feed consumption had the highest heritability (Koch et al., 1963). Koch et al. (1963) reported that the combined heritability of feed efficiency were 0.65 for gain on test, 0.64 for feed consumed, 0.62 for gain adjusted for differences in feed consumption, 0.28 for feed consumption adjusted for differences in gain, and 0.36 for the ratio of gain to feed consumed. This analysis indicated that 38% of the variation in gain could be attributed directly to genetic differences in feed efficiency. Genetic differences in feed consumption accounted for 25% of the variation in gain. The remaining 37% of the variation in gain was accounted for by variations in environmental influences (Koch et al., 1963).

Genetic improvement in feed efficiency can be achieved through selection without significant correlated responses in growth and the other postweaning traits (Arthur et al., 2001). Rolf et al., (2011) found that average daily gain was less heritable (0.26) than a midtest BW (MBW; 0.35), while the heritability estimate for G:F was 0.27. Feed intake measurements taken at 140-d had a genetic correlation of 0.40 DMI with a RFI at 0.52. A strong genetic (0.86) correlation was found between ADG and MBW; however, genetic correlations between DMI and ADG or MBW (0.56 and 0.71, respectively) were not as strong (Rolf et al., 2011). Herd et al. (2003) reported that genetic variation in the RFI of beef cattle exists both during growth towards a slaughter endpoint and growth of replacement females (heritability estimates since 1996 range from 0.16 to 0.43). Furthermore, they reported a heritability of 0.23 for RFI in adult cattle and the breeding herd (Herd et al., 2003).

Genetically, both residual feed intake and feed conversion ratio are negatively correlated with 200-d weight and 400-d weight (Arthur et al., 2001). The correlations between rib fat, ADG and the feed efficiency traits were near zero, except for the correlations between feed intake and FCR (r(g) = 0.31, r(p) = 0.23), feed intake and RFI (r(g) = 0.69, r(p) = 0.72), and rib fat depth and RFI (r(g) = 0.17, r(p) = 0.14). Results from a single generation of divergent selection based on phenotypic RFI (measured between 8 to 12 mo of age) demonstrated favorable changes in average daily feed intake (9.2 ± 0.2 vs. 9.8 ± 0.2 kg/d), RFI (−0.20 ± 0.11 vs. 0.17 ± 0.10 kg/d), and feed:gain ratio (F:G; 7.0 ± 0.2 vs. 7.6 ± 0.2 kg/kg) in Angus feedlot steers (Herd et al.,  2003).

**Genomic Markers- Single Nucleotide Polymorphism**

Recently, RFI has been the target of several studies to identify genetic markers (Sherman et al., 2010). A marker-assisted EPD is a new selection tool that incorporates genetic information from specific DNA segments of interest into traditional EPD calculations (Parish et al., 2008). Incorporation of genetic marker data into EPD calculations can improve EPD accuracy values. The use of marker data alone in selection decisions ignores the genetic contributions of other genes and may not explain significant amounts of the variation in a particular trait. However, this is a rapidly expanding field of study that seems to promise application for practical beef cattle production in the near future. Until marker data can sufficiently explain significant levels of the genetic variation in traits of interest, marker data should not be used in place of EPDs. Instead, marker data should be used in conjunction with EPDs in selection decisions (Parish et al., 2008).

Many quantitative trait loci (QTL) have been identified throughout the cattle genome (Nkrumah et al., 2007b; Sherman et al., 2010), and single nucleotide polymorphism (SNP) associated with RFI have been identified (Sherman et al., 2008). As well, a whole genome association (WGA) study by Barendse et al. (2007) identified many SNP throughout the bovine genome associated with RFI (Sherman et al., 2010).

Using 464 steers sired by Angus, Charolais, or Alberta Hybrid bulls, Sherman et al. (2010) investigated a total of 2,633 SNP across the 29 bovine autosomes for their association with RFI. One hundred and fifty SNP were associated with RFI, of which 23 were significant ($P < 0.01$); however, nine of the SNP pairs show high linkage disequilibrium ($r^2 > 0.80$), so only 1 of the SNP pairs was used in further multiple-marker analyses. (Sherman et al., 2010). Linkage disequilibrium measures the degree to which alleles at two loci are associated and it is essential in determining the extent to which association mapping can be used.

Sherman et al. (2010) used two methods to create a panel of SNP that were informative for RFI. In the first method, 141 unique SNP were combined in a single multivariate model and a backward elimination model was used to drop SNP until all SNP left in the model were significant at $P < 0.05$. In the second method, the estimates from the 141 SNP were used to create a sequential molecular breeding value (MBV) according to the compound covariate prediction (CCP) procedure (Sherman et al., 2010).

Sherman et al. (2010) found that the first method had greater effects when combined in the multivariate model than when tested individually. The second method, was built by adding the estimated effects one at a time, keeping SNP effects in the sequential MBV if the test statistic and the proportion of variance explained were improved. The 2 methods predictabilities were compared by regressing RFI on a final MBV, created from SNP that remained in each analytical model. (Sherman et al., 2010).

The significant SNP were tested for associations with DMI and FCR; and 9.5% of the SNP from the 2 models were within 5 cM of the previously identified RFI QTL. Overall, this study has identified a panel of SNP with significant effects on RFI. These SNP, need to be validated in an independent population and provide progress toward selecting markers for use in marker-assisted selection for feed efficiency in beef cattle (Sherman et al., 2010).

Zeng et al. (2012) suggested that residual feed intake (RFI) and carcass merit (CM) are complex traits emerging as critical targets for genetic improvement in beef production systems. They also suggested that genome-wide selection using DNA markers may be a potential alternative for genetic improvement of these traits. In this study, the efficiency of a genome-wide selection model for genetic improvement of RFI and CM was assessed. The Illumina Bovine50K bead chip was used to genotype 922 beef cattle from the Kinsella Beef Research Ranch of the University of Alberta. A Bayes model and multiple marker regression using a stepwise method were used to conduct the association test. The average prediction accuracies of phenotypic EBV for carcass weight, carcass back fat, rib eye area, carcass grade fat, lean meat yield, and residual feed intake, were increased by 0.05, 0.16, 0.24, 0.23, 0.17 and 0.19, respectively. This study indicated that the two-trait marker-assisted evaluation model used was a suitable alternative of genetic evaluation for these traits in beef cattle.

**Carcass**

It is suggested that selection on residual feed intake could be implemented to reduce feed intake and improve feed conversion without compromising growth or changing levels of subcutaneous fat (Schenkel et al., 2004). Although the concept of selecting for lower RFI animals can result in overall improved feed efficiency, carcass characteristics must be measured in order to understand the overall impact of RFI selection (Arthur and Herd, 2008). Arthur and Herd (2008) measured RFI based on production traits such as average daily weight gain, mid-test metabolic weight, hip height and scrotal circumference. Residual feed intake was additionally based on backfat thickness and production traits, which included ultrasound backfat thickness, longissimus muscle area, and predicted percentage of intramuscular fat in addition to the previous production traits listed. The genetic correlation between RFI production alone (RFIp) and RFI backfat thickness /production (RFIb) was high (0.99) within breeds, but breeds ranked differently with respect to RFIp and RFIb. Additionally genetic correlations of RFIb with ADG and backfat thickness were essentially zero, suggesting no compromise of carcass characteristics between RFI groups (Schenkel et al., 2004).

Rolf et al. (2011) compared carcass characteristics with a genomic relationship matrix based on breeding values and accuracies, to determine if selection for more efficient animals would compromise carcass quality. They found that the adjustment of measures of feed efficiency or residual feed intake adjusted for metabolic body size, BW for body fatness recorded at slaughter had little effect with the selection tool (Rolf et al., 2011).

Nkrumah et al. (2004) found that partial efficiency of growth (PEG), which is an energetic efficiency for ADG that is calculated by ADG divided by DMI for growth; was correlated with RFI ($r = -0.89$, $P < 0.001$) and was lower ($P < 0.001$) for high- vs. medium- or low-RFI animals. However, RFI was not related to ADG, midpoint weight (MWT), relative growth rate relative to instantaneous body size, or Kleiber ratio (ADG per unit of MWT; $r = -0.004$). Additionally, FCR was correlated ($P < 0.001$) with ADG ($r = -0.63$), partial efficiency growth ($r = -0.83$), relative growth rate ($r = -0.75$), and Kleiber ratio ($r = -0.73$), but not with

MWT (r = 0.07). The correlations of the measures of efficiency with ultrasound or carcass traits generally were not different from zero except for correlations of RFI, FCR, and PEG, respectively, with backfat gain (r = 0.30, 0.20, and −0.30), ultrasound backfat (r = 0.19, 0.21, and −0.25), grade fat determined at the 12$^{th}$ and 13$^{th}$ rib (r = 0.25, 0.19, and −0.27), lean meat yield (r = −0.22, −0.18, and 0.24), and yield grade (r = 0.28, 0.24, and −0.25). These phenotypic relationships indicate that, compared with other measures of energetic efficiency, RFI should have a greater potential to improve overall production efficiency and PEG above maintenance, and lead to minimal changes in carcass merit and body size (Nkrumah et al., 2004).

In an experiment conducted by Basarab et al. (2003), the relationships between RFI along with growth rate, body composition and heat production (HP) were determined in crossbred steers from the five BeefBooster strains (M1, M2, M3, M4 and TX). Residual feed intake differences were quantified independently of body compositions. Residual feed intake categories amongst the cattle were determined as High = > 0.5 SD above the mean; Medium = ± 0.5 SD above and below the mean; and Low = < 0.5 SD below the mean. There was a trend for low RFI steers to have less dissectible carcass fat (P = 0.08), intermuscular fat (P = 0.06), body cavity fat in the loin (P = 0.01), faster accretion rate of empty body water (P = 0.04) and a slower accretion rate of empty body fat (P < 0.01) than medium and high RFI steers (Basarab et al., 2003). A portion of the greater metabolizable energy intake by high RFI steer was accounted for by differences in the chemical composition of gain. However, a greater proportion was due to a disproportionate increase in the energy required for maintenance and heat increment of feeding in high RFI steers. An attempt should be made to adjust RFI for changes in the chemical composition of gain, possibly by the inclusion of ultrasound backfat thickness and marbling score into the equation for determining RFI (Basarab et al., 2003).

**Ultrasound and Carcass**

Because of the differences among animals in the composition of ADG and the differential energy demands of fat and protein gain (Berry and Crowley, 2013), it is now recommended to include (ultrasound measures of) fat and protein (gain) as regressor variables in the multiple regression model when calculating RFI (Baker et al., 2006; Basarab et al., 2011). This is particularly important because, all else being equal, animals depositing proportionally more protein than fat for the same ADG will, on average, be deemed more efficient, and if all animals are of similar age, then this may result in long-term selection for later maturing animals, which may have implications for the overall efficiency of the cow herd (Berry and Crowley, 2013).

Including ultrasound fat depth in a multiple regression model for RFI, alongside ADG and metabolic BW, explains only an additional 0% to 7% of the variation in DMI (Basarab et al., 2003, 2011; Baker et al., 2006; Crews et al., 2006; Durunna et al., 2011a, 2012). The inclusion of an additional adjustment for BF to calculate RFI based on backfat/production, which changes the definition of production from weight and weight gain to weight and weight gain adjusted to a similar end of test fatness, reduced the genetic correlation of residual feed intake with BF from 0.16 to essentially zero (–0.01) (Schenkel et al., 2007).

Lawrence et al. (2012), studied the phenotypic variation of RFI in pregnant beef heifers on a grass silage diet. Within the breed, heifers were ranked by RFI into low, medium, and high groups by dividing them into thirds. Based on the results reported, the RFI groups did not differ ($P > 0.05$) in ultrasound fat thickness, longissimus dorsi depth or visual muscular scores. At the end of the RFI measurement period, high RFI animals had lower ($P < 0.01$) body condition score (BCS) than medium and low RFI animals, but BCS change did not differ ($P > 0.05$) between the RFI groups. During the grazed herbage intake period, high RFI animals had lower ($P < 0.05$)

BCS than medium RFI animals, with low RFI animals being intermediate. At the end of the grazing season, medium RFI animals had greater ($P < 0.05$) BCS than high and low RFI animals, with no differences between RFI groups ($P > 0.05$) for skeletal measurements except for back length at the end of the RFI measurement period, which was shorter ($P < 0.05$) for high RFI than medium RFI animals, with low RFI animals being intermediate (Lawrence et al., 2012). This study suggests, that forage finished carcass ultrasound can also be used in RFI selection in the beef animal.

**Reproductive Performance**

Research on relationships of heifer RFI and reproductive performance is limited (Basarab et al., 2007). Reproductive performance is necessary in the breeding herd. Despite genetics, management of cows and replacement females is critical within the first year of breeding (Day, 2015). Heifer's ovulation from the first cycle to the third, suggests that conception rate of heifers increases by approximately 21% (Day, 2015; Byerley et al., 1987; Perry et al., 1991). Therefore age at which puberty occurs in addition to time of ovulation can potentially impact the time of conception in the first breeding season; which can continue to impact the heifer's lifetime of productivity (Day, 2015). Day (2015), also suggested that "heifers that calved first at 2 years of age would produce an average of 0.7 more calves than those calving first at 3 years of age by the time all cows were 6.5 years of age. The difference in profit at the end of 4 years was approximately $500/cow in 2013".

A prolonged calving season can result from reduced first service conception rate when selecting for efficiency (Donoghue et al., 2011). This decrease in early breeding season conception will result in a delay in calving that could negatively impact the reproductive efficiency of females for the remainder of their lives by delaying rebreeding in subsequent years

(Basarab et al., 2007). In a study measuring reproductive performance in cattle that had been selected into high and low phenotypic RFI groups, Donoghue et al. (2011) found that low RFI females had a delayed onset of puberty, lower backfat, and calved one week later than their high RFI contemporaries (35.7 days vs 27.6 days; $P < 0.05$). The results indicate that there is a delayed pregnancy date during the first mating season, but did not impact pregnancy and calving rates in low RFI heifers (Donoghue et al., 2011). This might be due to low RFI heifers with small amounts of subcutaneous fat leading to later onset of puberty.

Basarab et al. (2011) found that there was no difference in calving age between low RFI and high groups when accounting for adjusted 12$^{th}$ rib backfat in the regression equation to predict intake. By day 28 of the calving season, 95.0% of high RFI heifers had calved while only 82.6% of low RFI heifers had calved. This 12.6% difference in the percentage of cows calving early in the calving season between low and high RFI selected groups was completely removed when accounting for 12$^{th}$ rib backfat in the RFI calculation. This study suggests that predicted intake should be calculated using both midpoint metabolic body weight and ADG along with adjusted 12$^{th}$ rib backfat in order to prevent efficiency selection that may contribute to reduced pregnancy rates and a delayed age at calving (Basarab et al., 2011).

**Puberty in beef cattle**

Donoghue et al. (2011), studied RFI heifers that were the result of 1.0–2.5 generations of selection. Low and high RFI selection lines were based on post-weaning RFI of $-0.82 \pm 0.19$ kg/day and $0.57 \pm 0.18$ kg/day. Heifers that exhibited greater 12$^{th}$ rib fat (high RFI: 12.0 mm vs low RFI: 9.2 mm) tended to reach puberty earlier in life (Donoghue et al., 2011). Shaffer et al. (2011) found similar results when determining the relationships between RFI and growth rate, body composition, mature size, and fertility. In their study, heifers were housed in a dry lot facility during the experimental period, and data were collected over a 2-yr period (yr 1, n = 67; yr 2, n = 70). Individual feed intake, BW, BCS, hip height, and ultrasonic measurements [subcutaneous rib fat (UBF), rump fat (URF), LM area (LMA), and intramuscular fat (IMF)] of body composition were recorded. Individual feed intakes were used to calculate RFI combining both years of data. The results indicated that the high RFI heifers tended (*P* = 0.06) to reach puberty earlier in life than low RFI heifers (411 vs 425 d of age).

A possible explanation for the differences in age at puberty of heifers that were selected to differ in efficiency may be linked to the fat deposition of the pubertal heifers compared to non-pubertal heifers (Shaffer et al., 2011). Leptin production from additional adipose tissue present in heifers containing greater amounts of 12$^{th}$ rib backfat (Gentry Jr et al., 2013) may help contribute to the observed earlier onset of puberty. In regards to reproductive function, the regulators kisspeptin (KISS1) and its receptor (KISS1R), along with gonadoliberin (GnRH), gonadotropins (luteinizing hormone (LH) and follicle-stimulating hormone (FSH)), and sex steroid hormones can alter sexual maturation by mutations of their genes (Pankov, 2015). Leptin exerts a permissive effect in regulating fertility and facilitates the induction of puberty by hypothalamic KISS1 and GnRH and pituitary-derived LH and FSH, which support the reproductive function during further life (Pankov, 2015). The increased body fat may have resulted in more leptin production, signaling the body that there are sufficient body stores to initiate the onset of the reproductive cycle within the heifer (Gentry Jr et al., 2013). An increase in age of puberty or decrease in ovulatory activity would be expected in heifers that were not receiving adequate nutrition to meet their growth and maintenance requirements (Lents et al., 2011).

In previous studies conducted by Basarab et al. (2003) levels of fat deposition observed through divergent selection for efficiency could be related to the utilization of nutrients by the heifers. Basarab et al. (2011) analyzed RFI adjusted for off-test backfat thickness (RFIfat) and RFI adjusted for off-test backfat thickness in addition to feeding event frequency (RFIfat & activity) in relation to heifer fertility and productivity. Beef heifers in this study were grouped as either negative RFI (<0.0) or positive RFI (> 0.0). Heifer age (351 day, SD=43) and weight (367.3 kg, SD=45.0) at puberty were similar between groups, however age at puberty was delayed in low RFI heifers. Low RFI heifers, showed lower pregnancy percentages, (76.84 vs. 86.32%, P = 0.09) and calving rate (72.63 vs. 84.21%, P = 0.05) than their high RFI counterparts (Basarab et al., 2011).

No differences were observed between groups in calving difficulty, average calving date, and age at first calving, calf birth weight, calf pre-weaning ADG, calf weaning weight and heifer productivity (Barasab et al., 2011); indicating that selection for efficient heifers has no effect with calving performance. There was no variation of RFI adjusted for backfat thickness and feeding activity. Additionally, there was no effect of backfat thickness and feeding activity on fertility traits. This suggests that backfat thickness along with feeding activity may be associated with feed intake (Barasab et al., 2011). Similar to Donoghue et al. (2011), Barasab et al. (2011) found that the DMI of high RFI females contributes to increased fat deposition and an earlier age at puberty.

**Conclusion**

In the future of efficiency studies, there needs to be understanding of the selection using the RADG EPD in Angus cattle. The barriers in the adoption of efficiency measures in beef cattle breeding programs include the lack of accurate individual animal pasture intake measurement and the practical limitations, animal health concerns and cost associated with centralized feed efficiency testing (Arthur and Herd, 2005). However, RADG EPD calculation utilizes calf weaning weight, postweaning gain, ultrasound subcutaneous fat thickness, and genomic or actual dry-matter intake (Northcutt, 2010). The RADG EPD is a genetic value for an animal's average daily gain given a constant amount of feed in the postweaning period. It is expressed in pounds per day, therefore a higher value of RADG EPD is more favorable suggesting a more feed efficient (low RFI) animal and a lower value of RADG EPD predicts that an animal is not as feed efficient (high RFI). However, since the RADG EPD is a relatively new tool for potential genetic improvement in efficiency, investigation is needed to verify its potential and to determine the full utility of this EPD. Producers need the knowledge of how the RADG EPD is important in selection of replacement females and longevity of the breeding herd. Therefore, there needs to be more pressure in research for selection in high RADG heifers (low RFI) in regards to age at puberty. Based on RFI studies, the use of the RADG EPD can potentially be used as another measure of efficiency in steers. The future of this study may be based on genomic SNP data that can help improve selection of efficiency in beef cattle.

## Literature Cited


Anderson, R. V., Rasby, R. J., Klopfenstein, T. J., & Clark, R. T. (2005). An evaluation of production and economic efficiency of two beef systems from calving to slaughter. *J. Anim. Sci. 83*(3), 694-704.

Archer, J. A., Reverter, A., Herd, R. M., Johnston, D. J., & Arthur, P. F. (2002, August). Genetic variation in feed intake and efficiency of mature beef cows and relationships with postweaning measurements. In *Proc. 7th world congress on genet. App. Livest. Prod.* (Vol. 31, pp. 221-224).

Archer, J. A., P. F. Arthur, R. M. Herd, P. F. Parnell, and W. S. Pitchford. 1997. Optimum postweaning test for measurement of growth rate, feed intake, and feed efficiency in British breed cattle. *J. Anim. Sci.* 75: 2024-2032.

Archer, J. A., and L. Bergh. 2000. Duration of performance tests for growth rate, feed intake and feed efficiency in four biological types of beef cattle. *Livest. Prod. Sci.* 65: 47-55.

Archer, J. A., Richardson, E. C., Herd, R. M., & Arthur, P. F. (1999). Potential for selection to improve efficiency of feed use in beef cattle: a review. *Crop Pasture Sci. 50*(2), 147-162.

Arnold, J. W., Bertrand, J. K., Benyshek, L. L., & Ludwig, C. (1991). Estimates of genetic parameters for live animal ultrasound, actual carcass data, and growth traits in beef cattle. *J. Anim. Sci.* 69(3), 985-992.

Arthur, J. P. F., and R. M. Herd. 2008. Residual feed intake in beef cattle. *Rev. Brasileira de Zootecnia* 37: 269-279.

Arthur, P. F., and R. M. Herd. 2005. Efficiency of feed utilisation by livestock — Implications and benefits of genetic improvement. *Can. J. Anim. Sci.* 85: 281-290.

Arthur, P. F. et al. 2001. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. *J. Anim. Sci.* 79: 2805-2811.

Baker, S. D. et al. 2006. Residual feed intake of purebred Angus steers: Effects on meat quality and palatability. *J. Anim. Sci.* 84: 938-945.

Basarab, J. A., Price, M. A., Aalhus, J. L., Okine, E. K., Snelling, W. M., & Lyle, K. L. (2003). Residual feed intake and body composition in young growing cattle. *Can. J. Anim. Sci.* 83(2), 189-204.

Basarab, J. A., D. McCartney, E. K. Okine, and V. S. Baron. 2007. Relationships between progeny residual feed intake and dam productivity traits *Can. J. Anim. Sci.* 87: 489-502.

Berry, D. P., & Crowley, J. J. (2013). Cell biology symposium: genetics of feed efficiency in dairy and beef cattle. *J. Anim. Sci.* 91(4), 1594-1613.

Broadbent, P. J., McIntosh, J. A. R., & Spence, A. (1970). The evaluation of a device for feeding group-housed animals individually. *Anim. Prod. 12*(02), 245-252.

Capper, J. L. (2011). The environmental impact of beef production in the United States: 1977 compared with 2007. *J. Anim. Sci.* 89(12), 4249-4261.

Day, M. L. (2015, February). Nutritional Effects on Beef Heifer Development, Puberty and Subsequent Reproduction. In 2015 *Florida Ruminant Nutrition Symposium* (p. 69).

Donoghue, K. A., R. M. Herd, J. F. Wilkins, and P. F. Arthur. 2011. Onset of puberty and early-life reproduction in Angus females divergently selected for post-weaning residual feed intake [electronic resource]. *Anim. Prod. Sci.* 51: 183-190.

Durunna, O. N., Mujibi, F. D. N., Goonewardene, L., Okine, E. K., Basarab, J. A., Wang, Z., & Moore, S. S. (2011). Feed efficiency differences and reranking in beef steers fed grower and finisher diets. *J. Anim. Sci.* 89(1), 158-167.

Ferrell, C. L., and T. G. Jenkins. 1985. Cow type and the nutritional environment: nutritional aspects. *J. Anim. Sci.* 61: 725-741.

Ferrell, C. L., and T. G. Jenkins. 1998. Body composition and energy utilization by steers of diverse genotypes fed a high-concentrate diet during the finishing period: II. Angus, Boran, Brahman, Hereford, and Tuli sires. *J. Anim. Sci.* 76: 647-657.

Gentry Jr, G. T., L. R. Gentry, and R. A. Godke. 2013. The effect of exogenous follicle stimulating hormone (FSH) and endogenous plasma leptin concentrations on the pregnancy rate of beef heifers subjected to fixed-timed artificial insemination (FTAI). *Anim. Reprod. Sci*. 138: 49-54.

Hayes, B. J., Lewin, H. A., & Goddard, M. E. (2013). The future of livestock breeding: genomic selection for efficiency, reduced emissions intensity, and adaptation. *Trends. Genet.* 29(4), 206-214.

Herd, R. M., J. A. Archer, and P. F. Arthur. 2003. Reducing the cost of beef production through genetic improvement in residual feed intake: Opportunity and challenges to application. *J. Anim. Sci.* 81: E9-E17.

Herd, R. M., Arthur, P. F., Bottema, C. D. K., Egarr, A. R., Geesink, G. H., Lines, D. S., ... & Pitchford, W. S. (2014). Genetic divergence in residual feed intake affects growth, feed efficiency, carcass and meat quality characteristics of Angus steers in a large commercial feedlot. *Anim. Prod. Sci*.

Kelly, A. K., McGee, M., Crews, D. H., Sweeney, T., Boland, T. M., & Kenny, D. A. (2010). Repeatability of feed efficiency, carcass ultrasound, feeding behavior, and blood metabolic variables in finishing heifers divergently selected for residual feed intake. *J. Anim. Sci.*, 88(10), 3214-3225.

Kennedy, B. W., J. H. van der Werf, and T. H. Meuwissen. 1993. Genetic and statistical properties of residual feed intake. *J. Anim. Sci.* 71: 3239-3250.

Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of Feed Use in Beef Cattle1. *J. Anim. Sci*. 22: 486-494.

Kolath, W. H., Kerley, M. S., Golden, J. W., & Keisler, D. H. (2006). The relationship between mitochondrial function and residual feed intake in Angus steers. *J. Anim. Sci.* 84(4), 861-865.

Lancaster, P. A. et al. 2009. Phenotypic and genetic relationships of residual feed intake with performance and ultrasound carcass traits in Brangus heifers. *J. Anim. Sci.* 87: 3887-3896.

Lawrence, P., Kenny, D. A., Earley, B., & McGee, M. (2013). Intake of conserved and grazed grass and performance traits in beef suckler cows differing in phenotypic residual feed intake. *Livest. Sci.* 152(2), 154-166.

Lawrence, P., Kenny, D. A., Earley, B., & McGee, M. (2012). Grazed grass herbage intake and performance of beef heifers with predetermined phenotypic residual feed intake classification. *Anim.: Int. J. Anim. Biosci. 6*(10), 1648.

Lents, C. A., R. D. Randel, A. M. Stelzleni, L. C. Caldwell, and T. H. Welsh, Jr. 2011. Function of the corpus luteum in beef heifers is affected by acute submaintenance feeding but is not correlated with residual feed intake. *J. Anim. Sci.* 89: 4023-4031.

Montano-Bermudez, M., M. K. Nielsen, and G. H. Deutscher. 1990. Energy requirements for maintenance of crossbred beef cattle with different genetic potential for milk. *J. Anim. Sci.* 68: 2279-2288.

Nkrumah, J. D., Basarab, J. A., Price, M. A., Okine, E. K., Ammoura, A., Guercio, S., ... & Moore, S. S. (2004). Different measures of energetic efficiency and their phenotypic relationships with growth, feed intake, and ultrasound and carcass merit in hybrid cattle. *J. Anim. Sci. 82*(8), 2451-2459.

Nkrumah, J. D., Crews, D. H., Basarab, J. A., Price, M. A., Okine, E. K., Wang, Z., ... & Moore, S. S. (2007). Genetic and phenotypic relationships of feeding behavior and temperament with performance, feed efficiency, ultrasound, and carcass merit of beef cattle. *J. Anim. Sci.* 85(10), 2382-2390.

Northcutt, S. B., Bill. 2010. Angus feed efficiency selection tool: RADG ANGUS JOURNAL. p 2. Angus Productions, Inc, Saint Joseph, MO.

Parish, J. A., Rhinehart, J. D., & Smith, T. (2008). Expected progeny differences and selection indices for beef cattle selection.

Pullar, J. D., & Webster, A. J. F. (1977). The energy cost of fat and protein deposition in the rat. *Br. J. Nutrit. 37*(03), 355-363.

Pankov, Y. A. (2015). Kisspeptin and leptin in the regulation of fertility. *Molecular Biology*, *49*(5), 631-637.

Rolf, M. M., Taylor, J. F., Schnabel, R. D., McKay, S. D., McClure, M. C., Northcutt, S. L., ... & Weaber, R. L. (2010). Impact of reduced marker set estimation of genomic relationship matrices on genomic selection for feed efficiency in Angus cattle. *BMC Genet.* 11(1), 1.

Schenkel, F. S., Miller, S. P., & Wilton, J. W. (2004). Genetic parameters and breed differences for feed efficiency, growth, and body composition traits of young beef bulls. *Can. J. Anim. Sci.* 84(2), 177-186.

Shaffer, K. S., P. Turk, W. R. Wagner, and E. E. Felton. 2011. Residual feed intake, body composition, and fertility in yearling beef heifers. *J. Anim. Sci.*, 89: 1028-1034.

Stock, R. A. a. T. J. K. 1986. Calan gates for intake measurement Symposium on Feed Intake of Cattle. p 321-324.

Sherman, E. L., Nkrumah, J. D., & Moore, S. S. (2010). Whole genome single nucleotide polymorphism associations with feed intake and feed efficiency in beef cattle *J. Anim. Sci.*, 88(1), 16-22.

Tedeschi, L. O., D. G. Fox, M. J. Baker, and D. P. Kirschten. 2006. Identifying differences in feed efficiency among group-fed cattle. *J. Anim. Sci.* 84: 767-776.

Wang, Z. et al. 2006. Test duration for growth, feed intake, and feed efficiency in beef cattle using the GrowSafe System. *J. Anim. Sci.* 84: 2289-2298.

Zeng, Z., Tang, G., Ma, J., Plastow, G., Moore, S., Lai, S., & Wang, Z. (2012). Developing a genome-wide selection model for genetic improvement of residual feed intake and carcass merit in a beef cattle breeding program. *Chin. Sci. Bull.* 57(21), 2741-2746.

# CHAPTER 3

# THE IMPACT OF SELECTION USING RESIDUAL AVERAGE DAILY GAIN AND MARBLING EPDS ON GROWTH PERFORMANCE AND CARCASS TRAITS IN ANGUS STEERS[1]

[1] Detweiler, R.A., Wells, J.B., Stelzleni, A.M., Segers J.R., Pringle, T.D. To be submitted to *Journal of Animal Science*.

**Abstract**

One hundred ninety-one steers (Age= 1086.7 d ± 33.5, BW = 36.4 kg ± 4.2) over a 3-yr period, were used to compare growth performance, feed efficiency, body composition, and carcass characteristics from bulls divergently selected for feed efficiency. Angus sires were selected based on high (5$^{th}$ percentile or lower) and low (90$^{th}$ percentile or higher) residual average daily gain (RADG) EPDs and high (5$^{th}$ percentile of lower) and average (~ 50$^{th}$ percentile) marbling (MARB) EPDs. This resulted in a 2x2 factorial arrangement with four treatment combinations: high RADG, high MARB (Hi/Hi); high RADG, average MARB (Hi/Avg); low RADG, high MARB (Lo/Hi); and low RADG, average MARB (Lo/Avg). Steer weights and body composition, measured via ultrasound, were collected at weaning and yearling ages. Steers entered the feedlot at 454 days of age and were fed *ad libitum* for 2 wk prior to completing the 70-d GrowSafe™ Beef feed test. Weights were collected at the start, mid-point and end of test. The Growsafe™ Beef Feed test was used to determine DMI, ADG, and RFI, and then steers were slaughtered under federal inspection as they reached an approximate backfat of 1.3 cm. Carcasses were chilled for 48 h at 4°C, ribbed between the 12$^{th}$ and the 13$^{th}$ rib, and USDA yield grade and quality grade data were collected. The right side of the carcass was fabricated, and weights were collected on primal and subprimal cuts. A 2.5-cm longissimus steak was removed, vacuum-packaged, aged for 14 d, and frozen for slice shear force determination. Additionally, a 1.3-cm longissimus steak was removed from the year 3 steers for proximate composition determination. GLM procedures of SAS were used to analyze the data. The main effects of RADG and MARB and their interaction were tested by SIRE(RADG*MARB). Year was evaluated as a replicate in the model. Steer growth performance and ultrasound body composition for weaning and yearling was not significantly ($P \geq 0.30$) affected by RADG

selection, except for the Lo RADG steers having higher ($P \leq 0.02$) IMF values than the Hi RADG steers at both weaning and yearling times. For MARB selection, weaning weight, backfat and REA were higher ($P \leq 0.05$) in the Hi vs Avg MARB steers; however, no differences in weight or composition were noted at yearling. Feedlot gain, ADG, daily DMI and total DMI were not affected ($P > 0.20$) by selection using RADG or MARB EPDs. However, feed efficiency measured by RFI ($P = 0.05$) and trends were observed for Gain:Feed ($P = 0.11$) improvement in the Hi RADG steers compared to their Lo RADG counterparts. Selection using MARB EPDs did not significantly affect feed efficiency measures. Slaughter weight and hot carcass weight were heavier ($P \leq 0.03$) in the Hi vs Lo RADG groups; however, no other carcass traits were impacted ($P \geq 0.14$). Marbling score and adjusted 12$^{th}$ rib backfat tended ($P$ =0.10) to be higher in the Hi vs Avg MARB groups. An interaction ($P = 0.05$) between RADG and MARB selection was found for marbling score, with the LoHi steers having significantly higher marbling scores than all other groups which did not differ ($P > 0.05$) from each other. The distribution of quality grades across MARB groups found in this study revealed a higher percentage of low and average Prime carcasses in the Hi MARB and a higher percentage of low Choice in the Avg MARB groups. No major differences were observed across the RADG and MARB groups in primal and subprimal yields or meat tenderness. Longissimus proximate composition from year 3 steers showed that moisture was lower ($P = 0.03$) in Hi vs Avg MARB groups and lipid content was higher in the Hi MARB and Lo RADG groups compared to the Lo MARB and Hi RADG groups, respectively. These findings suggest that selection using RADG and MARB EPD has a minimal impact on carcass yield and that positive selection pressure using these genetic values can potentially improve efficiency and carcass quality, respectively.

Furthermore, it appears that improvements in efficiency can be attained without negatively impacting carcass merit, especially USDA quality grade.

**Introduction**

Approximately 65% of the total farm expenditures in beef cattle operations are associated with feed cost (Lancaster et al., 2009). Therefore, balancing output (growth) with input costs (feed) is needed in practicing selection (Rolf et al., 2011). Residual feed intake is a feed efficiency trait, which is independent of the component production traits, such as ADG, carcass merit, growth rates, and conformation or structural soundness. Residual feed intake is defined as the difference between actual and predicted intake at a constant level of growth (Berry and Crowley, 2013). Predicted intake of the individual animal is determined using the linear regression of midpoint metabolic body weight and average daily gain during a feed trial where individual animal's daily DMI is recorded over a defined time period (Koch et al., 1963). Residual feed intake offers the possibility to select on the portion of feed intake, which is not explained by the animal's requirements for maintenance and production (Arthur and Herd, 2005).

However, the main problem when attempting to select for efficiency is the lack of RFI data that is readily available for developing genetic values in beef cattle (Basarab et al., 2003). Unfortunately, this trait is relatively difficult and costly to measure because of the labor and expenses associated with feeding systems that measure individual intake (Herd and Arthur, 2008). The GrowSafe$^{TM}$ Beef system enables producers to more accurately measure feed intake in growing cattle through an electronic recording system that greatly reduces the time and money associated with recording feed intake (Wang et al., 2006). Increased use of this system (or similar feed intake measurement systems) should improve data availability for feed efficiency from test facilities across the country.

Until recently,, there was no genetic value available to beef producers to allow them to select for improved efficiency in their herds. However, the American Angus Association recently developed the Residual Average Daily Gain (RADG) expected progeny difference (EPD) in 2010. This new EPD incorporates calf weaning weight, postweaning gain, ultrasound subcutaneous fat thickness, and genomic dry-matter intake (Northcutt, 2010). The RADG EPD indicates the genetic value of an animal for the differences in average daily gain given a constant amount of feed in the postweaning period. It is expressed in pounds per day, therefore a higher value of RADG EPD is more favorable suggesting a more feed efficient (low RFI) animal and a lower value of RADG EPD predicts that an animal is not as feed efficient (high RFI). The objective of this study was to compare growth performance, carcass characteristics and feed efficiency in steers from Angus sires that were divergently selected, based on their RADG and marbling EPDs.

**Materials and Methods**

*Experimental Design*

For three years, commercial Angus cows from the Northwest Georgia Research and Education Center in Calhoun, GA have been assigned for breeding to Angus sires to determine the effect of selection using RADG and marbling (MARB) on growth, feed efficiency and carcass traits in Angus steers. Sires were selected to have either a high or low RADG EPD and within the RADG lines, half of the sires were selected to have high MARB EPDs while the remaining sires were selected to have near breed average MARB EPDs. This randomized complete block design resulted in a 2 x 2 factorial arrangement with RADG and MARB selection as the main effects.

*Sire Selection*

Bulls in this study were selected annually in January 2013, 2014 and 2015, from the American Angus Association's Sire Evaluation Report. At the time of selection, the high RADG bulls ranked in the top $5^{th}$ percentile (+0.29 or higher) and the low RADG bulls ranked in the $95^{th}$ percentile (+0.10 or lower) with accuracies of 0.40 or higher. Once the bulls were sorted into the RADG EPD lines, bulls, within a line, were then selected based on their MARB EPD. High MARB EPD bulls ranked in the $5^{th}$ percentile (+0.94 or higher) and average MARB EPD bulls ranked near the $50^{th}$ percentile (approx. +0.46). Bulls across the RADG EPD lines were also selected to be comparable in growth and carcass traits and to minimize the potential for inbreeding. Two bulls (one from each RADG EPD line) were used across subsequent years to assure connectivity of data collected across years and allow a more robust statistical inference. The two main sire selections created a 2 x 2 factorial design that contained two Angus sires in each of the following treatments: high RADG, high MARB (Hi/Hi); high RADG, average MARB (Hi/Avg) ; low RADG, high MARB (Lo/Hi); and low RADG, average MARB (Lo/Avg) for a total of eight bulls each breeding season in this experiment.

*Semen Procurement and Breeding*

After bulls were selected for the breeding season, the owners of the bulls were contacted and semen was procured. Next, the cows and heifers at the Northwest Georgia Research and Education Center were synchronized in March of 2013, 2014 and 2015. Cows and heifers followed the Select Synch + CIDR ® & TAI protocol. Annually, approximately 30 cows were bred to each bull.

*Calf Processing and Weaning*

All animals used in this study were humanely handled under the University of Georgia Animal Care and Use Committee guidelines (AUP #A2012 11- 006-R1). A total of 191 male calves were used in this study; year 1 (n=68) year 2 (n=63), year 3 (n=60). Each calving season, male calves were castrated via surgical castration, vaccinated with BoviShield Gold One Shot (Zoetis, Florham Park, NJ) and Ultra Choice 7 (Zoetis, Florham Park, NJ), then Dectomax (Zoetis, FlorhaM Park, NJ) pour-on was used for deworming. At weaning, weights were recorded and carcass ultrasound data were collected. Ribeye area, 12$^{th}$ rib backfat thickness, and intramuscular fat percentage were collected using an Aloka 500-V ultrasound unit with a 17.2 am, 3.5MHz linear probe (Corometrics Medical Systems, Wallingford, CT). Data collected was then interpreted using Beef Information Analysis Pro Plus software (Designer Genes USA, Harrison, AR). Steers from calving seasons were fence line weaned.

*Calf Backgrounding and Yearling*

Year one weaned calves were backgrounded on fescue (*Festuca arundinacea*) and annual ryegrass (*Lolium multiflorum*) pasture with Russell Bermudagrass (*Cynodon dactylon*) hay and baleage. Calves also received approximately 3.6 kg/hd/d of a coproduct-based supplement containing 50% corn gluten feed and 50% soybean hulls. Calves for years two and three, were shipped at weaning to Ridgefield Farm L.L.C. in Brasstown, North Carolina and backgrounded on a blended corn silage supplement containing soy hull pellets, minerals, dry distillers grain from late September until February. At approximately one year of age, BW was recorded and real-time carcass ultrasound data were collected. Ribeye area, 12$^{th}$ rib backfat thickness, and intramuscular fat percentage images were collected using an Aloka 500-V ultrasound unit with a 17.2 am, 3.5MHz linear probe (Corometrics Medical Systems, Wallingford, CT). Images were then interpreted using Beef Information Analysis Pro Plus software (Designer Genes USA, Harrison, AR).

*GrowSafe ™ Feed Trial*

After yearling ultrasound, year one steers were then shipped to Ridgefield Farm L.L.C. in Brasstown, North Carolina for finishing. Steers were allowed a 14 d acclimation period where they were given *ad libidum* access to a grain-based finishing diet (Table 3.1). Cattle were moved to the GrowSafe™ (GrowSafe Systems Ltd., Airdrie, Alberta, Canada) bunks and feed intake was measured over a 70-d period using the GrowSafe Beef™ system. Steer weights were collected at the beginning, midpoint, and end of the 70-d feed test. On test and off test weights were collected at the same time on two subsequent days and the average is reported to correct of differences in rumen fill. Ultrasound data were collected at the beginning and end of the 70-d feed test. A linear regression of midpoint metabolic body weight and average daily gain over the 70-d test was used to predict intake. Residual feed intake was then calculated by the following formula:

$$RFI = \text{Actual Intake} - \text{Predicted Intake}$$

*Harvest and Grading*

Steers were slaughtered at 1.3 cm of backfat. Steers were slaughtered at Waldrop's Meat Processing in Ellijay, GA, a USDA-inspected slaughter facility. Steers were held overnight at the plant with access to water and slaughtered the following morning under USDA inspection. Carcasses were held for 48 h at 2°C. For years 1 and 2, the right side of the carcasses were ribbed between the 12$^{th}$ and 13$^{th}$ ribs and USDA yield and quality data was collected by an experienced grader. For year 3, carcasses were cut into quarters between the 13$^{th}$ rib and 1$^{st}$ lumbar vertebrae, placed into gondolas and shipped immediately by refrigerated truck to

Nantahala Meats in Franklin, NC. Quarters were placed on the rail for 24 h and the forequarters were then ribbed between the $12^{th}$ and $13^{th}$ ribs and USDA quality and yield grade data were collected by the same experienced grader.

*Carcass Fabrication*

After grading, carcasses were fabricated into the following primals and subprimals and weights were recorded: brisket, shoulder clod, chuck roll, ribeye roll, mock tender, strip loin, tenderloin, top sirloin, knuckle, inside round, flat, eye of round, and flank steak. After weighing the strip loin, a 2.5-cm steak was removed from the anterior end, vacuum-packaged, aged, and frozen, after 14 d of aging, for slice shear force analysis.  For year 3 an additional 1.5-cm steak was removed, trimmed free of epimysium, vacuum-packaged and frozen for subsequent determination of proximate composition.

*Slice Shear Force Evaluation*

Steaks were removed from the packaging and a frozen weight was collected, then steaks were placed in the cooler to thaw at $2^{o}$ C overnight. The following morning, steaks were blotted dry and thawed weight was collected. Copper-constantan thermocouples attached to a potentiometer (Model No: 92000-00, Eutech Instruments Pte Ltd., Singapore) were placed in the approximate geometric center of the steak to record temperature. Steaks were then cooked on an electric grill (Model No: GR144, Salton Inc., Lake Forest, IL) until the internal temperature of $70^{o}$C was reached. Cooked weight was recorded, along with time to reach final temperature, and the final cook temperature. The procedure of Shackelford et al. (1997), was used to determine slice shear force for the cooked steaks. The lateral end of the steak was removed and the remaining steak was placed in a sizing box where a second parallel cut was made 5 cm from the initial cut. The 5 cm sample was then placed into a cutting box with two $45^{o}$ angled slots that line up with the muscle fiber orientation. A double bladed knife was then used to make two parallel cuts simultaneously across the sample in order to produce a 5-cm long and 1-cm thick slice that ran parallel to the muscle fibers. The sample was reoriented to collect an additional 5-cm x 1-cm slice. Samples were then placed on an Instron Universal Testing Machine 3365 (Instron Limited, High Wycombe, UK) and slice shear force was measured when a 1.02 mm thick blade, traveling 500 mm/min, sheared the slice perpendicular to the fiber orientation. The second sample was then sheared and slice shear force was averaged for the two slices.

*Proximate Analysis*

For proximate analysis, the 1.5-cm samples were thawed overnight at 2$^{o}$C, powder homogenized in liquid nitrogen, and the powdered samples were refrozen for subsequent analysis.

Crude protein was determined using a Nitrogen Analyzer (Model No: FP-628, LECO Corp., ST. Joseph, MI). Powdered samples were weighed and $N_2$ content was determined by combustion. Crude protein was calculated as the nitrogen % x 6.25.

For moisture and fat determination, a sample (approximately 2.0 g) was weighed and sealed in an ANKOM™ bag. Samples were placed in a drying oven (Model No: 1350 FM, Sheldon Manufacturing Co., Cornelius, OR) at 100$^{o}$C overnight, cooled in a desiccator for 10 minutes, and then weighed to determine moisture loss of the sample. Dried samples were then placed in the Crude Fat Extractor (Model No: ANKOM XT15, Ankom Technology, Fairport, NY). Following extraction, the samples were placed in a drying oven (Model No: 1350 FM, Sheldon Manufacturing Co., Cornelius, OR) at 100$^{o}$C for 15 min to remove any residual ether. Samples were then removed from the oven, cooled in the desiccator for 10 minutes, and weighed to determine the crude fat content of the samples.

*Statistical Analysis*

The experimental design for this study was a randomized complete block design that resulted in a replicated 2 x 2 factorial arrangement with the following two main effects: RADG line and MARB line. This resulted in four treatment combinations: high RADG, high MARB (Hi/Hi); high RADG, average MARB (Hi/Avg); low RADG, high MARB (Low/Hi); and low RADG, average MARB (Low/Avg). Data was analyzed using GLM procedures in SAS 9.4 (SAS Inst. Inc., Cary, NC). Sire was considered a random variable and SIRE(RADG*MARB) was used to test the main effects of RADG and MARB and their interaction. YEAR was analyzed as a replicate. Least squares means were calculated and separated using the LSD procedure of SAS 9.4 (SAS Ins t. Inc., Cary, NC).

**Results and Discussion**

Table 3.2 lists the EPD values for the sire treatment groups used in the study at the time of selection and as of March 2017. Steer age at weaning (WAGE) (Table 3.3) was not significantly affected by either RADG or MARB EPD selection *($P > 0.60$)*. Additionally, steer weaning weights (WW) were not different ($P = 0.78$) across RADG EPD groups; however, Hi MARB steers were heavier at weaning than their Avg MARB counterparts. None of the ultrasound compositional measures collected at weaning differed across RADG group, except for percentage IMF which was higher in the Lo RADG vs Hi RADG steers. This is likely due to the fact that 3 of the 4 bulls in the Lo/Hi category ranked in the first percentile of the Angus breed for marbling EPDs (Table 3.2). Weaning ultrasound BF and REA were higher ($P \leq 0.05$) in the Hi vs Avg MARB sires, while percentage IMF tended to be greater ($P = 0.07$). The fat and REA increases with MARB selection was again most likely due to minor differences in the genetic values for the Hi vs Avg MARB bulls (Table 3.2). Due to the low genetic correlations between marbling and BF and marbling and REA (www.angus.org) it would not seem logical to associate these differences with selection for increased marbling. Neither yearling weights nor compositional measures differed across RADG or MARB selection, except for the Lo RADG steers having greater (*P* = 0.01) percentage IMF compared to their Hi RADG counterparts.

Steers did not differ (*P* > 0.20) in starting or ending feedlot weight across either RADG or MARB group (Table 3.4). Gain did not differ (*P* > 0.70) between the RADG or MARB groups. Likewise, total DMI did not differ (*P* > 0.23) across either selection group. The lack of differences in gain and feed intake across the RADG and MARB groups would suggest that feed efficiency did not differ; however, RFI was significantly lower (*P* = 0.05) in the Hi RADG steers compared to their Lo RADG counterparts (Table 3.4). The difference between the Hi RADG and Lo RADG EPD is as follows: year one -0.24 to 0.28; year two -0.10 to 0.08 and year three -0.20 to 0.13, respectively (Figure 3.1). Similarly, G:F showed a tendency (*P* = 0.11) to be higher in the Hi RADG vs Lo RADG steers. The findings for RFI, weaning and yearling weights, gain, DMI, and ADG, concur with those of Koch et al. (1963) and Arthur et al. (2001) in that RFI measures appear to be independent of gain. Arthur et al. (2001), similarly found RFI and feed intake had a genetic correlation of 0.66 while ADG had a correlation of 0.04 suggesting that feed intake can be reduced without causing differences in ADG. A low genetic correlation indicates that one trait can be manipulated without affecting the other, therefore selection for feed intake appears to be independent of selection for ADG. This suggests that selection for the RADG EPD that incorporates genomic dry-matter intakte data or RFI can have a greater potential to improve overall production efficiency and growth above maintenance similar to RFI findings of Basarab et al. (2003).

Steer age at slaughter (SLAGE) (Table 3.5) was not significantly affected by the either RADG or MARB selection *(P > 0.40)*. Additionally, steer slaughter weights (SLWT) were not different (*P* = 0.46) across MARB groups; however, Hi RADG steers were heavier (*P* = 0.02) at slaughter than their Lo RADG counterparts were. Likewise, steer hot carcass weights were not different (*P* = 0.87) across MARB groups; but HCW (*P* =0.03) was higher in the Hi RADG vs Lo RADG steers. Even though there were significant differences in SLWT and HCW, this did not translate to differences (*P > 0.50*) in dressing percentage (DP) or yield grade (YG), across RADG and MARB selection. The dressing percent and YG results were expected due to the steers being slaughtered when they reached a back fat of 1.3 cm similar to findings of Schenkel et al. (2007). Other studies have reported decreased fat levels and increased muscling in steers phenotypically sorted into low RFI (Hi RADG) groups compared to high RFI (Lo RADG) steers (Behrens et al., 2011; Walter et al., 2011).

Marbling scores and adjusted 12$^{th}$ rib backfat tended to be higher (*P* = 0.10) in Hi MARB vs Avg MARB groups. There was also a significant interaction *(P=0.05)* between RADG and MARB for marbling score (Figure 3.2). The interaction resulted from the LoHi steers having higher marbling scores than all other treatment combinations, which did not differ (*P* > 0.05) from one another. This is most likely due to the fact that the average MARB EPD for the LoHi bulls ranked them in the top 1% of the Angus breed, compared to the 8$^{th}$, 37$^{th}$ and 41$^{st}$ percentile for the HiHi, HiAvg, and LoAvg sires, respectively. Additionally, there were several bulls in the HiHi group whose MARB EPDs decreased after selection, while several bulls in the HiAvg group had increases in their MARB EPDs after selection (Table 3.2; Figure 3.3). A number of studies have shown that selection using marbling EPDs in Angus cattle generally results in increased marbling scores in the selected progeny (Gwartney et al., 1993; Sapp et al., 2001).

Quality grade (QG) distribution for the Avg MARB group is as follows: high select - 2.2%, low choice - 18.5 %, average choice - 25%, high choice - 32.6%, low prime - 20.7%, and average prime - 1.1%. In contrast, the QG distribution for the Hi MARB group is as follows: high select - 3%, low choice - 6%, average choice - 22.2%, high choice - 31.3%, low prime - 25.3% and average prime - 12.1% (Figure 3.4). The major differences in the distributions of QG across MARB groups was that the Avg MARB group had higher percentages of Low Choice carcasses, while the Hi MARB group had higher percentages of Low and Average Prime carcasses. Over the course of this study, the numbers for low prime and average prime carcasses have increased in both Avg MARB and Hi MARB selection (Figure 3.4, 3.5, 3.6, 3.7). Marbling is considered to be a moderately heritable trait with heritability values of 0.35 (Arnold et al., 1991).

Hot side weights (HSW) tended to be heavier ($P$=0.08) in Hi RADG versus Lo RADG carcasses, due to difference in SLWT and HCW due to increase on time on feed. There was no RADG EPD selection ($P > 0.14$) impact on carcass subprimal weights (Table 3.6) with the exception of the mock tender (MT) ($P = 0.01$) and flat (F) ($P=0.01$), where Hi RADG groups had heavier weights than Lo RADG groups. When primal yields (as a percent of hot side weight) were assessed, MT and F yields were also significantly higher for the Hi vs Lo RADG groups (Table 3.7). The significance between MT and F between RADG selections has not been found among other studies. This could be due to fabrication variation between the changes in employee training of fabricating beef carcasses.

Weights (frozen, thawed, cooked) of the 2.54-cm thick steaks used for slice shear force determination did not differ ($P > 0.62$) across either RADG or MARB group (Table 3.8). There was no significant interaction ($P > 0.17$) for cook loss (CLOSS) and total loss (TLOSS), however loss was greater in Lo RADG vs. Hi RADG (Table 3.8). Slice shear force was not affected ($P > 0.45$) by RADG or MARB selection, indicating that selection for either efficiency or marbling has minimal impacts on meat tenderness.

Proximate composition of the longissimus was only determined in year 3 steers (Table 3.9). Crude protein percentage did not differ ($P > 0.35$) across either RADG or MARB groups. However, lipid percentage was greater ($P = 0.01$) in the Lo RADG and Hi MARB compared to the Hi RADG and Lo MARB groups, respectively. These findings are consistent with the differences noted in marbling score across the RADG and MARB groups

Some of the unexpected findings in this project may be due to changes in the genetic values (EPDs) of the sires as greater amounts of information were collected and evaluated (Figure 3.8). At the time of sire selection, the bulls used in this study ranked in the 5$^{th}$ percentile (+0.29 and higher) and 95th percentile (+0.10 and lower) for RADG EPD, with accuracies of 0.40 or higher. Over the last three years, the number of calves with feed intake data submitted to the American Angus Association has increased resulting in more accurate descriptions of the bull's genetic values. For example, the RADG EPD's of two high RADG sires used in year one of the study have fallen to +0.26 and +0.28, which places them in the 15th percentile of the breed. Similarly, RADG EPDs for two of the low RADG sires have increased to +0.16 and +0.14, placing them in the 70th percentile. In spite of the fact that the selection pressure applied to RADG in this study was not as great as originally thought, there was still a significant improvement in RFI after only 3 years of selection. Figure 3.1 shows the residual feed intake distribution in steers for RADG EPD selection. Across the study, the variation between Hi RADG and Lo RADG EPDs suggests that there has been an improvement in Lo RADG compared to Hi RADG. Studies have indicated, five generations of selection was required to see significant differences in RFI when using RFI phenotype (Low vs High RADG) as the selection criteria (Donohue et al., 2011). It is important to note that feed efficiency is only moderately heritable ($h^2 = 0.36$) in British breeds of cattle, so divergent selection resulting in significant changes in efficiency would not be expected in a single generation (Herd et al., 2003).

**Implications**

The RFI observed from the 191 steers in this study was significant in regards to RADG EPD selection. In an Australian study that focused on selection for efficiency in Angus cattle, divergent efficiency lines were created using phenotypic RFI values (Donoghue et al., 2011). The phenotypic selection used in their study required five generations of selection for a clear divergence in RFI to be observed. This three year study validates the potential for the RADG EPD to be used as a selection tool to improve feed efficiency. Parish et al. (2011) suggested the need for a reliable selection tool that incorporated weaning weight, postweaning gain, ultrasound subcutaneous fat thickness, and dry-matter intake of not only the individual sire, but also his relatives and progeny. The RADG EPD appears to meet these criteria and can offer producers the potential to improve feed efficiency without negatively impacting growth or carcass merit.

From an economic standpoint, actual intake of low RADG selected steers was 0.39 kg/d higher than high RADG while on test (Table 3.4). This observed difference in intake resulted in a $0.10/d difference in cost of feed consumed totaling a value of $7.00 over the 70-d feed trial. Continued selection pressure on this trait may result in significant improvement in efficiency and enhance the understanding of the biological and physiological basis of efficiency in beef cattle. Overall, the results from this study are significant in that selection for efficiency using RADG EPD does not affect carcass quality or cutability.

## Literature Cited

Arnold, J. W., Bertrand, J. K., Benyshek, L. L., & Ludwig, C. (1991). Estimates of genetic parameters for live animal ultrasound, actual carcass data, and growth traits in beef cattle. *J. Anim. Sci.* 69(3), 985-992.

Arthur, J. P. F., and R. M. Herd. 2008. Residual feed intake in beef cattle. *Rev. Brasileira de Zootecnia* 37: 269-279.

Arthur, P. F., and R. M. Herd. 2005. Efficiency of feed utilisation by livestock — Implications and benefits of genetic improvement. *Can. J. Anim. Sci.* 85: 281-290.

Arthur, P. F. et al. 2001. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. *J. Anim. Sci.* 79: 2805-2811.

Basarab, J. A., Price, M. A., Aalhus, J. L., Okine, E. K., Snelling, W. M., & Lyle, K. L. (2003). Residual feed intake and body composition in young growing cattle. *Can. J. Anim. Sci.* 83(2), 189-204.

Basarab, J. A., D. McCartney, E. K. Okine, and V. S. Baron. 2007. Relationships between progeny residual feed intake and dam productivity traits. *Can. J. Anim. Sci.* 87: 489-502.

Berry, D. P., & Crowley, J. J. (2013). Cell biology symposium: genetics of feed efficiency in dairy and beef cattle. *J. Anim. Sci.* 91(4), 1594-1613.

Day, M. L. (2015, February). Nutritional Effects on Beef Heifer Development, Puberty and Subsequent Reproduction. In *2015 Florida Ruminant Nutrition Symposium* (p. 69).

Donoghue, K. A., R. M. Herd, J. F. Wilkins, and P. F. Arthur. 2011. Onset of puberty and early-life reproduction in Angus females divergently selected for post-weaning residual feed intake [electronic resource]. *Anim. Prod. Sci.* 51: 183-190.

Herd, R. M., J. A. Archer, and P. F. Arthur. 2003. Reducing the cost of beef production through genetic improvement in residual feed intake: Opportunity and challenges to application. *J. Anim. Sci.*81: E9-E17.

Herd, R. M., Arthur, P. F., Bottema, C. D. K., Egarr, A. R., Geesink, G. H., Lines, D. S., ... & Pitchford, W. S. (2014). Genetic divergence in residual feed intake affects growth, feed efficiency, carcass and meat quality characteristics of Angus steers in a large commercial feedlot. *Anim. Prod. Sci.*

Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of Feed Use in Beef Cattle1. *J. Anim. Sci*. 22: 486-494.

Lancaster, P. A. et al. 2009. Phenotypic and genetic relationships of residual feed intake with performance and ultrasound carcass traits in Brangus heifers. *J. Anim. Sci.*87: 3887-3896.

Northcutt, S. B., Bill. 2010. Angus feed efficiency selection tool: RADG ANGUS JOURNAL. p 2. Angus Productions, Inc, Saint Joseph, MO.

Parish, J. A., Rhinehart, J. D., & Smith, T. (2008). Expected progeny differences and selection indices for beef cattle selection.

Rolf, M. M., Taylor, J. F., Schnabel, R. D., McKay, S. D., McClure, M. C., Northcutt, S. L., ... & Weaber, R. L. (2010). Impact of reduced marker set estimation of genomic relationship matrices on genomic selection for feed efficiency in Angus cattle. *BMC Genet*. 11(1), 1.

Schenkel, F. S., Miller, S. P., & Wilton, J. W. (2004). Genetic parameters and breed differences for feed efficiency, growth, and body composition traits of young beef bulls. *Can. J. Anim. Sci.* 84(2), 177-186.

Sherman, E. L., Nkrumah, J. D., & Moore, S. S. (2010). Whole genome single nucleotide polymorphism associations with feed intake and feed efficiency in beef cattle *J. Anim. Sci.* 88(1), 16-22.

Tedeschi, L. O., D. G. Fox, M. J. Baker, and D. P. Kirschten. 2006. Identifying differences in feed efficiency among group-fed cattle. *J. Anim. Sci.* 84: 767-776.

Wang, Z. et al. 2006. Test duration for growth, feed intake, and feed efficiency in beef cattle using the GrowSafe System. *J. Anim. Sci.* 84: 2289-2298.

Zeng, Z., Tang, G., Ma, J., Plastow, G., Moore, S., Lai, S., & Wang, Z. (2012). Developing a genome-wide selection model for genetic improvement of residual feed intake and carcass merit in a beef cattle breeding program. *Chin. Sci. Bull.* 57(21), 2741-2746.

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**Table 3.1 Composition and calculated nutrient content of the diet**

| Ingredients | % As-Fed Basis |
|---|---|
| Corn Silage | 25.0 |
| Corn | 37.9 |
| Soy Hull Pellets | 6.5 |
| Dry Distillers Grain | 27.0 |
| Beef Grower | 1.8 |
| | |
| Nutrient | Calculated Analysis Dry Matter Basis |
| Crude Protein, % (CP) | 17.49 |
| Fat, % (F) | 5.89 |
| Neutral Detergent Fiber, % (NDF) | 25.01 |
| Total Digestible Nutrients, % (TDN) | 81.16 |
| Net Energy Maintenance (Mcal/kg) | 1.98 |
| Net Energy Gain (Mcal/kg) | 1.33 |
| Calcium, % (Ca) | 0.81 |
| Phosphorous, % (P) | 0.52 |

**Table 3.2 Average EPDs, by selection group, of Angus bulls used in the study**

| Name | TRT* | BW** | WW** | YW** | RADG** | CW** | Marb** | REA** | Fat** |
|---|---|---|---|---|---|---|---|---|---|
| Current | HH | 0.63 | 52.7 | 102.7 | 0.29 | 37.2 | 0.93 | 0.67 | -0.03 |
| | LH | 1 | 50 | 88.5 | 0.15 | 22.5 | 1.4 | 0.45 | 0.007 |
| | HA | 1.5 | 54.7 | 97.7 | 0.31 | 46.2 | 0.57 | 0.72 | -0.06 |
| | LA | 1.1 | 57.5 | 95.8 | 0.13 | 39.2 | 0.54 | 0.59 | 0.012 |
| At Selection | HH | 0.97 | 57.3 | 115.7 | 0.29 | 40 | 1 | 0.8 | 0.009 |
| | LH | 1.5 | 56.7 | 100 | 0.06 | 22.7 | 1.3 | 0.71 | 0.01 |
| | HA | 1.9 | 61.2 | 110 | 0.27 | 37.8 | 0.51 | 0.62 | -0.02 |
| | LA | 1.5 | 62.7 | 105 | 0.06 | 28 | 0.44 | 0.62 | 0.005 |

*Sire selection: TRT= treatment groups; HH= HI RADG/ HI MARB; LH= Lo RADG/ HI MARB; HA= HI RADG/ Avg MARB; LA= Lo RADG/ Avg MARB.

**Sire EPD averages: BW= birthweight; WW= weaning weight; YW= yearling weight; RADG= residual average daily gain; CW= carcass weight; Marb= marbling; REA= ribeye area; Fat= 12$^{th}$ rib back fat.

**Table 3.3 Effect of selection using residual average daily gain (RADG) and marbling (MARB) EPDs on growth performance and ultrasound body composition of Angus steers**

| | RADG EPD | | | MARB EPD | | | RADG*MARB |
|---|---|---|---|---|---|---|---|
| **Trait** | **High** | **Low** | **P-value** | **High** | **Avg** | **P-value** | **P-value** |
| Weaning age, day (WAGE) | 228.7 | 228.8 | 0.96 | 228.2 | 229.3 | 0.66 | 0.40 |
| Weaning weight, kg (WW) | 276.6 | 277.6 | 0.78 | 281.8 | 272.4 | 0.02* | 0.21 |
| Weaning fat, cm (WFT) | 0.38 | 0.41 | 0.31 | 0.42 | 0.36 | 0.05* | 0.92 |
| Weaning ribeye area, $cm^2$ (WREA) | 52.3 | 52.0 | 0.79 | 53.9 | 50.3 | 0.01* | 0.07 |
| Weaning IMF, % (WIMF) | 3.8 | 4.2 | 0.02* | 4.1 | 3.9 | 0.07 | 0.13 |
| Yearling age, day (YAGE) | 365.1 | 365.2 | 0.96 | 364.5 | 365.6 | 0.66 | 0.40 |
| Yearling weight, kg (YWT) | 414.2 | 408.2 | 0.35 | 413.3 | 409.1 | 0.51 | 0.22 |
| Yearling fat, cm (YFT) | 0.54 | 0.57 | 0.31 | 0.57 | 0.54 | 0.39 | 0.75 |
| Yearling ribeye area, $cm^2$ (YREA) | 61.8 | 60.7 | 0.30 | 62.2 | 60.3 | 0.07 | 0.19 |
| Yearling IMF, % (YIMF) | 5.4 | 6.3 | 0.01* | 6.1 | 5.7 | 0.29 | 0.93 |

* Level of Significance indicated as $P < 0.05$

**Table 3.4 Effect of selection using residual average daily gain (RADG) and marbling (MARB) EPDs on feedlot performance, feed intake and feed efficiency of Angus steers**

| | RADG EPD | | | MARB EPD | | | RADG*MARB |
|---|---|---|---|---|---|---|---|
| **Trait** | **High** | **Low** | **P-value** | **High** | **Avg** | **P-value** | **P-value** |
| Start weight, kg (STWT) | 401.5 | 392.8 | 0.22 | 396.8 | 397.4 | 0.93 | 0.70 |
| End weight, kg (ENDWT) | 552.9 | 542.6 | 0.28 | 547.9 | 547.6 | 0.98 | 0.67 |
| Total gain, kg (TOTGAIN) | 151.4 | 149.7 | 0.68 | 151.0 | 150.2 | 0.84 | 0.72 |
| Average Daily Gain, kg/day (ADG) | 1.9 | 1.9 | 0.75 | 1.9 | 1.9 | 0.80 | 0.70 |
| Total intake, kg (TOTINT) | 1223.7 | 1262.1 | 0.22 | 1229.5 | 1256.3 | 0.39 | 0.30 |
| Total DMI, kg (TDMI) | 897.8 | 925.2 | 0.23 | 901.9 | 921.1 | 0.39 | 0.33 |
| Average intake, kg (AVGINT) | 17.3 | 17.8 | 0.22 | 17.4 | 17.8 | 0.39 | 0.37 |
| Average DMI, kg (AVGDMI) | 12.7 | 13.1 | 0.23 | 12.8 | 13.1 | 0.39 | 0.40 |
| RFI, kg | -0.27 | 0.27 | 0.05* | -0.13 | 0.13 | 0.30 | 0.28 |
| Feed:Gain, kg:kg (F:G) | 9.2 | 9.6 | 0.40 | 9.3 | 9.5 | 0.48 | 0.45 |
| DMFeed:Gain, kg:kg (DMF:G) | 6.9 | 7.1 | 0.42 | 6.9 | 7.1 | 0.49 | 0.48 |
| Gain:Feed, kg:kg (G:F) | 0.12 | 0.11 | 0.12 | 0.12 | 0.11 | 0.23 | 0.12 |
| DMGain:Feed, kg:kg (DMG:F) | 0.17 | 0.16 | 0.11 | 0.17 | 0.16 | 0.24 | 0.11 |

* Level of Significance indicated as $P < 0.05$

**Table 3.5 Effect of selection using residual average daily gain (RADG) and marbling (MARB) EPDs on carcass traits of Angus steers**

| | RADG EPD | | | MARB EPD | | | RADG*MARB |
|---|---|---|---|---|---|---|---|
| **Trait** | **High** | **Low** | **P-value** | **High** | **Avg** | **P-value** | **P-value** |
| Slaughter age, day (SLAGE) | 547.8 | 542.4 | 0.46 | 542.5 | 547.7 | 0.47 | 0.88 |
| Slaughter weight, kg (SLWT) | 592.4 | 573.9 | 0.02*** | 580.5 | 585.7 | 0.46 | 0.58 |
| Hot carcass weight, kg (HCW) | 367.5 | 356.5 | 0.03*** | 361.7 | 362.4 | 0.87 | 0.86 |
| Dressing percent, % (DP) | 62.2 | 62.3 | 0.89 | 62.5 | 62.1 | 0.51 | 0.67 |
| 12th Rib fat, cm (12RF) | 1.1 | 1.2 | 0.34 | 1.2 | 1.1 | 0.22 | 0.12 |
| Adj. 12th Rib fat, cm (ADJ12RF) | 1.1 | 1.2 | 0.62 | 1.2 | 1.1 | 0.10 | 0.80 |
| Ribeye area, $cm^2$ (REA) | 78.6 | 77.1 | 0.30 | 78.2 | 77.4 | 0.56 | 0.27 |
| KPH, % | 2.1 | 2.0 | 0.57 | 2.1 | 2.0 | 0.355 | 0.17 |
| Yield Grade | 3.2 | 3.2 | 0.86 | 3.2 | 3.2 | 0.58 | 0.19 |
| Bone Maturity | 142.4 | 143.2 | 0.68 | 142.1 | 143.5 | 0.45 | 0.58 |
| Lean Maturity* | 147.9 | 147.9 | 0.99 | 147.8 | 148.1 | 0.91 | 0.64 |
| Marbling Score** | 596.8 | 631.0 | 0.14 | 632.2 | 595.6 | 0.10 | 0.05*** |

*Lean Maturity 100 = A Maturity.
**Marbling Score 500 = Modest, 600= Moderate.
***Level of Significance indicated as $P < 0.05$

**Table 3.6 Effect of selection using residual average daily gain (RADG) and marbling (MARB) EPDs on carcass primal and subprimal weights (kg) of Angus steers**

| | RADG EPD | | | MARB EPD | | | RADG*MARB |
|---|---|---|---|---|---|---|---|
| Trait | High | Low | P-value | High | Avg | P-value | P-value |
| Hot Side Weight (HSW) | 182.6 | 178.1 | 0.08 | 180.7 | 180.1 | 0.78 | 0.49 |
| Shoulder Clod (SC) | 9.8 | 9.6 | 0.14 | 9.8 | 9.6 | 0.33 | 0.60 |
| Chuck Roll (CR) | 9.3 | 9.3 | 0.90 | 9.3 | 9.2 | 0.76 | 0.81 |
| Mock Tender (M) | 1.2 | 1.1 | 0.01* | 1.1 | 1.1 | 0.74 | 0.25 |
| Brisket (B) | 5.4 | 5.3 | 0.34 | 5.4 | 5.2 | 0.20 | 0.57 |
| Ribeye Roll (RR) | 5.0 | 4.9 | 0.59 | 5.0 | 5.0 | 0.61 | 0.62 |
| Tenderloin (T) | 1.8 | 1.8 | 0.21 | 1.8 | 1.8 | 0.85 | 0.83 |
| Strip loin (SL) | 3.9 | 3.9 | 0.66 | 3.9 | 3.9 | 0.92 | 0.37 |
| Top Sirloin (TS) | 4.8 | 4.6 | 0.15 | 4.6 | 4.7 | 0.45 | 0.78 |
| Knuckle (K) | 4.1 | 4.2 | 0.80 | 4.2 | 4.1 | 0.55 | 0.67 |
| Inside Round (IR) | 6.7 | 6.4 | 0.10 | 6.5 | 6.6 | 0.68 | 0.81 |
| Flat (F) | 5.1 | 4.8 | 0.01* | 4.9 | 4.9 | 0.57 | 0.33 |
| Eye Round (ER) | 1.7 | 1.6 | 0.46 | 1.7 | 1.6 | 0.86 | 0.76 |
| Flank Steak (FS) | 0.7 | 0.7 | 0.21 | 0.7 | 0.7 | 0.78 | 0.38 |

* Level of Significance indicated as $P < 0.05$

**Table 3.7 Effect of selection using residual average daily gain (RADG) and marbling (MARB) EPDs on primal and subprimal yields as a percentage (%) of hot side weight in Angus steers**

| | RADG EPD | | | MARB EPD | | | RADG*MARB |
|---|---|---|---|---|---|---|---|
| **Trait** | **High** | **Low** | **P-value** | **High** | **Avg** | **P-value** | **P-value** |
| Shoulder Clod (SC) | 5.4 | 5.4 | 0.79 | 5.4 | 5.3 | 0.30 | 0.96 |
| Chuck Roll (CR) | 5.1 | 5.2 | 0.23 | 5.2 | 5.1 | 0.85 | 0.85 |
| Mock Tender (M) | 0.66 | 0.62 | 0.02* | 0.64 | 0.64 | 0.81 | 0.31 |
| Brisket (B) | 2.9 | 2.9 | 0.83 | 3.0 | 2.9 | 0.18 | 0.80 |
| Ribeye Roll (RR) | 2.7 | 2.8 | 0.77 | 2.8 | 2.7 | 0.61 | 0.80 |
| Tenderloin (T) | 1.0 | 1.0 | 0.99 | 1.0 | 1.0 | 0.87 | 0.92 |
| Strip loin (SL) | 2.1 | 2.2 | 0.26 | 2.1 | 2.1 | 0.84 | 0.52 |
| Top Sirloin (TS) | 2.6 | 2.6 | 0.43 | 2.5 | 2.6 | 0.19 | 0.41 |
| Knuckle (K) | 2.2 | 2.3 | 0.24 | 2.3 | 2.3 | 0.60 | 0.44 |
| Inside Round (IR) | 3.7 | 3.6 | 0.26 | 3.6 | 3.7 | 0.45 | 0.51 |
| Flat (F) | 2.7 | 2.6 | 0.01* | 2.7 | 2.7 | 0.14 | 0.23 |
| Eye Round (ER) | 0.93 | 0.94 | 0.66 | 0.94 | 0.94 | 0.95 | 0.91 |
| Flank Steak (FS) | 0.42 | 0.41 | 0.64 | 0.42 | 0.42 | 0.87 | 0.46 |

* Level of Significance indicated as $P < 0.05$

**Table 3.8 Effect of selection using residual average daily gain (RADG) and marbling (MARB) EPDs on cooking characteristics and slice shear force of strip steaks from Angus steers**

| | RADG EPD | | | MARB EPD | | | RADG*MARB |
|---|---|---|---|---|---|---|---|
| **Trait** | **High** | **Low** | **P-value** | **High** | **Avg** | **P-value** | **P-value** |
| Frozen Weight, g (FWT) | 328.1 | 316.5 | 0.15 | 321.1 | 323.5 | 0.74 | 0.62 |
| Thaw Weight, g (THWT) | 320.9 | 309.9 | 0.17 | 314.1 | 316.7 | 0.72 | 0.73 |
| Initial Temperature, C$^{o}$ (IT) | 7.5 | 7.8 | 0.34 | 7.7 | 7.6 | 0.68 | 0.49 |
| Cook Weight, g (CWT) | 267.7 | 253.5 | 0.06 | 258.1 | 263.1 | 0.49 | 0.44 |
| Cook Time, min (CTIME) | 11.4 | 11.7 | 0.31 | 11.6 | 11.4 | 0.52 | 0.16 |
| Thaw Loss, % (TLOSS) | 2.2 | 2.1 | 0.70 | 2.3 | 2.1 | 0.82 | 0.06 |
| Cook Loss, % (CLOSS) | 16.4 | 18.1 | 0.02** | 17.7 | 16.8 | 0.19 | 0.17 |
| Total Loss, % (TLOSS) | 18.2 | 19.8 | 0.03** | 19.5 | 18.6 | 0.18 | 0.34 |
| Visual Score* (VS) | 4.1 | 4.2 | 0.36 | 4.3 | 4.1 | 0.12 | 0.50 |
| Slice Shear Force, kg (SF) | 17.9 | 17.7 | 0.69 | 18.0 | 17.6 | 0.46 | 0.63 |

*Visual Score, 1-6, 1= very raw, 6= very well done
** Level of Significance indicated as $P < 0.05$

**Table 3.9 Effect of selection using residual average daily gain (RADG) and marbling (MARB) EPDs on proximate analysis of Angus steers for Year 3**

| | RADG EPD | | | MARB EPD | | | RADG*MARB |
|---|---|---|---|---|---|---|---|
| **Trait** | **High** | **Low** | **P-value** | **High** | **Avg** | **P-value** | **P-value** |
| Moisture, % | 68.3 | 67.1 | 0.10 | 68.4 | 67.0 | 0.03 | 0.95 |
| Lipid, % | 6.6 | 8.7 | 0.01* | 8.6 | 6.8 | 0.01 | 0.83 |
| Crude Protein, % | 21.6 | 21.2 | 0.37 | 21.6 | 21.2 | 0.46 | 0.20 |

* Level of Significance indicated as $P < 0.05$

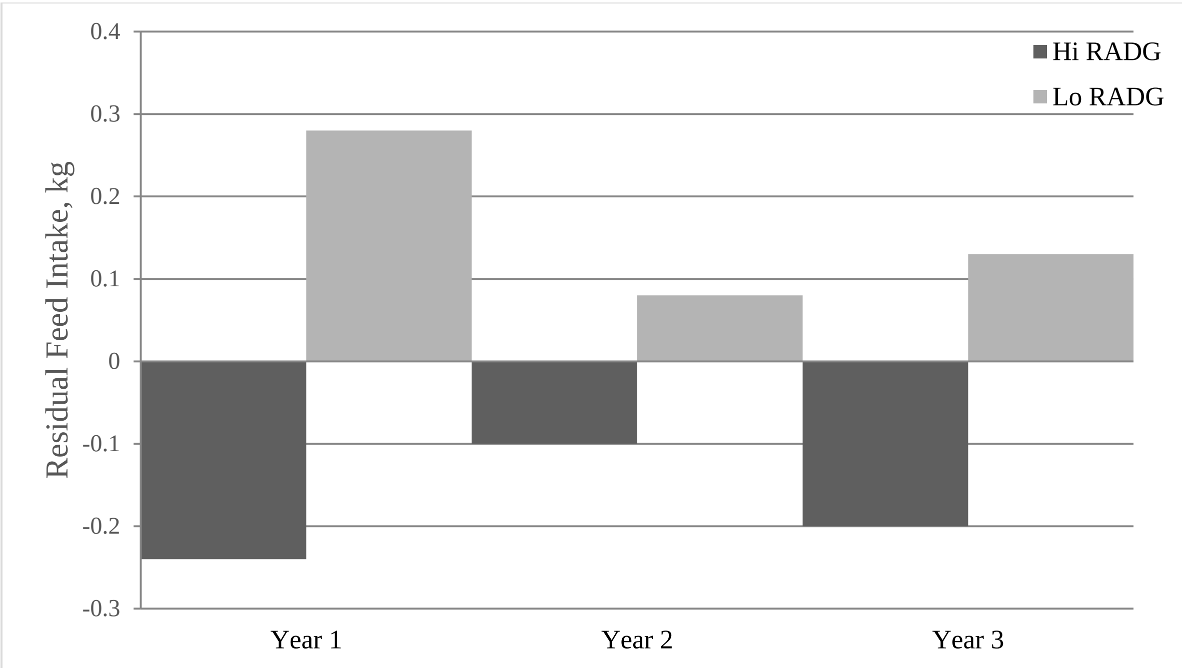


**Figure 3.1 Residual Feed intake distribution in steers for Hi and Lo RADG EPD across Year**

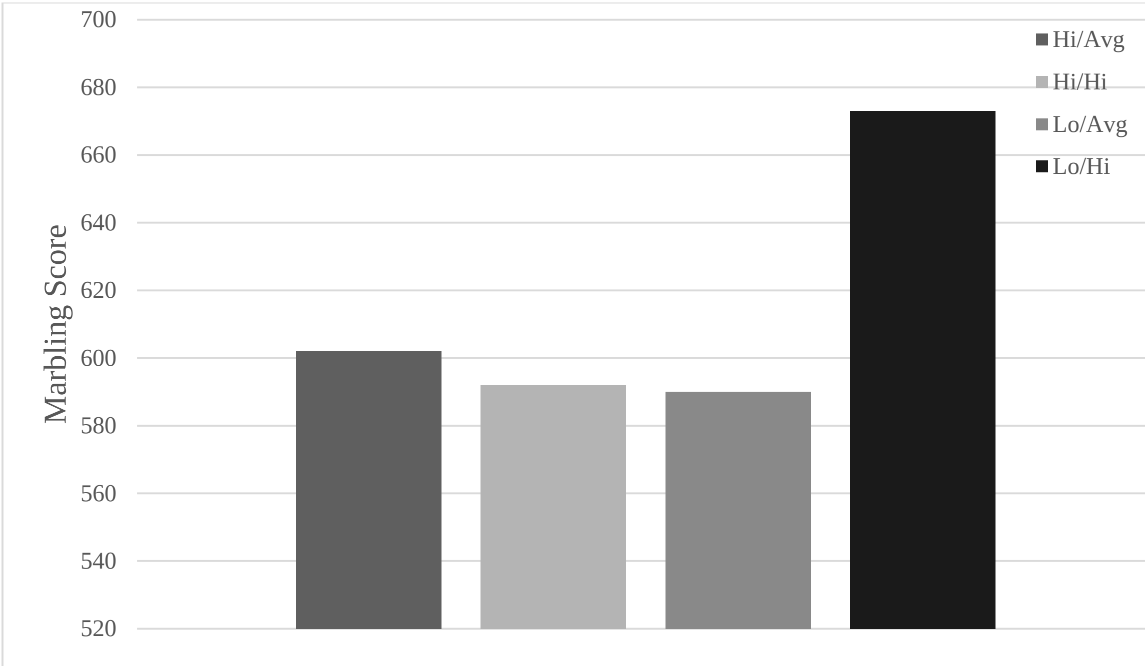

**Figure 3.2 Marbling score in steers for Hi and Avg Marbling EDP**

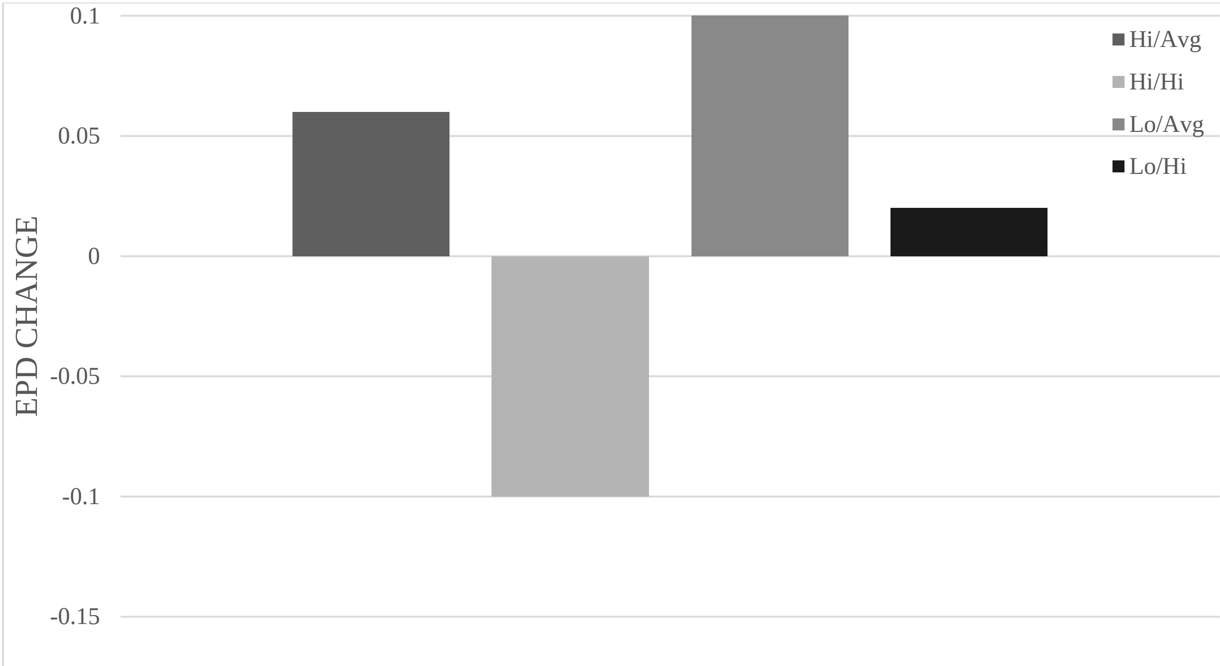


**Figure 3.3 MARB EPD change in steers for Hi and Avg Marbling EDP**

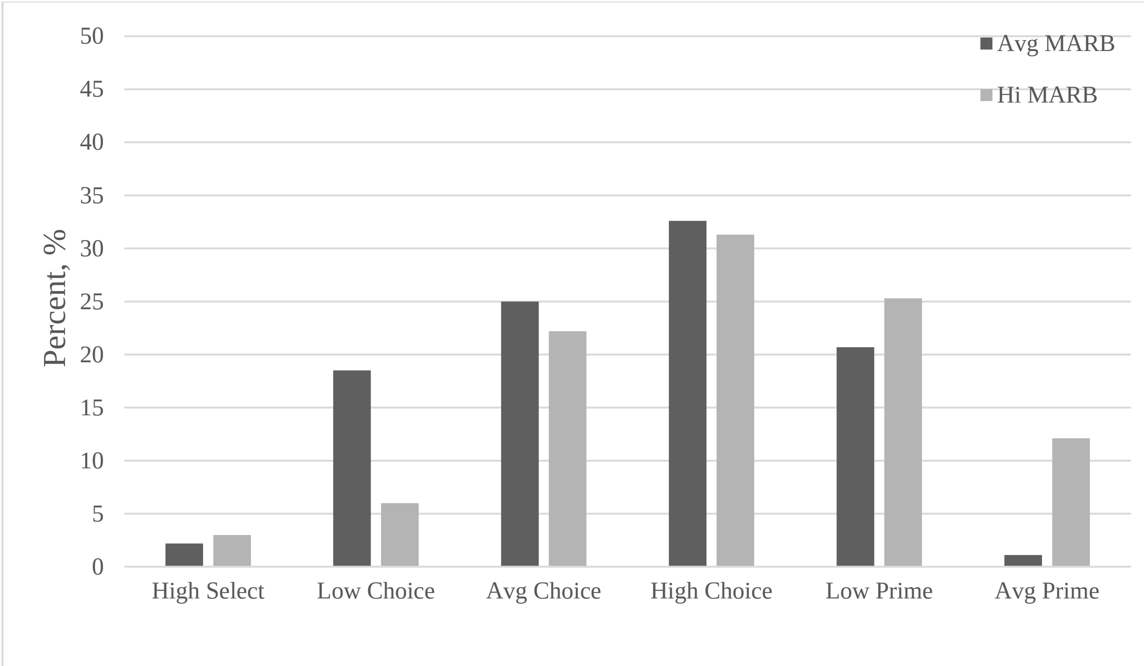


**Figure 3.4 Quality grade distribution in steers for Hi and Avg Marbling EPD**

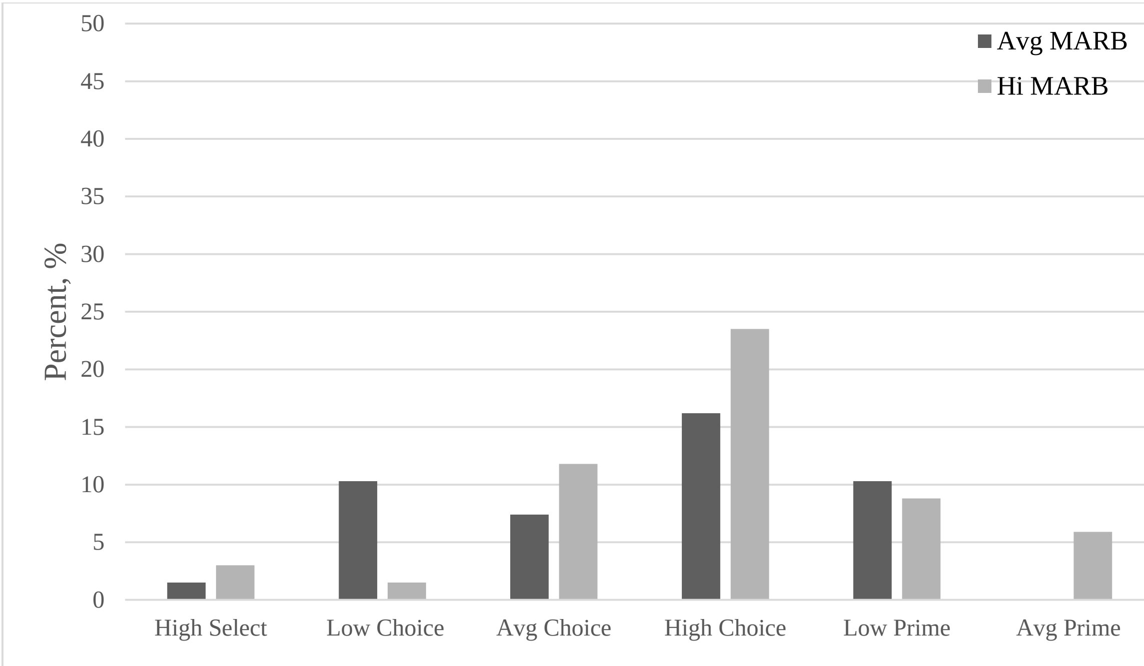


**Figure 3.5 Quality grade distribution in steers for Hi and Avg Marbling EDP across Year 1**

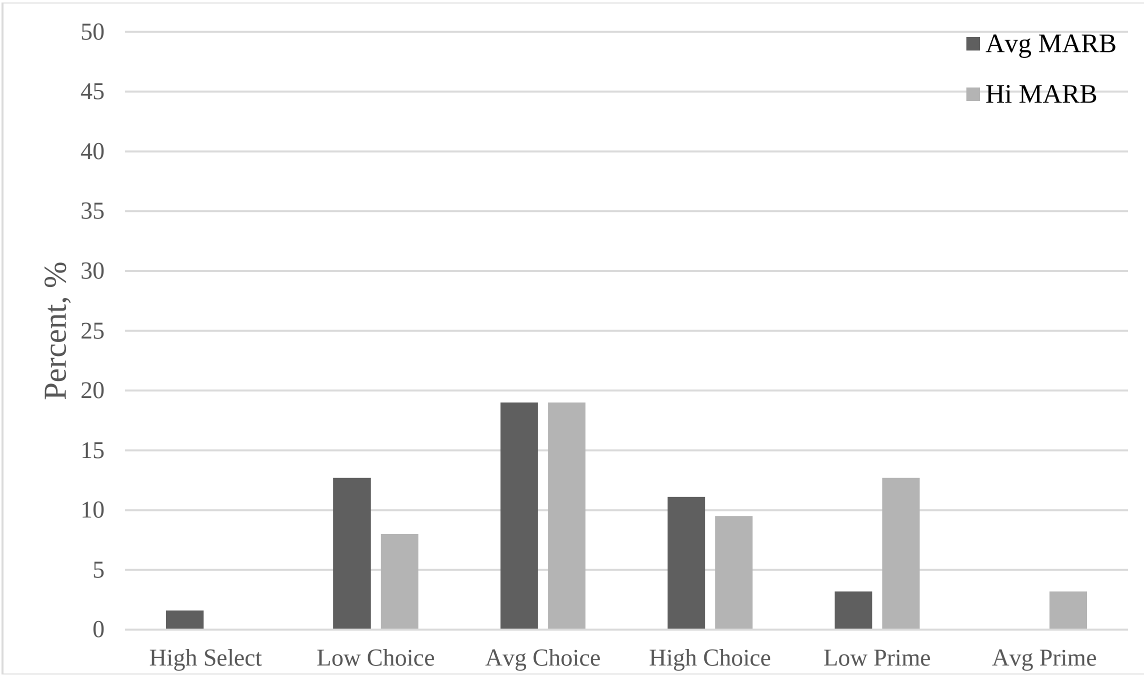

**Figure 3.6 Quality grade distribution in steers for Hi and Avg Marbling EDP across Year 2**

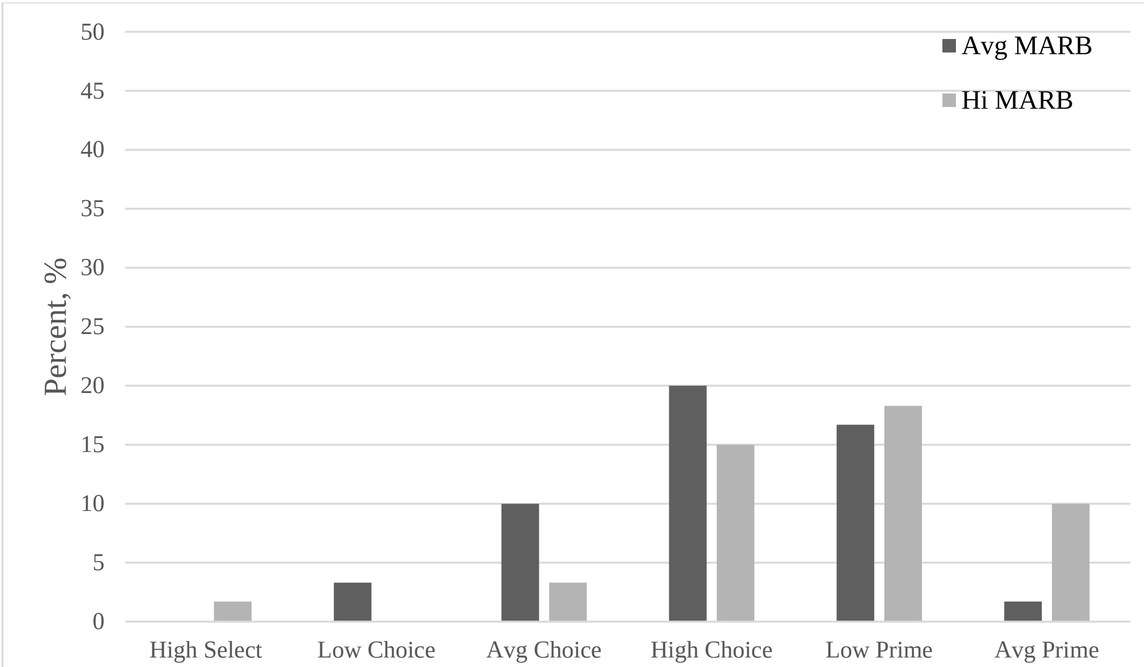


**Figure 3.7 Quality grade distribution in steers for Hi and Avg Marbling EDP across Year 3**

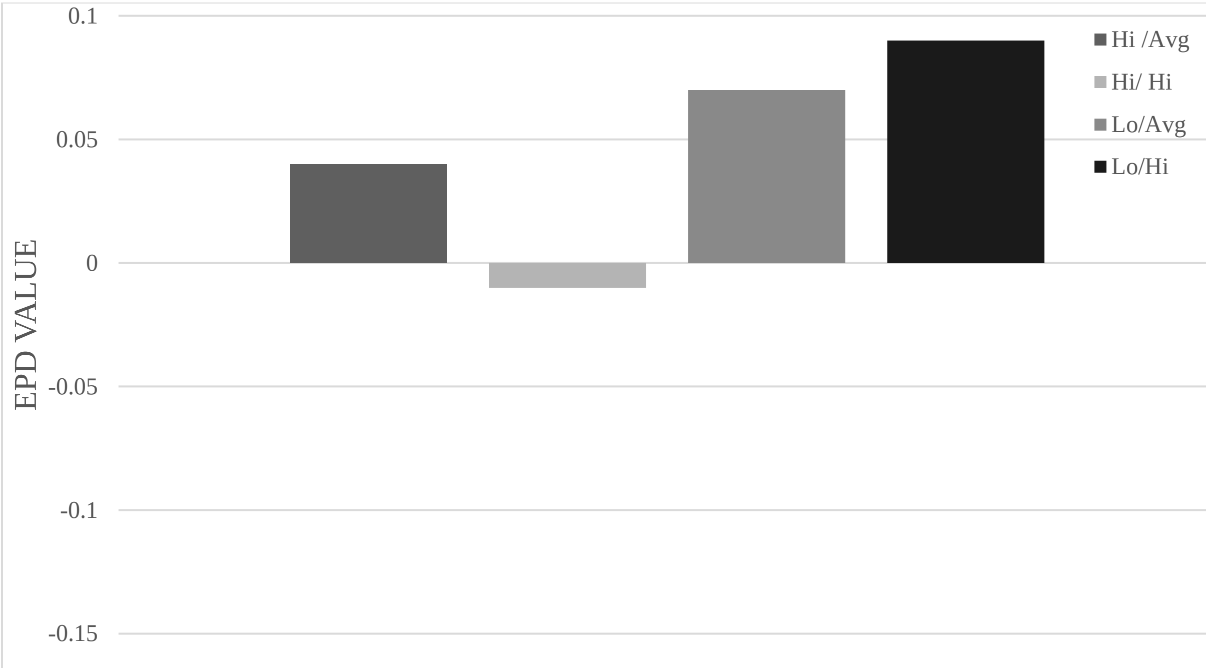


**Figure 3.8 RADG EPD change in steers for Hi and Lo RADG EPD**

CHAPTER 4

# THE IMPACT OF SELECTION USING RESIDUAL AVERAGE DAILY GAIN AND MARBLING EPDS ON GROWTH PERFORMANCE AND REPRODUCTIVE TRAITS IN ANGUS HEIFERS[2]

[2] Detweiler, R.A., Wells, J.B., Stelzleni, A.M., Segers J.R., Pringle, T.D. To be submitted to *Journal of Animal Science*.

**Abstract**

One hundred and forty-eight heifers, over a 3-yr period, were used to compare growth performance, feed efficiency, body composition, and reproductive performance from bulls divergently selected for feed efficiency. Angus sires were selected with high and low residual average daily gain (RADG) EPDs and high and average marbling (MARB) EPDs. This resulted in a 2x2 factorial arrangement with four treatment combinations: high RADG, high MARB (Hi/Hi); high RADG, average MARB (Hi/Avg); low RADG, high MARB (Low/Hi); and low RADG, average MARB (Low/Avg). Heifer weights were recorded at birth, weaning and yearling. Birth weights were different across RADG groups ($P < 0.01$); however, no other weight differences were noted at any measurement time. The only compositional difference noted was for IMF % at yearling. The Lo RADG heifers had greater IMF % than the Hi RADG heifers. No difference was observed between age at calving ($P > 0.76$), pelvic measurements ($P > 0.61$) or body condition scores ($P > 0.24$) across either RADG or MARB groups. Heifer blood samples from the first year of the study were collected to quantify levels of progesterone at 8 mo, 10 mo, and 12 mo. At 10 mo of age only 26% of low RADG, and at 12 mo 37% of low RADG heifers had reached puberty and 19% of high RADG heifers had reached puberty. All Heifers were bred via artificial insemination after synchronization using the 14-d CIDR-PG & TAI protocol, and if they returned to estrus 30 d later they were serviced a second time AI, and then exposed to a bull. Heifer feed intake data needs to be recorded, but selection of RADG and MARB EPD can affect heifer reproduction performance. Further work is needed to fully elucidate the effects of selecting for growth efficiency EPDs on reproduction and cow performance in the beef production system.

## Introduction

Feed efficiency is recognized as one of the most important factors in determining overall profitability in the cow-calf herd, and little information is available about the impact of selection for feed efficiency on growth and reproductive performance in replacement females (Shaffer et al., 2011). The mature cow herd uses an estimated 72% of all feed sources consumed, resulting in a large monetary cost to cow-calf producers (Ferrell and Jenkins, 1985). Anderson et al. (2005) reported that feed costs alone, represent the largest variable cost in beef cattle production, totaling approximately two-thirds of the cost in US beef cattle. Balancing output (growth) with input costs (feed) is needed in practicing selection (Rolf et al., 2011).

Two potentially negative effects that could result from selection for increased efficiency are the indirect selection for increased average daily gain and increased mature size (Basarab et al., 2003). Increased mature size of animals generally correlates to increased feed required by the mature animal in order to fulfill maintenance requirements (Ferrell and Jenkins, 1985; Montano-Bermudez et al., 1990; Ferrell and Jenkins, 1998). Over time, this can result in additional cow costs for cow-calf operations, which can be directly attributed to maintenance requirements of the mature females (Montano-Bermudez et al., 1990).

In Angus cattle particularly, the genetic correlation between postweaning RFI with average daily feed intake by the cow is high, and the correlation between postweaning RFI and cow RFI is very high. However, the correlation between postweaning RFI and cow F:G is low. These genetic correlations indicate that selection against postweaning RFI has the potential to lead to a decrease in feed intake and improvement in feed efficiency of growing animals and mature animals (Herd et al., 2003).

Additionally, prolonged calving season can result from reduced first service conception rate when selecting for efficiency (Donoghue et al., 2011). This decrease in early breeding season conception will result in a delay in calving that could negatively impact the reproductive efficiency of females for the remainder of their lives by delaying rebreeding in subsequent years (Basarab et al., 2007). In addition to the differences observed in the onset of puberty, based on high and low RFI selection, low RFI (delayed onset of puberty; lower backfat) females calved one week later than their high RFI contemporaries (Donoghue et al., 2011).

In order to help producers develop more efficient cows, the American Angus Association developed the Residual Average Daily Gain (RADG) expected progeny difference (EPD) in 2010. The new EPD incorporates calf weaning weight, postweaning gain, ultrasound subcutaneous fat thickness, and genomic dry-matter intake (Northcutt, 2010). Since this index included BW gain and RFI, it produced the best economic outcome for producers (Rolf et al., 2011).

The RADG EPD is used to show the differences in average daily gain given a constant amount of feed in the postweaning period. It is expressed in pounds per day, therefore a higher value of RADG EPD is more favorable suggesting a more feed efficient (low RFI) animal and a lower value of RADG EPD predicts that an animal is not as feed efficient (high RFI). Since this EPD is very similar to RFI, a lower RADG EPD values will require more feed to equal the same level of average daily gain as a higher RADG animal.

Not only are there advances with the RADG EPD, but Zeng et al. (2012) found that residual feed intake (RFI) and carcass merit (CM) are both complex traits emerging as critical for beef genetic improvement. Genome-wide selection using DNA markers may be a potential method for genetic improvement of these traits. However, with RADG being such a new selection tool, further investigation is needed to discover the full utility of this EPD. The objective of this study was to compare growth performance, body composition and reproductive performance along with feed efficiency, in heifers from Angus sires that were selected based on the RADG EPD and MARB EPD.

**Materials and Methods**

*Experimental Design*

For three years, commercial Angus cows from the Northwest Georgia Research and Education Center in Calhoun, GA have been assigned for breeding to Angus sires to determine the effect of selection using RADG and marbling (MARB) on growth, feed efficiency and carcass traits in Angus heifers. Sires were selected to have either a high or low RADG EPD and within the RADG lines, half of the sires were selected to have high MARB EPDs while the remaining sires were selected to have near breed average MARB EPDs. This resulted in a 2 x 2 factorial arrangement with RADG and MARB selection as the main effects.

*Sire Selection*

Bulls in this study were selected annually in January 2013, 2014 and 2015, from the American Angus Association's Sire Evaluation Report. At the time of selection, the high RADG bulls ranked in the top 5$^{th}$ percentile (+0.29 or higher) and the low RADG bulls ranked in the 95$^{th}$ percentile (+0.10 or lower) with accuracies of 0.40 or higher. Once the bulls were sorted into the RADG EPD lines, bulls, within a line, were then selected based on their MARB EPD. High MARB EPD bulls ranked in the 5$^{th}$ percentile (+0.94 or higher) and average MARB EPD bulls ranked near the 50$^{th}$ percentile (approximately +0.46). Bulls across the RADG EPD lines were also selected to be comparable in growth and carcass traits and to minimize the impacts of selection on these traits. Two bulls (one from each RADG EPD line) were used across subsequent years to assure connectivity of data collected across years and allow a more robust statistical inference. The two main sire selection criteria created a 2 x 2 factorial arrangment that contained two Angus sires in the following treatments: high RADG, high MARB (Hi/Hi); high RADG, average MARB (Hi/Avg) ; low RADG, high MARB (Lo/Hi); and low RADG, average MARB (Lo/Avg) for a total of eight bulls each breeding seasoning in this experiment.

*Semen Procurement and Breeding*

Once the bulls were selected for the breeding season, the owners of the bulls were contacted and semen was procured. Next, the cows and heifers at the Northwest Georgia Research and Education Center were synchronized in March of 2013, 2014 and 2015. Cows and heifers followed the Select Synch + CIDR ® & TAI protocol. Annually, approximately 30 cows were bred to each bull.

*Calf Processing and Weaning*

All animals used in this study were humanely handled under the University of Georgia Animal Care and Use Committee guidelines (AUP #A2012 11- 006-R1). A total of 148 female calves were used in this study. Each calving season, female calves were vaccinated with BoviShield Gold One Shot (Zoetis, Florham Park, NJ) and Ultra Choice 7 (Zoetis, Florham Park, NJ), then Dectomax (Zoetis, FlorhaM Park, NJ) pour-on was used for deworming. At weaning, weights were recorded and carcass ultrasound data were collected. Ribeye area, $12^{th}$ rib backfat thickness, and intramuscular fat percentage were collected using an Aloka 500-V ultrasound unit with a 17.2 am, 3.5MHz linear probe (Corometrics Medical Systems, Wallingford, CT). Data collected was then interpreted using Beef Information Analysis Pro Plus software (Designer Genes USA, Harrison, AR). Heifers from calving seasons were fence-line weaned.

*Replacement Heifer Development*

After weaning, heifers were developed on fescue and annual ryegrass pasture with Russell Bermuda hay and baleage. In order to reach dietary requirements, heifers also received approximately 2.75 kg/hd/d of a 50:50 corn gluten: soy hull grain supplement at 10 months of age. Heifer supplementation increased at 12 months of age to 3.75 kg/d.

*Puberty Determination*

Blood samples were collected from heifers at 8 mo, 10 mo, and 12 mo of age. Blood was drawn on day 0 and day 10 on all three collections via tail bleeding using BD Vacutainer® Serum 10.0 mL blood collection tubes (BD, Franklin Lakes, NJ). Tubes were then placed in refrigerated IEC Centra-GP8R centrifuge (Thermo Fisher Scientific Inc., Waltham, MA) at 4˚C and spun at 1600g for 20 minutes to harvest serum. One mL plastic transfer pipettes were used to collect serum from red blood cells. Serum was then transferred to 10 mL plastic scintillation vials. Samples were collected and stored at -20˚C until all samples had been collected.

The Siemens Coat-A-Count® Progesterone RIA (Siemens Medical Solutions Diagnostics, Dallas, TX) procedure was used to quantify the level of progesterone present in 2014 heifer samples. Samples were removed from the freezer, and thawed under refrigeration at 4˚C. One hundred µL of each sample was collected and transferred into coated tubes for the 125I Progesterone RIA procedure. Samples were then removed and allowed to reach room temperature. Duplicates were collected from each sample and the level of progesterone was recorded. Onset of puberty was determined by heifers that have reached the threshold level of 1 ng/mL of progesterone. All samples with intra-assay CV greater than 10% were identified and duplicate of the samples were prepared to ensure accuracy of the progesterone determination.

Intra- and interassay CV (n=5 assays) were 6.9 and 12.8% respectively with sensitivity for minimum detection at 0.02 ng/mL.

*Calf Yearling Data Collection*

At yearling, heifer calves weights were recorded and carcass ultrasound data was collected. A total of 148 heifer calves were used in this study. Each female calves were vaccinated with BoviShield Gold One Shot (Zoetis, Florham Park, NJ) and Ultra Choice 7 (Zoetis, Florham Park, NJ), then Dectomax (Zoetis, FlorhaM Park, NJ) pour-on was used for deworming. Ribeye area, 12$^{th}$ rib backfat thickness, and intramuscular fat percentage were collected using an Aloka 500-V ultrasound unit with a 17.2 am, 3.5MHz linear probe (Corometrics Medical Systems, Wallingford, CT). Data collected was then interpreted using Beef Information Analysis Pro Plus software (Designer Genes USA, Harrison, AR).

*Synchronization and Breeding*

Heifers from year 2013 and 2014 were synchronized at 15 mo of age using the 14 – Day CIDR® – PG & TAI protocol. However heifers from year 2015 were synchronized at 15 mo of age using the 7-Day CIDR® – PG & TAI protocol. Each year, heifers were artificially inseminated to bulls that were representative of their own breeding (Hi/Hi heifer bred to Hi/Hi bull; Hi/Avg heifer bred to Hi/Avg bull; Lo/Hi heifer bred to Lo/Hi bull; Lo/Avg heifer bred to Lo/Avg bull) in order to develop F2 generation offspring.

*Statistical Analysis*

The experimental design for this study was a randomized block design creating a 2 x 2 factorial arrangment with four treatment groups: high RADG, high MARB (Hi/Hi); high RADG, average MARB (Hi/Avg); low RADG, high MARB (Low/Hi); and low RADG, average MARB (Low/Avg). Data was analyzed using GLM procedures in SAS 9.4 (SAS Inst. Inc., Cary, NC) and means were separated using the LSD procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC). The main effects of RADG and MARB were tested by SIRE(RADG*MARB). Year was used as a replicate.

**Results and Discussion**

Growth performance traits in Angus heifers such as birthweights (BW), weaning weights (WW), November weights (NW), January weights (JW) and yearling weights (YW), were not different ($P \geq 0.25$) across RADG group. The Avg MARB group had heavier BW than the Hi MARB heifers (Table 4.1). This could be due to the slight differences in the BW EPD for the bulls used in the Avg and Hi MARB groups, however, there were no other differences in weight noted for the heifers across either main effect. This supports, Herd et al. (2003), who found genetic selection for reduced RFI has the potential to decrease feed intake and improve feed efficiency without affecting growth in heifers.

Trends were observed ($P = 0.06$) in ultrasound composition of the heifers at weaning for backfat thickness (WFT) and for IMF percentage (WIMF) for the interaction between the main effects (Table 4.2), however this trend was not observed in yearling fat or IMF percentage. There was an increase ($P = 0.04$) in the IMF % at yearling for Lo RADG heifers compared to Hi RADG heifers (Table 4.2).This was also noted in the steer contemporaries. Ribeye ultrasound composition was not significant for RADG and MARB EPD interaction, nor across the main effect of RADG EPD and MARB EPD. A possible explanation of the different levels of fat deposition observed through divergent selection for efficiency could be related to the utilization of nutrients by the heifers (Barasab et al., 2003). The additional caloric intake of high RFI (Lo RADG) females is likely the reason for increased back fat and IMF observed. A number of studies have shown that selection using marbling EPDs in Angus cattle generally results in increased marbling scores in the selected progeny (Gwartney et al., 1993; Sapp et al., 2001). Since marbling is considered to be moderately heritable (0.35) (Arnold et al., 1991), genomic testing for marbling should be completed to determine marbling levels present within the herd. There is a need for marbling selection not only paternally, but maternally as well.

Heifer pelvic measurements (PM) and age at first calving (CAGE) were not different ($P > 0.15$) across the RADG and MARB groups (Table 4.3). Similarly Barasab et al. (2003), found no differences between efficient and inefficient heifers in calving difficulty, average calving date, age at first calving, calf birth weight, calf pre-weaning ADG, calf weaning weight and heifer productivity.

Heifer age at puberty, determined by progesterone levels, were not accounted for in year two and three due to lack of funding (Figure 4.1). For year one heifers, at 10 mo of age, 26% of low RADG heifers had reached puberty while no high RADG heifers had reached puberty. By 12 mo of age, 37% of low RADG and 19% of high RADG heifers had reached puberty (Figure 4.1).

Heifer conception rate was greater in the Lo/Avg treatment followed by the Hi/Hi, Hi/Avg and Lo/Hi, respectively (Figure 4.2). Artificial insemination conception rates for first service were: Hi/Hi: 73%, Hi/Avg: 62%, Low/Hi: 48%, and Low/Avg: 54% (Figure 4.3). Second service rates were greater in Lo/Avg, with Hi/Avg and Lo/Hi being intermediate and lowest service rates in Hi/Hi treatment, respectively. The percent of heifers that were sired by the cleanup bull were greater in the Lo RADG groups than the Hi RADG. However, other studies have shown a decrease in AI conception rate for more efficient females (Hi RADG EDP) compared to the other treatment groups (Donoghue et al., 2011; Basarab et al., 2011). However, Barasab et al. (2011) noted that when adjusted 12$^{th}$ rib backfat was not accounted for in the equation for predicted intake there was a 12.6% difference in conception rates between low and high RFI selected groups with high RFI (Lo RADG EPD) calving slightly earlier in the breeding season. Shaffer et al. (2011) also found that heifers with higher levels of 12$^{th}$ rib back fat and IMF are inclined to earlier onset of puberty, which is associated with less efficient females (Lo RADG EPD) due to an increase in feed consumption.

The distribution of culling in heifers (Figure 4.4) shows that the greatest culling in treatments were in Lo/Hi and Hi/Avg sired heifers. Figure 4.5 shows the culling reasons across the study. Year 1 heifers, 18.0% of the group was culled based on failure to conceive. For year 2 heifers, 3 % were culled based on poor disposition, 5% was culled based on weight and small pelvic measurements, and 12% were culled based on small pelvic measurement alone, with only 5% failing to conceive. In year 3, 18% of heifers were culled based on failure to conceive and 4 % were culled based on small pelvic measurements or low weight and small pelvic measurements.

At the time of sire identification, the bulls used in this study were in the top 5th percentile (+0.29 and higher) and bottom 5th percentile (+0.10 and lower) for RADG EPD, with accuracies of 0.40 or higher. Over the last three years, the number of calves with feed intake data submitted to the American Angus Association has increased resulting in higher accuracies for the RADG EPD in the bulls used in this study. With the increase in RADG EPD accuracies, two high RADG sires used in year one fell to +0.26 and +0.28, which places them in the 15$^{th}$ percentile of the breed rather than in the 5$^{th}$ percentile. Similarly, RADG EPDs for two of the low RADG sires have increased to +0.16 and +0.14, placing them in the 70$^{th}$ percentile rather than the 90$^{th}$ percentile. These adjustments to the breeding values of the selected bulls for RADG may account for the fact that there were minimal differences in the heifers across the RADG selection groups. It is important to note that feed efficiency is only moderately heritable ($h^2 = 0.36$) in British breeds of cattle, so divergent selection resulting in significantly more efficient cattle in just one generation is not necessarily expected (Herd et al., 2003).

**Implications**

Improving feed efficiency within cow-calf operations can lead to large monetary savings for producers, additionally RFI is a more accurate way of measuring feed efficiency over the lifetime of the cow because it includes maintenance of body weight and the production of the cow, whether it be growth (ADG) as a weaned calf, or milk production as a lactating female (Basarb et al., 2007). Although RFI appears to be a better indicator of lifetime feed efficiency for a beef cow, low RFI (more feed efficient) females have been observed to have delayed onset of puberty (Shaffer et al., 2011). However, recent research has shown that including a third variable for predicted intake, adjusted 12th rib backfat thickness, provides feed efficiency information that is independent of fertility (Basarb et al., 2011). Future years of this study will need to have feed intake data collected that will allow for the calculation of RFI that can then be used to see how selection for high and low RADG EPD affects heifer efficiency. This feed intake data will help clarify the relationship between RADG EPD and efficiency within Angus heifers, and provide valuable information on how selection using RADG and marbling EPDs can affect heifer performance.

## Literature Cited


Anderson, R. V., Rasby, R. J., Klopfenstein, T. J., & Clark, R. T. (2005). An evaluation of production and economic efficiency of two beef systems from calving to slaughter. *J. Anim. Sci.* 83(3), 694-704.

Arnold, J. W., Bertrand, J. K., Benyshek, L. L., & Ludwig, C. (1991). Estimates of genetic parameters for live animal ultrasound, actual carcass data, and growth traits in beef cattle. *J. Anim. Sci.* 69(3), 985-992.

Basarab, J. A., Price, M. A., Aalhus, J. L., Okine, E. K., Snelling, W. M., & Lyle, K. L. (2003). Residual feed intake and body composition in young growing cattle. *Can. J. Anim. Sci.* 83(2), 189-204.

Basarab, J. A., D. McCartney, E. K. Okine, and V. S. Baron. 2007. Relationships between progeny residual feed intake and dam productivity traits. *Can. J. Anim. Sci.* 87: 489-502.

Basarab, J. A., Colazo, M. G., Ambrose, D. J., Novak, S., McCartney, D., & Baron, V. S. (2011). Residual feed intake adjusted for backfat thickness and feeding frequency is independent of fertility in beef heifers. *Can. J. Anim. Sci. 91*(4), 573-584.

Day, M. L. (2015, February). Nutritional Effects on Beef Heifer Development, Puberty and Subsequent Reproduction. In *2015 Florida Ruminant Nutrition Symposium* (p. 69).

Donoghue, K. A., R. M. Herd, J. F. Wilkins, and P. F. Arthur. 2011. Onset of puberty and early-life reproduction in Angus females divergently selected for post-weaning residual feed intake [electronic resource]. *Anim. Prod. Sci.* 51: 183-190.

Ferrell, C. L., and T. G. Jenkins. 1985. Cow type and the nutritional environment: nutritional aspects. *J. Anim. Sci.* 61: 725-741.

Ferrell, C. L., and T. G. Jenkins. 1998. Body composition and energy utilization by steers of diverse genotypes fed a high-concentrate diet during the finishing period: II.
Angus, Boran, Brahman, Hereford, and Tuli sires. *J. Anim. Sci.* 76: 647-657.

Herd, R. M., J. A. Archer, and P. F. Arthur. 2003. Reducing the cost of beef production through genetic improvement in residual feed intake: Opportunity and challenges to application. *J. Anim. Sci.* 81: E9-E17.

Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of Feed Use in Beef Cattle1. *J. Anim. Sci.* 22: 486-494.

Lancaster, P. A. et al. 2009. Phenotypic and genetic relationships of residual feed intake with performance and ultrasound carcass traits in Brangus heifers. *J. Anim. Sci.* 87: 3887-3896.

Lawrence, P., Kenny, D. A., Earley, B., & McGee, M. (2013). Intake of conserved and grazed grass and performance traits in beef suckler cows differing in phenotypic residual feed intake. *Livest. Sci.* 152(2), 154-166.

Lawrence, P., Kenny, D. A., Earley, B., & McGee, M. (2012). Grazed grass herbage intake and performance of beef heifers with predetermined phenotypic residual feed intake classification. *Anim.: Int.  J. Anim. Biosci. 6*(10), 1648.

Lents, C. A., R. D. Randel, A. M. Stelzleni, L. C. Caldwell, and T. H. Welsh, Jr. 2011. Function of the corpus luteum in beef heifers is affected by acute submaintenance feeding but is not correlated with residual feed intake. *J. Anim. Sci.* 89: 4023-4031.

Montano-Bermudez, M., M. K. Nielsen, and G. H. Deutscher. 1990. Energy requirements for maintenance of crossbred beef cattle with different genetic potential for milk. *J. Anim. Sci.* 68: 2279-2288.

Northcutt, S. B., Bill. 2010. Angus feed efficiency selection tool: RADG ANGUS JOURNAL. p 2. Angus Productions, Inc, Saint Joseph, MO.

Parish, J. A., Rhinehart, J. D., & Smith, T. (2008). Expected progeny differences and selection indices for beef cattle selection.

Rolf, M. M., Taylor, J. F., Schnabel, R. D., McKay, S. D., McClure, M. C., Northcutt, S. L., ... & Weaber, R. L. (2010). Impact of reduced marker set estimation of genomic relationship matrices on genomic selection for feed efficiency in Angus cattle. *BMC Genet.* 11(1), 1.

Shaffer, K. S., P. Turk, W. R. Wagner, and E. E. Felton. 2011. Residual feed intake, body composition, and fertility in yearling beef heifers. *J. Anim. Sci.* 89: 1028-1034.

Stock, R. A. a. T. J. K. 1986. Calan gates for intake measurement Symposium on Feed Intake of Cattle. p 321-32

**Table 4.1 Effect of selection using residual average daily gain (RADG) and marbling (MARB) EPDs on growth performance of Angus heifers**

| | RADG EPD | | | MARB EPD | | | RADG*MARB |
|---|---|---|---|---|---|---|---|
| **Trait** | **High** | **Low** | **P-value** | **High** | **Avg** | **P-value** | **P-value** |
| Birth weights, kg (BW) | 33.7 | 33.8 | 0.91 | 32.4 | 35.1 | 0.01 | 0.25 |
| Weaning Weight, kg (WW) | 269.7 | 266.8 | 0.51 | 271.7 | 264.9 | 0.14 | 0.43 |
| Nov, kg (NOV) | 297.2 | 291.3 | 0.39 | 294.0 | 294.5 | 0.94 | 0.81 |
| Jan, kg (JAN) | 356.4 | 345.6 | 0.15 | 353.8 | 348.2 | 0.45 | 0.39 |
| Yearling weight, kg (YW) | 392.9 | 382.7 | 0.12 | 388.7 | 386.9 | 0.78 | 0.39 |

* Level of Significance indicated as $P < 0.05$

**Table 4.2 Effect of selection using residual average daily gain (RADG) and marbling (MARB) EPDs on ultrasound body composition of Angus heifers**

| | RADG EPD | | | MARB EPD | | | RADG*MARB |
|---|---|---|---|---|---|---|---|
| **Trait** | **High** | **Low** | **P-value** | **High** | **Avg** | **P-value** | **P-value** |
| Weaning Fat, cm (WFT) | 0.43 | 0.47 | 0.24 | 0.45 | 0.45 | 0.86 | 0.06 |
| Weaning Ribeye Area, $cm^2$ (WREA) | 50.4 | 50.0 | 0.79 | 51.0 | 49.4 | 0.34 | 0.36 |
| Weaning IMF, % (WIMF) | 4.2 | 4.2 | 0.53 | 4.2 | 4.2 | 0.67 | 0.06 |
| Yearling Fat, cm (YFT) | 0.56 | 0.58 | 0.68 | 0.60 | 0.54 | 0.27 | 0.66 |
| Yearling Ribeye Area, $cm^2$ (YREA) | 62.2 | 62.4 | 0.92 | 63.4 | 61.3 | 0.31 | 0.37 |
| Yearling IMF, % (YIMF) | 6.3 | 7.3 | 0.04* | 7.1 | 6.5 | 0.15 | 0.32 |

* Level of Significance indicated as $P < 0.05$

**Table 4.3 Effect of selection using residual average daily gain (RADG) and marbling (MARB) EPDs on reproductive traits of Angus heifers**

| | RADG EPD | | | MARB EPD | | | RADG*MARB |
|---|---|---|---|---|---|---|---|
| **Trait** | **High** | **Low** | **P-value** | **High** | **Avg** | **P-value** | **P-value** |
| Pelvic Measurements, $cm^2$ (PM) | 172.7 | 172.1 | 0.87 | 175.4 | 169.4 | 0.18 | 0.60 |
| Age At Calving, days (CAGE) | 711.2 | 717.9 | 0.58 | 723.6 | 705.5 | 0.15 | 0.75 |

* Level of Significance indicated as $P < 0.05$

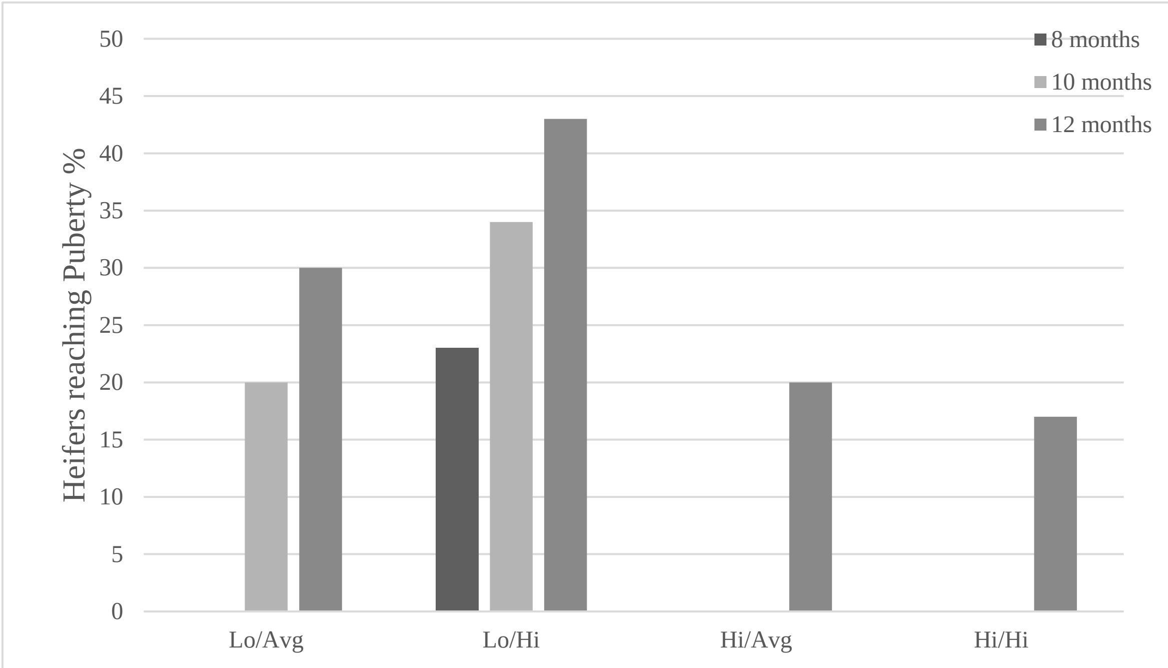


**Figure 4.1 Age at puberty distribution in heifers for Hi and Avg Marbling EPD Year 1**

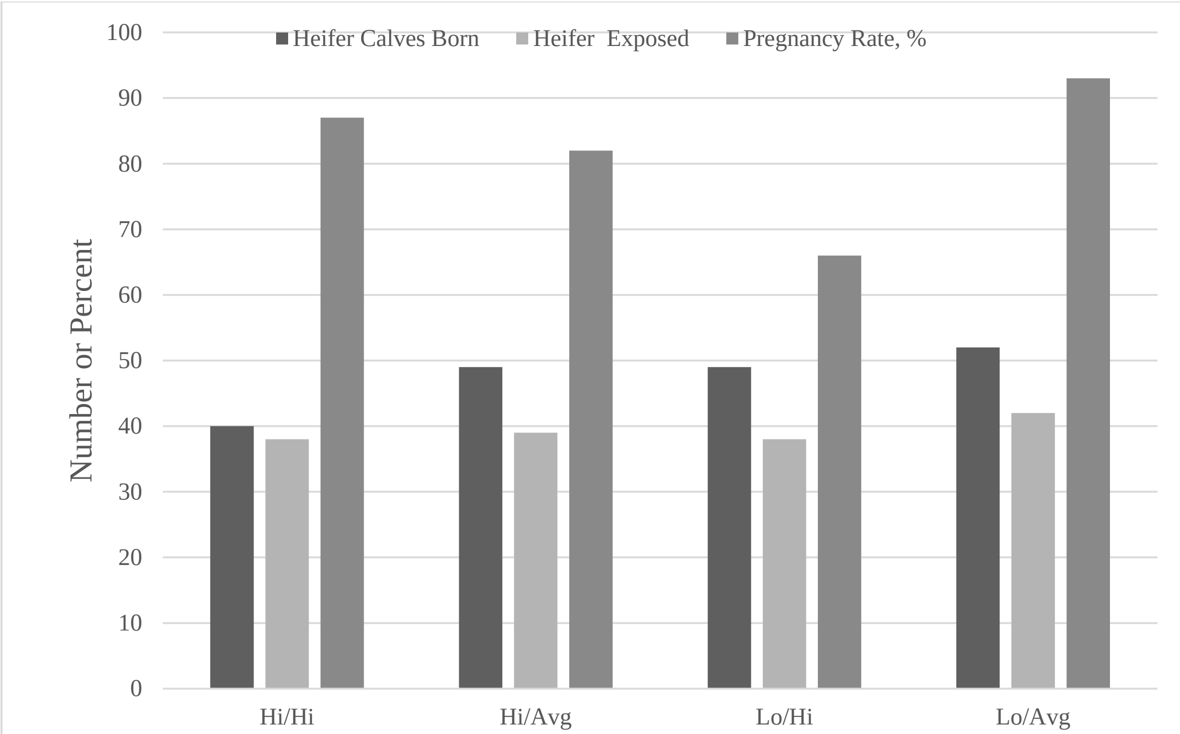


**Figure 4.2 Conception rate distribution in heifers for Hi and Avg Marbling EPD**

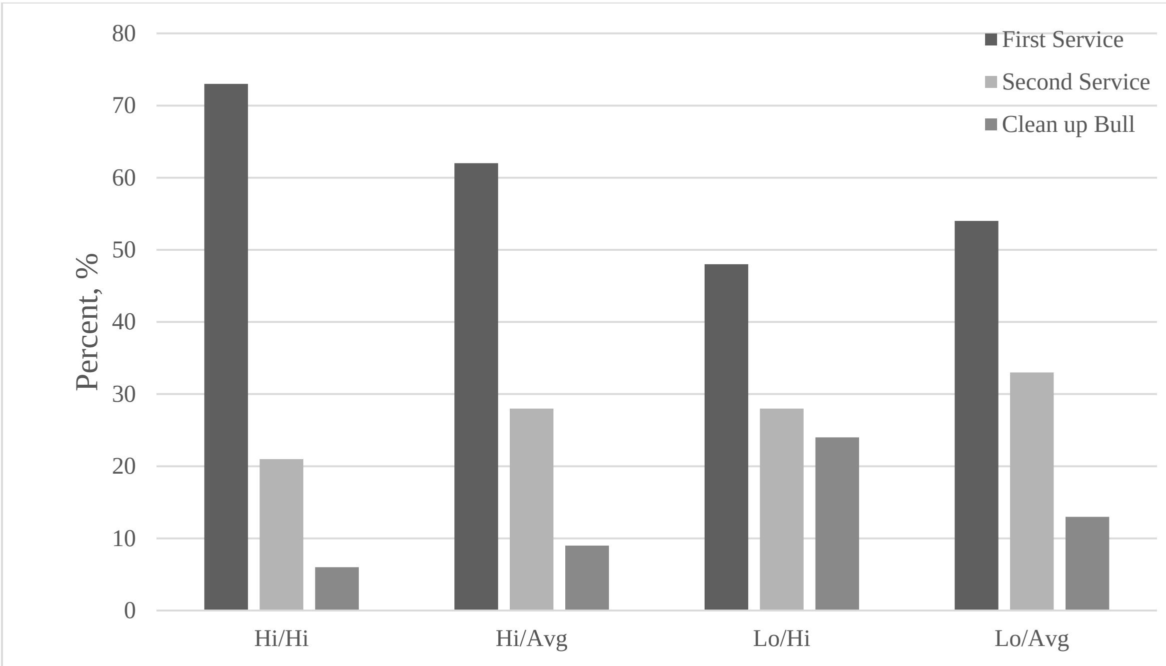


**Figure 4.3 Time of conception distribution in heifers for Hi and Avg Marbling EPD**

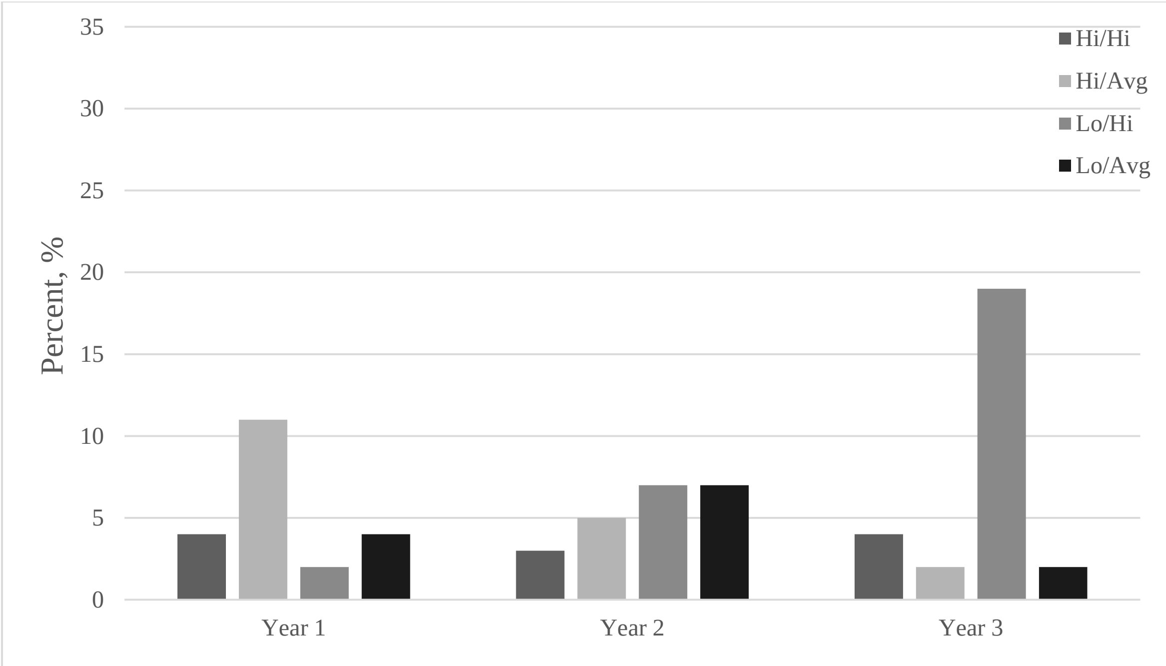


**Figure 4.4 Culling distribution in heifers for Hi and Avg Marbling EPD**

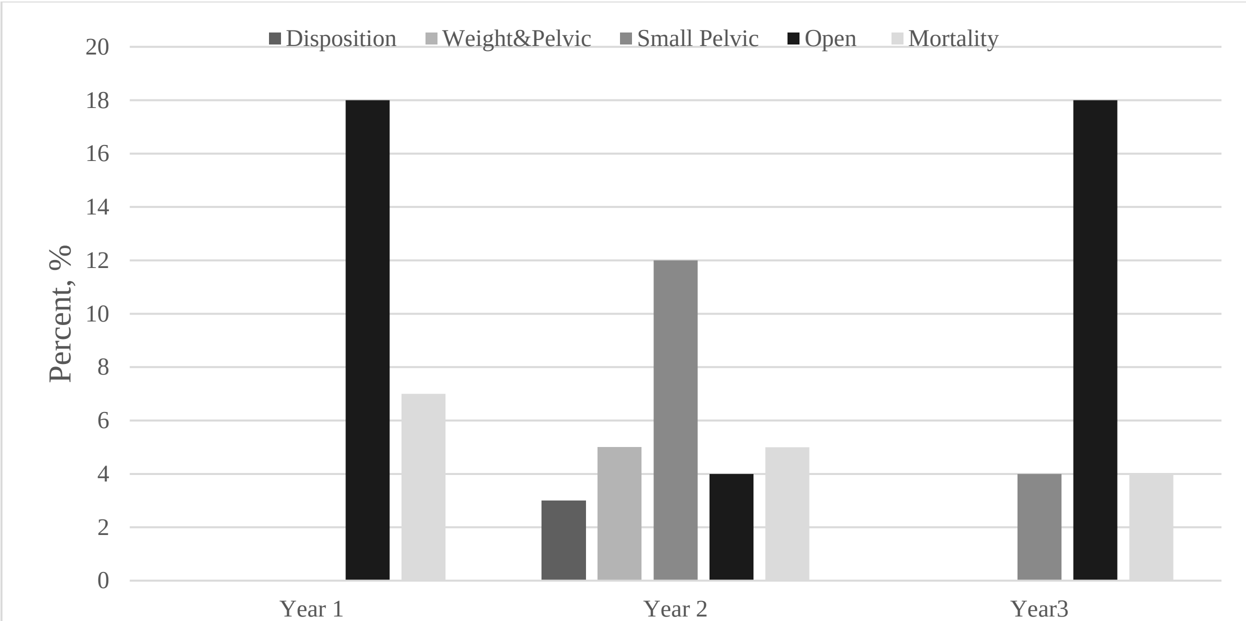


**Figure 4.5 Culling reason distribution in heifers for Hi and Avg Marbling EPD**

# CHAPTER 5

# CONCLUSION

Selection using RADG EPD resulted in a significant improvement in feed efficiency in the 191 steers used in this study. Thus, this three year study supports the use of the RADG EPD as a selection tool for improving feed efficiency in steers. Parish et al. (2011) reported the need for a reliable selection tool that incorporated weaning weight, postweaning gain, ultrasound subcutaneous fat thickness, and dry-matter intake of not only the individual sire used, but also his relatives and progeny on record, which the RADG EPD has to offer to producers.

The Hi RADG group had negative RFI values indicative of higher efficiency than the Lo RADG group. Even though the RFI selection via the RADG EPD had positive results in this study, additional data must be collected to accurately determine the value of RADG EPDs as a selection tool to improve cattle growth efficiency. Overall, the actual intake of low RADG selected steers was 0.39 kg/d higher than their high RADG contemporaries (Table 3.4).

There was a significant interaction between RADG and MARB selection for marbling score *($P = 0.05$)* with Lo/Hi steers having higher ($P < 0.05$) marbling scores than Hi/Avg, Hi/Hi, and Lo/Avg. In this study quality grade distribution for Avg MARB steers was as follows: high select 2.2%, low choice 18.5 %, average choice 25%, high choice 32.6%, low prime 20.7%, and average prime 1.1%. For Hi MARB quality grade distribution was as follows: high select 3%, low choice 6%, average choice was 22.2%, high choice was 31.3%, low prime 25.3% and average prime was 12.1% (Figure 3.4). Over the course of this study, the numbers for low prime and average prime have increased in both Avg MARB and Hi MARB selection (Figure 3.4, 3.5, 3.6, 3.7).

Although RFI appears to be a better indicator of lifetime feed efficiency for a beef cow, low RFI (more feed efficient) females have been observed to have delayed onset of puberty (Shaffer et al., 2011). However, recent research has shown that including a third variable for predicted intake, adjusted $12^{th}$ rib backfat thickness, provides feed efficiency information that is independent of fertility (Basarb et al., 2011).  However, this study provided valuable information on how selection using RADG and marbling EPDs can affect reproductive performance. No high RADG selected females reached puberty prior to 12 months of age, but over 26% of their low RADG contemporaries had reached puberty before 12 months of age. But, no difference was observed between reproductive traits amongst RADG and MARB selection (Table 4.3).

The GrowSafe™ feeding trial is needed for individual heifer intake. Although RFI could not be measured in the heifers used in the study, the high and low RADG EPD groups performed similarly to the high and low RFI phenotypic selection reported by Donoghue et al. (2011). Feed intake data needs to be recorded on future generations of heifers in this study in order to better understand the relationship between RADG EPD and efficiency within Angus heifers.This feed intake data will additionally provide valuable information on how selection using RADG and MARB EPDs can affect heifer performance.  Continued selection pressure on this trait may result in significant improvement in efficiency and enhance the understanding of the biological basis of efficiency in beef cattle. Further work is needed to explain the potential of selecting growth efficiency EPDs in the beef production system.

## Literature Cited


Arnold, J. W., Bertrand, J. K., Benyshek, L. L., & Ludwig, C. (1991). Estimates of genetic parameters for live animal ultrasound, actual carcass data, and growth traits in beef cattle. *J. Anim. Sci*. 69(3), 985-992.

Basarab, J. A., Colazo, M. G., Ambrose, D. J., Novak, S., McCartney, D., & Baron, V. S. (2011). Residual feed intake adjusted for backfat thickness and feeding frequency is independent of fertility in beef heifers. *Can. J. Anim. Sci. 91*(4), 573-584.

Donoghue, K. A., R. M. Herd, J. F. Wilkins, and P. F. Arthur. 2011. Onset of puberty and early-life reproduction in Angus females divergently selected for post-weaning residual feed intake [electronic resource]. *Anim. Prod. Sci.* 51: 183-190.

Parish, J. A., Rhinehart, J. D., & Smith, T. (2008). Expected progeny differences and selection indices for beef cattle selection.

Shaffer, K. S., P. Turk, W. R. Wagner, and E. E. Felton. 2011. Residual feed intake, body composition, and fertility in yearling beef heifers. *J. Anim. Sci.*, 89: 1028-1034.

Stock, R. A. a. T. J. K. 1986. Calan gates for intake measurement Symposium on Feed Intake of Cattle. p 321-324.