EFFECTS OF PHENOTYPIC SELECTION FOR RESIDUAL FEED INTAKE ON GROWTH PERFORMANCE AND CARCASS TRAITS IN ANGUS- AND BRAUNVIEH-SIRED CATTLE

by

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(Under the Direction of T. Dean Pringle)

ABSTRACT

The impact of RFI selection was investigated using offspring (n=67) from commercial Angus cows mated to Angus (AA) or Braunvieh (BA) bulls with large differences in RFI (high vs low). Following slaughter at predetermined endpoints of 1.4 cm for AA and 1.0 cm for BA, carcass data were collected and slice shear force was performed. Low RFI cattle gained faster, were heavier at slaughter, and tended to have higher G:F than high RFI. BA cattle were heavier entering the feedlot and spent longer on feed with lower G:F than AA. Breed nor RFI selection impacted RFI. Carcasses from low RFI sires were heavier with larger REA and lower USDA yield grades. Total primal yield (%) was higher in BA vs AA, low RFI vs high, and steers vs heifers. Findings suggest that selection using phenotypic RFI in bulls had no effect on RFI in their first generation calves, although certain measures of growth and efficiency were improved.

INDEX WORDS: Selection, Residual Feed Intake, Efficiency

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DEDICATION

I would like to dedicate this thesis to my loving wife Jessica and daughter Tessa. Jessica you've been my biggest supporter, motivator, and have stood by me from the start. I cannot thank you enough for your patience and understanding during this time and all you've done for our family. I love you. Would also like to dedicate this work to my father, who has taught me the ethics of working hard to accomplish the goals I've set in life.

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To all my relatives, Grandmother said it best when she told us to keep her family close and to help one another. In one way or another you've supported me either morally, financially, or physically. I cannot thank you enough.

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CHAPTER 1

INTRODUCTION

Over the past decade with input costs rapidly rising and increasing expectations from consumers for high quality, low cost foods, more emphasis has been put on feed efficiency in the US Beef Industry (Hill et al., 2012). At times when feed costs were more affordable, research focused primarily on the growth and quality of an animal. However with increasing food costs, which represents the greatest economic input liability in the beef production cycle, it is critical to evaluate the impact of efficiency in cattle, which could ultimately increasing profitability for the producer (Miller et al., 2001). Genetic selection for feed efficiency could result in cattle that require less feed per unit of gain, thus reducing production costs.

Feed efficiency has been estimated using a variety of measures, such as ADG and feed conversion ratio (FCR). Measuring the feed conversion ratio has been the most common method employed. Feed conversion ratio was originally expressed as feed:gain however more recently has been expressed as gain:feed to eliminate confusion in expressing efficiency (Sainz et al., 2004). One potential side effect of selection for efficiency using FCR is that it correlates closely to the animal's body size which could result in inadvertent selection for larger framed animals.

An alternative efficiency measure, that is adjusted for maintenance and growth, is residual feed intake. Residual feed intake is the difference between an animal's intake and its predicted feed intake based on gain (Koch et al, 1963). Genetic progress in the

U.S. cattle industry has been achieved primarily through the use of expected progeny differences (EPDs), which are a calculation of an animal's genetic potential to pass a given trait to its offspring. An EPD for RFI would allow more rapid selection for efficient cattle, however one does not currently exist. We hypothesized that phenotypic selection for RFI in bulls would improve efficiency and growth performance in their offspring. Therefore, the objective of this study was to determine the effects of sire phenotypic selection for RFI on growth performance and carcass traits in Angus and Braunvieh-sired cattle.

CHAPTER 2

LITERATURE REVIEW

Impact of Feed Efficiency on the Economy

With the world population projected to reach 9.7 billion by 2050, 4.11% of that being in the United States (UN Department of Economic and Social Affairs, 2015), and assessing the input costs to feed the population, production efficiency becomes a critical factor across all facets of animal agriculture. Additionally, being able to apply selection pressure for increased efficiency may help stabilize declining beef volume. Statistics by the National Cattlemen's Beef Association show that cattle breeding inventories have decreased from 97.3 million animals in 2001 to 89.8 million in 2015, resulting in a decrease of 9.9 million pounds of meat. Up until 2013, with the price of beef staying moderately low (Trading Economics, 2016) and input costs such as transportation, health, and feed rising, producers have been forced to reduce the size of their herds. From the mid 1980's to 2010 almost a quarter million cow/calf operations have been lost because of the inconsistency in profitability (Hill, 2012).

The decrease in cow/calf producers has a huge impact on the feedlot industry. Now in addition to the industry facing rising costs of inputs, it is also faced with the increased cost of feeder calves, due to a shortened supply. To help with the beef supply, feedlots are feeding cattle for a longer period of time in order to produce heavier carcasses. A study by the Professional Cattle Consultants which analyzed data on 443,000 steers over a six-year period from Certified Angus Beef found that the bottom third of the steers lost

$39.15 per head, due partly to the doubling of feed cost during the study (Stalcup, 2011).

Creating more efficient cattle will help to decrease costs in all aspects of the cattle industry. Feed accounts for about 65% of the total input costs; and it has been projected that a 1% improvement in feed efficiency would have the same economic impact as a 3% improvement in rate of gain (Weaber, 2011). With feed costs representing the highest cost of production, any decrease in feed utilization will help to improve global feed resources. It is estimated that a 10% improvement in efficiency in the feedlot industry could result in a $1.2 billion reduction in feed cost (Saatchi et al, 2014).

Measures of Production Efficiency

For sometime, the performance of cattle has been measured using average daily gain (ADG). It is the amount of weight gained over a certain period of time, expressed on a per day basis, and it is the cheapest measurement to acquire since a scale is the only tool needed. On the negative side, while ADG is correlated to feed efficiency, it does not account for a large amount of the variation reported in feed efficiency. Therefore, ADG is typically used in combination with other measurements to better assess growth efficiency.

As producers sought to understand efficiency of their cattle and the role intake plays in growth, the feed conversion ratio (FCR) was developed. This ratio consists of the amount of feed consumed by an animal or animals compared to the gain of the animal or animals during the same period of time. The ratio has been expressed as feed:gain (F:G) which is commonly used by producers, and gain:feed (G:F), which is the acceptable method for scientific literature according to the American Society of Animal Science (Archer et al., 1999, Retallick et al., 2012). One potential drawback to using FCR to estimate feed efficiency is the fact that body weight is not accounted for in this measurement and thus selection for FCR could result in increased mature size (Archer et al., 1999). Additionally, measuring feed intake on the individual animal is difficult and costly, thus FCR has been used more for estimating group intake and gains. Therefore, the value of the FCR for an individual animal would only be beneficial for a replicated group of animals or comparison to a group being fed an alternative diet (Retallick et al., 2012). Since this would not provide data for the individual animal's intake, the measurement would have limited value as a genetic prediction tool (Hill, 2012).

Residual feed intake (RFI) has been a topic of conversation for 50 years (Koch et al., 1963), however it has only become popular as a measure of efficiency in the last couple of decades in an effort to understand methods to reduce input costs across all sectors of the beef industry. Residual Feed Intake is defined as the difference between an animal's measured feed intake and its expected feed intake adjusted for that individual animal's maintenance requirements and growth (Koch et al., 1963). Since it takes into account the maintenance requirements and growth of the individual it has been suggested as a more accurate tool in determining feed efficiency than using a feed conversion ratio (Herd et al., 2014). Based on RFI, an efficient animal would consume less feed than expected for their size and growth and would have a negative value for the RFI whereas an inefficient RFI animal would consume more feed than expected and have a positive RFI value.

RFI Data Collection

When calculating the value of RFI, intake needs to be measured over an extended period of time. Animals on trial are weighed at the start of the trial and then several times throughout the trial to reduce measurement error in calculating the ADG for RFI.

Research has indicated that a feed trial should have at least a 70-d test period to accurately determine the average daily gain (ADG) for each animal (Archer et al., 1997). In order to assess individual animal intake, animals have been housed individually, however there is concern about stress due to lack of normal socialization. Therefore, group feeding helps to alleviate this stress factor.

The ability to measure the daily feed intake of cattle has become easier with the innovations in feeding systems. The Calan gate system uses an electronic sensor that is placed around the animal's neck to control access to the feed bunk. As the animal approaches the feed bunk, an electrical signal is transmitted to the circuit board on the door causing the lock to open (American Calan). This system allows each animal access to its own individual trough. With the Calan gate system, the daily feed amount is recorded and the amount of feed refusal is collected and weighed. The difference between feed provided and feed refusal is determined as feed intake. The use of a data ranger helps tremendously in this feeding process. It has the ability to weigh, mix, dispense the rations, and weigh any remainder not consumed by the animal.

Another system used in measuring feed intake of cattle is the GrowSafe™ system (GrowSafe Systems Ltd, Airdrie, AB, Canada). This computerized system was developed in 2001. Cattle are tagged with RFID tags and a reader attached to the feed bunks collects the ID number as they approach the bunk. The feed bunks are placed on load cells, and the feed disappearance can then be linked to the RFID tag. All the data are compiled using a proprietary software package (GrowSafe Systems Ltd, Airdrie, AB, Canada). The system records how many times a day the cattle enter the bunk, how long they eat, and the amount they consumed.

Once a trial is finished, the daily feed intake is calculated from the amount of feed fed and amount of refusal throughout the trial. The expected feed intake is obtained from either using feeding standards through NRC (2000) or a linear regression model of DMI on mid-test $BW^{0.75}$ and ADG (Sainz et al., 2004). The expected feed intake is calculated using the following equation:

$$Y = \beta_0 + \beta_1 (X_1)^{0.75} + \beta_2 X_2 + \varepsilon$$

Where Y is the dry matter intake, β_0 is the Y intercept of the line, β_1 and β_2 are the regression coefficients for the mid-test metabolic body weight raised to the 0.75 power (X1) and the average daily gain (X_2), and ε is the residual. Raising the mid-test metabolic body weight to the 0.75 power is done to balance the differences in maintenance requirements due to variation in the mature size of the animal (BIF,1986).

Reproduction and Fertility

Selecting for improvement in an individual trait may cause an area of concern in other traits, therefore it is best to understand the overall impact of selection on an animal. One of the areas of concerns with selection for increased efficiency is the effect on reproductive traits. From a production standpoint, the ability for a cow to calve and rebreed within 90 days, ensuring that a calf is produced each year, is essential to the operation. Cows are kept on pasture and unfortunately it is nearly impossible to measure RFI in cattle on pasture. Therefore, few studies have been conducted and little information is known about the impact that selection for RFI has on reproduction and fertility.

Nutritional plane plays a critical role in the development of the heifer. It is important for cows to achieve and maintain their ideal body condition score (BCS) of 5-7 for breeding (Eversole et al., 2009). Nutrition can affect the entire reproductive system from the anterior pituitary and hypothalamus glands to the ovaries (Schillo, 1992). Therefore, it is important to understand how selection for RFI affects the nutritional essentials for an animal and whether it negatively affects reproductive performance.

A study performed at Kansas State University used Angus-based commercial cows (n=136) bred to high- and low- RFI bulls selected based on their estimated breeding value (EBV) for RFI which ranged from -0.72 to 0.31 (Blair et al., 2013). Heifers from these matings were tested for RFI and then used to compare their reproductive efficiency by measuring pregnancy rate, calving percentage, and gestation length (Blair et al., 2013). Heifers were synchronized and artificially inseminated one time and then pregnancy status was determined 60 d. The study found no relationship between first service conception rate, pregnancy rate, calving rate or RFI in the study (Blair et al., 2013). Therefore, the limited data on the relationship between RFI and reproduction suggests that there are no negative effects in selecting for RFI on fertility in heifers.

In regards to bulls, several studies have been conducted to examine the effects of selecting for feed efficiency on bull fertility traits including sperm motility, morphology, viability, and scrotal circumference (Arthur et al., 2001a; Fox, 2004; Kelly et al., 2010; Wang et al., 2011; Awada et al., 2013). In a study using 110 bulls, the 10 with the highest RFI value and the 10 with the lowest RFI values were examined and it was determined that the sperm motility ($P < 0.01$), viability ($P < 0.05$), and progressive motility ($P < 0.05$) values of the highest RFI (least efficient) bulls were greater than the low RFI (most efficient) bulls (Awada et al. 2013). Other studies have shown that RFI is not phenotypically correlated to scrotal circumference in bulls (Arthur et al., 2001a; Fox, 2004; Kelly et al., 2010; Wang et al., 2011). Another study (Fox, 2004) using Bonsmara bulls on a 70-d feeding trial found no correlation between RFI and sperm motility. These results suggest that selection for improved efficiency in bulls should not affect their fertility.

Growth Performance

It is important to understand the effects RFI has on the growth performance in cattle. Research has confirmed that there is independence of RFI in relation to some production traits. For example, cattle selected for differences in RFI from their performance on feed, have stayed consistent in growth showing no significant differences in average daily gain. Baker et al. (2006) used individual feed intake and BW gain recorded for a 70-d post weaning period to calculate RFI on purebred Angus steers (n=54). Steers were separated into high, medium, and low RFI groups using standard deviation of the mean. Results from the study showed no differences in ADG, initial body weight, and end of trial body weight (Baker et al., 2006). However, RFI was correlated with DMI and FCR. Other studies have shown that low RFI cattle will have lower dry matter intakes and higher gain:feed than their high RFI counterparts (Herd et al., 2003; Castro Bulle et al., 2007; Ahola et al., 2011; Gomes et al., 2012; Perkins et al., 2014). This suggests that RFI is independent of ADG but is correlated to feed intake and feed conversion. In a 70-d feeding trial using Nellore steers (n=72) that were selected for low and high RFI, growth performance, and carcass value were measured (Gomes et al., 2012). Over the course of the feeding period, the low RFI steers had a greater G:F ($P <$ 0.0001), lower DMI ($P < 0.0001$), and lower RFI ($P < 0.0001$). However, no differences in ADG, BW, or any of the ultrasound composition data (ribeye area, back-fat, marbling) differed between the two groups (Gomes et al., 2012). Similar findings were observed in the growth of 575 steers selected to be high and low RFI. The low RFI cattle have a lower DMI ($P < 0.0001$), while final finish weights were not different (Nascimento et al., 2016).

Ultrasound

Ultrasound technology is a non-invasive tool that has become widely used due to its ability to assess carcass quality in the live animal. With its use of high frequency sound waves rebounding off the soft tissue, ultrasound can measure multiple traits of the carcass and help predict carcass measures in the live animal. Serial measurements of carcass values collected throughout a trial can be used to better understand the growth of an animal. In the cattle industry, the main traits measured with ultrasound are longissimus dorsi muscle area (ribeye area), 12^{th} rib back-fat thickness (BF), and intramuscular fat percentage (IMF), all of which are all measured between the 12^{th} and 13^{th} rib. Rump fat is another measure that has been used to predict carcass value. Research has shown that the average differences between ultrasound measurements and the actual carcass measurements for ribeye area to be $1.3cm^2$ and 0.18 cm in backfat (Greiner et al., 2003). Difference in marbling scans between scans and actual carcasses has been reported between 0.69 (Perkins et al., 1997) and 0.85% (Brethour, 2000). Correlations between RFI and ultrasound measurements have been variable (Arthur et al., 2001; Basarab et al., 2003) Arthur et al. (2001) evaluated Angus bulls and heifers (n=1180) to estimate genetic and phenotypic parameters for feed intake, efficiency, and other post weaning traits. They reported low phenotypic ($r<0.15$) and genotypic ($r<0.18$) correlations between RFI and ultrasound measurements for 12^{th} rib backfat, longissimus muscle area, and rump fat.

Carcass Value Measures

In addition to evaluating animal growth performance, it is critical to understand how much of an impact selection for efficiency will have on the value of the carcass. Carcass quality and yield grade are two of the main determinates in the retail value of the beef carcass. Carcasses are currently graded under the United States Department of Agriculture's grade scale (USDA 1997). Understanding the effects RFI may have on carcass traits is critical because a negative impact on either carcass grade due to selection for RFI could decrease profitability.

Although cattle selected for efficiency, based on RFI, have shown improvements in growth performance, carcass characteristics of those cattle have been similar to cattle deemed less efficient. Neither slaughter weight, hot carcass weight, longissimus muscle area, backfat thickness, yield grade, quality grade, nor shear force have shown a response to selection for RFI (Baker et al., 2006; Zorzi et al., 2012; Perkins et al., 2014; Reis et al., 2015). Nellore steers (n=72) selected for RFI after a 70-d feed trial showed no differences for HCW, dressing percentage, ribeye area, backfat thickness, intramuscular fat percentage(IMF), or product yield (Gomes et al., 2014). The amount of intramuscular fat, also known as marbling, is one of the main components determining the quality grade of beef carcasses. The United States Department of Agriculture (USDA) uses the amount of marbling in its grading system to assign the quality grades of Prime, Choice, Select, or Standard in younger cattle. Two studies found that the IMF scores were higher in carcasses from cattle that sorted into a low RFI group compared to their high RFI counterparts (Ahola et al., 2011; Perkins et al., 2014). In other studies, no differences in IMF were reported in response to group sorting for RFI (Baker et al., 2006; Castro et al., 2007; Gomes et al., 2014). Since the effect RFI has on intramuscular fat deposition in cattle has been inconsistent, more research should be conducted to further understand any relationship between these traits.

Tenderness/ Slice Shear Force

Due to consumer preferences, meat tenderness is a highly sought after trait in beef. However, there are many factors that can contribute to the degree of tenderness; genetics, age, sex, breed, health and nutritional status are some of the major contributing pre-harvest factors. At the molecular level, the ante and post-mortem characteristics of collagen, water holding capacity (WHC), sarcomere length, and the rate and extent of proteolysis after slaughter can also affect tenderness (Kazemi et al., 2009; Koohmaraie et al., 2002). Research determining the effects of RFI on tenderness suggests that there is not a significant relationship between these two economically important traits (Mcdonagh et al., 2001; Ahola et al., 2011; Behrens et al., 2011).

In order to determine the degree of tenderness, trained sensory panels and instrumental measures of shear force have been used. Warner-Bratzlar shear force (WBSF) has been used to measure tenderness since the 1930s (McKenna, 2012), and has been measured in cattle that differ in RFI levels (Mcdonagh et al., 2001; Ahola et al., 2011). This method requires a sample to be cooked and then cooled before removing 6 samples (12.7 mm diameter) parallel with the longitudinal orientation of the muscle fiber to be sliced using a slotted V-shape blade (Ross, 2008). Research by Wheeler et al. (1997) determined there were multiple errors with this method, but as long as equipment stayed calibrated and the protocol was followed correctly a high repeatability could be achieved.

To simplify the technique for measuring tenderness, Shackelford developed the Slice Shear Force method in the 1990's (Shackelford et al., 1999). This test involves removing only one or two cooked slices instead of six core pieces and does not require a cooling time decreasing measurement time. The sample is cut 1 cm thick and 5 cm long parallel to the muscle fibers. Instead of the V-shaped blade, this method requires a blade with a slightly beveled edge (Shackelford et al., 1999). In the procedure, slices should be sheared perpendicular to the muscle fibers. Once sheared, the shear force is the measured peak force required to shear through the sample.

Breed Selection

Through the years, multiple studies have been performed to evaluate differences between breeds as well as the effects of heterosis from crossbreeding. Angus, a British breed also known as Aberdeen Angus, are well known for their growth and ability to provide a high quality carcass. Records of the breed have been around since the 16th century. They originated from Scotland and became popular in the middle of the 18th century as they are very hardy and adapt easily to different environments. They are a moderately framed breed reaching typically 550 kilograms for cows and 850 kilograms for bulls.

The Braunvieh cattle, a continental breed that originated from Switzerland, may be the oldest pure breed with records dating back to 800 B.C. (Braunvieh Association). Unfortunately, the breed is not well known in the industry. Many producers have never heard of it or believe it is a cross between Brahman and a continental breed like Gelbvieh. Braunvieh cows excel in milk production for a beef breed and are known to be the breed from which Brown Swiss cattle originated. Having this increase in milk production, calves grow at a faster rate therefore resulting in a higher weaning weight. As for carcass data, Braunvieh tend to harvest with more muscle and less back-fat receiving a better yield grade (Braunvieh Association).

Comparing Angus versus Braunvieh, Gregory et al. (1994) reported a study measuring the backfat and marbling score of steers from a 4-yr period in the USDA Germplasm Utilization (GPU) Program. After weaning, calves were immediately started on feed and finished with the mean age at slaughter of 438 d. Angus cattle finished with 12^{th} rib adjusted backfat thickness of 1.2 cm and a marbling score of 540 (Average Choice), whereas Braunvieh finished with 0.46 cm adjusted backfat and a marbling score of 485 (Low Choice) (Gregory et al., 1994). This study suggests that Angus-sired cattle will have a higher quality grade than Braunvieh-sired cattle; however, Braunvieh-sired cattle will produce higher yielding carcasses.

Conclusion

Residual feed intake can be a useful tool for determining efficiency in cattle. Studies have shown there is minimal negative impact on production and carcass traits in cattle selected for efficiency (low RFI). Most of these studies selected cattle with high and low RFI values from a population where RFI was measured in a feed trial. However, few studies have been done using phenotypic RFI measures in breeding cattle to genetically select for improved efficiency.

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CHAPTER 3

EFFECTS OF PHENOTYPIC SELECTION FOR RESIDUAL FEED INTAKE ON GROWTH PERFORMANCE AND CARCASS TRAITS IN ANGUS- AND BRAUNVIEH-SIRED CATTLE

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Abstract

Improving feed efficiency has been identified as a priority by the US Beef Industry. Residual feed intake (RFI), defined as the difference between an animal's feed intake and its expected feed intake, is one tool that has been used to assess feed efficiency in cattle. Selection for improved feed efficiency using RFI is challenging because of the lack of EPDs for this trait and the difficulty of measuring feed intake in breeding cattle. Thus, the objective of this study was to determine the effects of phenotypic selection for RFI on the growth performance and carcass traits in Angus- and Braunvieh-sired cattle.

Angus cows were randomly mated to either Angus (A) or Braunvieh (B) bulls that had large measured differences in RFI (high vs low), resulting in four treatment groups: High RFI AA, Low RFI AA, High RFI BA, and Low RFI BA. Offspring (steers and heifers), over a 2-yr period, from the assigned matings (n=67) were used to investigate the impact of RFI selection on growth and carcass measures. After weaning, cattle from year 1 were placed on grass for a short time and then fed a concentrate diet. Feed intake was measured using a Calan gate feeding system. Cattle from year 2 were handled similarly except they were backgrounded for a longer period of time resulting in a shorter feeding period and older age at slaughter. Cattle were slaughtered as they approached a fat endpoint of 1.3 cm for AA 1.0 cm for BA and carcass data was collected. Carcasses were fabricated into the major primals and weights were recorded. A 2.5-cm steak was removed from the striploin and aged 14 d for SSF determination. The data were analyzed using ANOVA with the main effects of breed, RFI selection, sex, year, and their first order interactions.

Cattle from low RFI sires gained faster ($P = 0.01$), were heavier ($P = 0.01$) at slaughter, and tended to have higher ($P < 0.10$) gain:feed than cattle from high RFI sires. BA cattle were heavier ($P < 0.05$) entering the feedlot and tended ($P<0.10$) to spend longer on feed with a lower ($P < 0.05$) gain:feed ratio than AA cattle. As expected, steers were heavier ($P < 0.01$) throughout the feeding period than heifers. Neither breed nor RFI selection impacted ($P > 0.30$) RFI; however, steers had lower ($P < 0.01$) RFI measures than heifers. Carcasses from low RFI sires were heavier ($P = 0.02$) with larger ($P < 0.01$) REA and lower ($P = 0.01$) USDA yield grades compared to high RFI sires. No differences ($P > 0.05$) in USDA yield grade factors across breed type were found. Steers had heavier ($P < 0.01$) carcasses, lower ($P < 0.01$) back-fat, larger ($P < 0.01$) REA, and lower ($P = 0.01$) USDA yield grade than heifers. Heifers tended to have higher ($P < 0.10$) marbling scores than steers; however, marbling score was not affected by breed or RFI selection. Carcass weight differences across RFI selection, breed, and sex explained the majority of the differences found in primal weights. Total primal yield (%) was higher ($P < 0.01$) in BA vs AA, low RFI vs high, and steers vs heifers. Tenderness was not affected by breed or RFI selection; however, heifers had lower ($P < 0.01$) SSF than steers. These findings suggest that selection using phenotypic RFI in bulls had no effect on RFI in their first generation calves, although certain measures of growth and efficiency were improved. Further research is merited to determine the effects of phenotypic selection for RFI in a multi-generation study.

Keywords: cattle, growth, residual feed intake

Introduction

Over the past decade with input costs rapidly rising and increasing expectations of consumers for high quality, low cost foods, more interest has been put on feed efficiency through the US beef industry. At times when feed costs were more affordable, research was focused primarily on the growth of the animal and carcass quality. However, as feed costs rise, and since feed is the largest expense in beef production, it is critical to evaluate the impact of efficiency (Miller et al., 2001). Genetic selection for feed efficiency should result in cattle that require less feed per unit of gain, thus reducing production costs.

Feed efficiency has been estimated using a variety of measures such as average daily gain (ADG) which represents the gain over a period of time and feed conversion ratio (FCR) that consists of the amount of feed consumed by one animal in comparison to the gain in weight of that animal over a certain period of time. This measure was originally expressed as feed:gain, however, more recently has been expressed as gain:feed to eliminate confusion in expressing efficiency (Sainz et al., 2004). One potential side effect of selection for efficiency using FCR is that it correlates closely to the animal's overall body size which could result in the production of larger framed animals (Hill et al., 2012).

Feed efficiency has been studied in the livestock and poultry industries for multiple decades, and significant improvements through genetic selection have been reported. Average feed conversion ratio (FCR) has been improved to < 3.5:1 in the swine industry, < 2:1 in the poultry industry, and nearly 1:1 in the catfish industry (Shike, 2013). Unfortunately, the cattle industry has made minimal improvements in FCR during that same time period and the average FCR remains slightly greater than 6:1 (Shike, 2013).

The primary reason for this lack of improvements has to do with the difficulty in measuring feed intake for cattle on pastures and the cost of measuring intake during the finishing phase of beef production. Feed intake monitoring systems are expensive and labor intensive; however, recent advancements in technology are making it easier to collect this information, allowing the beef industry to place selection pressure on this important economic trait. An alternative efficiency measure, that is adjusted for maintenance and growth, is residual feed intake. Residual feed intake is the difference between an animal's actual intake and its predicted feed intake based on gain (Koch et al., 1963). When calculating the value of RFI, intake needs to be measured over an extended period of time. Animals on trial are weighed at the start of the trial and then several times throughout the trial to reduce measurement error in calculating the ADG for RFI. Research has indicated that a feed trial should have at least a 70-d test period to accurately determine the average daily gain (ADG) for each animal (Archer et al., 1997). In order to assess individual animal intake, animals have been housed individually, however there is concern about stress due to lack of normal socialization. Therefore, group feeding helps to alleviate this stress factor. Once a trial is finished, the daily feed intake is calculated from the amount of feed fed and amount of refusal throughout the trial. The expected feed intake is obtained from either using feeding standards through NRC (2000) or a linear regression model of DMI on mid-test $BW^{0.75}$ and ADG (Sainz et al., 2004). Expected feed intake is calculated using the following equation:

$$Y = \beta_0 + \beta_1 (X_1)^{0.75} + \beta_2 X_2 + \varepsilon$$

Where Y is the dry matter intake, β_0 is the equation intercept, β_1 and β_2 are the regression coefficients of the equation, X_1 is the mid-test metabolic body weight raised to the 0.75 power, X_2 is the average daily gain, and ε is the residual. Raising the mid-test metabolic body weight to the 0.75 power is done to balance the differences in maintenance requirements due to variation in the mature size of the animal (BIF, 1986).

Since genetic progress in the U.S. cattle industry has been achieved primarily through the use of expected progeny differences (EPDs), that represent the animal's genetic value for a given trait, it is critical for the industry to have an efficiency EPD. At this time, due to the difficulty in measuring feed intake in cattle, there is no genetic value for RFI available in the United States cattle industry. Therefore, the objective of this study was to determine the effects of phenotypic selection for residual feed intake on the growth performance and carcass traits in Angus- and Braunvieh-sired cattle.

Materials and Methods

Animals and Management

Commercial Angus cows at the J. Phil Campbell Experiment Station in Watkinsville, GA, were bred by artificial insemination, in April, over a two-year period using registered bulls with their pedigree information maintained by the American Angus Association and Braunvieh Association. The Angus cows were randomly mated to either Angus (A; n=4) or Braunvieh (B; n=4) bulls that had large measured differences in RFI (high vs low), resulting in four treatment groups; High RFI AA, Low RFI AA, High RFI BA, Low RFI BA. The semen was provided by cooperating producers who collect intake data in their bull development programs. The RFI values of the bulls is presented in Table 1.

Calf Processing/Weaning

Offspring (steers and heifers, n=67) were born over a two-year period during 2012 and 2013 and were humanely managed under the guidelines of the University of Georgia Animal Care and Use Committee (AUP# - A2012 11-006). All calves were tagged, tattooed within the 48 h of birth, and males were banded within 2-3 months. About a month prior to weaning, calves were treated with Pyramid 10 and Alfa 7 (Boehringer Ingelheim, St. Joseph, MO). Calves received a second dose of Pyramid 10 prior to weaning.

At weaning, calves were weighed and scanned to collect weaning ribeye area, backfat thickness, and intramuscular fat percentage. The ultrasound data were collected using an Aloka 500-V ultrasound unit (Corometrics Medical System, Wallingford, CT) with a 17.2 cm, 3.5 MHz linear probe and interpreted using Beef Information Management software (Designer Genes Inc., Harrison, AR). Calves were transported to the University of Georgia Wilkins' Beef Research Center in Washington, GA where they were backgrounded before starting the feeding trial. Year 1 calves were backgrounded for 4 months, and year 2 calves were backgrounded for 11 months before starting the feeding trial.

Feedlot Trial

Prior to the start of the feeding trial, the steers and heifers were transitioned to feed while on pasture over a 3 wk period. The diet composition and nutrient content are shown in Table 2. During the first week of the transition period, cattle were fed 2.27 kg/hd/d, followed by 4.54 kg/hd/d in wk 2, and 6.80 kg/hd/d during week 3. Following the transition period, cattle were moved into the feedlot which has four pens with nine Calan gates per pen (American Calan, Northwood, NH). Steers and heifers were randomly assigned to a pen, weighed, and fitted with collars containing the Calan gate controllers. A Data Ranger (America Calan) was used to weigh and dispense the daily feed allotment and measure weekly feed refusal. Cattle were trained to use the Calan gates over a 2-wk period. After successful training, cattle were weighed to start the trial and ultrasound ribeye area, intramuscular fat, and backfat thickness were measured. Cattle were scanned multiple times during the feeding trial to monitor their progress towards their assigned slaughter endpoint of 1.3 cm backfat for the AA cattle and 1.0 cm backfat for the BA cattle.

Harvest

As the cattle reached their preassigned slaughter endpoint they were weighed to obtain an off-test weight. Cattle were then delivered to the designated processing facility where they were held overnight with ad libitum access to water. Year 1 cattle were taken to the UGA Meat Science Technology Center, Athens, GA whereas Year 2 cattle were transported to Waldrop's Meat Processing in Ellijay, GA. The morning following transportation cattle were harvested under federal inspection at both locations. Hot carcass weight (HCW) were recorded immediately prior to carcasses entering the cooler.

Yield, Quality Grade, and Fabrication

After a 48-h chill (2°C), carcasses were weighed to get a chilled carcass weight (CCW) and the left side of the carcass was cut between the 12th and 13th ribs allowing the surface of the longissimus muscle to bloom for approximately 20 min. Quality grade and yield grade factors were measured by trained university personnel. Pictures, using a smart phone, and tracings were taken of the 12th rib cut surface of the longissimus muscle. Pictures included a ruler to allow calibration of the computer software used to measure ribeye area. Ribeye area from the image was measured using Image J software (National Institutes of Health) on a desktop computer. Ribeye tracings were digitized and measured with Image J software, as well as, the USDA ribeye area grid. Comparisons between each method were taken to determine the ability of the Image J software to accurately measure ribeye area.

During fabrication, the major primals were removed, trimmed to 0.635 cm, weighed, and then further fabricated into sub-primals. Weights of the following forequarter sub-primals were recorded: chuck roll, shoulder clod, mock tender, ribeye roll, and brisket. The following hindquarter sub-primals were weighed during fabrication: tenderloin, striploin, flank, top sirloin, knuckle, inside round, flat, and eye of round. A 2.54-cm steak from the anterior end of the striploin was removed, vacuum-packaged, and aged for 14 d in a 2°C cooler before being frozen for subsequent measure of slice shear force.

Slice Shear Force Determination

The 2.54-cm thick steaks were removed from the freezer, weighed and thawed overnight in a 2°C cooler. The following morning steaks were blotted dry and weighed to determine thaw loss. Copper-constantan thermocouples attached to a potentiometer (manufacturer) were inserted into the approximate geometric center of the steak to monitor temperature and the steaks were cooked on a grill (manufacturer). Initial temperature and starting time were recorded before steaks were placed on clamshell electric grills. Steaks were cooked to an internal temperature endpoint of 71°C (AMSA, 1995). Final temperature, cooking time, and cook weight were recorded as the steaks were removed from the grill.

Following the procedure of Shackelford et al. (1999), a 1 cm x 5 cm sample was removed from each steak. Samples were prepared by removing the lateral end of the steak and placing the remaining sample into a sizing box. A 5-cm wide piece of the lateral end of the steak. The sample was placed in a 45° cutting box that had two slots lined up with the muscle fiber orientation. A double bladed knife was used to cut two 1 cm x 5 cm slices. Degree of doneness was recorded (AMSA, 1995).

Slice shear force was then measured by shearing each sample once on an Instron Universal Testing machine, model 3365 (Instron Corp., Norwood, MA). A single slice was sheared perpendicular to the muscle fiber orientation using a 1.02 mm thick blade at a speed of 500 mm/min and the peak shear force was recorded.

Statistical Analysis

The experimental design for this study was a 3 x 2 arrangement with 2 treatments (high RFI vs low RFI bulls); 2 breed types (Angus- vs Braunvieh-sired calves) and 2 genders (steers vs heifers). Data were analyzed using analysis of variance in SAS 9.4 (SAS Inst. Inc., Cary, NC) for the main effects of RFI selection, breed type, gender, and their first order interactions. Year served as a replicate in the study. The level of significance chosen was $P = 0.05$.

Results and Discussion

Treatment Effects

Phenotypic selection for low RFI had no effect on RFI between the selection groups ($P > 0.59$; Table 3) which agrees with an Australian study that selected their cattle populations similar to the current study. In their study, feed intake data were collected on

Angus bulls and they were classified as either high or low RFI sires (Donoghue et al., 2011). The high and low RFI sires were then used to breed Angus cows over multiple generations creating divergent lines for efficiency using RFI values. Donoghue et al. (2011) did not see significant differences in RFI between the high and low RFI lines until the 5th generation of selected cattle were evaluated.

In this study, low RFI cattle were heavier at birth; however, no significant differences were found in body weight until the slaughter endpoint was reached. At slaughter, low RFI calves were heavier ($P = 0.02$) than high RFI cattle. Days on feed were similar between the high and low RFI groups; however low RFI cattle consumed more daily dry matter ($P < 0.02$), had a greater ADG ($P < 0.01$), and finished with a heavier feedlot weight ($P < 0.02$) as seen in Table 3. The only breed by treatment interaction for performance data was in days on feed, where High RFI AA cattle (158.1 d) were on feed longer ($P < 0.05$) than their Low RFI AA (138.4 d) counterparts. In contrast, High RFI BA cattle (150.7 d) did not differ ($P > 0.05$) from Low RFI BA (162.5d) in terms of days in the feedlot.

Even though the low RFI cattle consumed slightly more feed, the higher ADG and heavier slaughter weight should be more profitable to a producer and outweigh the slight increase in feed costs. In a number of other studies focused on RFI selection, low RFI cattle consumed less feed and had similar ADG, and finished with similar body weights compared to high RFI cattle. (Baker et al., 2006; Castro et al., 2007; Ahola et al., 2011; Gomes et al., 2014; Perkins et al., 2014). It has been suggested that some of the biological variation in RFI results from differences in digestion, heat increment of feeding and activity, or differences in heat production (Herd et al. 2004). RFI has also been shown to be correlated to heat (0.68) and methane (0.44) production in growing calves (Nkrumah et al., 2006).

Inconsistencies between this study and others could result from the fact that selection for RFI in their cattle came from selection, based on a feed intake trial, within a population and comparison of the extremes in RFI. In the current study, the cattle that were evaluated were a generation removed from those on the feed intake trial. Bulls of known RFI value were selected as the sires of the cattle studied and no RFI information was available on the cows used to generate the calves, thus the only selection pressure was from the sire.

Real-time ultrasound measurements collected at weaning, starting the feeding trial and ending the feeding trial (Table 4) showed that there were few differences in ultrasound measurements between treatment groups. Low RFI cattle had significantly less backfat thickness at weaning ($P < 0.01$) and larger ($P < 0.01$) ribeye areas (REA) at the end of the feeding trial compared to the high RFI group. There was also a tendency for low RFI cattle to have larger REA at the beginning of the feeding trial. No significant differences in intramuscular fat percentage (IMF) were noted across RFI selection at any of the measurement times.

Low RFI cattle entered the abattoirs with a heavier weight resulting in heavier HCW ($P = 0.02$; Table 5). No differences were seen in dressing percentage or backfat thickness. The low RFI cattle had a larger REA ($P < 0.01$) and lower USDA Yield Grade ($P < 0.01$). No RFI selection differences were found for KPH, maturity, marbling score, or USDA Quality Grade. Other studies have shown no response to selection for RFI in slaughter weight, HCW, backfat thickness, USDA Yield Grade, or USDA Quality Grade

(Baker et al., 2006; Castro et al., 2007; Ahola et al., 2011; Perkins et al., 2014; Reis et al, 2015). Gomes et al. (2014) selected for RFI in Nellore steers (n=72), and after a 70-d feed trial reported no differences in HCW, dressing percentage, REA, backfat thickness, IMF, marbling score, or product yield. In the current study, there were no effects on marbling score, lean and bone maturity, or USDA Quality Grade which is in agreement with previous research (Baker et al., 2006; Castro et al., 2007; Gomes et al., 2014). However, some studies have shown more efficient animals produce less intramuscular fat (Richardson et al., 2005; Welch et al., 2012; Nascimento et al., 2016).

Treatment effects on carcass yields are shown in Table 6. Low RFI cattle out performed high RFI cattle for all primal weights in the forequarter and hindquarter. This led to higher total primal weights ($P < 0.01$) and total primal yield percentages ($P < 0.01$) in low RFI cattle compared to their high RFI counterparts. Results from the cooking trial (Table 7) revealed no differences in thaw loss across the treatments, however there was a tendency for cook loss percentage ($P = 0.07$) in steaks from the low RFI cattle to be lower than high RFI. No significant RFI selection differences in either total loss or slice shear force were noted in the study. Therefore, selecting for RFI in bulls does not appear to have a negative impact on tenderness. These results are in agreement with Reis et al. (2015) who studied the effects of RFI selection on beef tenderness. Their study evaluated Warner Bratzler shear force in crossbred heifers (n=37) segregated into RFI groups, based on an intake trial, and found no differences in shear force.

Breed Effects

Braunvieh-sired (BA) calves were heavier at weaning ($P < 0.05$), entering the feedlot ($P < 0.05$) heavier and tended to be heavier at slaughter ($P = 0.08$) compared to

Angus-sired (AA) calves (Table 3). Feed intake tended to be lower ($P < 0.10$) in Angus-sired cattle compared to those from Braunvieh sires, which translated into higher gain:feed ($P < 0.01$) for Angus-sired cattle. In contrast, RFI was not different ($P > 0.46$) across breed type. A study evaluating the effects of different sire breeds on steers that had the same initial start weights and days on feed, found that Angus-sired steers had a higher ADG and heavier carcass compared to steers from Braunvieh sires (Gardner et al., 1996).

The effects of breed type on ultrasound measures are shown in Table 4. BA cattle tended ($P < 0.06$) to have a larger REA at weaning than AA cattle. As the cattle grew, the differences in REA across breed types became significant, with the BA cattle having larger REA at the start and end of the feeding trial. Additionally, BA cattle had lower ($P < 0.01$) IMF at all measurement times. This is consistent with the findings of Gregory et al. (1994), who reported that Angus-sired cattle had higher marbling scores than Braunvieh-sired cattle.

Breed differences for carcass traits revealed no significant differences for HCW, dressing percentage, 12^{th} rib backfat, KPH%, USDA Yield Grade or USDA Quality Grade (Table 5); however, carcasses from the BA cattle had a larger REA ($P < 0.04$) compared to those from AA cattle. Results from the USDA Germplasm Utilization (GPU) program, conducted over a 4-yr period, found that Angus cattle finished with 12^{th} rib adjusted backfat thickness of 1.17 cm and a 540 score (Average Choice) for marbling compared to Braunvieh cattle that finished with 0.46 cm adjusted backfat and a score of 485 (Low Choice) for marbling (Gregory et al., 1994). This suggests that Angus cattle will have a higher quality grade; however, the reduced backfat thickness, heavier carcass weights and higher dressing percentages of the Braunvieh carcasses translated to improved carcass Yield Grades.

Forequarter primal weights were similar (P $\geq$ 0.09) between sire breeds except that carcasses from the BA cattle yielded a heavier shoulder clod ($P < 0.03$) than carcasses from AA. However, in hindquarter fabrication showed that carcasses from BA cattle produced significantly heavier primal and subprimal weights (Table 4) which equated to a greater total primal weight ($P < 0.01$) and total primal yield percentage ($P < 0.01$) for the BA cattle compared to carcasses from AA.

Comparison of the cooking and tenderness data between the breeds (Table 7) showed no significant differences in thaw loss, however after cooking there was a higher cook loss and total loss percent (P < 0.04) for longissimus steaks from the BA cattle compared to those from the AA cattle. Steaks from the BA cattle had a greater degree of doneness ($P = 0.05$), compared to AA steaks; however, there was no difference noted for slice shear force determination between the two breed types.

Gender and Year Effects

In order to increase the number of cattle available for the study of both RFI selection and sire breed effects, data were collected on steers and heifers produced in two calf crops (Year 1 and 2). As expected, steers were heavier ($P < 0.01$) throughout the feeding period, had a higher feed intake ($P< 0.03$), and steers had lower RFI measures than heifers ($P < 0.01$). For carcass performance, steers had heavier carcasses ($P < 0.01$), lower backfat ($P < 0.01$), larger REA ($P < 0.01$), therefore having a higher total primal yield (%) ($P < 0.01$), and lower USDA Yield Grade ($P = 0.01$) than heifers. Although USDA Quality Grade did not differ across gender, heifers had higher ($P < 0.01$) skeletal maturity scores, indicative of greater skeletal ossification, than steers. Heifers were also more tender, due to their lower slice shear force than steers ($P < 0.01$). The differences in growth and composition noted between steers and heifers can be explained by differences in hormone production and the rate of maturation. At the slaughter age for this study, heifers would be post-puberal and their rate of skeletal growth would be slowing while their rate of fat accretion would be increasing compared to the steers. The growth rate and RFI differences in the heifers and steers are consistent with the compositional differences noted between the genders during the intake trial, as fatter heifers were slower growing and less efficient than leaner steers (Vaz et al., 2010).

Year differences for the various traits are reported in each table. Significant differences between years were expected due to management differences across the years. Cattle in year 1 were backgrounded on pasture for 4 months prior to the feed intake trial and were slaughtered and fabricated at the University of Georgia Meat Science and Technology Center. In contrast, year 2 cattle were backgrounded on pasture for 11 months prior to their feed intake and were slaughtered at Waldrep's Meat Plant in Ellijay, GA. These management differences across the two years resulted in age differences that impacted most of the growth and carcass traits measured in the study. Management changes across the years were implemented as cost saving steps and so that cattle in the second year of the study could be used in additional backgrounding research trials.

Conclusion

This study evaluated the growth performance and carcass traits of first generation offspring from Angus and Braunvieh bulls selected phenotypically for divergent RFI values. Although there were no significant differences in RFI between the RFI selection groups or breed types, improvements were found in other areas of growth performance. The study found that low RFI sired offspring had higher ADG, resulting in a heavier carcass and an improved yield grade. There were no differences in quality grade between treatment groups, with both groups averaging a low Choice grade. Tenderness was also not impacted by RFI selection. Therefore, phenotypic selection for RFI does not appear to negatively affect beef quality parameters. Since this study only included the first generation crosses of sires selected for differences in RFI, and improvements in growth performance and carcass traits were seen, further research is merited to determine the effects of phenotypic selection for RFI in a multi-generation study.

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Table 1. Sire RFI Values

Year 1		Year 2	
High RFI A	1.5	High RFI A	4.28
Low RFI A	-8	Low RFI A	-3.45
High RFI B	0.74	High RFI B	----
Low RFI B	-5.4	Low RFI B	-3.5

Table 2. Composition and Calculated Nutrient Content of the Diet

Ingredients	% As-fed Basis
Corn	55.7
Corn Gluten	24.4
Cottonseed hulls	10.0
Citrus Pulp	7.70
Mineral Premix*	2.00
Calculated Analysis	
Dry Matter, %	90.0
CP, %	11.8
TDN, %	83.0
Ca, %	0.19
P, %	0.36

*47.3% Sodium Bicarbonate, 37.8% Calcium Carbonate, 4.7% Ammonium Chloride, 4.7% Vitamin ADE, 4.7% Trace Mineral, 0.7% Bovalec

Table 3. Effects of phenotypic selection for residual feed intake (RFI) on growth and feedlot performance in Angus- and Braunvieh-sired cattle

	Sire Breed			RFI Selection			Gender			Year			RMSE
TRAIT	Angus n=35	Braun n=32	*P* < *F*	High n=36	Low n=31	*P* < F	Heifer n=32	Steer n=35	*P* < F	1 n=32	2 n=35	*P* < F	
Birth weight, kg	35.5	36.0	0.41	35.2	36.3	0.05	34.6	36.9	<0.01	35.5	36.0	0.37	4.52
Weaning weight, kg	227	246	0.01	235	238	0.71	222	252	<0.01	220	253	<0.01	58.6
Initial feedlot weight, kg	312	338	<0.01	320	330	0.25	307	343	<0.01	260	390	<0.01	68.3
Final feedlot weight, kg	525	547	0.08	521	551	0.02	505	568	<0.01	493	580	<0.01	97.0
Days on Feed, d	148	157	0.15	154	150	0.49	152	153	0.76	194	111	<0.01	20.3
Age at Slaughter, d	576	583	0.28	581	578	0.63	580	579	0.95	507	652	<0.01	20.8
Total feed intake, kg	1617	1731	0.07	1644	1704	0.34	1599	1749	0.03	1901	1447	<0.01	495
Average daily gain, kg/d	1.50	1.43	0.34	1.38	1.56	0.01	1.43	1.50	0.38	1.22	1.72	<0.01	0.58
Daily dry matter intake, kg/d	10.3	10.4	0.57	10.0	10.7	0.02	10.2	10.6	0.18	8.89	11.8	<0.01	2.28
Residual feed intake, kg	0.06	-0.10	0.46	-0.08	0.04	0.59	0.26	-0.31	0.02	-0.14	0.095	0.30	1.73
Gain:Feed, kg:kg	0.133	0.122	0.03	0.124	0.132	0.09	0.126	0.129	0.47	0.056	0.06	0.10	0.017
Feed:Gain, kg:kg	7.67	8.33	0.03	8.26	7.74	0.08	8.09	7.91	0.56	8.09	7.91	0.08	1.06

SE=RMSE/√n

Table 4. Effects of phenotypic selection for residual feed intake (RFI) on ultrasound measurements in Angus- and Braunvieh-sired cattle

	Sire Breed			RFI Selection			Gender			Year			RMSE
TRAIT	Angus n=35	Braun n=32	*P < F*	High n=36	Low n=31	*P* < F	Heifer n=32	Steer n=35	*P* < F	1 n=32	2 n=35	*P* < F	
Weaning fat thickness, cm	0.36	0.33	0.32	0.38	0.30	<0.01	0.36	0.33	0.21	0.30	0.38	0.01	0.03
Weaning ribeye area, cm^2	45.8	49.0	0.06	47.7	47.1	0.98	43.9	51.0	<0.01	43.9	51.0	<0.01	0.98
Weaning intramuscular fat,%	3.30	2.80	<0.01	3.10	3.00	0.22	3.00	3.10	0.63	2.70	3.40	<0.01	0.42
On feed fat thickness, cm	0.33	0.36	0.51	0.36	0.33	0.24	0.33	0.33	0.99	0.30	0.36	0.10	0.04
On feed ribeye area, cm^2	52.9	57.4	0.02	53.5	56.8	0.09	52.3	58.1	0.01	47.7	63.2	<0.01	1.06
On feed intramuscular fat, %	4.10	3.40	<0.01	3.70	3.80	0.67	3.60	3.90	0.07	3.70	3.70	0.93	0.59
Off feed fat thickness, cm	1.19	1.02	<0.01	1.12	1.09	0.47	1.12	1.09	0.32	1.12	1.09	0.29	0.06
Off feed ribeye area, cm^2	84.5	89.7	0.04	83.9	90.3	<0.01	83.2	91.0	<0.01	85.2	89.0	0.18	1.41
Off feed intramuscular fat, %	5.50	4.40	<0.01	4.90	5.00	0.75	4.90	5.00	0.53	4.90	5.00	0.87	0.68

SE=RMSE/√n

Table 5. Effects of phenotypic selection for residual feed intake (RFI) on carcass traits in Angus- and Braunvieh-sired cattle

	Sire Breed			RFI Selection			Gender			Year			RMSE
TRAIT	Angus n=35	Braun n=32	*P* < *F*	High n=36	Low n=31	*P* < F	Heifer n=32	Steer n=35	*P* < F	1 n=32	2 n=35	*P* < F	
Slaughter weight, kg	525	547	0.08	521	551	0.02	505	568	<0.01	493	580	<0.01	97.0
Hot carcass weight, kg	316	330	0.08	314	332	0.02	303	344	<0.01	311	335	<0.01	60.7
Dressing percentage, %	60.4	60.5	0.78	60.5	60.4	0.82	60.2	60.7	0.35	63.1	57.8	<0.01	1.75
Actual 12th rib back-fat, cm	0.97	0.91	0.37	0.91	0.97	0.56	0.99	0.91	0.18	0.99	0.89	0.04	0.04
Adjusted 12th rib back-fat, cm	0.99	0.97	0.36	0.97	0.99	0.65	1.04	0.91	<0.01	1.02	0.94	0.05	0.06
Ribeye area, cm^2	78.7	83.9	0.04	76.1	85.8	<0.01	77.4	85.2	<0.01	79.4	83.2	0.10	1.41
Kidney, pelvic, and heart fat, %	1.90	2.00	0.30	1.90	2.00	0.80	2.10	1.90	0.11	2.20	1.70	<0.01	0.39
USDA Yield Grade	2.6	2.5	0.21	2.7	2.4	<0.01	2.6	2.5	0.39	2.6	2.5	0.30	0.35
Lean maturity*	156	162	0.08	159	158	0.80	160	158	0.65	163	155	0.02	12.8
Bone maturity*	153	156	0.46	155	154	0.75	165	144	<0.01	155	154	0.86	13.9
Average maturity*	154	159	0.09	157	156	0.68	162	151	<0.01	159	154	0.10	9.52
Marbling score**	492	470	0.32	478	485	0.76	494	469	0.29	464	499	0.11	77.0
USDA Quality Grade***	6.4	6.2	0.37	6.3	6.3	0.98	6.4	6.2	0.54	6.1	6.5	0.16	0.86

* 100 = A maturity

** 400 = small; 500 =modest

*** 6 = low Choice

SE=RMSE/√n

Table 6. Effect of phenotypic selection for high/low residual feed intake (RFI) on carcass primals and yields in Angus- and Braunvieh-sired cattle

	Sire Breed			RFI Selection			Gender			Year			RMSE
TRAIT	Angus n=35	Braun n=32	*P* < *F*	High n=36	Low n=31	*P* < F	Heifer n=32	Steer n=35	*P* < F	1 n=32	2 n=35	*P* < F	
Chuck roll, kg	7.75	8.11	0.16	7.61	8.24	0.03	7.25	8.61	<0.01	6.52	9.33	<0.01	2.2
Shoulder clod, kg	8.61	9.20	0.03	8.65	9.11	0.13	8.34	9.47	<0.01	7.93	9.83	<0.01	2.13
Mock tender, kg	1.18	1.22	0.09	1.13	1.27	<0.01	1.13	1.27	<0.01	1.13	1.27	<0.01	0.32
Ribeye roll, kg	4.80	5.03	0.11	4.67	5.16	<0.01	4.58	5.25	<0.01	4.89	4.98	0.55	1.15
Brisket, kg	4.21	4.12	0.68	3.81	4.48	<0.01	3.76	4.58	<0.01	3.35	4.98	<0.01	1.53
Forequarter primal wt., kg	26.6	27.7	0.15	26.0	28.2	<0.01	25.1	29.1	<0.01	23.7	30.5	<0.01	40.9
Forequarter primal yield, %*	16.7	16.8	0.76	16.4	17.0	<0.01	16.5	17.0	0.02	15.3	18.1	<0.01	0.71
Tenderloin, kg	2.08	2.22	0.09	2.04	2.27	<0.01	2.04	2.27	<0.01	2.36	1.90	<0.01	0.48
Strip loin, kg	3.94	4.48	<0.01	4.03	4.39	<0.01	3.90	4.48	<0.01	4.58	3.81	<0.01	1.04
Top sirloin, kg	4.30	4.67	0.03	4.39	4.62	0.11	4.17	4.80	<0.01	4.03	4.98	<0.01	1.28
Knuckle, kg	4.67	5.12	<0.01	4.53	5.21	<0.01	4.53	5.25	<0.01	5.53	4.21	<0.01	1.26
Inside round, kg	7.02	7.75	<0.01	7.02	7.75	<0.01	6.66	8.11	<0.01	7.93	6.89	<0.01	1.68
Flat, kg	5.03	5.48	<0.01	5.03	5.48	<0.01	4.80	5.71	<0.01	5.66	4.85	<0.01	1.12
Eye round, kg	1.86	1.99	0.06	1.81	2.04	0.01	1.68	2.17	<0.01	2.17	1.68	<0.01	0.66
Flank, kg	0.77	0.77	0.96	0.72	0.82	<0.01	0.72	0.82	0.018	0.72	0.77	0.27	0.23
Hindquarter primal wt., kg	30.7	33.5	<0.01	30.5	33.6	<0.01	29.4	34.7	<0.01	35.0	29.1	<0.01	6.37
Hindquarter primal yield, %*	19.5	20.4	<0.01	19.5	20.4	0.01	19.7	20.2	0.11	22.5	17.4	<0.01	1.20
Total primal wt., kg	57.3	61.1	0.01	56.7	61.7	<0.01	54.6	63.8	<0.01	58.7	59.7	0.49	11.03
Total primal yield, %*	36.1	37.2	0.01	35.9	37.4	<0.01	36.1	37.2	0.01	37.8	35.4	<0.01	1.41

* Expressed as a percentage of hot carcass weight
SE=RMSE/√n

Table 7. Effect of phenotypic selection for high/low residual feed intake (RFI) on cook data in Angus and Braunvieh sired cattle

	Sire Breed			RFI Selection			Gender			Year			RMSE
TRAIT	Angus n=35	Braun n=32	*P < F*	High n=36	Low n=31	*P* < F	Heifer n=32	Steer n=35	*P* < F	1 n=32	2 n=35	*P* < F	
Frozen weight, g	306	336	0.01	311	331	0.09	300	342	<0.01	320	322	0.88	40.9
Thaw weight, g	303	333	0.01	309	327	0.11	298	338	<0.01	316	319	0.79	40.7
Initial temperature, C	6.8	7.5	0.20	7.3	7.0	0.53	7.6	6.7	0.09	6.2	8.1	<0.01	1.71
Final temperature, C	70.8	70.6	0.71	70.2	71.2	0.16	70.3	71.1	0.29	70.8	70.6	0.70	2.40
Cook time, min	10.3	11	0.22	11	10.3	0.24	10.3	11	0.32	9.2	12.1	<0.01	2.14
Cook weight, g	258	275	0.13	255	278	0.04	252	281	0.02	276	258	0.10	38.7
Degree of doneness*	4.0	4.3	0.05	4.1	4.2	0.82	4.1	4.2	0.81	4.3	4.1	0.23	0.64
Slice shear force, kg**	16.0	17.7	0.20	17.5	16.3	0.33	15	18.8	<0.01	16.2	17.6	0.24	4.54
Thaw loss, %	0.83	0.92	0.73	0.67	1.08	0.11	0.65	1.1	0.11	1.13	0.62	0.05	0.92
Cook loss, %	15.0	17.4	0.04	17.2	15.1	0.07	15.3	17.1	0.16	12.9	19.5	<0.01	4.13
Total loss, %	15.7	18.2	0.04	17.8	16.0	0.14	15.9	18.0	0.10	13.9	20.0	<0.01	4.26

* Degree of doneness, 4 = medium

** Slice shear force was analyzed with degree of doneness as a covariate

SE=RMSE/√n

CHAPTER 4

CONCLUSION

This study evaluated the growth performance and carcass traits of first generation offspring from Angus and Braunvieh bulls selected phenotypically for divergent RFI values. Although there were no significant differences in RFI between the RFI selection groups or breed types, improvements were found in other areas of growth performance. The study found that low RFI sired offspring had higher ADG, resulting in a heavier carcass and an improved yield grade. There were no differences in quality grade between treatment groups, with both groups averaging a low Choice grade. Tenderness was also not impacted by RFI selection. Therefore, phenotypic selection for RFI does not appear to negatively affect beef quality parameters. Since this study only included the first generation crosses of sires selected for differences in RFI, and improvements in growth performance and carcass traits were seen, further research is merited to determine the effects of phenotypic selection for RFI in a multi-generation study.