THE RELATIONSHIP OF FEED EFFICIENCY WITH PERFORMANCE, ULTRASOUND, CARCASS, AND NON-CARCASS TRAITS IN BEEF CATTLE

A Dissertation

by

FLÁVIO RODRIGUES BORGES RIBEIRO

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

DOCTOR OF PHILOSOPHY

May 2009

Major Subject: Animal Science

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Approved by:

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ABSTRACT

The Relationship of Feed Efficiency with Performance, Ultrasound, Carcass, and Non-Carcass Traits in Beef Cattle. (May 2009)

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The first objective was to estimate total internal fat in beef cattle based on a technique that measures kidney fat (**uKFd**) using real-time ultrasound (**RTU**). Data were obtained from 109 cattle from four studies, and animals were scanned 7 d preslaughter for uKFd and ultrasound backfat thickness. At slaughter carcass kidney fat depth (**cKFd**), KPH weight, and total internal fat were measured. The second objective was to characterize residual feed intake (**RFI**) in finishing cattle fed high grain diets and to examine the relationships with growth, ultrasound, carcass, non-carcass, and tenderness traits in two studies involving Santa Gertrudis (n = 114) steers, and Angus bulls (n = 16) and heifers (n = 16). In both experiments, RFI was calculated as the difference between actual DMI and predicted DMI.

Results for the first objective indicated that RTU can be used to estimate cKFd, KPH weight and total internal fat (**IFAT**). Prediction equations developed to predict IFAT had R^2 that ranged from 0.65 to 0.97 ($P < 0.05$). Results for the second objective indicate that RFI was not correlated with ADG, but was positively correlated with DMI

and feed conversion ratio. Carcass 12th-rib fat depth was positively correlated with RFI in Santa Gertudis steers, such that steers with low RFI were leaner than steers with high RFI. Residual feed intake was not correlated with carcass or non-carcass composition traits in Angus bulls and heifers. Marbling and tenderness traits were not associated with RFI. Results from these studies indicate that we are able to measure IFAT with RTU, and that beef cattle producers can utilize RFI to identify animals that are more efficient with minimal impacts on growth, carcass composition and tenderness.

DEDICATION

I dedicate this dissertation in the memory of my father, Murilo Borges Ribeiro, who has always been my source of inspiration throughout this process. Also to my mom, Sandra Rodrigues Borges Ribeiro, who has made all my dreams come true including this one of finishing my Ph.D. My mom has always been there for me and her love and support has helped me to overcome challenges and frustrations that are part of life. "*All your dreams can come true if you have the courage to pursue them*". Walt Disney

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TABLE OF CONTENTS

CHAPTER Page

LIST OF FIGURES

LIST OF TABLES

TABLE Page

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

The major objective of the beef cattle industry is to produce high-quality meat products in a profitable manner. For a long period of time, genetic improvement has mainly focused on selection of output traits such as fertility, live weight, and recently carcass and meat quality traits. There has been little emphasis on selection programs to reduce feed inputs to improve profitability (Arthur et al., 2001b). Feeding animals is the major cost in all animal production systems (Herd et al., 2003). Selection of animals that are more efficient will increase profitability by decreasing the amount of feed a animal needs for a given level of performance.

In order to select cattle for feed efficiency, genetic variation in feed intake needs to exist. Archer et al. (1999) reported that there is genetic variation in feed efficiency in beef cattle and that feed intake (**FI**) is a moderately heritable. Robinson and Oddy (2004) estimated heritability of FI in finishing cattle to be 0.27. Arthur et al. (2001a, b), and Schenkel et al. (2004) reported higher heritabilities estimates for FI of 0.39, 0.48 and 0.44, respectively, in growing beef cattle.

Feed conversion ratio has been used as a trait to determine feed efficiency in beef cattle. Studies by Arthur et al. (2001a, b), and Schenkel et al. (2004) reported heritability estimates for FCR of 0.29, 0.46 and 0.37, respectively, in beef cattle. Arthur et al.

This dissertation follows the style of Journal of Animal Science.

(2001a, b), Herd and Bishop (2000) and Schenkel et al. (2004) evaluated the use of FCR to improve feed efficiency. Results from these studies showed that FCR was strongly correlated to ADG, and mature body size. Therefore, selection for improved FCR would increase mature cow size, and as a result maintenance requirements would be increased.

Koch et al. (1963) was the first group to propose residual feed intake (**RFI**) as a method to measure feed efficiency in beef cattle. Residual feed intake is the measurement of actual feed intake minus expected feed intake based on growth rate and body size of the animal. This means that an animal with a negative value (low RFI) is more efficient than an animal with a positive value (high RFI). Several studies have shown that there is sufficient genetic variation in RFI to allow for selection to improve efficiency (Archer et al., 1999; Arthur et al., 2001b; Schenkel et al., 2004).

Several studies have demonstrated the heritability for RFI to be between 0.16 and 0.43 (Herd and Bishop 2000; Arthur et al., 2001a, b; Schenkel et al., 2004). Residual feed intake is not related to growth traits. So selecting animals for low RFI has the potential to improve the efficiency of beef production by reducing feed intake without changing genetic merit for growth rate, or mature cow size (Herd and Bishop, 2000; Herd et al., 2003).

When selecting for improved feed efficiency, regardless of trait used, it is important to understand the relationships with economically important output traits, such as carcass characteristics and carcass quality traits (tenderness). Muscle is the most important tissue in meat animals, because the highest values are from carcasses with higher lean percentage. Excess fat deposition in subcutaneous and intermuscular depots

is undesirable due to price discounts based on yield grade. On the other hand, intramuscular fat or marbling, is the fat depot that impacts quality grade, which determines how much premium a carcass will receive. Marbling is also important in order to enhance eating quality. Tenderness has been reported to be the most desirable characteristic in beef by consumers.

Real-Time Ultrasound to Measure Body Composition in Beef Cattle

The use of ultrasound to measure body composition in beef cattle started in the 1950s. The first publication of researchers attempting to measure body composition in live beef cattle was in 1956. Temple et al. (1956) used a somascope to measure backfat thickness in beef cattle. Thereafter, many other researchers throughout the world started doing research with ultrasound to predict body composition. The first instruments used were called amplitude mode (A-mode), and were capable of measuring fat and muscle depth. The second instruments were called brightness mode (B-mode), and were capable of measuring fat thickness and *longissimus* muscle area. The third advancement in instrumentation used to measure carcass traits in beef cattle, which is widely used today, was real-time ultrasound (**RTU**; a form of B-mode). This instrument is capable of measuring subcutaneous fat (**SC**) thickness and *longissimus* muscle area in real time.

Real-time ultrasound is a non-invasive technique to measure body composition in live animals and has been used for genetic evaluation, management and research purposes for the past 20 years. Several studies have been conducted to evaluate the accuracy of both ultrasound technicians and instruments. Perkins et al. (1992b) compared results from two technicians and found that ultrasound and carcass traits

measurements were not different (P > 0.10) between technicians. However, both technicians overestimated ultrasound backfat thickness (**uBF**) and underestimated ultrasound ribeye area (**uREA**) compared to carcass measurements. Hassen et al. (2001) compared two ultrasound machines (Aloka 500V and Classic Scanner 200) to predict percentage intramuscular fat in live cattle and concluded that both ultrasound machines could accurately predict the percentage of intramuscular fat. The overall R^2 were 0.71 and 0.67 and the RMSE were 0.87 and 0.89% for the Aloka 500V and the Classic Scanner 200 instruments, respectively.

Fat thickness at the 12-13th rib over the *longissimus* muscle is the most commonly used trait to measure carcass fat composition in live animals. Stouffer et al. (1961) found correlations between ultrasound and carcass measurements of fat depth were between 0.04 and 0.92. Houghton and Turlington (1992) reported correlations for uBF with carcass measurements between 0.20 and 0.94. Greiner et al. (2003a) reported correlations between carcass fat thickness (**cBF**) and uBF of 0.89. Perkins et al. (1992b) reported correlations of 0.90 for successive ultrasound measures of uBF on the same animal by the same technician. May et al. (2000) found a lower correlation between cBF and uBF of 0.81. Hamlin et al. (1995) and Rouse et al. (1993) found similar correlations between uBF and cBF of 0.86 and 0.84, respectively. Tait (2002) found a correlation of 0.68 between cBF and uBF. Ribeiro et al. (2006b) reported an overall correlation of 0.80 between cBF and uBF. Subcutaneous fat depth is one of the most accurate and repeatable traits that can be measured with RTU.

The prediction of carcass fat depth of live animals may be under- or overestimated by ultrasound. This statement is supported by results from several studies. Stouffer et al. (1961) reported that the underestimation of fat depth may be partially due to the amount of pressure against the hide with the transducer. Greiner et al. (2003a) reported that ultrasound estimates of carcass fat depth was overestimated in leaner cattle and overestimated in fatter cattle compared to carcass data collected at slaughter. Perkins et al. (1992a) found that uBF was within 0.25 cm of cBF 70% of the time and ultrasound measurements of fat depth were more accurately predicted in thinner cattle. Brethour (1992) reported the average absolute difference between two consecutive ultrasound measurements was 1.57 mm, but that the discrepancies were larger when backfat thickness was greater. Cattle with backfat thickness of < 10 mm averaged 1.43 mm absolute difference and cattle with backfat > 10 mm averaged 1.89 mm.

Ultrasound measurements of the ribeye area (**REA**) are typically collected as a cross sectional image between the 12 and 13th ribs. *Longissimus* muscle area is the most common estimate of total carcass muscle, and is used in yield grade calculation (Williams, 2002). In a review of the applications of ultrasound, it was reported that correlations between uREA and carcass REA (**cREA**) ranged from 0.20 to 0.94 (Houghton and Turlington, 1992). Greiner et al. (2003a) reported a correlation coefficient between uREA and cREA of 0.86 (collected 5 days prior to slaughter by a BIF certified technician) with ultrasound overestimating the cREA by 0.71 cm^2. Ribeiro et al. (2006b) found an overall correlation between cREA and uREA of 0.66. Griffin et

al. (1999) found a correlation coefficient between cREA and uREA of 0.52. This lower correlation value reported by Griffin et al. (1999) was likely to be due to the evaluation method that consisted of collection of the ultrasound images following exsanguination, before hide removal. May et al. (2000) compared ultrasound measurements of LM area taken one day prior to slaughter and at chain speed after exsanguination with cREA and found correlations of 0.61 and 0.55, respectively.

According to Greiner et al. (2003a), ultrasound measurements tend to underestimate cREA in leaner cattle (< 0.51 cm cBF) and overestimate cREA in fatter cattle (> 1.27 cm cBF). They also reported that ultrasound overestimated cREA in light-muscled steers (< 77.4 cm^2 cREA) and underestimated cREA in heavy-muscled steers (> 83.9 cm^2 cREA). Perkins et al. (1992a) reported correlation coefficients of 0.60 between ultrasonic and carcass measurements of REA, and found that ultrasound more accurately predicted cREA in more lightly muscled cattle. Perkins et al. (1992a) also found that live weight was a highly significant source of variation for LM area measurements.

Intramuscular fat or marbling is a trait that has significant economic importance, because premiums are paid for animals that grade Choice or higher, and also because it enhances eating quality of beef. Images are collected longitudinally between the 12^{th} and 13^{th} ribs. Considerable effort has gone into development of methodologies to more accurately measure the percentage of intramuscular fat (**IMF**) in live animals using ultrasound. Rouse et al. (1992) used a technique to measure intramuscular fat in live cattle that includes tissue characterization using a histogram that determines the pixel count in each of 64 shades of gray. They found that the 64 shades of gray accounted for

41 to 46% of the variation in marbling score and between 34 and 44% of the variation in percent ether extract. Brethour (1990) used a system of speckles in tomograms of LM area over the 12-13th rib interface to measure marbling and found that the speckle score was highly correlated with marbling score ($P < 0.001$). The speckle scores in live animals classified carcasses as Select or Choice with 77% accuracy (Brethour, 1990). Izquieredo et al. (1994) developed several models to predict intramuscular fat in live animal (animals were slaughtered no more than three days after scanning) with ultrasound in bulls and steers and reported a correlation between live animal evaluation and actual percent of intramuscular fat (using n-hexane chemical extraction) of 0.67. Ribeiro et al. (2006b) found overall simple correlations between ultrasound IMF and carcass marbling score of 0.48.

Hassen et al. (1999) reported overall repeatability of ultrasound IMF was 0.63 ± 0.03. Brethour (2000) assessed the accuracy of ultrasound to predict the proportion of cattle grading choice, and found that accuracies of prediction were lower in early stages (64 %) than later stages (75 %). Hassen et al. (1999) suggested that three to four images should be collected and averaged to more accurately predict intramuscular fat percentage with ultrasound. Hassen et al. (2001) compared accuracies of two instruments to predict IMF, and found that both machines could accurately predict percent intramuscular fat.

Numerous techniques have been investigated to predict carcass and non-carcass composition in the live animal including RTU, computer tomography (**CT**), and nuclear magnetic resonance imaging (**NMR**). Lambe et al. (2003) used CT to measure total body tissue in sheep, by taking cross-sectional scans at seven different locations. Results

demonstrated that five reference scans were sufficient to enable accurate predictions of total weights of bone, muscle and fat (carcass and internal). The R^2 values for total weights of carcass fat, muscle, bone, internal fat, SC, and intermuscular fat were 0.99, 0.81, 0.58, 0.77, 0.96, and 0.95, respectively. Lambe et al. (2006) also used CT to estimate total dissectible internal fat (**IFAT**) weight in sheep, using two cross-sectional images were taken at the hip and loin. Results showed that total internal fat can be predicted with moderate accuracy (adjusted $R^2 = 0.62$). Teixeira et al. (2008) used RTU to estimate intermuscular, kidney, pelvic, omental, mesenteric and total body fat in goats ($R^2 = 0.89$, 0.87, 0.71, 0.91, 0.80, and 0.92, respectively). Recently Ribeiro et al. (2008) reported on an ultrasound technique to estimate dissectible IFAT in beef cattle. Ribeiro et al. (2008) reported that ultrasound kidney fat depth (**uKFd**) alone and uBF plus uKFd accounted for 89 and 92% of the variation in IFAT, respectively.

The use of RTU to measure body composition in beef cattle has greatly increased in the past years and still growing. This technology is the best available to measure body composition in beef cattle. Although, other instruments are more accurate (CT and NMR), these instruments require sedation of the animal to acquire accurate images and are more expensive. Regardless of the imaging instrument used, it is important to use well trained technician in order to obtain accurately and repeatable results.

Factors That Affect Body Composition in Beef Cattle

Growth of animals is often quantified as an increase in size, which involves weight, height, width, and girth. The most common measurements of animal growth are weight and height (hip height). Tissue development is defined as individual cellular

changes or changes in form which allow tissue and organs to assume different roles and functions. Growth of tissue does not happen without development. Tissue growth may occur from hyperplasia (increase in cell number), hypertrophy (increase in cell size), or both. Tissue growth is primarily due to hyperplasia during prenatal phase and primarily by hypertrophy during postnatal development. Muscle tissue growth also occurs by satellite cell replication and incorporation, however, fat can still grow by hyperplasia. When animal postnatal growth to maturity is plotted against age, the growth curve is typically sigmoidal.

Organs and tissues that are critical for life are deposited in earlier stages than organs and tissues that are not critical (Jones, 2004), with nervous tissues receiving first priority followed by bone, muscle and fat. Muscle matures earlier than fat and has nutrient priority (Rouse et al., 2003). As animals grow, fat accumulates and is deposited differentially in various depots.

Numerous factors can affect the rate and composition of growth in animals, including nutrition, genetics, environment, mature size, sex, hormones, backgrounding, compensatory gain, and others. A good plane of nutrition is required in order fro animals to express their full genetic potential. The proportion of body fat has an important role in determining the composition of growth and thus energy requirements of beef cattle (Geay, 1984). Restriction of energy intake slows muscle and adipose tissue deposition rates, with fat being the tissue most affected (Jones, 2004).

Meat animals have shown dramatic phenotypic changes over the years due to focus on selection for rapid early growth of muscle tissue. Selection for rapid early

growth to improve animal performance and to respond to consumer demands for leaner animal products has been a key emphasis of breeding programs in past several decades. Perry and Arthur (2000) examined differences in, fat partitioning in tissue growth in Angus cattle divergently selected for yearling growth rate. Cattle selected for fast growth had significantly more muscle, bone and visceral tissues, and less total fat than cattle selected for slow growth when compared at a constant EBW of 360 kg. Breedtype also influences growth, with dairy breeds depositing a higher proportion of their total fat internally and a lower proportion subcutaneously than beef breeds (Kempster, 1981).

According to Owens et al. (1993), mature size is considered the point at which muscle mass reaches a maximum, and Jones (2004) defined mature size as the point at which weight change with time is minimal and there is little or no change in fat content. Owens et al. (1993) reported that maximum body size is genetically determined and it can be altered by nutritional and hormonal factors. Gender of animals has a profound effect on muscle and fat growth patterns (Jones, 2004). Bulls have more muscle in the neck and thoracic region and steers have more muscle in the posterior region than bulls. Heifers deposit fat sooner than steers and steers sooner than bulls. Compensatory gain occurs when animals are placed on a high plane of nutrition following a period of growth restriction. When animals are subjected to these production scenarios , the rate and efficiency of growth is enhanced compared to growth patterns of animals that are not restricted (Gerrard and Grant, 2003; Jones, 2004; Owens et al., 1993). Carstens et al. (1991) reported that the impact of compensatory growth on changes in deposition of fat and protein were more evident in non-carcass than in carcass tissue.

Priority for deposition of the kidney fat occurs first, followed by intermuscular fat, subcutaneous fat, and intramuscular fat (Gerrard and Grant, 2003; Jones, 2004). In a review of growth and development of adipose tissue, Robelin (1986) reported that fat was recognizable in the kidney and intermuscular depots in 5 and 20 kg fetuses, but that subcutaneous fat depots were not present until just before birth. Robelin (1986) reported that the proportion of fat in the empty body decreased from 6.5% at birth to 5% at 120 kg live weight, which demonstrates that the relative rate of fat deposition is low during early postnatal period. Thereafter, the rate of fat tissue deposition increased rapidly with empty body fat reaching 26% at 700 kg EBW. Robelin (1986) demonstrated that fat partitioning between depots changed greatly during growth with an increasing proportion of omental fat (7-13% of EBF), KPH (4-9% of EBF), and SC (6-17% of EBF), while intermuscular fat decreased (59-41% of EBF). Tatum et al. (1986) reported similar results with increasing total carcass separable fat weight, the proportion of intermuscular fat declined slightly, SC increased and the percentage of KPH remained relatively constant in feeder cattle from different frame size and muscle thickness.

Frame size also can affect the proportion of carcass and non-carcass fat. Dolezal et al. (1993) reported that large-frame steers had a lower percentage of SC and a higher percentage of KPH fat compared to medium- and small-frame steers, and that light-muscle steers deposited a higher percentage of KPH fat when compared at a constant backfat thickness of 13.5 mm. Cianzio et al. (1982) did not find differences in fat depots between small- and large-frame steers. The first study used beef and dairy crossbred steers and animals were fed to a constant fat thickness, while the later used continental

breed crosses and were slaughtered at random, which could be the reason why the differences were not expressed.

The development of models to predict carcass and non-carcass composition in beef cattle has been examined by numerous researchers (Fox and Black, 1984; Oltjen et al., 1986; Sainz and Hastings, 2000; Tedeschi et al., 2004; McPhee et al., 2008). The assessment of carcass composition in the live animal with RTU has been discussed previously. Fewer studies have evaluated the use of non-invasive techniques to predict composition of non-carcass tissues. Sainz and Hastings (2000) developed a model to predict total body fat and to partition fat into four depots: visceral, intermuscular, SC, and intramuscular fat. McPhee et al. (2008) used published data to develop equations to predict growth of total visceral and SC fat depots. In order to utilize these equations, methods to estimate these fat depots in the live animal are needed. Current methods are available to predict the SC and IMF fat depots fairly accurately with RTU in beef cattle (Wilson, 1992; Greiner et al., 2003b; Ribeiro et al., 2006b), however it was not until recently that methods to predict IFAT in live cattle have been proposed. Ribeiro et al. (2008) developed a technique to estimate KPH and IFAT in beef cattle using RTU. McPhee et al. (2008) reported that SC fat could be predicted from cBF ($R^2 = 0.88$) and visceral fat from KPH ($R^2 = 0.95$) in beef cattle.

Murphey et al. (1960) reported that cBF and percent KPH fat were each correlated with wholesale, bone-in, and boneless retail cuts (-0.68, -0.83, -0.79, and -0.42, -0.66, -0.63, respectively). When cBF and percent KPH fat were added the

correlation with wholesale, bone-in, and boneless retail cut was even higher (-0.78, -.98, -0.94, respectively).

Factors That Affect Tenderness in Beef

Consumers consider tenderness to be the single most important component of meat quality. Numerous pre-harvest (genetics, nutrition, etc) and post-harvest (electric stimulation, calpastatin activity, postmortem aging, etc) factors have been shown to influence tenderness.

Tenderness increases as time postmortem increases (Wheeler and Kohmaraie, 1994; Morgan et al., 1993; and Wulf et al., 1996), which is a result of postmortem proteolysis caused by the calpain system (Wheeler and Koohmaraie, 1994). The calpain system has three components: a low-calcium-requiring (10μM) enzyme (μ-calpain), a high-calcium-requiring (200-300 μM) enzyme (m-calpain) and an inhibitory enzime (calpastatin), which specifically inhibits the activity of the calpains (Koohmaraie, 1992; Koohmaraie et al., 1995). In postmortem muscle, the free calcium concentrations are sufficient to activate only μ-calpain. Calpastatin is the major inhibitor of the calpain system in postmortem muscle (Koohmaraie, 1992). Several studies have demonstrated that calpastatin activity is negatively correlated with tenderness (Whipple et al., 1990; Shackelford et al., 1994; Wulf et al., 1996) and highly heritable (Shackelford et al., 1994).

Numerous studies have examined the effect of breedtype on tenderness in beef cattle. Most research have demonstrated that *Bos indicus*-influenced breedtypes produce less tender beef than *Bos taurus* breedtypes (Crouse et al., 1989; Shackelford et al.,

1991, 1995; and Bidner et al., 2002). The differences in tenderness between these two breedtypes are more pronounced as the percentage of *Bos indicus* inheritance increased (Crouse et al., 1989). *Bos indicus* cattle have higher levels of calpastatin (Shackelford et al., 1991; O'Connor et al., 1997; Pringle et al., 1997), which could explain why *Bos indicus*-influenced cattle are less tender than *Bos taurus*-influenced cattle. Generally, the difference in tenderness due to breedtype is reduced as postmortem aging increases.

Plane of nutrition and days on feed can have an impact on meat quality and tenderness. Studies by Aberle et al. (1981) and Miller et al. (1987) demonstrated that as days on a high-energy diet prior to slaughter increased that tenderness also increased. Aberle et al. (1981) found that tenderness was not further improved by feeding cattle a high-energy diet for more than 70 d.

Metabolic modifiers are defined as compounds that are either fed, injected, or implanted in animals to improve gain, efficiency, meat yield, visual meat quality, extend shelf life, and improve meat palatability (Dikeman, 2007). These compounds are widely used in the beef cattle industry in order to improve profitability, however sometimes they can have detrimental effects on carcass quality traits. Some of the most common metabolic modifiers used in the beef industry are anabolic steroids and β-adrenergic agonists (**BAA**). There have been numerous studies that have looked at the effects of anabolic steroids on carcass-quality traits. There have been some inconsistencies; but most can be explained by the frequencies, doses and time of exposure of the implants used. Some studies show that use of aggressive strategies of implants decrease

tenderness (Samber et al., 1996; Roeber et al., 2000). Platter et al. (2003) found that implanting steers at branding or weaning did not affect tenderness (Platter et al., 2003).

Since the approval of BAA for use in beef cattle, research has been conducted to evaluate their beneficial and detrimental effects on carcass quality and palatability. The two BAA approved for use in beef cattle are Zilpaterol hydrochloride (**ZH**) and Ractopamine hydrochloride (**RH**). Avendaño-Reyes et al. (2006) compared ZH and RH in beef cattle and found that both BAA reduced tenderness. In a review, Brooks et al. (2008) found that ZH produced less tender beef as measured by Warner-Bratzler shear force (**WBSF**), slice shear force and sensory panel. Gruber et al. (2006) reported that feeding RH to different biological types of cattle increased WBSF, however the magnitude of the increase in WBSF due to RH was more pronounced among Brahman crossbreds than in Continental or British steers.

Electric stimulation (**ES**) and postmortem aging are two post-harvest strategies that have a large impact in tenderness. Electric stimulation hastens the onset of rigor by increasing glycogen breakdown to lactic acid and reducing pH. Electric stimulation causes resolution of rigor much faster, which prevents cold shortening and hastens the aging period quicker in order to take more advantage of the μ-calpain muscle degradation. Research has demonstrated that ES improves tenderness (Savell et al., 1977; McKeith et al., 1980; Wheeler et al., 1990). Postmortem aging for 14 d also improve tenderness (Wheeler et al., 1990; Shackelford et al., 1995).

It is important to understand how animals grow in order to maximize production, efficiency, and to produce a high quality product. Development of methods to more

accurately estimate carcass and non-carcass composition of live animals would be useful to implement individual cattle management systems to predict energy requirements and days on feed in order to reduce excess fat deposition and maximize profitability.

Measures of Feed Efficiency

There are many ways to measure feed efficiency in beef cattle. The most common are feed conversion ratio (**FCR**), defined as the amount of DMI per unit of gain (DMI ÷ADG); partial efficiency of growth (**PEG**), defined as the ratio of ADG to DMI expected for growth; Kleiber ratio (**KR**), defined as ADG per unit of metabolic body weight; RFI or net feed intake (**NFI**), defined as the difference between actual feed intake and expected feed intake.

In order to select cattle for feed efficiency, genetic variation needs to exist. Archer et al. (1999) reported that there is genetic variation in feed efficiency in beef cattle and that FI was a moderately heritable. Robinson and Oddy (2004) estimated heritability for FI in finishing cattle of 0.27. Arthur et al. (2001a, b), and Schenkel et al. (2004) reported higher heritabilities estimates for FI of 0.39, 0.48 and 0.44, respectively.

Koch et al. (1963) were the first group to propose residual feed intake as a method to measure feed efficiency. Residual feed intake is the measurement of actual feed intake minus expected feed intake based on growth rate and body size of the animal. This means that an animal with a negative value (low RFI) is more efficient than an animal with a positive value (high RFI). Several studies have shown that there is enough genetic variation in RFI to allow for selection to improve efficiency (Arthur et al., 2001b; Archer et al., 1999; Schenkel et al., 2004). Several studies have demonstrated

the heritability for RFI to be between 0.16 and 0.43 (Arthur et al., 2001a, b; Herd and Bishop, 2000; Schenkel et al., 2004). Arthur et al. (2001a) found that heritability estimates of RFI at 15 and 19 months of age were similar (0.39 and 0.43, respectively).

Residual feed intake is not related to growth traits. Thus, selecting animals for low RFI has the potential to increase the efficiency of beef production by reducing feed intake without affecting genetic merit for growth rate, or mature cow size (Herd and Bishop, 2000; Herd et al., 2003). This is not the case when selecting animals for low FCR, because genotypes with improved FCR tend to have higher mature cow weights and consequently higher feed requirements, which are undesirable (Archer et al., 1999).

Richardson and Herd (2004) summarized the contribution of biological processes responsible for inter-animal variation in RFI. They reported that variation in digestion, body composition, feeding patterns, protein turnover and stress, heat increment, activity accounted for 10, 5, 2, 37, 9, and 10% of inter-animal variation in RFI, respectively. Richardson and Herd (2004) also reported that 27 % of the variation in RFI could not be attributed to known sources of variation in specific biological processes.

Measuring feed intake in individual animals is very expensive and requires a large amount of time and labor. In the past, feed efficiency was measured in individual stalls with animals fed manually and orts measured daily to determine feed intake over time. The Calan-gate system was developed to collect feed intake data of individual animals fed in small group pens. This system requires animals to use a key that opens individual gates to allow animals to eat from only one specific bunk at a time. The labor required to collect feed intake data using the Calan-gate system remains cost prohibiting

for commercial use. A few years ago a system that measures individual animal intake electronically, was developed (GrowSafe System). This system allows us to measure feed intake more cost effectively as it requires less labor and allows measurement of feed intake in group pens with animals that are from the same contemporary group.

Relationships between RFI and Body Composition and Tenderness

Although, RFI is phenotypically unrelated to body size or growth rate it is important to evaluate the relationship of RFI with body composition and meat quality (tenderness) traits. Richardson and Herd (2004) reported that body composition may account for approximately 5% of the variation in RFI. Basarab et al. (2003) reported that carcass fat composition traits explained 9% of the variation in RFI of finishing steers. Likewise, Lancaster et al. (2008c) found that variation in uBF and uREA explained 9 % of the variation in RFI in growing bulls.

Several studies have examined at the relationships of RFI with ribeye area, subcutaneous and intramuscular fat in the carcass (Arthur et al., 1997, 2001b; Archer et al., 1997; Basarab et al., 2003; Crews et al., 2003) or with real-time ultrasound measurements (Carstens et al., 2002; Fox et al., 2004; Brown et al., 2005; Lancaster et al., 2008a; and Ribeiro et al; 2006a).

Arthur et al. (1997) reported phenotypic correlations between RFI and back fat thickness and ribeye area of 0.19 and -0.01, respectively, in bulls and heifers (Angus, Hereford, Poll Hereford and Shorthorn). In another study, Arthur et al. (2001b) reported similar correlations of 0.14, and 0.06, respectively, for Angus bulls and heifers. Archer

et al. (1997) found that RFI was not significantly correlated with cREA, cBF or marbling score (**MARB**) in beef cattle.

Arthur et al. (2001b) reported genetic correlations of 0.17, and 0.09 between RFI with back fat and ribeye area, respectively. These results show that if animals are selected for improved efficiency based on RFI it will not have detrimental effects on carcass traits.

Carstens et al. (2002) found positive correlations between RFI and final back fat and rump fat thickness (0.22 and 0.18, respectively), but that final REA and IMF were not significantly correlated with RFI. Likewise, Fox et al. (2004) found that RFI was correlated with back fat and intramuscular fat (0.20 and 0.23), but not with ribeye area (-0.01).

Brown et al. (2005) fed Santa Gertrudis steers during a growing phase and a finishing phase. During the growing phase they found that RFI was not correlated with any of the ultrasound traits. However, during the finishing phase RFI was correlated to back fat thickness (0.30, $P < 0.05$), but was not correlated to ribeye area and percent intramuscular fat. Lancaster et al. (2005) found significant correlations between RFI and final back fat thickness and initial ribeye area (0.16 and -0.13, $P < 0.05$) but not with percent intramuscular fat in Angus and Brangus steers. Ribeiro et al. (2006a) found no correlation ($P > 0.05$) between RFI and ultrasound traits in Brahman cattle.

Since nutrition affects beef tenderness it is important to investigate if selection for more efficient animals will impact meat quality traits. There is limited literature that has investigated the relationship between RFI and meat quality traits.

McDonagh et al. (2001) examined the effects of a single generation of divergent selection for RFI on meat quality traits. There were no significant differences between low and high RFI steers in the percentage of intramuscular fat, WBSF values for samples aged 1 or 14 d, m-calpain or μ-calpain. However, they found that steers selected for low RFI had 13 % higher calpastatin activities and lower myofibrilar fragmentation index (breakdown of structural elements which occur as an initial step in the process of protein degradation and meat tenderization) values than steers selected for high RFI. This study suggests that selection for low RFI could negatively affect meat tenderness in beef, which is attributed to higher calpastatin activity.

Another study by Baker et al. (2006) found no significant differences in WBSF, sensory panel tenderness, flavor and calpastatin activity in Angus steers classified as having divergent phenotypic RFI. The authors concluded that there was no relationship between RFI and beef quality in purebred Angus steers. It is important to point out that Baker et al. (2006) accounted for variation in carcass traits in computing RFI, which may have contributed to the lack of an association between RFI and WBSF. These studies suggest that variation in RFI is not associated with meat quality traits in *Bos taurus* cattle. However, additional research is needed to further examine the relationship between RFI and tenderness and marbling in other breedtypes and production systems.

Interest in RFI as a trait to select for more efficient cattle has increased in recent years. More research is needed to examine the genetic relationships between RFI and biological processes associated with efficiency including feeding behavior, flight speed, IGF-1, mitochondrial proton leak, digestibility, CO_2 production, heat production, organ

size, methane production and many others. Commercial developments of genetic markers for feed efficiency are currently being validated. Indicator traits could play a big role in identifying more efficient animals.

In conclusion RFI is a trait that should be investigated in more detail, because of its potential impact to reduce cost and increase profits in the bee cattle industry. Moreover, success selection for improved feed efficiency will also reduce the impact of beef production systems on the environment. Also it could have a great impact in reducing amount of grain used and maybe less impact on the environment.

CHAPTER II

TECHNICAL NOTE: A NOVEL TECHNIQUE TO ASSESS INTERNAL BODY FAT OF CATTLE USING REAL-TIME ULTRASOUND*

Introduction

A persistent positive energy balance leads to deposition of fat in the animal body. Fat deposition can be chemically characterized by a continued accretion of lipids, primarily in the form of triacylglycerides, and morphologically characterized by hyperplasia and hypertrophy (Nürnberg et al., 1998). In beef cattle, body fat is accumulated in different parts of the body so that KPH and gastrointestinal tract fat is the first to be deposited, followed by intermuscular, subcutaneous, and intramuscular fat depots (Gerrard and Grant, 2003; Jones, 2004). Several factors affect onset and amount of fat that is deposited such as breed, sex, and level of nutrition. Body fat has an important role in determining body composition and energy requirements of growth in beef cattle (Geay, 1984). Body fat is classified into carcass and internal organ fat. Ribeiro et al. (2006b) indicated that carcass fat can be assessed using RTU, which is a non-invasive technique that requires immobilization of the animal for a short period of time. On the other hand, total physical separable internal fat (**IFAT**) assessment is difficult, expensive, and usually requires slaughter of the animal. The A-mode ultrasound has been used to measure fat and muscle depth (Temple et al., 1956) LM area

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*Reprinted with permission. Ribeiro, F. R. B., L. O. Tedeschi, J. R. Stouffer, and G. E. Carstens. 2008.Technical note: A novel technique to assess internal body fat of beef cattle by using real-time ultrasound. J. Anim. Sci. 86:763-767.

(Stouffer et al., 1961) in beef cattle. Since the 1990's, numerous studies (Wilson, 1992; Greiner et al., 2003b; Ribeiro et al., 2006), have been conducted to examine the efficacy of RTU to quantify LM area, back and rump fat thicknesses (Realini et al., 2001; Tait et al., 2005), and percent intramuscular fat (Hassen et al., 1999, 2001). However, similar noninvasive techniques have not been developed to quantify IFAT with RTU. The objective of this study was to develop a technique that could be used to assess total separable IFAT based on the measurement of KPH and IFAT with RTU.

Materials and Methods

Animal and Diet Description

Steers were fed and managed under the guidelines of the Texas A&M University Institutional Animal Care and Use Committee.

Data for this study were obtained from Angus steers (n = 24) fed either hay- or corn-based diets during the backgrounding phase at the Texas A&M University Agricultural Research Center at McGregor. Steers were serially slaughtered based on predetermined ages. Steers were weighed and sorted into 3 groups: baseline, hay-fed or corn-fed steer treatment. Baseline steers (n = 4) were slaughtered 1wk after being weaned (8 mo of age). Of the remaining 20 steers, 12 were assigned to a hay-based diet and 8 to a corn-based diet. Four months after weaning, 8 animals were harvested (4 hay- and 4 corn-based diets) and the remaining steers from the hay- (n = 8) and corn-based (n = 4) diet groups were placed in the same diet and fed on an ad libitum basis. Eight months after weaning, 8 animals were slaughtered (4 from each group). The remaining 4 steers from the hay-based diet were slaughtered 40 d after the third slaughter group.

Ultrasound Data

The RTU measurements were collected every 2 mo, with a pre-slaughter scan approximately 7 d before harvest. Real-time ultrasound measurements consisted of 12th- to 13th-rib backfat thickness (**uBF**), 12th- to 13th-ribeye area, percent of i.m., and kidney fat (**uKFd**) by an Ultrasound Guidelines Council field-certified technician.

Hassen et al. (2001) used 2 ultrasound machines (Aloka 500V and Classic Scanner 200) to predict i.m. fat from 500 steers. Both machines had similar accuracies with r^2 for the model without transformation of 0.72 and 0.68, and with logarithmic transformation of 0.84 and 0.87 for the Aloka 500V and Classic Scanner 200, respectively. Therefore, an Aloka 500V instrument with a 17-cm, 3.5 MHz transducer (Aloka Co. Ltd., Wallingford, CT, USA) was used in this study. Images were collected and interpreted on site at the ultrasound console and the percentage i.m. fat images were analyzed by Beef Image Analysis Pro software (Designer Genes Inc., Harrison, AR).

Real-Time Ultrasound of the Kidney Fat

The RTU kidney fat image was collected between the first lumbar vertebra and the 13^{th} rib as shown in Figure 2.1, as a cross sectional image. The ultrasound probe was placed on the flank region approximately 15 cm from the midline of the animal. Hair was clipped (if longer than 0.64 cm) to increase image quality and vegetable oil was used as coupling agent. Images were stored in the ultrasound console and interpreted chute side by the same technician. The uKFd measurement was taken between the ventral part of the abdominal muscles (*iliocostalis, obliquus abdominis interni and obliquus abdominis externi*) and the end of the kidney fat as shown in Figure 2.2.

Slaughter Data Collection

Feed was withheld overnight with free access to water and steers were slaughtered at the Rosenthal Meat Science and Technology Center, Texas A&M University, College Station, TX. Live BW and HCW were recorded. Whole gastrointestinal tracts were removed and dissected to obtain total physical separable IFAT weights. Measurements of carcass kidney fat depth (**cKFd**) were taken from the hot carcass using a tape measure. The measurement was taken from the midline (vertebrae) to the end of the kidney fat. The KPH depot was removed from the carcass before splitting.

Statistical Analyses

All statistical analyses were performed using the PROC GLM and PROC REG (SAS Institute Inc., Cary, NC). The statistical model was a complete randomized design in which each animal was the experimental unit. Steers were assigned to 2 treatments: corn-corn or hay-corn. In the corn-corn treatment, steers were fed the corn-based diets during the backgrounding and finishing phases, whereas those steers in the hay-corn treatment were fed the hay-based diet during the backgrounding and the corn-based diet during the finishing phase. The STEPWISE statement was used to identify the best predictors of IFAT. Outliers were tested by plotting studentized residual vs. the

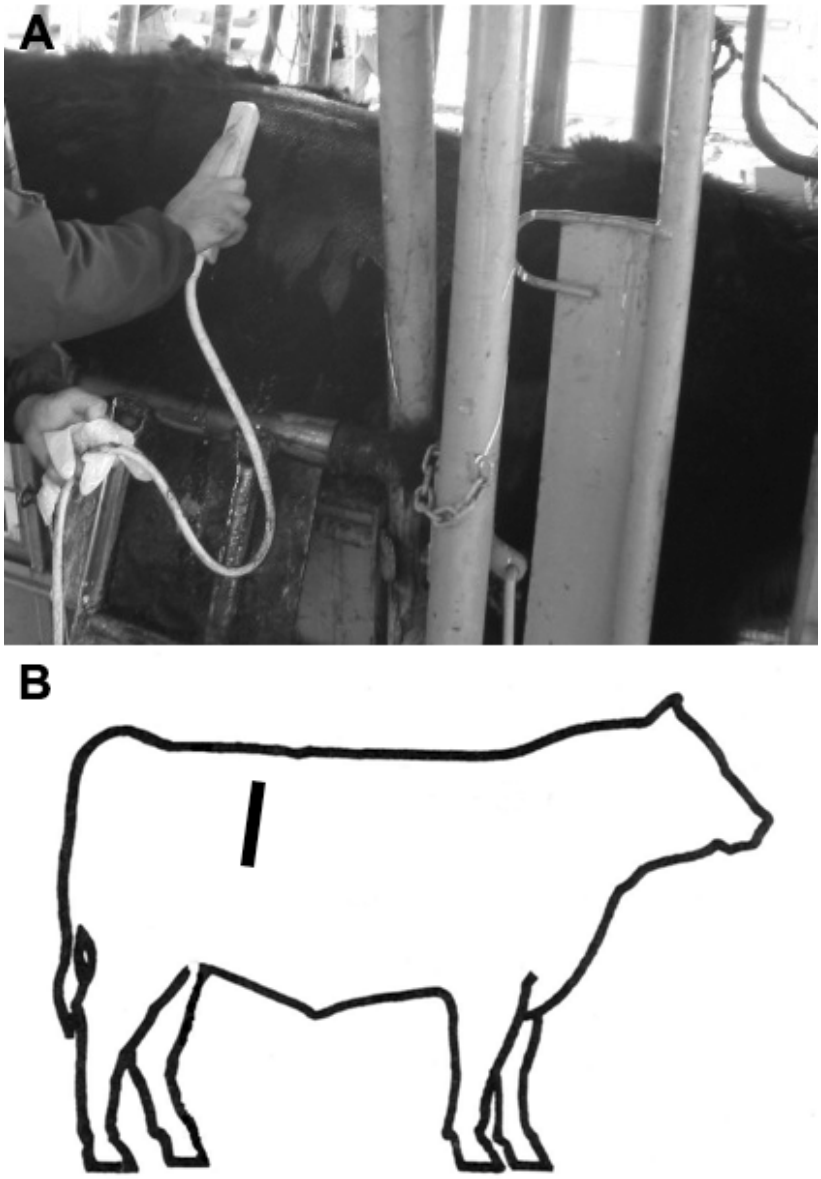

Figure 2.1. (A) Photograph and (B) schematic of scanning locations for real-time ultrasound image collection of the kidney fat depth.

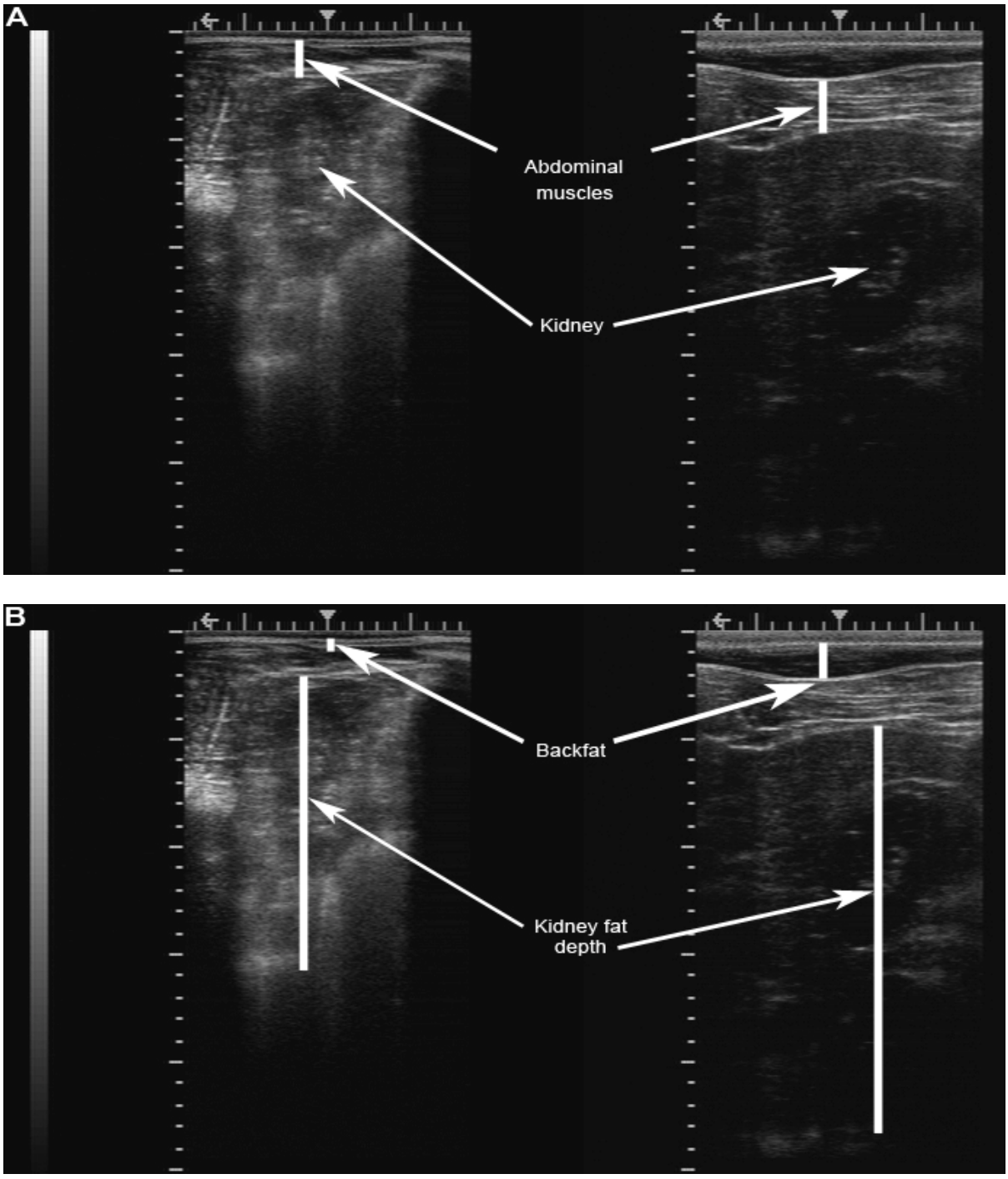

Figure 2.2. Detailed images of 2 steers showing (A) the point of measurement of the kidney (between the first lumbar and the 13th rib) and (B) backfat and kidney fat depths using real-time ultrasound with landmarks.

predicted values and removed if the Studentized residual was outside the range of -2.5 to 2.5. Adequacy of the models developed to predict IFAT was determined by using several measurements as discussed by Tedeschi (2006), including the root of mean square error of prediction and concordance correlation coefficient.

Results and Discussion

Group means of animal BW and carcass measurements are listed in Table 2.1. Steers from the corn-fed group deposited more IFAT than steers from the hay-fed group ($P < 0.001$), which was expected because the corn-based diet provided more energy than the hay-based diet. The development of KPH fat weight and cKFd (Table 2.1) and IFAT (Table 2.1) for steers fed either hay or corn followed an exponential pattern, probably because the rate of accretion of fat increases with maturity (Owens et al., 1995). Other studies have shown that RTU can also be used to predict carcass weight and the percentage of beef carcass retail product (Greiner et al., 2003a), but RTU has not previously been used to predict noncarcass components in beef cattle.

When all ultrasound measurements (Table 2.1) were used to predict observed IFAT, the stepwise procedure selected uBF and uKFd, accounting for 92% of the variation with an RMSE of 4.61 kg (Eq. 1 in Table 2.2). Because uKFd accounted for more of the variation, we removed uBF and obtained Eq. 2 in Table 2.2 ($r^2 = 0.89$ and RMSE = 5.32 kg). This suggested that ultrasound measurements might be able to explain the variation in IFAT of growing and finishing steers fed either hay- or corn-based diets. Previous work using ultrasound measurements to predict carcass traits have shown that this technology is useful in measuring body composition. Perkins et al. (1992a) reported

Table 2.1. Description of body and carcass data of steers fed corn or hay and serially slaughtered [1].

Traits [2]	Slaughter group [3]					
	8 mo.	12 mo.		16 mo.		18 mo.
	Baseline	Corn	Hay	Corn-Corn	Hay-Corn	Hay-Corn
N	4	4	4	4	4	4
Ultrasound BW, kg	218 ± 34	397 ± 21	326 ± 34	545 ± 23	512 ± 37	543 ± 47
BW, kg	175 ± 32	376 ± 19	298 ± 28	488 ± 44	514 ± 20	504 ± 48
HCW, kg	103 ± 18	220 ± 18	173 ± 17	314 ± 17	292 ± 18	318 ± 35
Ultrasound REA, cm^2	33.7 ± 9.93	69.3 ± 4.59	60.3 ± 2.31	88.8 ± 6.50	85.0 ± 1.76	92.3 ± 11.28
Ultrasound FT, cm	0.25 ± 0.06	0.85 ± 0.10	0.33 ± 0.08	1.28 ± 0.13	1.18 ± 0.05	1.35 ± 0.13
Ultrasound IMF, %	2.19 ± 0.46	4.21 ± 0.38	3.01 ± 0.17	3.95 ± 0.27	4.01 ± 0.11	4.43 ± 0.58
Ultrasound KFd, cm	5.78 ± 0.38	12.5 ± 0.92	10.3 ± 0.56	16.6 ± 1.09	16.0 ± 0.66	16.9 ± 1.01
Carcass KFd, cm	6.75 ± 6.75	12.9 ± 0.85	10.1 ± 0.48	17.6 ± 1.03	15.9 ± 1.44	17.9 ± 1.93
KPH weight, kg	1.40 ± 0.67	6.69 ± 1.74	2.85 ± 0.24	12.9 ± 2.61	9.82 ± 2.60	11.4 ± 3.21
Internal fat weight, kg	5.03 ± 2.24	25.1 ± 3.05	10.4 ± 1.15	43.2 ± 4.71	36.7 ± 6.79	38.8 ± 8.52

[1] Steers in the Corn-Corn category were fed corn-based diets during backgrouding and finishing phases, whereas those in the hay-corn category were fed hay-based diet during the backgrounding phase and corn-based diet during the finishing phase.
[2] Ultrasound BW = BW taken 7 d before slaughter when the steers were being scanned, REA = *Longissimus dorsi* muscle ribeye area; FT = 12th- 13th-rib fat thickness; IMF = percent of intramuscular fat; KFd = kidney fat depth.
[3] Values are mean ± SD.

Table 2.2. Regression equations to predict carcass kidney fat depth (cKFd, cm), carcass KPH weight (cKPHwt, kg), and internal fat (IFAT, kg).

#	Equations [1]	r^2	RMSE [2]	N
1	IFAT = -11.46292 + 16.23754×uBF + 1.83249×uKFd	0.92	4.61 kg	24
2	IFAT = -18.81364 + 3.4829×uKFd	0.89	5.32 kg	24
3	cKFd = 0.57131 + 0.99478×uKFd	0.93	1.14 cm	24
4	Log(cKPHwt) = -4.25407 + 2.34887×Log(cKFd)	0.96	0.18	24
5	$cKPHwt = 0.01421 \times cKFd^{2.34887}$	---	1.19 kg	24
6	IFAT = 2.47187 + 3.20619×cKPHwt	0.98	2.67 kg	24

[1] uBF = ultrasound 12th- to 13th-rib fat thickness; uKFd = ultrasound kidney fat depth, cm.
[2] RMSE = root mean square error.

simple correlations between uBF and ultrasound 12th- to 13th-ribeye area and carcass measurements of 0.60 and 0.75, respectively, in feedlot steers and heifers.

However, because of the nonlinear relationship among some of the variables of interest (Table 2.1), a more complicated system to predict IFAT was developed that would allow stepwise calculations of variables of interest. Equation 3 in Table 2.2 estimated cKFd from uKFd with an r^2 of 0.93 and RMSE of 1.14 cm. The relationship between carcass KPH weight and cKFd was nonlinear (Eq. 4 in Table 2.2) and the untransformed equation yielded a RMSE of 1.20 kg (Eq. 5 in Table 2.2). Finally, the relationship between IFAT and carcass KPH weight was close, with an r^2 of 0.97 and RMSE of 2.67 kg (Eq. 6 in Table 2.2).

Despite the strong relationships obtained in this study, additional work is needed to study the impact of using uKFd measurements to predict IFAT at different stages of growth. Brethour (2000) reported that uBF measures taken 30 d or less before slaughter could be used to predict carcass back fat thickness more accurately. The author also reported that marbling score could be predicted more accurately by RTU measurements later in the feeding period.

When we compared the adequacy of predicting IFAT between the single linear regression (Eq. 2 in Table 2.2) and the stepwise model (Eq. 3 to 6 in Table 2.2), the stepwise model had a lower root mean square error of prediction than the single linear regression (4.80 and 5.10 kg, respectively) and greater coefficient of determination (0.91 and 0.89, respectively). The concordance correlation coefficient for the stepwise model was 0.943, and for the single linear regression it was 0.939. The pair-wise mean square

error of prediction analysis (Tedeschi, 2006) indicated that 2 approaches were not different in computing IFAT ($P = 0.4936$).

Implications

Our findings indicated that RTU measurements adequately predicted IFAT. This technique might improve our ability to estimate total body fat content in growing and finishing steers fed either hay- or corn-based diets. Consequently, this technique might be used in feedlot sorting systems to better allocate animals into different feeding and management strategies to improve profitability.

CHAPTER III

THE USE OF REAL-TIME ULTRASOUND AND CARCASS MEASUREMENTS TO ESTIMATE TOTAL INTERNAL FAT IN BEEF CATTLE

Introduction

The use of non-invasive techniques to measure body composition in livestock for genetic evaluation, management and research purposes has increased in the past 20 years. Real-time ultrasound, computer tomography, and magnetic resonance imaging are the most common methods used to measure body composition in the live animal. Real-time ultrasound is more widely used in livestock animals because it is cheaper and can be easily used in typical animal handling facilities. Computer tomography and nuclear magnetic resonance are more expensive and animal sedation required to obtain good images. Thus, the use of these techniques to assess body composition in animals has been limited to sheep, goats and pigs (Silva et al., 2006; Lambe et al., 2003, 2006). Several researchers have applied these non-invasive techniques to measure body composition in livestock. Lambe et al. (2003) used a computed tomography scan to measure total body tissue in sheep and Lambe et al. (2006) used the same technique to estimate IFAT weight in sheep. Silva et al. (2006) used RTU to estimate sheep carcass composition. Teixeira et al. (2008) used RTU to estimate intermuscular, KPH and total carcass fat in goats. Others have specifically evaluated the applications of RTU to measure body composition (carcass traits) in beef cattle (Wilson, 1992; Greiner et al., 2003b; and Ribeiro et al., 2006b). Fat is categorized by Rouse and Wilson (2001) as taste fat (intramuscular fat) and waste fat (internal, seam, and subcutaneous fat). Waste fat is expensive to the

industry and require a lot of energy to be deposited. Therefore, more accurate assessment of non-carcass fat depots in the live animal are needed so we can make better management decisions and decrease the waste fat. Recently, Ribeiro et al. (2008) reported a technique to be used to estimate IFAT in beef cattle. The objective of this study was to revise and further evaluate the technique reported by Ribeiro et al. (2008) to estimate IFAT using RTU and carcass measurements.

Materials and Methods

Animal and Diet Description

Animals used in this study were fed and managed under the guidelines of the Texas A&M University Institutional Animal Care and Use Committee. Data for this study were obtained from 4 different studies.

Study 1 consisted of 24 Angus steers that were fed either a hay- or corn-based diets during the backgrounding phase at the Texas A&M University Agrilife Research Center at McGregor, TX. Steers were serially slaughtered based on predetermined ages. More detail and description of the experimental design are reported by Ribeiro et al. (2008).

Study 2 consisted of 16 Angus bulls and 16 Angus heifers that were progeny from parents divergently selected for serum IGF-I concentration for more than 10 years at the Eastern Agricultural Research Station of The Ohio State University. Selection procedures were reported by Davis et al. (1995). Animals were shipped to the O.D. Butler, Jr. Animal Science Complex at Texas A&M University and fed a corn-based diet for an average of 126 days. More detail and description of the experimental design are reported by Lancaster et al. (2008b).

Study 3 consisted of 36 crossbred steers that were used in a trial to test the effects of two sources of tannins: mimosa- and chestnut-tannin, when applied as an antimicrobial hide-spray intervention against generic *E. coli*, total coliforms and total aerobic bacterial loads and as a feed supplement against generic *E. coli*, total coliforms, and *Campylobacter* spp. in steers fed high grain diets. Animals were shipped to the O.D. Butler, Jr. Animal Science Complex at Texas A&M University a fed a high grain diet for 60 days. More detail and description of the experimental design are reported by Bañuelos (2008).

Study 4 consisted of 18 crossbred steers (Angus x 5/8 Angus x 3/8 Nellore) used on a trial that tested the use of a slow release urea product on N balance and performance of cattle fed steam-flaked corn. Steers were fed for 105 days at the Texas A&M University Agricultural Research Center at McGregor, TX.

Ultrasound Measurements

The RTU measurements were taken at the end of each test 7 d before slaughter. Real-time ultrasound measurements consisted of 12th- to 13th-rib backfat thickness, 12th- to 13th-ribeye area, percentage of i.m. fat and kidney fat depth. Images were collected by an Ultrasound guidelines Council field-certified technician using an Aloka 500V instrument with a 17-cm, 3.5-MHz transducer (Aloka Co. Ltd., Wallingford, CT). Images for study 1 were collected and interpreted on site at the ultrasound console and for studies 2, 3, and 4 were saved in an image capturing system and sent to the National Cup Lab (Ames, IA) for interpretation. The uKFD images were interpreted chute side for all 4 studies.

RTU of Kidney Fat

The uKFD image collection protocol used in this study was reported by Ribeiro et al. (2008). Briefly, hair was clipped (if longer than 0.64 cm) and oil used as a coupling agent. Images were collected between the 13th rib and first lumbar. The uKFD measurement was taken between the ventral part of abdominal muscles and the end of the kidney fat.

Slaughter Data Collection

All animals were withheld of feed overnight with free access to water, and slaughtered at the Rosenthal Meat Science and Technology Center, Texas A&M University (College Station, TX). Live BW and HCW were recorded. Whole gastrointestinal tracts were removed and dissected to obtain total physical separable internal fat weights. Linear measurements of the cKFd were obtained immediately postmortem from the hot carcass by using a tape measure. The measurement was taken from the midline (vertebrae) to the end of the kidney fat. The KPH depot was removed from the carcass before splitting.

Calculation of the Frame Score

The frame score (**FS**) of the animals was assumed to be small, medium, and large based on the relationship between the standard reference weight (**SRW** of 478 kg) of a medium-frame size steer and the shrunk BW adjusted to 28% empty body fat (**AFBW**) as computed by the NRC (2000). The FS was assumed 1 (small-frame score) if the ratio of SRW and AFBW was greater than or equal to 1.13, 2 (medium-frame score) if the ratio of SRW and AFBW was greater than or equal to 0.95 and less than 1.13, and 3 (large size) if this ratio was less than 0.95. These ratio thresholds were obtained from

adjustment factors proposed by Fox and Black (1984) to compute frame size of growing steers. The AFBW was computed based on the equation proposed by Guiroy et al. (2001) in which empty BW (**EBW**) changes 14.26 kg per unit of change in Empty body fat (**EBF**) as shown in Eq. 1. [AFBW = (EBW + (28 – EBF)×14.26)/0.891]. The EBF of the animals was computed based on the carcass traits, including cBF in cm, HCW in kg, quality grade (**QG**; 4 = select, 5 = Choice-, 6 = Choice, 7 = Choice +, and 8 = Prime), and cREA in cm^2 as shown in Eq.2 [EBF = 17.76207 + (4.68142×cBF) + (0.01945×HCW) + (0.81855×QG) − (0.06754×cREA)]

Statistical Analyses

All statistical analyses were performed using the PROC GLM and PROC REG (SAS Institute Inc., Cary, NC). The STEPWISE statement was used to identify the best predictors of IFAT. Outliers were tested by plotting studentized residual vs. the predicted values and removed if the studentized residual was outside the range of -2.5 to 2.5. Adequacy of the models developed to predict IFAT was determined by using several measurements as discussed by Tedeschi (2006), including the root of mean square error of prediction and concordance correlation coefficient.

Results and Discussion

Group means and SD of animal's BW, RTU, and carcass measurements are listed in Table 3.1. Steers BW from study 1 had a larger SD because they were serially slaughtered and heifers from study 2 were lighter as expected. Ultrasound and carcass BF for steers in study 3 were smaller, and this is attributed to these set of steers being larger frame compared to animals in the other 3 studies. Across studies the IFAT values had a

Table 3.1. Description of body and carcass composition [1].

	Study 1	Study 2		Study 3	Study 4
Trait[2]	Steers	Bulls	Heifers	Steers	Steers
N	24	16	16	36	18
Ultrasound BW, kg	423 ± 128	488 ± 46.4	373 ± 24.0	480 ± 47.8	480 ± 40.1
BW, kg	393 ± 131	480 ± 46.2	354 ± 21.7	468 ± 44.9	451 ± 37.7
HCW, kg	237 ± 83.3	296 ± 28.9	220 ± 13.7	279 ± 28.9	278 ± 24.9
Ultrasound REA, cm^2	71.6 ± 21.7	82.6 ± 6.18	65.8 ± 5.36	73.7 ± 6.28	77.8 ± 5.37
Ultrasound BF, cm	0.87 ± 0.46	0.82 ± 0.18	1.01 ± 0.20	0.72 ± 0.16	0.94 ± 0.17
Ultrasound IMF, %	3.63 ± 0.86	3.19 ± 0.54	4.31 ± 0.43	3.09 ± 0.55	4.23 ± 0.58
Ultrasound KFd, cm	13.0 ± 4.17	16.2 ± 1.10	15.2 ± 0.90	17.8 ± 0.99	16.9 ± 1.26
Carcass REA, cm^2	65.0 ± 13.4	79.9 ± 8.19	61.0 ± 5.58	78.2 ± 7.09	71.2 ± 6.24
Carcass BF, cm	1.05 ± 0.67	0.96 ± 0.32	1.14 ± 0.30	0.70 ± 0.25	1.14 ± 0.20
Carcass Marbling score	4.83 ± 1.19	5.3 ± 0.75	6.13 ± 0.94	4.91 ± 0.71	5.38 ± 0.89
Carcass KFd, cm	13.5 ± 4.30	14.8 ± 1.26	15.8 ± 1.55	16.7 ± 1.58	18.2 ± 1.69
KPH weight, kg	7.50 ± 4.75	7.18 ± 1.57	8.70 ± 1.54	5.11 ± 1.38	9.15 ± 2.05
Internal fat weight, kg	26.5 ± 15.4	28.4 ± 6.05	33.3 ± 4.55	26.6 ± 5.43	42.7 ± 7.36

[1] Values are means ± SD.

[2]Ultrasound BW = BW taken 7 d before slaughter when steers where being scanned, REA = 12th- to 13th-ribeye area, BF = 12th- to 13th-rib fat thickness, IMF = percent of intramuscular fat, KFd = kidney fat depth.

Table 3.2. Correlations among traits used to develop the prediction equations of internal fat weight (IFAT).

Trait	BW	uBF	uKFd	cBF	cKFd	KPH weight	IFAT
uBW	**0.97**	**0.42**	**0.77**	**0.40**	**0.66**	**0.45**	**0.56**
BW		**0.38**	**0.79**	**0.34**	**0.65**	**0.38**	**0.51**
uBF			**0.34**	**0.86**	**0.53**	**0.72**	**0.71**
uKFd				**0.28**	**0.81**	**0.36**	**0.56**
cBF					**0.48**	**0.76**	**0.72**
cKFd						**0.65**	**0.81**
KPH weight							**0.88**

[1] uBW = BW taken 7 d before slaughter when steers where being scanned uKFd = ultrasound kidney fat depth; uBF 12th- to 13th-rib fat thickness, cBF = carcass 12th- to 13th-rib fat thickness; cKFd = carcass kidney fat depth; IFAT = total internal fat.

large variation to represent the beef cattle population fed in feedyards.

Table 3.2 shows the correlations among all traits used to develop the prediction equations. The high correlation between cBF and uBF indicated that the RTU measurements were accurate compared to the carcass measurements. The uKFD was also highly correlated to cKFd. However, the correlation between uKFd with KPH weight and IFAT were not as high as cKFD (0.36 and 0.56 vs. 0.65 and 0.81, respectively). This suggests that the cKFd might be a better predictor of KPH weight and IFAT.

The prediction equations developed are listed in Table 3.3. Equation 1 used uKFd and uBF to predict IFAT with an R^2 of 0.65 and root mean square error (**RMSE**) of 6.07 kg. The R^2 for the present Eq. 1 is smaller than the previous R^2 for Eq. 1 reported by Ribeiro et al. (2008), using a similar approach. The relationship between KPH weight and uKFd was not linear and the untransformed equation yielded an R^2 of 0.52 and a RMSE of 0.36 kg.

The best predictors of IFAT were carcass measurements. When we used only KPH weight to predict IFAT (Eq. 4) a R^2 of 0.84 and RMSE of 4.23 kg was obtained. The prediction of IFAT using cKPHd and cBF (Eq. 6) was very similar to Eq. 4 with an R^2 of 0.83 and RMSE of 4.33 kg. These results are similar to Ribeiro et al. (2008), however a little lower, which could be explained by the inclusion of 3 other studies and animals with different frame sizes and fat levels.

Similar studies using different species had results that were compared to ours. Silva et al. (2006) used the same ultrasound equipment; however, two different probes (5 MHz and 7.5 MHz) to predict sheep carcass composition. The locations of the fat

Table 3.3. Equations to predict carcass kidney fat (cKFd, cm), carcass KPH weight (KPHwt, kg), and internal fat (IFAT, kg).

Eq. no.	Equation[1]	R^2	RMSE	n
1	IFAT = -28.61853 + 14.52776×log(uKFd) + 22.242×uBF	0.65	6.07	109
2	Log(KPHwt) = (3.158233068 + A) + (– 0.4632258 + B)×log(uKFd)	0.52	0.36	109
3	$KPHwt = 10^{(3.158233068 + A)} \times loguKFd^{(- 0.4632258 + B)}$			109
4	IFAT = (11.79444828 + C) + (2.63100813 + D)×KPHwt	0.84	4.23	109
5	cKFd = (-0.086067367 + E) + 0.941562887×uKFd	0.68	1.63	109
6	IFAT = (-3.84221299 + F) + (1.34341477 + G)×cKPHd + (14.07377538 + H)×cBF	0.83	4.33	109

[1] uKFd = ultrasound kidney fat depth; uBF 12th- to 13th-rib fat thickness; A, B, C, D, E, F, G and H = adjustment for frame score; A = -6.55, -3.74, and 0 for frame score 1, 2, and 3, respectively; B = 2.50, 1.35 and 0 for frame score 1, 2, and 3, respectively; C = -11.06, 1.89, and 0 for frame score 1, 2, and 3, respectively; D = 1.12, -0.2, and 0 for frame score 1, 2, and 3, respectively; E =1.58, 0.99, and 0 for frame score 1, 2, and 3, respectively; F = -10.97, -20.78, and 0 for frame score 1, 2, and 3, respectively; G = 1.26, 1.35, and 0 for frame score 1, 2, and 3, respectively; H = -8.10, -2.06, and 0 for frame score 1, 2, and 3, respectively.

measurements were over the 13th thoracic vertebra (**FAT13**) and the 4th lumbar vertebrae (**FAT4**). Their results showed that when an ultrasound fat measurement was added to the prediction equation with BW it improved the prediction of IFAT by (0.11 and 0.10 for 5 MHz, and 0.13 and 0.17 for 7.5 MHz for FAT13 and FAT4, respectively). Teixeira et al. (2008) used the same RTU machine with a 5 MHz probe to estimate body fat partition in goats. The fat measurement was taken at the sternum fat depth at third sternebra (**STFAT**). Results showed that STFAT alone explained 75% of the variation in kidney fat and 77% in omental fat. Body weight and STFAT together explained 78% of the variation in mesenteric fat.

Implications

These studies and our results suggest that ultrasound can be used to predict carcass and non-carcass fat in livestock. However, animals under different feeding regimen and dietary composition have to be evaluated and also evaluation of these new equations is needed.

CHAPTER IV

RELATIONSHIPS OF FEED EFFICIENCY WITH CARCASS AND NON-CARCASS TISSUE COMPOSITION IN ANGUS BULLS AND HEIFERS

Introduction

Amount and type of feed consumed, breed, age, sex, and environmental conditions are known to contribute to between-animal variation in efficiency of feed utilization for maintenance and growth (Channon et al., 2004). Feed conversion ratio is typically used as the measure of feed efficiency. However, FCR is negatively correlated with growth such that selection for low FCR will result in increased mature cow size thus increased feed requirements for maintenance (Herd and Bishop, 2000).

Residual feed intake is an alternative feed efficiency trait that measure the variation in feed intake beyond that needed to support maintenance and growth requirements. Residual feed intake has been shown to be moderately heritable and genetically independent of growth and body size (Archer et al. 1999; Herd and Bishop 2000; Arthur et al. 2001a). Thus, RFI has potential to be used in a selection program to improve feed efficiency without impacting cow mature size (Herd and Bishop, 2000) and growth performance (Arthur et al., 2001a). Herd et al. (2004) estimated that approximately one third of the biological variation in RFI could be explained by differences in digestion, heat increment of feeding and activity, and that the other two thirds was likely due to differences in heat production (mechanisms unknown). In addition, Basarab et al. (2003) found that low RFI cattle had lower proportion of

gastrointestinal tissue per unit of EBW than high RFI cattle. Visceral organ metabolism has been shown to be a major contributor to whole body energy expenditure (> 40%, Webster, 1981), which could explain why low RFI cattle are more efficient.

Residual feed intake has a weak positive correlation between RFI and uBF for growing cattle ranging from 0.14 to 0.20 (Arthur et al., 2001a; Schenkel et al., 2004; Lancaster 2008c). However, in finishing cattle the correlation between RFI and uBF become stronger ranging from 0.23 to 0.30 (Nkrumah et al., 2004, 2007). Therefore, the objective of this study was to examine the relationships between RFI and carcass and non-carcass tissue deposition and visceral organs.

Materials and Methods

Animals and Management

Angus bulls (n = 27) and heifers (n = 29) from a divergent selection study (Eastern Agricultural Research Station, Ohio State University) for insulin-like growth factor-I (**IGF-I**) were used in this study. Calves were weaned on October 5, 2005 and transported to the O.D. Butler Jr. Animal Science Complex at Texas A&M University on January 11, 2006. Weaning calves were fed fescue hay ad libitum and offered a supplement (80% soybean hulls: 20% shelled corn) at 2.7 kg/head/day for 98 days prior to being transported to Texas A&M University. Upon arrival, bulls and heifers were blocked by gender and BW, randomly assigned to pens (6 calves per pen), and adapted to a grain-based diet (ME = 2.85 Mcal/kg DM) for 32 d. Individual feed intake was measured by using Calan gate feeders (American Calan, Northwood, NH) for 70 d.

Diet ingredient samples were collected weekly throughout the experiment and composited by weight for chemical analyses. Moisture analyses were conducted by drying in a forced-air oven for 48 h at 105°C (AOAC, 1990). Chemical analysis was conducted by an independent laboratory (Cumberland Valley Analytical Service Inc., Hagerstown, MD), and ME concentration of the diet was computed by using the Cornell Net Carbohydrate and Protein System (version 5.0, Cornell University, Ithaca, NY).

Growth and Ultrasound Measurements

Body weights were measured every 7 d. Ultrasound measurements of 12-13th rib backfat, 12-13th ribeye area, and percent intramuscular fat were obtained on days 0, and 70 d of feeding and 7 d preslaughter by an Ultrasound Guidelines Council field certified technician using an Aloka 500-V instrument with a 17-cm 3.5 MHz transducer (Corometrics Medical Systems, Inc., Wallingford, CT, USA). Images were collected and stored by Beef Image Analysis Field software (Designer Genes Inc., Harrison, AR), and sent to The National Centralized Ultrasound Processing Lab, Ames, IA, for processing.

Growth rates of individual calves were obtained by linear regression of BW against day of study, using the GLM procedure (SAS Inst. Inc., Cary, NC). The slope of this regression was assumed to be the ADG and the regression coefficients were used to compute initial and final BW, and metabolic BW (**MBW**; midtest BW$^{0.75}$).

Residual feed intake was calculated as the difference between actual DMI and expected DMI obtained from the regression of actual DMI on ADG and MBW (Arthur et al., 2001b) using PROC GLM of SAS within gender. Calves were ranked by RFI within gender. Standard deviations above and below the mean RFI were used to group

bulls and heifers into low (< 0.5 SD), medium (± 0.5), and high (> 0.5 SD) RFI and the eight most and eight least efficient calves within gender were selected for subsequent carcass and non-carcass measurements.

Carcass and Non-Carcass Measurements

Following the 70 d test period, bulls (n = 16) and heifers (n = 16) were harvested (48 and 64 d after the 70 d test period). Feed was withheld overnight, but animals had free access to water. Bulls and heifers were slaughtered at the Rosenthal Meat Science and Technology Center, Texas A&M University, College Station, TX. Live BW and HCW were recorded. Whole gastrointestinal tract (**GIT**) and visceral organs were removed, dissected, and weighed to obtain IFAT. Empty GIT, heart, liver and total dissectible internal fat were weighed and expressed per unit of EBW. After a 48-h chill, carcass data consisting of HCW (kg), 12-13th rib backfat (mm), 12-13th ribeye area (cm^2), and marbling score was obtained and the 9-11th rib section was removed according to Hankins and Howe (1946).

Empty BW was calculated by subtracting the digesta from the animal's live weight at slaughter. Empty body fat was calculated using the following equation EBF = 17.76207 + (4.68142×cBF) + (0.01945×HCW) + (0.81855×QG) − (0.06754×cREA), where QG = quality grade (4 = select, 5 = Choice-, 6 = Choice, 7 = Choice +, and 8 = Prime) by Guiroy et al. (2001).

The 9-11th rib sections were dissected into separable fat, lean and bone tissue, and separable fat and lean tissue analyzed to determine moisture, fat and protein content according to Hankins and Howe (1946) procedure. Protein was determined using a Leco

analyzer, moisture percentage was calculated using an oven-dry procedure, and fat content determined by Soxhlet apparatus using diethyl ether (AOAC, 1990).

Statistical Analyses

Residual feed intake was calculated as the difference between actual DMI and expected DMI obtained from the regression of actual DMI on ADG and MBW (Arthur et al., 2001b) using PROC GLM of SAS. Standard deviations above and below the mean RFI were used to group steers into low (< 0.5 SD), medium (± 0.5), and high (> 0.5 SD) RFI.

Analysis of variance using the PROC GLM function of SAS was used to examine the effects of RFI group on performance, feed efficiency, carcass, and non-carcass data. The model included fixed effects of RFI group, IGF-I selection line and gender and all interaction terms. Least squares means were calculated and when p-value was significant ($P < 0.05$) differences in least squares means were determined using the PDIFF option. All interaction terms were tested and only interactions between IGF-I line and RFI group that were significant were kept in the model. Phenotypic correlation coefficients among performance, feed efficiency, ultrasound, carcass and non-carcass traits were determined using PROC CORR function of SAS with the partial option used to adjust for the fixed effects of gender.

Results and Discussion

Phenotypic correlations between performance, feed efficiency and ultrasound traits with RFI and feed conversion ratio FCR are presented in Table 4.1. Residual feed

intake was strongly, positively correlated with DMI and FCR (0.74 and 0.63, respectively, $P < 0.001$), but not correlated with ADG, initial BW or final BW (**IBW** or **FBW**). Feed conversion ratio was correlated to ADG, DMI, IBW and FBW ($P < 0.05$). There were no differences in IBW, FBW and ADG between low RFI and high RFI groups (Table 4.2). Calves with low RFI calves consumed 15% less DMI and had a 13% better FCR than high RFI. Previous research has shown similar results (Nkrumah et al., 2007; Castro Bulle et al., 2007; Lancaster et al., 2008c) with no differences between ADG, IBW and FBW and DMI improvements ranging form 12 to 18%. Castro Bulle et al. (2007) reported a lower improvement in FCR than Nkrumah et al. (2007), Lancaster et al. (2008c) and the present study (6.4 vs. 18.7, 18, and 13%, respectively).

Real-time ultrasound is an important tool to measure live animal body composition and has been widely used since the early 1950's (Temple et al., 1956). Recent reports have shown that RTU is an accurate and effective way to measure body composition in beef cattle (Wilson 1992; Hamlin et al., 1995; Ribeiro et al., 2006a). Ultrasound i.m. fat collected at d 70 and pre-slaughter were correlated to RFI (r = 0.40 and 0.40, $P < 0.04$); however, uBF was not correlated with RFI at any time point. Feed conversion ratio was only correlated to uBF at d0. There were no differences ($P > 0.1$) between low and high RFI calves for any RTU traits (Table 4.3). Some studies have shown a weak positive correlation (Arthur et al., 2001a; Schenkel et al., 2004) and others a stronger correlation (Nkrumah et al., 2004; Lancaster et al., 2008c) between RFI with uBF. Basarab et al. (2003), and Baker et al. (2006) reported no differences in uBF

Table 4.1. Phenotypic correlations (P-values) between residual feed intake (RFI) and feed conversion ration (FCR) with performance and ultrasound traits for Angus bulls and heifers.

Trait	RFI	FCR
Performance traits		
ADG	0.02 (0.931)	-0.49 (0.007)
DMI	0.74 (<0.001)	0.56 (0.002)
RFI	-	0.63 (<0.001)
FCR	0.63 (<0.001)	-
Initial BW	-0.01 (0.970)	0.53 (0.003)
Final BW	0.00 (0.990)	0.38 (0.044)
Ultrasound traits[a]		
uREA d0	- 0.30 (0.112)	0.05 (0.806)
uBF d0	0.19 (0.334)	0.42 (0.022)
uIMF d0	0.23 (0.224)	0.00 (0.992)
uREA d70	-0.14 (0.483)	0.03 (0.877)
uBF d70	0.13 (0.503)	0.19 (0.319)
uIMF d70	0.40 (0.031)	0.18 (0.361)
uREA presl	-0.22 (0.244)	0.14 (0.463)
uBF presl	-0.07 (0.723)	0.20 (0.302)
uIMF presl	0.40 (0.032)	0.08 (0.697)

[a] uBF = ultrasound 12th- to 13th-rib backfat thickness; uREA = ultrasound 12th- to 13th-ribeye area; uIMF = ultrasound percent i.m. fat; presl = measurements taken 7 d preslaughter.

Table 4.2. Performance and feed efficiency traits for Angus bulls and heifers with low and high residual feed intake (RFI).

	RFI Group				Gender			
Traits[a]	Low	High	SE	*P-value*	Bulls	Heifers	SE	*P-value*
n	16	16			16	16		
Initial BW, kg	281	283	7.28	0.867	304	260	7.46	< 0.001
Final BW, kg	358	361	7.60	0.749	393	326	7.80	< 0.001
ADG, kg/d	1.57	1.60	0.04	0.573	1.81	1.35	0.05	< 0.001
DMI, kg/d	9.45	11.1	0.20	< 0.001	10.7	9.79	0.21	0.004
FCR, (DMI:ADG)	6.18	7.09	0.17	0.001	5.99	7.28	0.18	< 0.001
RFI, kg/d	-0.76	0.85	0.10	< 0.001	0.10	-0.01	0.10	0.457

[a] FCR = feed conversion ratio

between RFI groups; however, other studies have found that uBF is slightly lower in low RFI compared to high RFI cattle (Nkrumah et al., 2004; Lancaster et al., 2005, 2008c). Lancaster et al. (2008c) and Nkrumah et al. (2004) reported that there was a difference (P<0.05) in uBF at the end of the test between low and high RFI (0.59 vs. 0.67, and 0.53 vs. 0.63 cm, respectively). The differences in results between these studies could be attributed to differences in breed, frame size, ultrasound technician, and software used to measure the ultrasound traits.

Table 4.4 shows the phenotypic correlations between carcass and non-carcass traits with RFI and FCR. Residual feed intake was moderately correlated with cREA and 9-11th-rib protein (-0.37 and -0.41, respectively, $P < 0.05$). There were no correlations between RFI and HCW, cBF, MARB, KPH, and 9-11th-rib lipid. Feed conversion ratio was correlated to KPH (0.39, $P = 0.035$) but not with HCW, cREA, cBF, MARB, 9-11th-rib protein and 9-11th-rib lipid. The low RFI group had similar cBF, cREA, and MARB ($P > 0.1$; Table 4.5). Low RFI calves had greater 9-11th-rib protein than high RFI claves (14.6 vs. 13.7 %, respectively, $P = 0.05$), but similar 9-11th-rib lipid (35.7 vs. 37.5, respectively, $P > 0.1$). Basarab et al. (2003) also reported no significant correlation between RFI with cBF, or MARB ($P > 0.05$) in crossbred steers, but Nkrumah et al. (2004) a moderately positively correlation of RFI with cBF (P<0.05). Baker et al. (2006) reported that there were no differences between low RFI and high RFI steers cBF (1.2 vs. 1.1 cm, respectively), which is in contrast with data of McDonagh et al. (2001) and Nkrumah et al. (2004) who reported a significant difference between low and high RFI cBF (0.92 vs. 1.01, and 0.88 vs. 1.16 cm, respectively).

Table 4.3. Characterization of ultrasound traits in Angus bulls and heifers with low and high residual feed intake (RFI).

	RFI Group				Gender[a]			
Traits[b]	Low	High	SE	*P-value*	Bulls	Heifers	SE	*P-value*
n	16	16			16	16		
uREA d0, cm^2	46.0	43.8	1.17	0.195	48.1	41.7	1.20	0.001
uBF d0, cm	0.35	0.38	0.02	0.342	0.33	0.40	0.02	0.007
uIMF d0, %	3.42	3.50	0.10	0.593	3.22	3.70	0.10	0.002
uREA d70, cm^2	67.5	67.0	1.34	0.819	74.5	60.0	1.38	< 0.001
uBF d70, cm	0.66	0.72	0.04	0.333	0.59	0.79	0.04	0.003
uIMF d70, %	3.55	3.72	0.13	0.363	3.04	4.23	0.13	< 0.001
uREA presl, cm^2	75.2	73.1	1.36	0.322	83.3	65.0	1.42	< 0.001
uBF presl, cm	0.92	0.89	0.05	0.713	0.80	1.00	0.05	0.008
uIMF presl, %	3.61	3.86	0.12	0.158	3.19	4.28	0.12	< 0.001

[a] Heifers were harvested on d 118 and bulls on d 134 of the study.

[b] uBF = ultrasound 12th- to 13th-rib backfat thickness; uREA = ultrasound 12th- to 13th-ribeye area; uIMF = ultrasound percent i.m. fat; presl = measurements taken 7 d preslaughter.

Table 4.4. Phenotypic correlations (P-values) between residual feed intake (RFI) and feed conversion ration (FCR) with carcass and non-carcass traits.

Trait[a]	RFI	FCR
Carcass traits		
HCW	-0.11 (0.586)	0.28 (0.144)
cREA	-0.37 (0.051)	-0.09 (0.627)
cBF	0.12 (0.519)	0.26 (0.174)
MARB[b]	0.25 (0.185)	0.19 (0.320)
KPH	0.15 (0.426)	0.39 (0.035)
9th- to 11th-rib composition[c]		
Lipid	0.29 (0.133)	0.18 (0.364)
Protein	-0.41 (0.029)	-0.30 (0.111)
Non-carcass traits		
EBW	-0.10 (0.623)	0.32 (0.096)
EBF	0.25 (0.195)	0.35 (0.065)
EGIT	0.12 (0.535)	0.50 (0.006)
IFAT	0.11 (0.561)	0.46 (0.012)
Liver	-0.06 (0.742)	0.31 (0.105)
Heart	0.07 (0.714)	0.35 (0.061)

[a] cBF = carcass 12th- to 13th-rib backfat thickness; cREA = carcass 12th- to 13th-ribeye area; EBW = empty body weight; EBF = empty body fat (Guiroy et al. (2001); EGIT = empty gastrointestinal tract; IFAT = total internal fat.

[b] MARB = marbling score (Slight^{00} = 4.00; Small^{00} = 5.00; and Modest^{00} = 6.00).

[c] Hankins and Howe (1946).

However, Basarab et al. (2003) and Baker et al. (2006) adjusted RFI for body composition Most studies have shown no differences in MARB between RFI groups (McDonagh et al., 2001; Nkrumah et al., 2004; Baker et al., 2006), which is in agreement with our study. Basarab et al. (2003), reported that low RFI steers had greater carcass lipid but similar carcass protein when compared to high RFI. Richardson et al. (2001) reported no differences between RFI groups in carcass protein or fat content between steers divergently selected for RFI for one generation. Results from previous research and our study are not consistent in regard to carcass fatness (cBF and MARB). Richardson et al. (2001) evaluated progeny from parents selected for low RFI and high RFI and concluded that steers from low RFI parents were more efficient, however this increase in efficiency was accompanied by small changes in body composition with low RFI having greater lean and less fat than progeny from high RFI parents. Our study shows that selection for low RFI would not affect carcass fatness, but there is a numerical decline in cBF and MARB, indicating that more animals might be needed to find a difference.

Residual feed intake was not correlated to any of the non-carcass traits (Table 4.4), but FCR did correlate with EGIT, and total IFAT ($P < 0.05$). Low RFI calves had similar EBW, EBF, EGIT, IFAT, liver and heart. There was a difference in EGIT as a percentage of EBW between RFI groups. Richardson et al. (2001) reported no correlation between RFI groups with EGIT, however there was a strong positive correlation (0.42, $P < 0.05$) between RFI and IFAT. Basarab et al. (2003) reported no differences between RFI groups with EBW, but reported a difference between RFI

Table 4.5. Characterization of carcass and non-carcass traits in Angus bulls and heifers with low and high residual feed intake (RFI).

	RFI Group				Gender[a]			
Traits[b]	Low	High	SE	*P-value*	Bulls	Heifers	SE	*P-value*
n	16	16			16	16		
Carcass data								
HCW, kg	258	258	5.63	0.997	298	218	5.77	< 0.001
cREA, cm2	72.0	68.8	1.44	0.127	81.1	59.8	1.48	< 0.001
cBF, cm	1.01	1.07	0.08	0.624	0.95	1.13	0.08	0.127
MARB[c]	5.63	5.80	0.23	0.615	5.30	6.13	0.23	0.020
KPH, %	3.24	3.24	0.11	0.992	2.46	4.01	0.11	0.008
9th- to 11th-rib composition[d]								
Lipid, %	35.7	37.5	1.25	0.310	30.3	43.0	1.29	< 0.001
Protein, %	14.6	13.7	0.33	0.052	16.1	12.2	0.34	< 0.001
Non-carcass data								
EBW, kg	383	383	8.30	0.965	438	328	8.51	< 0.001
EBF, kg	27.3	27.9	0.50	0.393	26.9	28.3	0.51	0.064
Empty GI tract, kg	37.5	39.1	1.11	0.304	39.4	37.2	1.14	0.192
Total IFAT, kg	30.7	31.8	1.30	0.587	29.0	33.4	1.33	0.030
Liver, kg	5.18	5.22	0.10	0.752	6.32	4.08	0.10	< 0.001
Heart, kg	1.43	1.45	0.03	0.598	1.64	1.24	0.03	< 0.001
Empty GI tract, % of EBW	9.93	10.4	0.15	0.055	8.99	11.3	0.15	< 0.001
Total IFAT, % of EBW	8.21	8.49	0.21	0.362	6.60	10.1	0.22	< 0.001
Liver, % of EBW	1.35	1.35	0.02	0.898	1.45	1.25	0.02	< 0.001
Heart, % of EBW	0.37	0.38	0.01	0.519	0.38	0.38	0.01	0.954

[a] Heifers were harvested on d 118 and bulls on d 134 of the study.

[b] cBF = carcass 12th- to 13th-rib backfat thickness; cREA = carcass 12th- to 13th-ribeye area; EBW = empty body weight; EBF = empty body fat (Guiroy et al. (2001); Empty GI tract = empty gastrointestinal tract; Total IFAT = total internal fat.

[c] MARB = marbling score (Slight^{00} = 4.00; Small^{00} = 5.00; and Modest^{00} = 6.00).

[d] Hankins and Howe (1946).

groups and EBF. The difference in EGIT as percentage of EBW triggers the question if more efficient animals are more efficient because of smaller GI tracts or are the GI tracts smaller because they are more efficient? The liver and gastrointestinal tracts have a major impact on energy expenditures and about 20 to 25% of the total energy could be attributed to these organs (Ferrell, 1988). Johnson et al. (1990) reported that as intake increase liver and gastrointestinal tract weights also increased. The high RFI animals consumed more DMI, however no differences in liver and EGIT were observed.

There was an interaction between RFI group and IGF-I selection line for liver and empty GIT weight, uREA d70, uREA presl and cREA. For live weight, there was not a differences between low IGF-I and high IGF-I selection line calves for high RFI (0.0997), however high IGF-I calves liver was heavier than low IGF-I (P = 0.002) for the low RFI group. Therefore for efficient calves there is an impact of high and low IGF-I selection line on liver weight. In contrast, for empty GIT, within high RFI group, the low IGF-I selection line calves was heavier than high IGF-I and there was not a difference within low RFI calves. For uREA d70, uREA presl and cREA, there was not a difference between low and high IGF-I selection line for high RFI.

Previous research has indicated that bulls generally have higher ADG than heifers (Hendricks et al., 1969; Berg and Butterfield, 1976; and Arthur et al., 1997) and convert feed more efficiently than heifers (Berg and Butterfield, 1976 and Arthur et al. 1997). The results of our study shows that bulls had heavier IBW and FBW (304 vs. 260 kg, and 393 vs. 326 kg, respectively, $P < 0.001$), had higher ADG (1.81 vs. 1.35 kg, $P <$

0.001) and were more efficient (5.99 vs. 7.28, DMI:ADG) than heifers. These results are in agreement with results from Berg and Butterfield (1976) and Arthur et al. (1997).

Heifers are usually fatter than bulls at the same BW and also start depositing fat earlier in life than bulls (Berg and Butterfield, 1976). Bulls had larger uREA at days 0, 70 and preslaughter compared to heifers (48.1 vs. 41.7, 74.5 vs. 60.0, 93.3 vs. 65.0 cm^2, respectively, $P < 0.001$). As expected, heifers were fatter than bulls at a 3 scanning days (0.40 vs. 0.33, 0.79 vs. 0.59, and 1.00 vs. 0.80 cm, respectively, $P < 0.01$) and also had greater uIMF percentage (3.70 vs. 3.22, 4.23 vs. 3.04, and 4.28 vs. 3.19, respectively, $P < 0.01$). Results from serially scanned Angus bulls and heifers show that bulls have larger uREA, and smaller uBF, and uIMF (Hassen et al., 1998). Crews et al. (2002) also reported similar results.

The gender differences in carcass data results are very similar to the RTU data presented in Table 4.3 with the exception to cBF. The cBF values for bulls and heifers were not different ($P > 0.1$) which could be explained by the bulls being on feed for an extra 16 days when compared to heifers.

Implications

Results from this study demonstrate that variation in carcass and non-carcass composition had minimal impact on accounting for inter-animal variation in RFI in Angus bulls and heifers. Selection for RFI will have minimal effects on body composition as measured by ultrasound, carcass and non-carcass composition.

CHAPTER V

RELATIONSHIPS BETWEEN RESIDUAL FEED INTAKE AND CARCASS-QUALITY TRAITS IN SANTA GERTRUDIS STEERS

Introduction

Feeding animals is the major cost in almost all animal production systems (Herd et al., 2003), so selection for animals that are more efficient will increase profitability by decreasing the amount of feed needed for a given level of performance. Residual feed intake measures the difference in feed intake beyond that needed to support maintenance and growth requirements and it is independent from growth and body size (Herd and Bishop, 2000; Arthur et al., 2001a). Additionally, RFI has been shown to be moderately heritable (0.16 to 0.43; Herd et al., 2003). Several studies have evaluated relationships between RFI and ultrasound and carcass traits (Basarab et al., 2003; Nkrumanh et al., 2007; 2003; Lancaster et al., 2008). Results from these studies indicated a weak correlation (0.02 to 0.22) between RFI and ultrasound or carcass traits.

Tenderness has been reported to be the most desirable characteristic in beef by consumers. Few studies have examined the relationships between RFI and carcass quality and tenderness traits, especially with *Bos indicus*-influenced cattle. In Angus cattle divergent selected for RFI for one generation low RFI McDonagh et al. (2001) found that steers with low RFI had higher MFI and calpastatin activity, but similar Warner Bratzler shear force values compared to high RFI steers. However, Baker et al. (2006) found that calpastatin activity and Warner-Bratzler shear force values were

similar in Angus steers with divergent RFI phenotypes. Results in regard of tenderness and RFI, however, have not been consistent and need to be further evaluated. Therefore, the objective of this study was to examine the phenotypic associations between RFI and carcass composition and meat quality traits (tenderness and marbling) in Santa Gertrudis steers fed high-grain diets.

Materials and Methods

Animal and Management Description

Cattle used in this study were fed and managed under the guidelines of the Texas A&M University Institutional Animal Care and Use Committee. One hundred and fourteen Santa Gertrudis steers from the King Ranch (Kingsville, TX) were used in this study. Steers were transported to the O.D. Butler, Jr. Animal Science Complex at Texas A&M University and adapted to the experimental diet and trained to eat from Calan gates prior to the commencement of the experiment. A high-grain diet (3.0 Mcal/kg of ME and 10.1% of CP; DM) was fed for 80 d. The diet consisted of 76.5% dry rolled corn, 7.5% cottonseed meal, 5% chopped alfalfa hay, 5% coastal hay, 4% molasses, and 2% premix. Steers were approximately 13 to 15 mo of age and weighed 430 ± 42.5 kg at the start of the study. The diet was fed twice daily in sufficient amounts to allow ad libitum intake. Individual feed intake data was recorded daily and feed refusals weighed weekly for each steer. Steers had ad libitum access to fresh drinking water. Anabolic implants were not administered to steers during the study.

Individual feed ingredients were sampled at 14-d intervals, and composited samples sent to Dairy One Inc., Forage Testing Lab (Ithaca, NY) for chemical analysis

using the Cornell Net Carbohydrate and Protein System fractionation (Fox et. al., 2004). Estimates of TDN were derived from chemical analyses results using equations from Weiss et al. (1992), and estimates of ME, NE_m, and NE_g determined according to NRC (2000) as discussed by Tedeschi et al. (2005).

Growth and Ultrasound Data Collection

Steers were weighed at 14-d intervals and real-time ultrasound measurements obtained on d 0 and d 80 of the study. Real-time ultrasound measurements consisted of 12-13th rib backfat thickness, 12-13th-*longissimus* muscle area, and percentage of i.m. fat collected by an Ultrasound Guidelines Council field-certified technician using an Aloka 500V instrument with a 17-cm, 3.5-MHz transducer (Aloka Co. Ltd., Wallingford, CT).

Carcass and 9th- to 11th-rib Data Collection

Following the 80-d test period, steers were harvested in 2 groups (11 d and 40 d following the end of the 80-d test period) at approximately 10 mm of rib fat thickness, as determined by RTU measurements. Steers were transported to Sam Kane Beef Processors, Inc. (Corpus Christi, TX) to be harvested. After a 48 h chill, HCW (kg) 12th- to 13th-rib backfat thickness, 12-13th-rib LM area, marbling score, KPH and yield grade (**YG**) were obtained by Texas A&M University trained personnel. The 6-12th-rib sections were removed from the carcass, vacuum packaged, and transported to the Rosenthal Meat Science Center (Texas A&M University, College Station, TX).

The 9-11th-rib sections were removed from the 6-12th-rib sections and dissected into separable fat, lean, and bone tissue, and moisture. Protein and lipid content of

separable fat and lean were assayed to determine carcass chemical analyses according to Hankins and Howe (1946). Protein was determined using a Leco analyzer, moisture percentage was calculated using the oven-dry procedure, and fat content was determined by a Soxhlet apparatus using diethyl ether (AOAC, 1990).

Calpastatin and Tenderness Data Collection

After a 24 h chill, a 50 g sample was collected from the LM to determine calpastatin activity (**CALP**). Samples were transported approximately 5 h from Sam Kane Beef Processors, Inc. (Corpus Christy, TX) to the Rosenthal Meat Science Center (Texas A&M University, College Station, TX) and immediately extracted to determine CALP following the procedure of Wheeler and Koohmaraie (1991) and Koohmaraie et al. (1995). Two steaks were removed from the 12th-rib section, vacuum packaged and aged for 1- and 14-d and frozen after appropriate aging time to determine WBSF. The WBSF was performed on samples according to AMSA (1995). Steaks were thawed in a 4°C cooler for 48 h prior to cooking. Copper constantan thermocouples were inserted into the geometric center of each steak and temperature monitored. Steaks were cooked on a Faberware Open Hearth broiler (Faberware Company, Bronx, NY) to an internal temperature of 70°C. When steaks reached 35°C, they were turned and cooked to the final temperature and allowed to equilibrate to room temperature for a minimum of 4 h. Six, 1.27 cm, cores were taken parallel to the steak's muscle fiber orientation. The WBSF force was determined using a Universal Testing Instrument (Model SSTM-550, United Calibration Corp., Huntington Beach, CA, U.S.A.) with a WBS device, 20 kg

compression load cell with a crosshead speed of 200 mm/min, and maximum force recorded in kg as a mean of the 6 cores.

Calculations and Statistical Analysis

Growth rates of individual steers were obtained by linear regression of serial 14-d BW on days on test using the PROC REG procedure of SAS (SAS, Inst., Cary, NC version 9.18). The regression coefficients were used to derive ADG, initial and final BW, and mid-test $BW^{0.75}$ (MBW). Total feed intake of each animal collected over the 80-d test was used to compute average DMI based on moisture analyses of feed ingredients samples.

The RFI was calculated as the difference between actual DMI and expected DMI was obtained from the regression of actual DMI on ADG and MBW (Arthur et al., 2001b) using PROC GLM of SAS with herd as a random effect. Steers were classified into low, medium and high RFI phenotype groups based on ± 0.5 SD from the mean RFI of -0.01 ± 1.0 kg/d for the 80-d study.

Analysis of variance using the PROC GLM function of SAS was used to examine the effects of RFI group on performance, efficiency, carcass, and tenderness data. The model included fixed effects of RFI group and the random effects of herd, slaughter date and interaction of herd and RFI group. Least squares means were calculated and when p-value was significant ($P < 0.05$) then differences in least squares means were determined using the PDIFF option. Partial correlation coefficients among traits were determined using PROC CORR function of SAS and the random effect of herd was accounted for by using the partial correlation option.

Results and Discussion

Summary statistics are presented at Table 5.1. Steers began the study averaging 430 kg in BW, 1.05 kg/d for ADG, 9.07 kg/d for DMI, -0.01 kg/d for RFI, and 8.91 DMI/ADG for FCR. Final ultrasound measurements were 0.89 cm for uBF, 80.1 cm^2 for uREA, and 2.98 % for uIMF. Carcass back fat thickness was 1.15 cm, cREA was 76.8 cm^2, and MARB was 483. Warner Bratzler shear force values for d 1 and d 14, and calpastatin activity was 2.83, and 2.23 kg, and 2.67 activity/g, respectively. There were no differences in ADG between RFI groups, but steers had an unexpected low performance (ADG = 1.05 kg/d). The reasons for the low performance were not evident, but could be related to weather.

Phenotypic correlations between RFI and FCR are shown in Table 5.2. Residual feed intake was correlated to DMI and FCR (0.58 and 0.51, respectively, $P < 0.01$). Feed conversion ratio was correlated to ADG, RFI, and IBW (-0.65, 0.51, and 0.23, respectively; $P < 0.05$). Similarly RFI groups did not differ in ADG, IBW, and FBW (Table 5.3). Significant differences were observed between RFI groups and DMI and FCR. Low RFI steers consumed 19.4% less feed and had a 22.6% improvement in FCR when compared to high RFI steers. These results were in agreement with Nkrumah et al. (2006) who reported that low RFI consumed 17.2% less feed and had a 18.1 % better FCR than high RFI steers. Baker et al. (2006) reported that low RFI steers consumed 9.7 % less feed and 13 % better FCR than high RFI steers. Similarly, Basarab et al. (2003) reported 10.4% and 9.4%, respectively. These differences could be explained by the period that RFI was measured. In our study, as well as in Nkrumah et al. (2006) RFI was

Table 5.1. Summary statistics of performance, feed efficiency, ultrasound, carcass, chemical composition, and tenderness traits in Santa Gertrudis steers.

Trait	Mean	SD	Minimum	Maximum
ADG, kg	1.05	0.25	0.36	1.61
DMI, kg/d	9.07	1.69	4.05	13.0
RFI, kg/d	-0.01	1.00	-2.00	2.84
FCR (DMI:ADG)	8.91	1.69	4.05	13.0
Initial BW, kg	430	42.5	304	529
Final BW, kg	513	51.1	384	647
d 80 uBF, cm	0.89	0.29	0.28	1.57
d 80 uREA, cm^2	80.1	9.08	59.7	102
d 80 uIMF, %	2.98	0.75	0.88	4.66
HCW, kg	320	28.3	241	397
KPH, %	2.21	0.68	1.00	4.00
LM area, cm^2	76.8	5.78	62.9	90.0
Fat thickness, cm	1.15	0.48	0.25	2.92
Marbling score	483	83.8	285	775
Shear force d 1, kg	2.83	0.73	1.74	5.01
Shear force d 14, kg	2.23	0.47	1.33	4.19
Calpastatin, activity/g	2.67	0.42	1.28	4.10

[1] Initial = 35 d prior to beginning of trial; uBF ultrasound 12th- to 13th-rib backfat thickness; uREA = ultrasound 12th- to 13th-ribeye area; uIMF = ultrasound percent i.m. fat.

Table 5.2. Phenotypic correlations (*P*-values) between residual feed intake (RFI) and feed conversion ratio (FCR) with several traits.

Trait	RFI	FCR
Performance traits		
ADG, kg	0.00 (0.995)	-0.65 (<0.001)
DMI, kg/d	0.58 (<0.001)	0.07 (0.461)
RFI, kg/d	-	0.43 (<0.001)
FCR (DMI:ADG)	0.51 (<0.001)	-
Initial BW, kg	-0.02 (0.831)	0.23 (0.015)
Final BW, kg	-0.01 (0.899)	-0.04 (0.670)
Ultrasound traits[1]		
Initial uBF, cm	0.16 (0.082)	0.09 (0.348)
Initial uREA, cm^2	-0.22 (0.017)	0.08 (0.377)
Initial uIMF, %	0.08 (0.380)	-0.01 (0.928)
d 80 uBF, cm	0.29 (0.002)	0.07 (0.428)
d 80 uREA, cm^2	0.05 (0.632)	-0.05 (0.581)
d 80 uIMF, %	0.08 (0.405)	-0.10 (0.282)
Carcass traits		
HCW, kg	0.02 (0.844)	-0.04 (0.673)
KPH, %	0.10 (0.281)	-0.08 (0.3883)
LM area, cm^2	-0.04 (0.645)	-0.03 (0.715)
Fat thickness, cm	0.26 (0.005)	0.01 (0.904)
Yield grade	0.24 (0.012)	-0.01 (0.913)
Marbling score	0.11 (0.229)	0.14 (0.125)
Chemical composition		
LM lipid, %	0.15 (0.117)	0.15 (0.127)
Lipid, %	0.26 (0.006)	0.02 (0.861)
Protein, %	-0.27 (0.004)	-0.04 (0.655)
Tenderness traits		
Shear force d 1, kg	0.03 (0.791)	-0.03 (0.788)
Shear force d 14, kg	0.05 (0.627)	-0.09 (0.326)
Shear force change	0.01 (0.942)	0.05 (0.573)
Calpastatin, activity/g	0.19 (0.048)	0.07 (0.445)

[1] Initial = 35 d prior to beginning of trial; uBF ultrasound 12th- to 13th-rib backfat thickness; uREA = ultrasound 12th- to 13th-ribeye area; uIMF = ultrasound percent i.m. fat.

measured in finishing cattle whereas in other two studies, RFI was measured during the growing phase.

Correlations between RFI with uIMF and uREA d80 were not different from zero ($P > 0.1$). However, initial uREA was negatively correlated (r = -0.22, $P = 0.017$) and final uBF was correlate to RFI (r = 0.29, $P = 0.002$). There were no significant correlations between FCR and any of the ultrasound traits. Arthur et al. (2001a) reported a positive genetic correlation ($r_g = 0.17$) between RFI and uBF in young Charolais bulls. Robinson and Oddy (2004) reported a higher positive genetic correlation ($r_g = 0.48$) between RFI and cBF in steer and heifers. However Crews et al. (2003) and Jensen et al. (1992) reported negative genetic correlation between RFI and cBF in bulls and steers, respectively. These results indicate that RFI is genetically associated with subcutaneous fat deposition. Recent studies are not consistent when reporting phenotypic correlations between RFI and uBF, which is related to the time when RFI is measured (growing vs. finishing). Some studies have reported weak positive phenotypic correlations between RFI and uBF for growing cattle ranging from 0.14 to 0.20 (Arthur et al., 2001a; Schenkel et al., 2004; Lancaster et al., 2008c). However, in finishing cattle the phenotypic correlation between RFI and uBF was stronger ranging from 0.23 to 0.30 (Nkrumah et al., 2004, 2007). Means for RTU traits are presented in Table 5.3. The low RFI steers had less ($P < 0.05$) initial uBF than high RFI (0.29 vs. 0.37 cm, respectively). This difference in uBF was not observed at d 80 uBF, which low RFI steers tended to be leaner than high RFI steers (0.81 vs. 0.93 cm, respectively). Residual feed intake impacted composition of steers at the beginning of the high concentrate feeding period.

Table 5.3. Characterization of performance, ultrasound, and feed efficiency traits in Santa Gertrudis steers with high (> 0.5 SD above the mean), medium (± 0.5 SD above the mean), and low (< 0.5 SD below the mean) residual feed intake (RFI).

	RFI group[1]				
Trait[2]	High	Medium	Low	SE	P-value
n	36	39	39		
ADG, kg	1.00	1.06	1.07	0.05	0.513
DMI, kg/d	10.0^{x}	9.10^{y}	8.28^{z}	0.29	<0.001
RFI, kg/d	1.14^{x}	-0.05^{y}	-1.03^{z}	0.09	<0.001
FCR, DMI:ADG	10.4^{x}	8.80^{y}	8.07^{y}	0.36	<0.001
Initial BW, kg	428	429	436	6.53	0.557
Final BW, kg	507	512	519	7.52	0.441
Initial uBF, cm	0.37	0.33	0.29	0.03	0.123
Initial uREA, cm^2	58.8^{x}	58.4^{x}	64.2^{y}	1.16	<0.001
Initial uIMF, %	1.90	2.00	1.71	0.14	0.236
d 80 uBF, cm	0.91	0.90	0.83	0.05	0.336
d80 uREA, cm^2	80.7	79.5	79.9	1.73	0.864
d 80 uIMF, %	3.00	3.19	2.83	0.15	0.122

[1] Least square means within a row with different superscripts differ ($P < 0.05$).
[2] RFI = residual feed intake; FCR = feed conversion ratio; uBF = ultrasound 12th- to 13th-rib backfat thickness; uREA = ultrasound 12th- to 13th-ribeye area; uIMF = ultrasound percent i.m. fat.

The LRFI steers initial uREA was significantly larger than HRFI steers (63.9 vs. 59.0 cm^2, respectively). Recent studies are not consistent when reporting the differences between RFI groups and uBF. Baker et al. (2006) found no differences in initial or final uBF in growing cattle. Lancaster et al. (2008c) found no differences in initial uBF, but final uBF was different between high and low RFI groups in growing bulls. Some of these discrepancies could be explained by the model used to compute RFI, Baker et al. (2006) adjusted RFI for body composition and Lancaster et al. (2008c) used the base model. Nkrumah et al. (2004) and Richardson et al. (2001) reported results with finishing cattle show that more efficient animals tend to be leaner. According to our results high RFI steers had higher initial uBF and smaller uREA, and after 80-d on feed, uBF, uREA and uIMF did not differ between RFI groups.

Marbling score and cBF are key carcass traits used to determine USDA quality and yield grades that subsequently impact carcass value. Since feed efficiency has become an important trait for beef cattle production, carcass traits were evaluated to determine if selection for RFI was associated with carcass traits in Santa Gertrudis steers. As selection for low RFI cattle will reduce cost of production (less feed), it is important to not simultaneously decrease carcass value.

Table 5.2 shows correlations between RFI and carcass traits. Residual feed intake was not correlated to HCW, KPH, cREA, and MARB, but was correlated to cBF and YG (0.26 and 0.24, respectively). Carcass traits and FCR were not correlated (Table 5.2). Results have not been consistent across studies and much of this variation could be due to time when RFI is measured (growing vs. finishing), breed, and type of diet. There

Table 5.4. Characterization of carcass traits in Santa Gertrudis steers with high (> 0.5 SD above the mean), medium (± 0.5 SD above the mean), and low (< 0.5 SD below the mean) residual feed intake (RFI).

	RFI group[1]				
Trait[2]	High	Medium	Low	SE	P-value
n	36	39	39		
HCW, kg	317	320	321	5.02	0.790
KPH, %	2.19	2.26	2.12	0.12	0.669
LM area, cm^2	76.0	76.7	78.1	1.12	0.323
Fat thickness, cm	1.18^{xy}	1.27^{x}	0.99^{y}	0.09	0.030
Yield grade	3.03	3.13	2.77	0.14	0.100
Marbling score	474	503	474	16.8	0.281
LM lipid, %	4.03	3.64	3.52	0.41	0.588
9-11th-rib lipid, %	34.4^{xy}	35.5^{x}	32.2^{y}	1.05	0.034
9-11th-rib protein, %	29.3^{xy}	28.4^{x}	31.4^{y}	1.12	0.075

[1] Least square means within a row with different superscripts differ ($P < 0.05$).
[2] Marbling score = $Slight^{00}$ = 4.00, $Small^{00}$ = 5.00, $Modest^{00}$ = 6.00.

were no differences between RFI groups in HCW, KPH, cREA and MARB (Table 5.4). However RFI groups differed in cBF. Low RFI carcasses had less cBF than medium RFI carcasses (0.99 vs. 1.27, respectively). Richardson et al. (2001) reported no significant difference in cBF and cREA between steer progeny from cattle selected for low RFI and high RFI. Steers from low RFI progeny were 10% leaner than high RFI steers. Basarab et al. (2003) reported very similar cBF for low RFI and high RFI steers (9.7 vs. 9.9 mm, respectively), but found that MARB and YG approached significance ($P = 0.077$ and 0.074, respectively). Baker et al. (2006) and Castro Bulle et al. (2007) also reported no differences in cBF, MARB and YG ($P > 0.3$) between RFI groups. Discrepancies in results can be attributed to differences in RFI calculation, breedtype, and time when RFI was measured. Basarab et al. (2003) and Baker et al. (2006) measured RFI in growing cattle and also had body composition adjustments on the calculations, while Castro Bulle et al. (2007) used the base RFI model. Our results suggested that low RFI steers would produce carcasses with similar marbling score, HCW, KPH,cREA and lower YG. Therefore, selection for low RFI may decrease cBF deposition over time and potentially slightly decrease YG.

The correlation between RFI and 9-11th rib physical and chemical composition were significant ($P < 0.01$). The low and high RFI steers had similar chemical lipid % ($P = 0.07$) and protein % ($P = 0.09$), and also similar physically separated lean, subcutaneous fat and total fat (53.1 vs. 51.6 %, 9.34 vs. 9.95 %, and 23.4 vs. 25.7, respectively, $P > 0.05$). However, medium RFI calves had more chemical lipid (35.5 vs. 32.3 %), less chemical protein and separable lean (28.4 vs. 31.4 %, and 51.1 vs. 53.1 %,

respectively) than LRFI calves. Basarab et al. (2003) reported that LRFI steers tended (P = 0.08) to have less carcass dissectible fat; however, Ribeiro et al. (2007) found no difference in carcass chemical lipid between LRFI and HRFI bulls and heifers. Ribeiro et al. (2007) also reported that LRFI animals had more carcass protein than HRFI animals. Basarab et al. (2003) adjusted RFI for carcass composition. The results from the 9-11th-rib chemical composition supports the carcass data, high RFI steers and low RFI steers had similar chemical lipid % (34.4 vs. 32.2 %; $P > 0.05$, Table 5.4).

Tenderness increases as time postmortem increases (Wheeler and Kohmaraie, 1994; Morgan et al., 1993; Wulf et al., 1996), which is a result of postmortem proteolysis caused by the calpain system (Wheeler and Koohmaraie, 1994). Calpastatin is the major inhibitor of the calpain system in postmortem muscle (Koohmaraie, 1992). Several studies have indicated that calpastatin activity is correlated with tenderness (Whipple et al., 1990; Shackelford et al., 1994; Wulf et al., 1996) and highly heritable (Shackelford et al., 1994). Since consumers are willing to pay a premium for more tender beef (Miller et al., 2001), it is important to evaluate the relationship of WBSF and CALP with RFI. Correlations were not significant between RFI and FCR with WBSF for d 1 or d 14, and WBSF change (Table 5.2). However, correlation were significant (P = 0.048) between RFI and CALP. The low RFI steers had numerically lower d 1 and d 14 WBSF (2.83 vs. 3.18 kg and 2.26 vs. 2.40, respectively) and significantly (P = 0.03) lower CALP than high RFI steers (Table 5.5). Two studies reported the relationship between RFI and tenderness traits. McDonagh et al. (2001) found no differences in WBSF between LRFI and HRFI steers, but HRFI steers had 13 % higher CALP then

Table 5.5. Characterization of tenderness traits in Santa Gertrudis steers with high (>0.5 SD above the mean), medium (±0.5 SD above the mean), and low (<0.5 SD below the mean) residual feed intake (RFI).

	RFI group[1]				
Trait	High	Medium	Low	SE	P-value
n	36	39	39		
Shear force d 1, kg	3.18^{x}	2.74^{y}	2.83^{xy}	0.14	0.042
Shear force d 14, kg	2.40^{x}	2.10^{y}	2.26^{xy}	0.09	0.044
Shear force change, kg	0.77	0.63	0.56	0.12	0.386
Calpastatin, activity/g	2.84^{x}	2.69^{xy}	2.60^{y}	0.07	0.032

[1] Least square means within a row with different superscripts differ ($P < 0.05$).

LRFI. In contrast, Baker et al. (2006) reported that HRFI and LRFI steers had similar WBSF and CALP. Our study is in agreement with McDonagh et al. (2001) and Baker et al. (2006) showing no differences in WBSF between both RFI groups; however, LRFI steers had lower CALP when compared to HRFI steers. Protein turnover is an energetically expensive process. Oddy (1999) reported that selection for high growth rate impacted CALP, in which animals selected for high growth had higher CALP. Selection for RFI could reduce calpastatin level and improve tenderness, but additional research is needed to clarify these relationships.

Implications

Results from this study showed that more efficient animals (low RFI) are leaner than least efficient animals (high RFI). However, there were no differences in marbling and tenderness between RFI groups. There are differences between the way RFI is calculated and that need to be taken in consideration. Also the time (growing vs. finishing phase) when RFI is measured can affect the results. Further research is needed to compare RFI of cattle from different breeds and different feeding strategies.

CHAPTER VI

SUMMARY

The results of this dissertation indicate that real-time ultrasound can be used to measure carcass and non-carcass fat in beef cattle. This technique enables us to predict kidney fat depth, total KPH weight and total internal fat weight in live animals from different gender and frame score. The results also indicate that residual feed intake is independent of growth traits and body size. There were no correlations between body weight and average daily gain. Feed intake and feed conversion ratio was strongly correlated to residual feed intake. In one study there were no differences in ultrasound and carcass traits; however in another study more efficient animals were leaner when compared to more efficient animals. Results also show that selection for more efficient animals (mow residual feed intake) will not impact tenderness or marbling in beef cattle. The different results in ultrasound and carcass traits could be attributed o breed differences, since one study used Santa Gertrudis steers which are know to be leaner and the other study used Angus cattle which are known to deposit more fat.

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