THE EFFECT OF TEMPERAMENT AT FEEDLOT ARRIVAL ON GROWTH EFFICIENCY, FEEDING BEHAVIOR, AND CARCASS VALUE IN BEEF HEIFERS

A Thesis

by

CAMERON ALEXANDER OLSON

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

MASTER OF SCIENCE

Chair of Committee,	Andy D. Herring
Co-Chair of Committee,	Daniel S. Hale
Committee Member,	Gordon E. Carstens
Head of Department,	G. Cliff Lamb

August 2017

View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Texas A&M University

Major Subject: Animal Science

Copyright 2017 Cameron Alexander Olson

ABSTRACT

Temperament of cattle is defined as the animal behavioral response to humans. Objectives of this study were to evaluate the effects of temperament and breed type (Angus, Braford, Brangus, and Simbrah) on productivity, feed intake and efficiency, feeding behavior patterns and carcass-quality traits in finishing heifers. In 3 trials, heifers (N = 415, BW = 280 kg) were fed a high grain diet in pens equipped with electronic feeders to measure DM intake and feeding behavior traits. Heifers were slaughtered at a backfat thickness of 1.2 cm, and data collected to determine yield and quality grades. Warner-Braztler shear force was measured on steaks at 1- and 14-d post-mortem aging. Residual feed intake (**RFI**) was calculated as the residual from regression of DMI on mid-test $BW^{0.75}$ and ADG. Relative exit velocity (**REV**) was recorded at feedlot arrival and used as a covariate in Mixed models to assess the effects of temperament and interactions with breed on response variables. Calm heifers had 4% heavier initial BW, gained 12% more per day, consumed 8% more DMI per day and had 4% more favorable G:F than excitable heifers. There was a temperament x breed interaction ($P < 0.01$) for RFI, whereby DMI per $BW^{0.75}$ and RFI decreased as REV increased in Braford heifers but not in heifers of the other 3 breeds. Calm heifers had 10% greater head-down duration, 9% greater bunk visit (**BV**) duration, and had 11% shorter time-to-bunk than excitable heifers. Calm heifers had 9% greater meal duration, and consumed meals that were 22% longer and 17% larger compared with excitable heifers. Frequency of BV and meal events were not affected by temperament, but calm heifers had 12% more BV events per meal then excitable heifers. Carcasses of calm heifers were 4% heavier, had 7% greater BF depth, and 4% higher YG than carcasses of excitable heifers. Steaks from calm heifers were more tender then steaks from excitable heifers. Based on a carcass grid that accounted for tenderness-value differences, calm heifers generated $62 more income then excitable heifers, demonstrating that temperament is an important economically relevant trait. Systems that sort calves based on temperament into targeted production-outcome groups, could reduce within-group variation in production efficiency and carcass quality, adding value to the beef production chain.

DEDICATION

For my Mom, Dad, and Brother

ACKNOWLEDGEMENTS

Thank you to my family, parents Doug and Donna Olson and brother Lance, for supporting me emotionally, physically and financially for the course of my academic career. I could not have completed this without you. Further, thanks to my grandparents, Wayne and Betty Morris, for having the foresight to financially secure an education for each of their four grandchildren. I hope I have made them proud of my accomplishments. Also, to Kenneth and Nancy Allen, for their constant support and hospitality toward me and my family during my time in Texas.

Thanks to my friends in Texas and Canada, and especially those on the 2013 Texas A&M Meats Judging Team, thanks for your encouragement and support. To Dr. Leslie Frenzel, thanks for pushing me along this path.

Thank you to my committee, Drs. Andy Herring, Dan Hale, and Gordon Carstens, for giving me the opportunity to pursue this thesis, and for their support and guidance over the last two years.

“[25]God made the beasts of the earth after their kind, and the cattle after their kind, and
everything that creeps on the ground after its kind; and God saw that it was good.”

Genesis 1:25

“[2]Great are the works of the Lord;
They are studied by all who delight in them.”

Psalms 111:2

CONTRIBUTORS AND FUNDING SOURCES

This work was supported by a thesis committee consisting of Dr. Andy Herring (co-chair) and Dr. Dan Hale (co-chair) of the Department of Animal Science, and committee member Dr. Gordon Carstens of the Department of Animal Science.

The data analyzed for Chapter II was provided by Dr. Carstens. The statistical analyses used in Chapter II were conducted with the aid of Mr. William Kayser of the Department of Animal Science.

All other work conducted for the thesis was completed by the student independently.

Graduate study was supported by a teaching fellowship from Texas A&M University.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

The livestock industry continues to be challenged with increases in demand, rising costs of production, and societal concerns about the environmental impact of livestock production systems. By the year 2050, global human population is expected to reach over 9 billion (UN, 2015) ,which will nearly double the predicted demand for animal protein. Beef production must continue to adapt and make improvements to meet rising demand associated with higher incomes and larger middle-class populations. To meet these increases in demand and maintain a sustainable production system, the implementation of new management techniques and technology will be necessary.

Beef cattle temperament has been monitored for several decades by certain beef breed associations, as some breeds have been noted to have issues with excitability. In addition to easing animal stress and mitigating facility and handler damage, calmer animals have also been noted to have improved weight gain and feed performance (Tulloh, 1961). Temperament was defined by Fordyce et al. (1988a) as the fear response of cattle when handled by humans. Burrow et al. (1988) introduced a method of assessing temperament by measuring the animal's velocity upon exiting a squeeze chute, which provided a more objective evaluation of temperament phenotypes. Temperament has subsequently been determined as a moderately heritable trait, with implications for feedlot production, feed efficiency, animal health, carcass weight and beef quality.

Temperament

Temperament is generally defined as the fear-related responses of cattle to human interaction (Fordyce et al., 1988a). Historically, most of the focus on temperament of beef cattle has been due to concerns over human and animal safety. Cattle with excitable temperaments can pose a significant threat to the safety of employees, other cattle, and even to themselves. Indeed, several North American breed associations have developed genetic evaluation programs for docility. These docility EPD's are based on subjective evaluation temperament by farm or ranch operators. Continental breeds, including Limousin, Charolais, and Salers regularly use breeder-submitted docility scores similar to those developed by Grandin (1993). Today, even breeds noted for calm dispositions relative to other breeds, such as Angus, are encouraging breeders to record and submit docility scores for genetic evaluation (Northcutt and Bowman, 2010).

Methods for the evaluation of temperament

An animal which one person might consider "wild" or "unmanageable" might be considered "normal" or "workable" by another. The various production systems in which beef cattle are raised all over the world dictate that there would be vast differences in the expectations and acceptability of cattle temperament. Cattle raised with minimal human interaction might be expected to be more excitable, aggressive, and fearful than animals raised more intensively (Grandin, 1993). Beef cattle have been shown to learn some of their behavioral responses over time, with repeated exposure to handling. Even so, Grandin (1993) reported that some extremely excitable cattle do not seem to calm down when exposed to repeated handling, but always remained agitated at elevated levels, regardless of how innocuous the previous handling experiences were. However, most animals can learn that human contact is not necessarily adverse, and calm down more and more as they are handled. In general, beef cattle tend to exhibit more excitable temperaments than dairy cattle, as beef animals are not as frequently exposed to human interaction. Therefore, when evaluating the temperament of beef cattle, the evaluation technique should account for animal’s learned behavior over time or be collected before learned responses can be established.

Several subjective protocols have been established and utilized to assess animal temperament based on behavioral responses. For such protocols to be useful, temperament values must be assigned under normal handling conditions and on an individual-animal basis (Fordyce et al., 1982). The subjective scoring system recommended by the Beef Improvement Federation (**BIF**) uses a 6-point scale to adjudicate animal behavior in a squeeze chute; where 1 = docile, mild disposition and 6 = Very Aggressive, pronounced attack behavior (BIF, 2016). Currently, most breed associations have adopted this method for genetic evaluation of docility. In Queensland, Fordyce et al. (1982) evaluated 5 subjective methods of assessing temperament in Brahman, Afrikander, and British-cross heifers, cows, and bulls including the assessment of behavior in (1) restraint in a squeeze chute; (2) the snake alley of a handling facility; (3) restraint in a squeeze chute with a head gate; (4) releasing the animal into a solitary pen with a single human present (“pound” test); and (5), challenging the flight distance of individually penned cattle by approaching them and estimating a flight distance (Fordyce et al., 1982). In the restrained circumstances, animals were evaluated and scored based on the extent of their movement (1- stands quietly; 7- struggles violently), and the degree of audible respiration (1- no audible respiration; 4- blowing or snorting frequently; Fordyce et al., 1982). In the solitary pound test, while one person stood in the center of a 6 m-diameter round pen, animals were scored on the number of times they moved between pen quadrants, and the speed of their movement (1- stands; 5- gallops; Fordyce et al., 1982). Finally, the flight distance test estimated the nearest distance an animal would allow a human to approach before defensive movement was made (Fordyce et al., 1982). An issue with these subjective scores as discussed by Fordyce et al. (1982) was that they are reliant on the opinion of the evaluator. One evaluator might have a different opinion or threshold than another, and repeatability of evaluators can be low. Furthermore, the subjective evaluation of temperament tends to be labor intensive and time consuming (Burrow et al., 1988). This can make comparison of studies difficult, as training evaluators and different measurement techniques may not correlate between studies.

Burrow et al. (1988) first presented the concept of using the velocity of an animal upon exit from a chute or scale as an objective method to assess temperament in beef cattle. Burrow et al. (1988) hypothesized that cattle with more excitable temperaments would likely exit the chute faster than cattle with calm temperaments. To measure exit velocity (**EV**), infrared sensors were used at the front of the chute, with the timer starting when the animal broke the first sensor and stopping when it broke the second sensor (Burrow et al., 1988). Length between the sensors used in numerous studies is not consistent, with distances ranging from 1.7 to 2.44 m, although 1.8 m has been established as an unofficial standard distance (Burrow et al., 1988; Burrow and Corbet, 2000; Curley et al., 2006; Nkrumah et al., 2007; Behrends et al., 2008).

Curley et al. (2006) verified that the concept presented by Burrow et al. (1988) was repeatable and was related to animal-stress responsiveness. Interestingly, Curley et al. (2006) observed that there was a significant decrease in EV of young Brahman bulls between d 0 and d 60 of the trial, suggesting that animals with excitable temperaments may become less excitable with repeated exposure to human interaction, though the insignificance of the difference between d 60 and d 120 suggested that there may be a limit to how much the excitable cattle will settle. However, Grandin (1993) found that *Bos taurus* steers and bulls that had high subjective chute scores (more excitable) did not become more docile with repeated handling. Curley et al. (2006) concluded that EV may be a more useful tool to assess temperament in cattle than subjective evaluations of pen or chute temperament scores.

Impact of temperament on stress responsiveness and productivity

Cattle are regularly subjected to multiple stressors, including inclement weather, scarcity of food resources, immune challenges from bacteria and viruses, and threat of predation. The stress response of prey animals like cattle allows them to discover new food resources, outrun or fight off predators, and potentially boost their immune system during illness. Today, cattle are produced in environments where humans implement management strategies to mitigate the effects of stressful conditions. However, human interactions and the associated stress responses are often unavoidable. All cattle will experience some close-quartered human handling. In modern feedlot conditions, cattle might be exposed to humans on a daily basis, with pen riders constantly checking clinical signs of illness and cattle weighed to monitor animal growth and development (Cooke, 2014). The effects of stress responses in beef cattle on feed are noticeable and economically relevant (Cooke, 2014), and include possible reductions in productivity (Voisinet et al., 1997b), reduced dry matter intake (DMI) (Nkrumah et al., 2007) and less favorable feed efficiency (Petherick et al., 2002).

Beef cattle exhibit a hormonal stress response when handled by humans (Curley et al., 2006; Llonch et al., 2016). The extent of the release of stress-related hormones, such as cortisol, varies between animals. Cortisol levels have been shown to be positively correlated with temperament (Curley et al., 2006; Llonch et al., 2016). Curley et al. (2006) found that EV was positively correlated ($r = 0.26$; $P < 0.05$) with serum cortisol concentrations among yearling Brahman bulls, suggesting that EV was indicative of stress responsiveness of cattle to human interaction, possibly relating to a behavioral fear response to human contact. When the hypothalamic-pituitary-adrenal axis (**HPA**) and sympathomedullary system (**SMS**) are stimulated in a stressful situation, (e.g. when handling cattle in a squeeze chute or on foot in a pen), corticotropin releasing hormone (**CRH**), vasopressin, epinephrine, and norepinephrine are produced (Burdick et al., 2011). Corticotropin releasing hormone stimulates the release of adrenocorticotropic hormone from the pituitary, which causes the secretion of cortisol into the blood stream from the adrenal cortex (Burdick et al., 2011). Once released into the circulatory system, these stress-induced hormones simulate the catabolism of glycogen, protein, and triglycerides to provide energy to aid in the flight-or-fight response of the animal (Burdick et al., 2011). As the primary goal of the beef cattle industry is to produce muscle protein and lipid tissue to cattle in an efficiency manner, the degradation of muscle tissue is a fundamental problem. Prolonged or repeated stress responses can affect the performance of the digestive system, limiting the amount of nutrients obtained from feed, further impairing the efficiency of the cattle.

The reported effects between various temperament scores and animal performance are not consistent across or even within some studies (Turner et al. (2011). This may be due to as-yet unidentified genetic correlations (Turner et al., 2011). Several genes, which may be responsible for controlling temperament have been identified, (Schmutz et al., 2001; Cooke, 2014), and as a result, it is possible that genetic correlations exist between behavior and production traits (Schmutz et al., 2001).

As temperament has been established as moderately heritable (Haskell et al., 2014), selection for cattle with improved temperament will likely have positive economic impacts. While temperament is clearly an economically important trait, caution in selecting overly docile replacement females should be considered. Indeed, Sandelin et al. (2005) stated that some cattle are so docile that maternal instincts to protect and nurture their calf are reduced. Among various purebred breeds at the University of Arkansas over a 25 year period, Sandelin et al. (2005) reported that calves from a very attentive mother had a survival rate of 93% compared to only 60% for calves born to cows described as apathetic at calving. Obviously, lack of maternal protection can leave calves vulnerable to death by predation or exposure. Care should be taken to ensure that mothering instinct are being preserved when selection for favorable animal temperament is emphasized.

Cooke et al. (2012) found that the pregnancy and calving rate of excitable cows where lower than the same rates in dams with calm temperaments. Among aggressive *Bos taurus* cows, Cooke et al. (2012) reported higher blood cortisol concentrations (22.7 ng/mL), lower pregnancy rate (88.7%) and lower calving rate (85.0%) than their calm counterparts (17.8 ng/mL, 94.6%, and 91.8%, respectively). Correspondingly, the excitable cows had fewer kg of calf born per cow exposed (34.1 kg compared to 39.7 kg), a tendency toward lower weaning percentages ($P = 0.09$) and fewer calves weaned per cow exposed ($P = 0.08$). Cooke et al. (2012) concluded that excitable cows were subject to impaired reproductive efficiency due to increased blood concentrations of stress-related hormones.

The effects of temperament on feed efficiency and growth performance

Feedlot cattle and cattle raised in other types of intensive production systems are subjected to stressors which are not typically placed on extensively raised animals. Animals fed for slaughter are often subjected to stressful conditions including abrupt changes in diet format, and quality, differences in activity schedules, and exposure to pathogens. Furthermore, calves are often commingled and exposed to several new social groups over the course of their lives. In pasture settings, stressors may include the availability of food, water, and shelter over large acreage, as well as situations of predation. Intensively raised animals are subjected to different, artificial or man-made stressors, which cattle may not have an instinctive ability to handle. Among weaned

Angus X Hereford calves, Fell et al. (1999) observed that nervous animals did not appear to cope as well and, as a result, had lower productivity (ADG = 1.04 ± 0.10 kg^{-1} compared to 1.46 ± 0.05 kg/d for excitable and calm temperament cattle, respectively). Excitable cattle also tend to have higher incidence of disease, with 5 of 12 excitable cattle treated for disease during the study, compared to none of the 12 calm animals being treated for disease (Fell et al., 1999).

Inter-animal variation in temperament has also been shown to be associated with productivity and feed efficiency. Several studies have shown that temperament has a significant impact on ADG and BW of growing cattle. Burrow and Dillon (1997) reported significant differences among 5/8 Brahman, 3/8 Shorthorn cattle analyzed for EV. Excitable cattle reported ADG as low as 0.79 kg/d, and calm animals as high as 1.14 kg/d. In agreement, Behrends et al. (2008) found that feedlot ADG of crossbred Bonsmara steers with a “fast” and “medium” EV (measured at weaning) had higher ADG than steers with a “slow” classification. Additionally, Petherick et al. (2002) reported a similar trend among *Bos indicus*-cross cattle, which were classified by temperament. Animals with excitable temperaments tended to have lower ADG than cattle with calm temperaments (excitable = 1.37 kg/d, calm = 1.54 kg/d,). Cattle with excitable temperaments also displayed decreased feed efficiency, gaining less per unit of feed consumed than calm cattle (Petherick et al., 2002). Fell et al. (1999) reported similar differences, as did Cafe et al. (2011). Among cattle, Voisinet et al. (1997b) reported that ADG was significantly lowered in cattle with excitable temperaments. Among *Bos taurus* cattle, animals that had a chute score of 1 had a significantly higher

ADG (1.38 kg/d) than animals which scored a 2 or 3 (1.29 kg/d and 1.19 kg/d, respectively) (Voisinet et al., 1997b). Among *Bos indicus*-cross cattle, a similar trend for ADG was observed as temperament scores increased (Voisinet et al., 1997b). These decreases in ADG may be partially explained by reduced DMI (Nkrumah et al., 2007). Exit velocity had a negative phenotypic correlation with DMI (-0.35; $P < 0.001$), indicating that as EV increased, DMI decreased (Nkrumah et al., 2007). These results agree with Burrow and Dillon (1997), who reported evidence that animals with faster EV (< 0.7 s) grew more slowly than animals with slower EV (≥ 0.9 s).

The reason for lowered ADG and DMI in excitable cattle is not yet thoroughly understood. It has been proposed that basal metabolic rates may be higher in excitable cattle than in calm cattle, as excitable animals appear to spend more time in a state of nervousness than their calmer counterparts (Burrow and Dillon, 1997; Petherick et al., 2002; Ferguson et al., 2006). In genetically stress-prone hogs, exposure to a stressful situation resulted in more rapid increase in stress hormones and a longer recovery time than the same stressful situation in genetically calmer hogs (Veum et al., 1979). Similarly, it is thought that excitable cattle may have a longer recovery time and a sharper decrease in DMI and ADG than calm cattle as a result of substantially higher amounts of stress hormones in the blood. Higher levels of blood cortisol of excitable cattle may impair efficient use of feed and (or) limit the accretion of lipid and protein deposits (Fell et al., 1999). This would help to explain why calm cattle were more efficient at converting feed to gain (Petherick et al., 2002; Cafe et al., 2011).

Associations between feeding behavior and temperament

Due to the relative novelty of effective methods to monitor feeding behavior in beef cattle, there is little available research documenting the associations between animal temperament and feeding behavior (Nkrumah et al., 2007). Nkrumah et al. (2007) measured the EV of Angus, Charolais, and commercial bulls over the span of three years (2002-2005), and evaluated the association between EV and feeding frequency (FF), feeding duration (FD), and head-down duration (HDD). Exit velocity was unrelated to any of these measures of feeding behavior, despite the fact that EV was negatively correlated with DMI (-0.35; $P < 0.05$). The results of the study indicated that assessments of temperament and feeding behaviors may not be phenotypically related (Nkrumah et al., 2007).

Impact of temperament on carcass composition and quality

Studies have found that animal temperament is associated with carcass quality grades, tenderness, dark cutting, and bruising (Burrow and Dillon, 1997; Voisinet et al., 1997a; King et al., 2006; Nkrumah et al., 2007; Behrends et al., 2008; Cafe et al., 2011). The ability of cattle to cope with stress when handled in conventional production environments likely influences their meat quality and may have genetic correlations with deposition of fat and muscle tissue. However, results and the significance of phenotypic and genotypic correlations vary across studies performed.

In a study involving mixed-gender Brahman and Angus cattle in New South Wales and Western Australia, Cafe et al. (2011) found that cattle with high EV during both grower and finisher phases produced steaks that were tougher compared to cattle with lower EV. A relationship was established between background feeding phase EV and Warner Bratzler Shear (**WBS**) force of tender-stretched, 7 d aged m. longissimus lumborum (**LL**) among Brahman cattle, indicating that increases in EV could predict tougher carcasses. Similarly, increased backgrounding EV was negatively related to Warner-Bratzler shear (WBS) force measurements in Achilles tendon-hung, 1-d post-mortem aged Angus cattle. Feedlot EV was also observed to have a relationship in both Angus and Brahman cattle. Warner-Bratzler shear force increased as EV increased in both 1 d post-mortem aged, Achilles tendon-hung LL in Brahman and tender-stretched LL Brahman and Angus. Further, evidence of a relationship between increased cooking loss and background phase EV was found in Brahmans. Interestingly, there seemed to be a stronger correlation between WBS force and temperament when LL and m. semitendinosus were aged 1 d post-mortem, compared to when they were aged 7 d post-mortem (Cafe et al., 2011), suggesting that the post-mortem aging process may mitigate the effects of temperament and breed on tenderness. This may indicate that there is another, unknown, factor affected by temperament other than proteolysis of muscle (Cafe et al., 2011). In agreement with Cafe et al. (2011), Fordyce et al. (1988b) reported significant differences in WBS force of longissimus dorsi from crossbred Brahman X Shorthorn and purebred Shorthorn cows and bullocks. Animals assigned a score of 5 (excitable) for their pen movement assessment had significantly higher WBS force scores than animals in group 1 through 4 (Fordyce et al., 1988b).

Nkrumah et al. (2007) reported several significant interactions between EV and various carcass traits among Angus, Charolais, and various commercial hybrid bulls.

Exit velocity had a correlation of -0.25 with carcass weight (kg), carcass grade fat (mm), and carcass yield grade. Exit velocity also had a negative correlation of -0.22 with marbling score, and had positive correlations with loin muscle area (0.14), and a moderate correlation with carcass lean meat yield (0.30). In agreement with Nkrumah et al. (2007), Burrow and Dillon (1997) reported a regression coefficient of -1.52 between dressing percentage and EV in their study group of 5/8 *Bos indicus*, 3/8 *Bos taurus* heifers. In the second trial, carcasses of the fastest animals yielded as much as 1.8% less than the carcasses of the slowest animals. The effects of temperament on fat depth and carcass bruising were not significant (Burrow and Dillon, 1997). When EV was measured at weaning, WBS force was higher in fast EV (mean + 0.5 SD) than slow EV (mean -0.5 SD), 2.83 kg compared to 2.46 kg, respectively (Behrends et al., 2008). King et al. (2006) examined the relationship between temperament and tenderness among three different cattle groups (A, B, and C). Within each group, cattle were separated into excitable, intermediate, and calm categories using a combination of EV, pen scores and chute scores. They found Group C excitable steers had higher WBS values than the calmer Group C steers. This trend was observed in group A steers, although the values were not significant. The trend was not reported in Group B steers. Behrends et al. (2008) found that fast EV animals have a significantly higher numerical yield grade than slow EV animals, and significantly smaller LMA than both medium and slow EV animals. In contrast, King et al. (2006) reported that temperament categories, also based on EV, did not have a significant effect on USDA yield grade. Further, no significant interaction between percent chemical fat in the longissimus dorsi, % moisture, L*, a* and b* color characteristics, or calpastatin activity existed between calm, intermediate and excitable cattle (King et al., 2006). Voisinet et al. (1997a) and Grandin (1993) reported significant incidence of dark lean percentage among cattle classified on a 4 point chute score scale. In the Behrends et al. (2008) study, EV at weaning had a stronger correlation with economically relevant carcass traits, indicating that weaning EV is likely a more reliable measurement of cattle temperament than EV recorded later in life.

Carcass bruising is another area of interest where temperamental animals are concerned. Excitable temperament animals have been perceived to cause either more bruising to themselves, and/or more bruising to other animals they are penned with (Burrow and Dillon, 1997). When *Bos indicus* steers were analyzed for correlations between bruising and temperament, Fordyce et al. (1985) discovered that there was no more frequent bruising in cattle with a higher chute score (more agitation) than in cattle with lower chute scores (less agitation). This lack of significance was attributed to the previous handling experience the steers had endured, and their resulting relative docility (Fordyce et al., 1985). In another study, Fordyce et al. (1988b) examined the incidence of bruising among Brahman-cross and Shorthorn cows and bullocks, and found cattle with excitable temperaments during chute scoring had significantly more bruising. In bulls, the total bruise score increased significantly as chute scores and pen scores increased (Fordyce et al., 1988b). In the cows, there was no relationship between temperament scores and bruising over the rump, loin, rub or chuck areas, although there were significant differences between temperament groups and bruising over the back, hips and pin bone areas (Fordyce et al., 1988b).

Feed Efficiency

Applying the term, “Improved Efficiency,” to any system implies that more units of product are produced per unit of input. Recently, the beef cattle industry has come under scrutiny by the public due to the fact that feed efficiency is relatively more favorable for non-ruminant systems. These accusations come on the heels of recent United Nations reports stating that global population will be approaching 9.7 billion by 2050 (UN, 2015). Further, it has been projected that consumption of animal food products (meat and dairy) is expected to increase as the global middle-class economy grows. This will be especially true in Asian countries, where rising incomes are allowing for an improvement in quality of life, which is usually associated with increased demand for animal proteins (Kharas, 2010; UN, 2015). To remain a relevant, cost effective protein source, domestically and internationally, beef must and improve efficiencies in the production system.

Measures of beef cattle efficiency focus on feedstuffs, the largest single input costs in beef cattle production (Arthur et al., 2004; Lancaster et al., 2009a,b). Feed cost is a majority of the costs associated with beef cattle production, and can escalate to as much as 85% in the cow-calf sector (Arthur et al., 2004). This percentage of total cost can get even higher in the feedlot sector, where intensive feeding of high-priced commodities such as corn is common (Vasconcelos and Galyean, 2007). Thus, it is in the best interests of the industry to ensure that every unit of feed is maximized in beef output. Analyzing and improving animal efficiency is paramount to not only ensuring a stable, high quality food source for an expanding global population, but also for continuing to make feeding cattle a profitable, sustainable industry.

Examination of feed efficiency measures

Feed Conversion Ratio

Feed conversion ratio (**FCR**) is the most popular and widely-used method of evaluating animal efficiency (Archer et al., 1999). It is simple to understand and obtain: feed intake and weight are measured over a set period (feedlot duration, for example). The weight of feed consumed by the animal is then compared to the weight gained by the animal over the same period and a conversion ratio is found. Very high correlations exist between desirable production traits and FCR, however, selection to improve FCR will not automatically lead to improved system efficiency (Archer et al., 1999). Feed conversion ratio favors animals which grow faster, on less feed, which is desirable economically in terminal production systems such as feedlots. However, using FCR to select animals in the cowherd can lead to increased mature cow size, which in turn results in higher cowherd maintenance costs (Archer et al., 1999).

Residual Feed Intake

Koch et al. (1963) introduced the method now referred to as residual feed intake (**RFI**), as a measure of individual animal efficiency. The advantages of using RFI to measure feed efficiency and select for genetic improvement of efficiency were confirmed by Arthur, et al., (2001). Residual feed intake is a measure of feed efficiency that is independent of growth traits in growing beef cattle. Residual feed intake is calculated by regressing dry matter intake (DMI) on mid-trial metabolic body weight (MBW, $BW^{0.75}$) and average daily gain (ADG) to obtain an expected intake value for an animal. Residual feed intake compares expected feed intake for a given ADG and BW and actual feed intake for that same period (Herd and Arthur, 2009). Thus, within a contemporary group, cattle which have a higher RFI value are less efficient (consumed more than expected) than cattle which have a lower RFI value (consumed less than expected). Residual feed intake has been suggested as a selection tool to improve the feed conversion of beef cattle without correspondingly increasing mature body weight (Herd and Bishop, 2000).

Historically, measuring feed intake in individual animals has been difficult and expensive to generate. However, the GrowSafe® Feed Intake Monitoring System, created in the early 1990's by GrowSafe® Systems Ltd, in Airdrie, Alberta, has made collecting feed intake data easier and more accurate. The GrowSafe® system was developed with a series of feed bunks equipped with load cells, which have the capability of reading radio frequency identification ear tags (RFID tags) of individual animals as they feed. Feed disappearance is monitored and assigned to the RFID tag present at the bunk during the feed disappearance event. GrowSafe® feed systems also record feeding behaviors of individuals, as only one animal can access a feed bunk at a time during the trial period. Availability of this technology has facilitated more research into factors affecting feed efficiency in beef cattle.

Residual Gain

In addition to RFI, Koch et al. (1963) also proposed residual gain (**RG**). Residual gain is computed in a similar manner to RFI, except that RG is the difference between actual and expected gain, with expected ADG based on body weight and feed intake of the individual compared to the average of the cattle in the contemporary group (Koch et al., 1963). Residual gain was found to have low-moderate heritability [0.28, ± 0.06 (Crowley et al., 2010)]. However, some industry organizations have been slower to recognize RG as useful, because selection for increased RG can lead to an increase in mature BW.

Ultimately, improvements in beef cattle feed efficiency are economically, socially and environmentally crucial to the continued success of the beef industry. Every endeavor to lessen the amount of feed, increase beef production, and shorten time spent on feed, must be given attention to verify its efficacy within the entire beef production system.

Associations between residual feed intake, productivity, carcass composition, and quality

Residual Feed Intake and Productivity

For obvious reasons, there has been intense interest in examining the effects of selection for low RFI (efficient) cattle in relation to other productivity traits. How RFI affects cattle behavior, productivity, BW, and body composition, cow productivity and longevity, beef production and quality are all areas of interest in current literature. These traits have an economic relevance to cattle breeders, cattle feeders, and beef processors, and ultimately to the beef consumer.

Several studies have reported RFI to have moderate-strong phenotypic correlation with dry matter intake (DMI) among breeds of English and Continental beef cattle (Archer et al., 1997; Herd and Bishop, 2000; Herd et al., 2003; Baker et al., 2006; Nkrumah et al., 2006; Lancaster et al., 2009a; Welch et al., 2012). Residual feed intake has also been shown to be moderately correlated both genetically and phenotypically with feed conversion ratios (FCR, feed intake divided by ADG; r = 0.66 and r = 0.53, respectively), with low RFI cattle having a more desirable FCR than high RFI cattle (Arthur et al., 2001). Additionally, Schenkel et al. (2004) reported a positive correlation of 0.69 between RFI and FCR among purebred beef bulls. In a study of purebred Brangus heifers, Lancaster et al. (2009a) reported that heifers with low RFI consumed as much as 15% less DMI than heifers with high RFI, but had similar ADG and final BW.

Residual Feed Intake and Carcass Characteristics and Meat Quality

The primary purpose of feeding cattle a high-concentrate, energy-dense diet in North America is to produce beef that is easily marketed to consumers that value beef as a high-quality product. Consumers demand beef which is tasty and palatable. Therefore, it is prudent for the beef industry to ensure that implementation of selection criteria does not negatively affect the carcass characteristics and eating quality of the beef being produced (Welch et al., 2012). Due to the potential for differences in RFI to be explained by physiological processes, some of which do affect carcass characteristics and meat quality, extensive research has been done to examine the impacts of RFI on carcass characteristics and meat quality.

A study performed with Red Angus steers revealed that post weaning RFI was not correlated with any carcass traits of economic relevance (hot carcass weight, LMA, subcutaneous fat, KPH, and yield grade) or with any final-product quality measures (marbling score, quality grade) (Welch et al., 2012). Of the economically important carcass traits, the one most sensitive to change is intramuscular fat, or marbling. McDonagh et al. (2001), Baker et al. (2006), and Welch et al. (2012) reported no significant correlation between RFI and intramuscular fat (**IMF**) deposition. This is in disagreement with Basarab et al. (2003), who reported a tendency for positive phenotypic correlation between RFI and carcass marbling ($r = 0.15$, $P = 0.07$) among crossbred steers. In support of this study, Baker et al. (2006) found no difference in USDA quality grade between low, medium and high RFI Angus steers. However, using yearling Angus steers, Richardson et al. (2001) reported numerical tendencies for low RFI cattle to have less IMF fat than high RFI cattle (low RFI = 25.3, ± 1.13 kg, high RFI = 28.9, ± 1.92 kg). However, when IMF and sub-cutaneous fat weights from carcasses with low and high RFI values were combined and compared, Richardson et al. (2001) reported significant differences. To further these observations, Carstens et al. (2002) observed that IMF was not correlated with RFI in crossbred steers. Altogether, these studies have shown there is reason to be vigilant, but no significant negative effects have been consistently observed between RFI and IMF.

Herd and Bishop (2000) provided evidence from British Hereford cattle, that animals with low RFI have less backfat (BF-measured ultrasonically) at the 10th and 13th ribs and therefore slightly leaner carcasses than high RFI cattle. In a study of Angus, Charolais and University of Alberta Hybrids, Nkrumah et al. (2004a) found positive correlations between RFI and gain in BF, ultrasound BF, and carcass grade fat depth (0.30, 0.19, and 0.25, respectively). Carstens et al. (2002) reported a slight trend for low RFI animals to have less 12th rib BF depth than medium and high RFI animals. Therefore, it is important that the beef industry monitor trends in BF as advances in RFI are made, to ensure that increasing animal efficiency does not have unintentional negative impacts.

Cattle which differ in RFI may also differ in lean meat yield and the area of the m. longissimus dorsi (LMA). Nkrumah et al. (2004a) reported correlations of -0.22 and 0.28 for lean meat yield and carcass yield grade, respectively. As animals are selected for lower RFI (increased feed efficiency), there may be a trend toward larger LMA and leaner carcasses with lower USDA yield grades. Herd and Bishop (2000) reported phenotypic and genotypic correlations with carcass leanness and RFI. Carcass leanness in this study was estimated from ultrasound BF measurements at the 10th and 13th rib, and the third lumbar vertebra. Phenotypic (-0.22) and genotypic (-0.43) correlations between carcass leanness and RFI were observed (Herd and Bishop, 2000). This indicates again that, as selection for low RFI animals occurs, carcass leanness may increase. Lancaster et al. (2009b) did not show any difference between LMA of low, medium, and high RFI Angus bulls at the beginning or end of the trial, however, low

RFI bulls gained less LMA than high RFI bulls over the duration of the trial (18.99 cm^2 compared to 22.04 cm^2). Continued selection pressure for low RFI cattle may result in increased lean meat yields over time.

Feeding Behavior

Evaluation of feeding behavior

Feeding behavior of beef cattle can be influenced by a wide variety of external factors, including the weather (Schwartzkopf-Genswein et al., 2003), animal temperament (Voisinet et al., 1997b), animal health (Wolfger et al., 2015), and animal management practices such as bunk space allotment and bunk management. The full effects of beef cattle feeding behavior are yet to be fully identified (Schwartzkopf-Genswain et al., 2003, 2011).

Radio frequency identification (**RFID**) tags have recently allowed for remote monitoring of cattle behaviors at the feed bunk. The GrowSafe system, developed by GrowSafe Systems, Ltd (Airdrie, Alberta, Canada) utilizes RFID technology and sensitive load bars to identify and assign feed disappearance to individual animals. The GrowSafe system is a series of individual feed bunks, each of which have an RFID tag reader located around the top lip of the bunk. Thus, when an animal approaches the bunk and inserts its head to feed, that animal's unique RFID is recorded by a computer. The system can record a series of events at each bunk simultaneously. While the animal is feeding, the weight of the bunk is taken every second to account for feed disappearance, providing daily feed intake, as well as meal size at each feeding event during the day. The data points are transmitted wirelessly to a central computer, and analyzed.

With GrowSafe® systems, researchers are able to remotely monitor feed bunk attendance, without needing visual evaluation (Gibb et al., 1998). Additionally, when combined with scales, the GrowSafe® system allows for the collection of frequency and duration of bunk visit events, head down duration (**HDD**- total time spent with head in trough per day), feeding rate (**FR**- grams of feed consumed per minute), as well as time to bunk (**TTB**- the amount of time an animal takes to approach the feed bunk after fresh feed is provided). These traits have been found to be associated with performance and feeding efficiency. Interesting patterns have been observed in different animal types, and between different diets, with the use of these parameters.

It has been observed that type of diet affects feeding behavior. Nkrumah et al. (2007) and Durunna et al. (2011) reported that frequency of BV events was greater in crossbred steers consuming a grower ration than in those same animals consuming a finishing ration. Inter-animal variation in feed efficiency has also been shown to be associated with differences in feeding behavior. Schwartzkopf-Genswein et al. (2011) found that BV frequency was lower in cattle with high G:F compared to those with low G:F.

Feeding duration is defined as the sum of the total time spent feeding and performing the associated activities, such as prehension, mastication in the bunk and out of the bunk, socializing at the feed bunk, and scratching and licking in the feed bunk (Nkrumah et al., 2007). Feeding duration has also been shown to be positively correlated with DMI in growing calves (Nkrumah et al., 2007; Lancaster et al., 2009a; Durunna et al., 2011). Nkrumah et al. (2007) and Lancaster et al. (2009b) also found significant, positive correlations between FD and RFI, indicating that FD is a valuable selection trait for producers with goals of reducing feed costs.

Head down duration is a measurement of the number of times an animal is recorded by the GrowSafe system, multiplied by the scan frequency of the system (how often the system scans for RFID tags) (Lancaster et al., 2009b). Nkrumah et al. (2007), Lancaster et al. (2009b) and Durunna et al. (2011) reported correlations of 0.33, 0.36, and 0.32 between HDD and DMI, respectively.

Feeding rate is a ratio of the daily DMI and daily FD, and is expressed in g/min (Durunna et al., 2011). Feeding rate differs between diets (Durunna et al., 2011). When fed a grower (high roughage) feedlot diet, steers exhibited a feeding rate of 4.93 kg/h, however, when fed a high-concentrate, low-roughage finishing diet, steers had a feeding rate of 5.60 kg/h (Durunna et al., 2011). These differences were significant and likely reflect the amount of forage present in the diet, which increased the amount of sorting and chewing that was performed (Durunna et al., 2011). Similar to the previous traits, feeding rate is also correlated with DMI, however, the strength of this relationship is considerably more variable between studies than correlations between DMI and HDD, FF, and FD. Lancaster et al. (2009b) reported a significant correlation between feeding rate and DMI of 0.53, whereas Durunna et al. (2011) found a much lower phenotypic correlation trend of 0.13. As a result of this variability in the literature, it is likely that feeding rate is less helpful when considering animal efficiency than other traits, and appears to vary considerably based on diet type, sex, and perhaps stocking rate.

Associations between feeding behavior traits and residual feed intake

Beef cattle have considerable phenotypic and genetic variation for traits used to measure feeding behavior (Nkrumah et al., 2007). As such, researchers have been able to compare the feeding behaviors of different groups of cattle, selected for differences in RFI, and analyze their feeding behavior. In general, cattle that have a lower RFI value tend to have fewer feeding events of any kind measured in the GrowSafe® system than cattle with high RFI values. The literature reports that high efficiency cattle have fewer feeding events per day than their low efficiency contemporaries, they spend less time consuming feed, they eat at a slower rate, and generally spend less time with their head in a feed bunk (Nkrumah et al., 2007; Lancaster et al., 2009b; Durunna et al., 2011). Additionally, Schwartzkopf-Genswein et al. (2011) reported significant differences between high, medium and low G:F animals in terms of bunk attendance frequency, bunk attendance duration, and eating rate. Inefficient animals attended the bunk more often and for longer periods every day over the entirety of the trial (Schwartzkopf-Genswein et al., 2011).

Lancaster et al. (2009b) found that low RFI Angus bulls consistently spent less time at the feed bunk over the duration of a day (93, 99, and 107 min/d for low, medium and high RFI bulls, respectively), medium and low RFI bulls had fewer bunk visits than high RFI bulls (7.28, 7.64, and 8.17 events/day, respectively), low RFI bulls spent less time with their heads down in the bunk (41.99 min/d) than medium RFI (45.31 min/d) and high RFI (49.48 min/d) bulls, and finally, the meal eating rate of low, medium and high RFI was not significantly different, yet low RFI bulls consumed feed at a numerically lower rate than medium and high RFI bulls.

Durunna et al. (2011) found similar trends to Lancaster et al. (2009b). Among crossbred (Angus or Charolais-sired) steer calves, low RFI animals consistently spent less time at the feed bunk over the course of a day. During the grower period of the trial, low, medium and high RFI cattle spent 104, 111, and 118 min/d at the bunk, respectively, and similar differences were observed during the finishing period (63, 72, and 78 min/d, for low, medium and high RFI cattle, respectively) (Durunna et al., 2011). Bunk visit frequency also differed between low and high RFI steers in both the grower and finisher phases (32.2 Vs. 36.6 events/d during grower phase, respectively; 19.9 Vs. 22.9 events/d during finishing, respectively,). Durunna et al. (2011) reported that HDD was significantly different between all RFI classifications within feeding phase (53.3, 63.9, and 69.9 min/d during the growing phase, respectively; 24.3, 33.7, and 40.2 min/d during the finishing phase, respectively). Feeding rate was not affected by RFI for either phase of the study.

In a large, 3 year study with Angus, Charolais and hybrid bulls, Nkrumah et al. (2007) found that FD differed significantly between animals of low, medium and high RFI groups (56.41 min/d, 65.64 min/d, and 74.62 min/d, respectively). Again, Nkrumah et al. (2007) indicated that FF differed significantly between RFI groups (27.24 events/d, 30.36 events/d, and 31.50 events/d for low, medium and high RFI, respectively), and that HDD differed significantly between RFI groups (30.28 min/d, 37.06 min/d, and 42.37 min/d for low, medium and high RFI bulls, respectively). Feeding rate was not measured in the study by Nkrumah et al. (2007). A considerable amount of variation in RFI can be accounted for by including feeding behavior traits in the RFI model (Lancaster et al., 2009b).

Individual Animal Management

Converting a highly heterogenous incoming cattle population into easily managed, uniform groups or pens is one of the challenges facing management in many feedlots. Typical feedlots deal with feeder calves and yearlings with highly variable phenotypes for initial BW, muscling, and initial carcass composition due to differences in environment and genetics. Having pens of homogenous phenotypes is beneficial, as management decisions are made easier by pen. Feedlot management can improve the efficiency of feed delivery, customize the addition of feed pharmaceuticals and implants when cattle within a pen or group are more similar. Additionally, prediction of finished weights, days on feed (**DOF**), and feed resources required are easier to predict when phenotypes are similar. Individual animal management can generally increase the predictability of animal performance and provide a more consistent beef product to the consumer.

Grouping cattle of similar type, weight, frame size, background, genetics and any other known traits permits the use of prediction equations. These equations can be used to estimate how much feed will be needed and when and how to purchase feed, and when to market cattle to maximize profits. However, simply grouping incoming cattle into pens based on few parameters can lead to heterogenic pens in certain aspects. For example, if cattle are grouped by weight and sex alone, feedlot operators are frequently left with pens that contain overfed cattle, which can take a carcass weight or backfat depth discount, and underfed cattle, which can take a quality grade or lightweight carcass discount (Pyatt et al., 2005b). Further economic harm is done by overfeeding cattle to fatter endpoints, as gain efficiency decreases as cattle age and fatten (Pyatt et al., 2005b). A 10% improvement in feed efficiency has been predicted to result in a 43% increase in profits (Fox et al., 2001b), indicating the need for attention to this problem.

Individual animal management systems (**IAM**) can improve profitability by allowing feedlot operators to reduce within-group variation in production efficiency and carcass quality, increasing the consistency of beef quality and identifying and rewarding owners based on the performance of their cattle. This is successful when cattle are marketed on a grid concept as individuals at their unique, optimum carcass composition. Formula marketing is becoming increasingly popular in the US beef industry, and can be attractive to feedlots (Link et al., 2011). Formula marketing profits benefit from using IAM programs to maximize carcass weight, while minimizing profit lost to discounts and penalties (Link et al., 2011). To create homogenous pen populations that can be marketed together, feedlots are sometimes required to mix cattle from several diverse sources. As a result of mixing and segregating, individual animal billing systems have been developed (Fox et al., 2001a). Fox et al. (2001a) identified three major areas that must be addressed by any IAM system: 1.) The system must accurately predict optimum finished weight, incremental cost of gain, and days to finish; 2.) The system must accurately predict carcass composition and backfat deposition rate to avoid discounts for excess; 3.) The system must allocate feed to individuals and determine the cost of gain for the purposes of billing feed expenses and providing information, which could be used for selecting for feed efficiency and profitability. Individual animal management systems cater to the animal, not the group. Metrics used to estimate these outcomes vary, but currently include biometrics (weight, body composition determined by ultrasound, sex, implants), environment (environment and seasonality, feedstuffs and days on feed) and genetics, such as leptin genotyping (currently not well utilized) (Tedeschi et al., 2004; Kononoff et al., 2013).

Among commercial steers fed in two separate southern Alberta feedlots, Basarab et al. (1999) found that cattle sorted using an equation developed at Kansas State University (Brethour, 1991) were higher quality, higher yielding and more profitable as compared to unsorted pens. Basarab et al. (1999) showed that the use of the KSU system increased AAA grades 40.8% over cattle sorted only on weight (Canadian beef grading system). Further, use of the KSU system reduced over-fat incidence by 47.7% over the weight-sorted cattle, and improved per animal profitability by $27.67 in Feedlot 1 and $15.22 in Feedlot 2 (Basarab et al., 1999). It is also worth noting that there was no incidence of B4 (dark cutting) in the cattle sorted by the KSU equation (Basarab et al., 1999). The authors attributed this to the likelihood of a more uniform, favorable muscle energy status in these cattle (Basarab et al., 1999). The KSU equation combines initial measures of body weight, ultrasound backfat depth, and marbling scores with current economic conditions (carcass prices, production costs) to estimate the necessary number of DOF which maximize profit (Basarab et al., 1999).

In addition to measuring biometrics, inclusion of genetic parameters to homogenize cattle has the potential to be valuable. Currently, however, there are challenges associated with broad-spectrum genetic testing of cattle entering a feedlot, including the cost of the test and the time necessary for tissue samples to be analyzed and returned to feedlot management, and the degree of variation explained in distinct types of cattle. However, genes for the expression of leptin, a hormone associated with predicting animal fatness, have been shown to influence carcass fatness (Nkrumah et al., 2004b; Kononoff et al., 2013). Among 4,178 British X continental steers sorted based on leptin genotype (**TT**, **CT**, and **CC** genotypes, with most to least leptin expression, respectively), TT steers produced a higher percentage of USDA yield grade (**YG**) 4 or higher carcasses (5.36% compared to 3.28% [CT] and 2.73% [CC]), but also had a higher percentage of carcasses that graded USDA Choice or higher, compared to CC steers (63.8% compared to 59.2% [CT] and 47.9% [CC]) (Kononoff et al., 2013). Nkrumah et al. (2004b) reported that presence of the T allele had an additive effect on carcass backfat, and thus, TT steers possessed lower lean meat yield than CT and CC steers.

Wolfger et al. (2016) exhibited possible benefits to sorting cattle based on coat color, especially in instances where other information about the cattle is not available. Coat color can predict the amount of α-melanocyte stimulating hormone (α-MSH) available in the body. The α-melanocyte stimulating hormone is thought to have an impact on appetite and satiety. Sixty-eight Angus and Red Angus heifers were fed in two randomly assigned pens, where feeding behaviors and feed intake were recorded. They reported that Angus cattle spent 18.4 min per d longer at the feed bunk and had 0.62 more meals per d than Red Angus cattle. Additionally, Red Angus heifers had higher gain to feed ratios, and more Red Angus heifers than Angus heifers were assigned to Canadian yield grade of 1 (≥ 59% lean meat). Angus heifers were carried more backfat for the duration of the study (Wolfger et al., 2016). The efficacy of genetic sorting has been shown to be significant, but challenges remain in making genetics an efficient method of creating feedlot pens. It is likely that genetic information, such as leptin identification, will need to be collected before cattle arrive at the feedlot, passing a significant expense on to cow/calf producers.

CHAPTER II

EFFECT OF TEMPERAMENT AT FEEDLOT ARRIVAL ON FEEDLOT PERFORMANCE FEEDING BEHAVIOR, ULTRASOUND CARCASS TRAITS AND CARCASS CHARACTERISTICS OF BEEF HEIFERS

Introduction

Temperament is defined as the fear response of cattle to human interaction (Fordyce et al., 1988a). Increased incidence of damage to facilities, employees, other cattle, and themselves are all factors implicated in the higher cost of feeding cattle with excitable temperaments (Haskell et al., 2014). Cattle with excitable temperaments are prone to increased cortisol release compared to calm cattle during novel experiences, such as transportation, handling, or sorting, (Curley et al., 2006; Burdick et al., 2011), and have increased basal cortisol levels (Curley et al., 2007). Elevated levels of stress hormones increases animal susceptibility to pathogens (Fell et al., 1999), negatively impacts growth and performance of cattle on feed, and can result in lessened carcass value at slaughter (Voisinet et al., 1997b; King et al., 2006; Nkrumah et al., 2007; Burdick et al., 2011).

Exit velocity (**EV**; Burrow et al. 1988) and subjective chute scores (**CS**; Grandin, 1997) are two of the most common methods used to measure temperament in beef cattle. Excitability, as measured by either method, has negative relationships with measures of performance and carcass productivity, and it has been established that temperament measured at weaning is more predictive than temperament measured later in the production cycle (Behrends et al., 2008), as cattle adapt to handling over time and may exhibit a less pronounced response (Grandin, 1993). Temperament has also been established as an heritable trait, (Haskell et al., 2014).

While the effects of temperament on performance and carcass characteristics are well-documented, research is lacking in areas regarding the relationship between temperament and measures of animal efficiency. Petherick et al. (2002), Nkrumah et al. (2007), and Llonch et al. (2016) all reported no relationship between temperament measures and feed efficiency measures, except that Nkrumah et al. (2007) found a slight negative correlation of temperament with partial efficiency of growth. Further, an evaluation of temperament and carcass quality traits and their grid value is missing from the literature. While differences in carcass value could be implied from differences in carcass USDA yield grade (**YG**) and quality grade (**QG**), no overt monetary differences in carcasses have been reported. Therefore, the purpose of this study was to further investigate any relationship between feed efficiency and temperament, and to determine whether differences in carcass value and income exist between temperament scores.

Materials and Methods

Animals and experimental design

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

Purebred Angus (n = 64), Braford (n = 117), Brangus (n= 123), and Simbrah (n = 111) heifers (n = 415) from Deseret Ranches (St. Cloud, FL) with an average initial BW of 280 ± 35 kg and mean initial age of 340 ± 35 d were used in this study. Data were collected from 3 trials conducted during 3 consecutive years. Heifers were fitted with passive, half-duplex radio frequency identification ear tags (**RFID** tags, Allflex USA Inc., Dallas, TX), and randomly assigned to 1 of 2 pens, each equipped with 4 feed bunks at the McGregor Research Center (McGregor, TX), or to 1 of 4 pens, each equipped with 10 feed bunks at the Beef Research Center (College Station, TX; GrowSafe Systems, Ltd., Airdrie, AB). Prior to the start of the trials, heifers were adapted to a high-grain feedlot diet for 28 d (Table A-1) in pens with GrowSafe bunks. Heifers were fed ad-libitum and individual feed intake and feeding behavior data were collected for 70 d.

Data collection

The GrowSafe system (DAQ 4000E) used in these studies consisted of feed bunks equipped with load bars to measure feed disappearance. Antennae within each bunk detected animal presence by recording the RFID tag upon animal entry to a feed bunk. Feed intake was allocated to each individual animal based on continuous recordings of feed disappearance during each bunk visit (**BV**) event. The GrowSafe system recorded the RFID number, scale number, and a time stamp, which was logged in the data acquisition computer. The GrowSafe system used in this study had a scanning frequency of 3 s.

All default settings (GrowSafe, 2009) were used in this study, apart from the parameter setting for maximum duration of time between consecutive RFID recordings to end an uninterrupted BV event. For these studies, a parameter setting of 100 s was used, as recommended by Mendes et al. (2011). Feed intakes and feeding behavior data were omitted for 27, 3, and 2 d for trials 1, 2, and 3, respectively, due to power outage, equipment malfunction, or when the proportion of assigned feed disappearance (**AFD**) was less than 95%. The average AFD for the days retained for data analysis were 98.9, 99.4, and 98.1%, for the 3 trials, respectively. Estimates for missing feed intake data were derived from linear regression of the feed intake on the day of the trial as recommended by Hebart et al. (2004).

Cattle were weighed at 14-d intervals, and ultrasound measurements of subcutaneous backfat (**BF**) depth, intramuscular fat percentage (**IMF**), and loin muscle area (**LMA**) collected on days 0 and 70 of each trial by a certified ultrasound technician using an ALOKA 500-V instrument with a 17 cm, 3.5 MHz transducer (Corometrics Medical Systems Inc, Wallingford, CT). Images were analyzed by the Centralized Ultrasound Processing Laboratory (Ames, IA).

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

Heifers were slaughtered at Kane Beef, Corpus Christi, TX. For each trial, cattle were slaughtered in 2 groups, 4-6 weeks apart at a targeted BF depth of 1.4 cm.

Approximately 48 h post-mortem, the carcasses were ribbed between the 12th and 13th rib interface, and HCW, 12th rib back fat depth (**BF**), estimated percentage of kidney, pelvic and heart fat (**KPH**), United States Department of Agriculture (**USDA**) quality grade (**QG**), and yield grade (**YG**) and loin muscle area (**LMA**) were determined as defined by the USDA (USDA, 1997). Two, 2.5-cm thick steaks were cut from the 13th rib for Warner-Bratzler shear (**WBS**) force. These steaks were vacuum-packaged and placed in a 4 °C cooler for 14 d. At 1- and 14-d post-mortem aging, WBS force measurements were collected. The steaks were cooked on a Faberware Open-Hearth grill (Faberware Co., Bronx, NY) until the internal temperature reached 70 °C. For 4 h post-cooking, steaks were allowed to cool at room temperature before six, 1.27-cm diameter cores were obtained from each steak. Each core was sheared once with a Universal Testing Instrument (Model SSTM-500, United Calibration Corp. Huntingtin Beach, CA) equipped with a V-notch Warner-Bratzler blade, and a 50-kg compression load cell with a cross-head speed of 200 mm/min, as described by AMSA (2015). The average force (kg) required to segment the 6 cores was reported for each steak.

Carcass value ($/kg) and income ($/animal) were determined using a marketing grid with premiums and discounts based on 3-year average (2014-2016) premiums and discounts for USDA YG, QG, and HCW (**Grid 1**; Table A-15). Carcass value and income were also determined using a grid that included premium and discount values for tenderness based on the difference consumers were willing to pay between guaranteed tender (≤ 3.0 kg WBS, d-14 post-mortem aging) and tough (> 4.9 kg WBS, d-14 post-mortem aging) steaks, as reported by Miller et al. (2001). No premium or discount was applied to carcasses with WBS forces between 3.0 kg and 4.9 kg. These premium and discount values were adjusted for inflation ($1 USD 2001 = $1.40 USD 2017; Bureau of Labor Statistics) and converted to a carcass basis for inclusion in Grid 2 (Table A-15).

Temperament was evaluated by measuring exit velocity (**EV**) upon feedlot arrival, and on days 0 and 70 of each trial. Exit velocity was measured as the velocity (m/s) animals travelled at over a fixed distance of 1.8 m upon exiting the squeeze chute using 2 sets of infrared sensors (Farm Tec, Inc. North Wylie, TX). Exit velocity data were transformed to relative EV (**REV**) as the difference of each animal's EV from the mean divided by the mean EV for each day. Initial REV was computed as the average of REV measurements at feedlot arrival and on d 0 of the trials.

In addition to measuring EV, chute scores (**CS**) were recorded on days 0 and 70 of trials 1 and 2. Chute scores were recorded while the animals were without head or squeeze restraint, in a solid-sided (College Station) or open-sided (McGregor) weigh scale preceding the squeeze chute, in close proximity to the evaluator. The CS were based on subjective evaluation of animal movement for approximately 1 min, and scores were assigned as described by Grandin (1993) based on animal behavior: 1 = calm, no movement; 2 = slight restlessness; 3 = squirming, occasional shaking of the squeeze chute; 4 = continuous, very vigorous movement and shaking of the chute; 5 = rearing, twisting, and violent struggling.

Computations

Growth rates of individual heifers were modeled using linear regression of BW on day of test using PROC GLM (SAS Inst., Cary, NC), and these regression coefficients used to compute initial and final BW, ADG, and mid-test $BW^{0.75}$. Moisture analyses of the diet ingredients were used to generate average daily DMI from feed intake data supplied by the GrowSafe system.

Residual feed intake (**RFI**) was calculated as the difference between actual DMI and expected DMI to meet growth and maintenance energy requirements (Koch et al., 1963). Expected DMI was generated based on linear regression of DMI on ADG and mid-trial $BW^{0.75}$ using PROC GLM procedure of SAS, with year and pen included as fixed effects. Stepwise multiple regression (PROC REG, SAS) was used to determine which ultrasound carcass variables accounted for significant ($P < 0.05$) variance in RFI. As a result, final ultrasound BF depth was included in the original regression model, and ultrasound carcass composition-adjusted RFI (**RFI_C**) calculated as deviations of DMI from composition-adjusted expected DMI. Residual gain was calculated as actual ADG minus expected ADG based on DMI and mid-trial $BW^{0.75}$, with expected ADG generated based on linear regression of ADG on DMI and mid-trial $BW^{0.75}$ using PROC GLM (SAS), with year and pen included as fixed effects. Gain:feed ratio was calculated as the ratio of ADG to daily DMI.

Feeding behavior traits were based on the frequency and duration of BV events, meal frequency and duration, head-down (**HD**) duration, and time for an animal to approach the feed bunk following feed delivery (time-to-bunk; **TTB**). A BV event began when an animal was detected at a feed bunk, and ended when the time between the previous 2 recordings exceeded 100 s, or when the RFID tag was detected at another feed bunk (Jackson et al., 2016). Bunk visit duration was defined as the sum of the lengths of all BV events recorded each d (Jackson et al., 2016). Head-down duration was the number of RFID recordings each d multiplied by the scanning rate of the GrowSafe system (3.0 s; Jackson et al., 2016). R statistical software (R Core Team, 2014) was used to calculate TTB daily as the length of the interval between feed-truck delivery and the first BV event following feed delivery recorded each day. Bunk visit eating rate (g/min) was computed as daily DMI divided by daily BV duration (Jackson et al., 2016). A subroutine of GrowSafe 4000E software (Process Feed Intakes) was used to calculate daily feed intake.

The longest non-feeding interval considered to be part of the meal event is referred to as meal criterion. To compute meal data, a 2-pool Gaussian-Weibull distribution model was fitted to log-transformed non-feeding interval data, and the intercept of the two distributions used to define meal criterion (Yeates et al., 2001). Meal criterion was used to compute individual animal meal frequency, meal duration, and meal size (Yeates et al., 2001; Bailey et al., 2012). For this study, meal eating rate (g/min) was equal to daily DMI divided by daily meal duration.

Statistical analysis

Data were analyzed using a mixed model (Proc Mixed; SAS Inst., Cary, NC) that included breed as a fixed effect, initial REV as a covariate, the interaction of breed × initial REV, and pen within trial as random effects. Least square differences among breeds means were evaluated using the Tukey's post-hoc test. An unequal slopes model was fitted to examine possible interactions between breed and initial REV. For dependent variables with significant ($P < 0.05$) breed x initial REV interactions, mean separation tests (Tukey's post-hoc) were performed at the mean initial REV minus 1 SD (calm heifers), and mean initial REV plus 1 SD (excitable heifers) to examine the nature of the interactions between temperament × breed. A separate model was used to examine the effects of breed on temperament traits (REV, chute scores), which included the fixed effect of breed and random effects of trial and pen. Simple linear correlations (PROC CORR) were investigated among response variables.

Multiple linear regression models (PROC GLM) that included pen within year as a fixed effect were used to examine sources of variation in RFI associated with ultrasound (initial and final LMA, BF depth, and IMF) and feeding behavior traits (HD duration, BV duration, BV eating rate, meal frequency, meal duration, meal eating rate). The model evaluating efficiency included BV and meal traits, and carcass ultrasound traits. Likewise, multiple linear regression analyses, with pen within trial as fixed effects, were performed to examine sources of variation in carcass income due to HCW, YG, QG, and tenderness.

To examine the effects of temperament classification (± 0.5 SD from the mean of initial REV; Calm = < 0.5 SD from the mean, Moderate = ± 0.5 SD, Excitable = > 0.5 SD from the mean) on the proportion of carcasses with tender (≤ 3.0 kg WBS) or tough (> 3.0 kg WBS) beef and USDA QG, χ^2 analysis were conducted using PROC FREQ. Additionally, the distribution of temperament class within breed was analyzed using PROC FREQ, as was the distribution of USDA QG by breed.

Results and Discussion

Summary statistics for data collected from the 3 trials are presented in Table A-2. The mean initial age and BW of the heifers was 339.8 ± 35.3 d and 280.5 ± 35.9 kg, respectively. Averages for ADG, DMI, and RFI_C were 1.53 ± 0.32, 9.28 ± 1.67, and 0.00 ± 0.87 kg/d, respectively. Head-down duration ranged from 3.80 to 101.26 min/d, with an average of 41.96 min/d. Frequency of BV events averaged 64.97 ± 19.72, with the lowest frequency of visits at 26.01 events/d and the highest at 126.30 events/d. Bunk visit duration averaged 63.00 ± 18.68 min/d. The variance in TTB, which averaged 121 min, was relatively high, and ranged from 5.64 to 562.88 min following feed delivery. Meal frequency and duration of the 3 trials were 9.27 ±4.52 events/d, and 138.80 ± 36.77 min/d, respectively, established using an average meal criterion of 10.99 ± 8.31 min. Average meal length was 19.79 ± 12.49 min, and feed was consumed at an average rate of 72.92 ± 20.51 g/min. Heifers increased an average of 20.37 ± 7.02 cm^2 LMA, and an average of 0.33 ± 0.19 cm BF depth. Final LMA ranged from 36.77 to 98.06 cm^2, with an average LMA of 64.53 cm^2. Final 12th rib fat depth ranged from 0.23 to 1.57 cm, averaging 0.65 cm. Hot carcass weights (**HCW**) averaged 282.8 ± 29.0 kg. Carcasses exhibited between 0.1 and 2.74 cm of 12th rib fat depth, with average LMA of 74.13 ± 7.81 cm^2. These measurements resulted in an average USDA YG of 2.75 ± 0.60, with the lowest yield grade reported 0.92, and the highest 4.72. USDA quality grade ranged from 557 (USDA QG Prime) to 290 (USDA QG Select). Warner-Bratzler shear forces were measured on d-1 and d-14 post-mortem aging, and averaged 3.63 ± 0.98 and 2.35 ± 0.58 kg, respectively. Initial REV for each of the 3 trials averaged 0.00, with SD from

0.20 to 0.22. Subjective CS were not available for the third trial, however, initial and final CS for the first and second trials averaged 1.49 ± 0.67 and 1.94 ± 0.84, respectively.

Effect of breed on temperament

There were no significant differences among the 4 breeds evaluated in this study for initial ($P = 0.79$) and final ($P = 0.14$) REV, and for initial ($P = 0.85$) and final ($P = 0.09$) CS. Furthermore, χ^2 analysis revealed that the proportion of heifers in each temperament classification (± 0.5 SD from mean initial REV) were similar within breed ($P = 0.37$; Table A-8). The absence of temperament differences between breed types is in contrast with most studies that have compared subjective (Hearnshaw and Morris, 1984; Voisinet et al., 1997b) and objective (Cafe et al., 2011; Thomas et al., 2012) temperament traits among *Bos indicus* and *Bos taurus* cattle. Cafe et al. (2011) conducted trials at 2 locations with Angus and Brahman cattle, and found that Angus cattle had consistently calmer temperaments based on EV and CS compared to Brahman cattle. Thomas et al. (2012) reported that Brahman and Brahman-cross cattle had more excitable temperaments than *Bos taurus* cattle in some trials, whereas in other trials, no differences in temperament were detected between biological types. In a study that compared 3 American breeds and 3 *Bos taurus* breeds, Voisinet et al. (1997b) found that the *Bos indicus*-influenced American breeds had higher subjective CS than the 3 *Bos taurus* breeds. Likewise, Hearnshaw and Morris (1984) found that Brahman and Brahman-cross cattle consistently had higher temperament scores than purebred and crossbred *Bos taurus* cattle. The authors noted that the breed differences in temperament increased as the percentage of *Bos indicus*-inheritance increased, which suggested an additive temperament effect related to *Bos indicus* genetics. The amount of *Bos indicus*-influence in the Braford, Brangus and Simbrah heifers in the current study may not be sufficient to create a distinguishable difference when compared to the Angus heifers. Unlike Voisinet et al. (1997b) who compared breeds similar to the current study, the cattle for the current study were all sourced from the same ranch; therefore, environmental factors could play a role in these breeds having similar temperament phenotypes in the current study.

Effect of temperament and breed on feedlot performance

Initial REV was a significant covariate for initial BW, but not age, such that calm heifers had greater initial BW but similar age compared to heifers with excitable temperaments (± 1 SD from mean initial REV; Table A-3). While Burrow and Dillon (1997) reported no difference in initial BW due to temperament in their study, Tulloh (1961), Cafe et al. (2011), and Reinhardt et al. (2009) reported that calm cattle consistently exhibited greater initial BW than excitable cattle, based on EV, CS, or a combination of temperament scores. In a study involving 433 cow-calf pairs, Cooke et al. (2012) found that temperament of the dam (EV + CS) did not affect calf weaning BW or age. Francisco et al. (2012) reported that weaning BW were greater in calm calves than in excitable calves (EV + CS), even though calf age was not different between temperament scores. The differences in weaning BW among calves of the same age indicated that there may have been an influence of calf temperament on pre-weaning gain that was independent of the temperament of the dam. Therefore, the differences in initial BW between calm and excitable heifers in the current study were likely influenced by their temperament as calves, not differences in age.

Simbrah heifers had greater initial BW (282.8 kg), then Angus and Braford, with Brangus heifers being intermediate (265.7, 269.7, and 277.5 kg, respectively), even though Angus, Braford and Simbrah heifers were similar in age at the beginning of the trials. This is in agreement with breed differences in weaning BW Williams et al. (2010), who indicated that crossbred Continental × Zebu cattle had greater weaning BW than British × Zebu cattle. Both Zebu crosses had greater weaning BW than either purebred British, Continental, or British × Continental cattle (Williams et al., 2010).

Heifers with calm temperaments had 12% greater ($P < 0.001$) ADG based on computed means at ± 1 SD from mean initial REV than heifers with excitable temperaments (Table A-3). These results are consistent with previous studies that have examined the effects of temperament on performance of growing cattle (Burrow and Dillon, 1997; Voisinet et al., 1997b; Nkrumah et al., 2007; Cafe et al., 2011; Francisco et al., 2015; Bruno et al., 2016; Llonch et al., 2016). Burrow and Dillon (1997) found an increase of 43% in the ADG of the calmest animals compared to most excitable animals, and proposed that the greater ADG of calm animals was likely a function of greater DMI. In the current study, the greater ADG in calm heifers is explained by 8% greater ($P = 0.001$) DMI compared to excitable heifers, which is in agreement with several studies (Nkrumah et al., 2007; Cafe et al., 2011; Bruno et al., 2016; Llonch et al., 2016). Turner et al. (2011) suggested that differences in ADG may also be attributed to long-term stress susceptibility in excitable cattle. Veum et al. (1979) suggested that excitable animals may not return to a productive homeostasis as quickly as calm animals. However, the mechanisms associated with this reduction in DMI and ADG due to excitable temperament have not been fully explained.

Temperament had a significant impact on feed efficiency as measured by G:F ratio and RG (Table A-3), such that calm heifers were more ($P < 0.05$) efficient than their excitable counterparts. There was no temperament × breed interaction for G:F or residual gain. The effects of temperament on G:F and RG were not unexpected, given the high ($P < 0.001$) correlations ($r = 0.46$ and 0.71, respectively) with ADG, and the fact that G:F was strongly ($P < 0.001$) correlated with RG (Table A-7). While G:F was affected by temperament in this study, Llonch et al. (2016) found that temperament (EV + CS) did not affect F:G, even though excitable cattle consumed less DMI and tended to have lower ADG than calm cattle. Petherick et al. (2002) reported calm cattle had more favorable F:G than excitable cattle.

Residual feed intake was not affected by the initial REV covariate, however, the temperament × breed interaction was significant for both RFI and RFI_C (Figure A-1). Analysis of the slopes revealed that the effects of initial REV on RFI were breed dependent. As the initial REV of the Braford heifers increased, RFI decreased, indicating that excitable Braford heifers were more efficient than the calm Braford heifers. In contrast, the slopes were not different from zero for the other breeds indicating the lack of a temperament effect on RFI Angus, Brangus and Simbrah heifers. Similar to RFI, the temperament x breed interaction was also significant for $DMI:BW^{0.75}$, and was also indicating that as initial REV increased, Braford heifers consumed considerably less DM per unit of $BW^{0.75}$ compared to the other 3 breeds. However, there was not a corresponding decline in the ADG of Braford heifers, which contributed to a reduction in RFI as REV increased in these heifers. The biological basis for this interaction is not readily apparent. Llonch et al. (2016) proposed that lack of an effect of temperament on RFI could be due to the concurrent reductions in DMI and ADG observed in excitable cattle.

The phenotypic correlations between temperament, and performance and feed efficiency traits are presented in Table A-11. In agreement with Behrends et al. (2008), temperament measured at feedlot arrival and d 0 of the trials (initial REV) were correlated with initial BW, ADG, DMI, and G:F ($P < 0.05$; Table A-11). However, temperament measured on d 70 of the trials were not correlated with any of the performance or efficiency traits. This was likely due to the effects of repeated handling. King et al. (2006) reported that EV declined with repeated measures ($P < 0.05$) of temperament, probably reflecting acclimation to handling. Likewise, King et al. (2006) reported that differences in temperament declined over time, which likely indicates that cattle were acclimating to handling. Therefore, evaluation of temperament earlier in life, near to weaning, likely reflected future performance more accurately than measurements taken later in life.

Angus heifers had more favorable G:F than Braford heifers, with Brangus and Simbrah being intermediate. That pattern was repeated with residual gain (**RG**; Table A-3). Gain:feed was highly correlated with ADG (0.46, $P < 0.05$; Table A-7), and reinforced that Angus heifers in this study gained the most, and Braford heifers gained the least. Schenkel et al. (2004) reported that, among several Continental and British breed bulls, the leaner breeds had more favorable feed conversion ratios, with Blonde d' Aquitaine and Limousin having the most efficient ratios. This is in contrast with the current study, where Simbrah heifers were intermediate for efficiency of gain, yet were consistently leaner throughout the study. Elzo et al. (2009) concluded that, as the percentage of Brahman genetics increased, the amount of feed required per unit of BW gain also increased, and the authors indicated a less favorable feed conversion ratio among *Bos indicus*-influenced cattle compared to *Bos taurus* cattle, which is in agreement with the current study.

There was no effect of breed on RFI or $\mathrm{RFI_C}$, which is in agreement with Nkrumah et al. (2004a), who found no effect of sire breed on RFI or partial efficiency of growth among bulls and steers. Crowley et al. (2010) found that Limousin- and Charolais-sired cattle had lower RFI values than Angus, Hereford and Simmental cattle. Schenkel et al. (2004) also found significant breed effects on several. The continental cattle breeds Blonde d' Aquitaine, Limousin, Charolais, and Simmental had more favorable RFI than Angus and Hereford. When RFI was adjusted for variation in BF depth, Blonde d' Aquitaine and Limousin retained their rank as 1st and 2nd most efficient, but Hereford bulls moved to 3rd most efficient, indicating the importance of adjusting for carcass fatness when evaluating RFI. Elzo et al. (2009) suggested that the differences in RFI between *Bos indicus*-influence and *Bos taurus* breeds may be larger than the differences between *Bos taurus* breeds, though few other reports comparing the different biological types of cattle exist in the literature.

Effect of temperament and breed on feeding behavior

The effects of temperament, breed, and temperament × breed on feeding behavior are presented in Table A-4. Excitable heifers had 9% shorter HD duration, 8% shorter BV duration ($P < 0.05$), and tended ($P = 0.08$) to have longer TTB than calm heifers. The shorter BV duration and longer TTB are indicative that excitable cattle may be more reluctant to approach the feed bunk and consume feed. Bunk visit frequency and BV eating rate were similar between calm and excitable heifers. As BV eating rate is derived from DMI and BV duration, the lack of significance between BV eating rate and the initial REV covariate reinforces that excitable heifers were consuming less feed, in shorter BV, than calm heifers. Nkrumah et al. (2007) found that, among Angus, Charolais, and crossbred bulls, EV was not significantly correlated with any of the feeding behaviors analyzed (BV duration and frequency, and HD duration. However, consistent with the current study, Nkrumah et al. (2007) found that DMI decreased as EV increased, suggesting that excitable calves in their study consumed feed at a faster rate than calm calves.

In a similar manner, meal duration was 9% shorter, meal length 18% shorter, and meal size 15% smaller in excitable heifers compared to calm heifers (Table A-4). Although meal frequencies were similar, excitable heifers consumed meals that were shorter in length and 15% smaller in size, such that total meal duration was 9% shorter and DMI 7% less in excitable heifers compared to calm heifers. Additionally, calm heifers had a greater frequency of BV events per meal than excitable heifers.

There were significant ($P < 0.05$) temperament × breed interactions for HD duration, BV duration, and meal eating rate, and tendencies ($P < 0.10$) for these interactions to be significant for meal duration, and meal length and size (Figure A-2). As initial REV increased, both HD and BV duration decreased in Braford heifers, whereas, in Angus, Brangus, and Simbrah heifers, HD and BV duration was not affected by REV. As REV increased, the decline in HD and BV duration matched the decline in DMI, such that meal eating rate was not affected by REV in Braford heifers. In addition, as REV increased for Braford and Simbrah heifers there was a decrease in meal duration. However, in Angus and Brangus heifers REV did not affect meal duration. The decrease in meal duration for Simbrah heifers was not accompanied by a decrease in DMI (g/BW$^{0.75}$), which resulted in excitable Simbrah heifers having a 14% greater meal eating rate than calm Simbrah heifers. In contrast, while Braford heifers also reported shorter meal duration with increasing initial REV, they had a corresponding drop in DMI (g/BW$^{0.75}$; $P < 0.05$), which resulted in no change in Braford meal eating rate as the initial REV covariate increased. Therefore, it appears that breed may have different manifestations of temperament effects on feeding behavior patterns.

Breed significantly affected feeding behaviors, such that HD duration, BV duration, and BV eating rate were different between the 4 breeds. Angus and Brangus heifers reported greater HD duration than Braford and Simbrah heifers, Angus and Brangus heifers had greater BV duration than in Braford and Simbrah heifers, and BV eating rate was greater for Simbrah heifers than for the other 3 breeds. Breed did not affect BV frequency or TTB. These results are supported by Kayser and Hill (2013), who reported differences in feeding behaviors between Angus and Hereford bulls, such that BV frequency was similar between Angus and Hereford, though Angus bulls reported greater HD duration than Hereford bulls. Breed also affected ($P < 0.001$) meal frequency, duration, length and size, such that Angus heifers had fewer meal events/d than either Braford or Brangus, while Simbrah heifers were intermediate. Further, length of individual meals was shorter for Braford cattle than for the other 3 breeds, consistent with the lessened DMI observed in the Braford heifers. Meal size was greatest for Angus heifers and smallest for Braford, with Brangus and Simbrah heifers intermediate. Finally, Angus and Simbrah heifers had more BV per meal than Braford and Brangus. Further research into the causes of differences in feeding behaviors between breeds would be useful in identifying cattle types who are more likely to consume more feed.

Effect of temperament and breed on ultrasound carcass and slaughter carcass traits

The effects of temperament and breed on ultrasound carcass traits, carcass characteristics, and carcass value and income are presented in Tables A-5 and A-6. Initial REV was a significant covariate ($P < 0.05$) for final ultrasound BF depth and percentage IMF, such that calm heifers had 8% greater BF depth and 3% higher percentage IMF than excitable heifers. Nkrumah et al. (2007) reported no relationships between EV, and ultrasound BF depth and IMF, although a positive correlation (0.22) was reported between EV and LMA. Calm and excitable heifers did not differ in final ultrasound LMA, but calm cattle exhibited 13% greater ($P < 0.001$) gain in ultrasound BF depth and 6% greater gain in ultrasound LMA than excitable cattle. These differences in ultrasound carcass composition suggest that temperament altered rate as well as composition of gain during this study.

Breed significantly affected final ultrasound LMA, BF depth, and IMF, although no temperament × breed interactions were found for the ultrasound traits. Final ultrasound LMA were largest in Brangus heifers, and smallest in Braford heifers, with Brangus and Simbrah heifers intermediate ($P < 0.001$). Final ultrasound BF depth was considerably lower in Simbrah cattle compared to the other 3 breeds ($P < 0.001$). Angus heifers had the greatest amount of final ultrasound IMF, while Simbrah had the least, with Braford and Brangus intermediate ($P < 0.001$) These results are corroborated by Schenkel et al. (2004), who found that ultrasound IMF was highest in Angus bulls on test than in Hereford and 4 continental breeds. Schenkel et al. (2004) found ultrasound LMA to be greater in Continental bulls than in English bulls, whereas, the current study reported that the Angus-influenced Brangus heifers possessed larger final ultrasound LMA than the Simmental-influenced Simbrah heifers.

Excitable heifers had 4% lighter ($P < 0.001$) HCW, 6% less ($P < 0.05$) BF depth and tended ($P = 0.09$) have greater LMA than calm heifers. Several studies have reported indicated that calm cattle had larger HCW than excitable cattle (Burrow and Dillon, 1997; Nkrumah et al., 2007; Reinhardt et al., 2009; Cafe et al., 2011; Francisco et al., 2015). Cafe et al. (2011) found that increasing EV was associated with significant reductions in rib-fat or rump-fat depth in both Brahman and Angus cattle. Additionally, Reinhardt et al. (2009) reported that cattle with more excitable subjective CS had less BF depth than cattle with calmer temperaments. Both Cafe et al. (2011) and Behrends et al. (2008) reported that LMA decreased as EV increased.

Loin muscle area tended ($P = 0.09$) to be greater in calm heifers than in excitable heifers. Behrends et al. (2008) reported that LMA decreased as EV increased, as did Cafe et al. (2011). USDA YG tended ($P = 0.07$) to be greater in calm cattle, reflecting the larger carcass weights and greater BF depth among the calm cattle. King et al. (2006) reported a similar numerical trend in USDA YG due to temperament. Marbling scores were not different between calm and excitable heifers ($P = 0.17$), despite the additional subcutaneous fat the calm heifers possessed. Lean and bone maturity scores (data not shown) and USDA quality grade ($P = 0.15$) were not affected by REV. The proportion of carcasses grading USDA Choice or higher was numerically greater in calm (63.5%) vs excitable heifers (55.5%; $P = 0.18$; Table A-10). In contrast, Reinhardt et al. (2009), found that feedlot cattle with more excitable temperaments had lower USDA QG than those with calm temperaments. Likewise, Francisco et al. (2015) reported that Nellore cattle with calm temperaments had higher marbling scores than excitable Nellore cattle.

Breed differences in carcass data have been well documented (Cundiff, 1970; Koch et al., 1976; Crockett et al., 1979; Peacock et al., 1979; Johnston et al., 2003; Reverter et al., 2003; Reinhardt et al., 2009). In the current study, breed affected HCW, such that Simbrah heifers exhibited the largest HCW, averaging 296.1 kg, while Braford heifers had the smallest (268.6 kg), with Angus and Brangus heifers intermediate ($P < 0.001$). In tandem, Simbrah cattle also exhibited the largest LMA (78.07 cm^2), with Braford having the smallest (69.83 cm^2) and Angus and Brangus intermediate (74.87 and

74.81 cm^2, respectively; $P < 0.001$). Simbrah heifers exhibited the least fat cover, with 0.88 cm of BF depth, with the other 3 breeds not different. As a result, USDA YG were lowest for Simbrah (2.45), while Braford (3.00), Angus (2.92) and Brangus (2.87) were not different. Marbling score differed with breed, such that Angus cattle reported the highest proportion of marbling scores above Small^{00} (79.6%, $P < 0.001$; data not shown), and Braford heifers had the highest frequency of carcasses with marbling scores below Slight^{100} (48.7%; data not shown). Each of the American breeds reported at least 1 carcass with a marbling score less than Traces^{100}. Lean and bone maturity scores for each of the breeds were all younger than A^{100}, resulting in little difference between marbling scores and USDA QG. The frequency of USDA QG differed between breeds, such that Angus had the highest proportion of carcasses that graded USDA Choice or higher (85.7%; $P < 0.001$; Table A-9). Braford and Simbrah cattle reported more carcasses which graded USDA Select or lower (48.7 and 46.3%, respectively, $P < 0.001$; Table A-9). These results are confirmed by Crockett et al. (1979) and Peacock et al. (1979), both of whom reported greater HCW, less BF depth, and lower QG in Continental and *Bos indicus* purebred and crossbred cattle than in English cattle. However, in contrast to the current study, Peacock et al. (1979) found that LMA were largest in purebred Angus and crossbred Charolais × Angus cattle. Crockett et al. (1979) found that, among many crossbreds, Maine Anjou sired calves by Brangus dams produced the largest LMA, and concluded that breed of dam was more influential over LMA than breed of sire.

Warner-Bratzler shear forces were 8% lower ($P < 0.05$; Table A-6) in calm cattle compared to excitable cattle at day 1 post-mortem aging. This trend continued through day 14 post-mortem aging, where calm cattle had WBS forces that were 7% lower ($P < 0.003$) than excitable cattle. Ninety-three percent of calm heifers had WBS force less than 3.0 kg at day 14 post-mortem aging compared to 80% of excitable heifers ($P < 0.05$; Table A-9). Similarly, Fordyce et al. (1988b), Behrends et al. (2008), and Voisinet et al. (1997a) reported that cattle with higher subjective and objective measures of temperament had tougher WBS force values. Cafe et al. (2011) indicated, and the data presented here corroborated, that differences in tenderness values between calm and excitable cattle were less in steaks aged 14 d than steaks aged 1 d, which implies that variation in tenderness was related to factors other than proteolytic enzyme degradation post-mortem. One possibility for the consistent difference in tenderness was presented by King et al. (2006), who reported that excitable cattle had tougher steaks than calm cattle, and found that muscle sarcomere lengths were shorter in excitable cattle than those from calm cattle. Petherick et al. (2002) found a small, but significant, negative correlation between carcass pH and temperament, which may help to explain the differences in carcass tenderness. As muscle pH is a function of antemortem glycogen depletion, temperamental cattle who are stressed immediately prior to slaughter could have muscle pH which descended past 6.0 before the muscle internal temperature fell below 35 °C (Petherick et al., 2002). This condition is referred to as heat shortening. Petherick et al. (2002) found a greater percentage of carcasses from excitable cattle were subject to the necessary conditions to cause heat shortening (12.1%, $P < 0.01$) than carcasses from calm cattle. A portion of consumer acceptance of beef relies on tenderness. Miller et al. (2001) reported that consumers were willing to pay a \$1.08/kg premium for steaks with WBS force scores less than 3 kg, over steaks with WBS force greater than 4.9 kg. Similarly, Boleman et al. (1997) reported that consumers were willing to place a \$1.10/kg price difference on between three tenderness categories.

The influence of breed and biological type on beef tenderness has been thoroughly examined (Crouse et al., 1989; Whipple et al., 1990; Shackelford et al., 1995). Consistently, beef from cattle with higher influence of *Bos indicus* genetics has been found to be tougher than beef from *Bos taurus* cattle. Day-1 post-mortem aging WBS force scores were lower for Angus cattle (3.35 kg) than Braford (3.75 kg) and Simbrah (3.70 kg) cattle, with Brangus (3.44 kg) being intermediate ($P = 0.02$). At day 14 post-mortem aging, differences in tenderness between breed were not discernable. Among steers and heifers of a variety of breeds (*Bos indicus* and *Bos taurus*), O'Connor et al. (1997) indicated that the SD of WBS forces decreased with increasing post-mortem aging time, which implied that aging reduced tenderness variation between breeds.

Carcass value (\$/kg) was not affected by temperament, either on Grid 1 or on Grid 2 (Table A-16). However, carcass income (\$/animal) was significantly different between calm and excitable heifers on both grids. Calm heifers generated 4% more and 5% more carcass income based on Grid 1 and 2, respectively compared to excitable heifers. Few studies have examined the effects of temperament on carcass value and income, and further research could be performed to elucidate the impact that temperament had on carcass income and profitability of feedlot cattle.

In addition to differences in temperament, breed significantly impacted carcass value and income on Grid 1 and Grid 2, such that the higher USDA QG Angus heifers earned more per kg than the smaller, lower USDA QG Braford heifers on both Grid systems (*P* < 0.001; Table A-6). Due to carcass weights, Simbrah heifers had the highest per animal income ($1388) and Braford heifers had the lowest ($1223) on Grid 2, with Angus and Brangus intermediate (*P* < 0.001).

Carcass income from Grid 1 was largely driven by HCW (92.39%), USDA QG (2.79%), and USDA YG (0.17%). Carcass income from Grid 2 was explained by HCW (92.17%), USDA QG (2.85%), and USDA YG (0.22%). Pyatt et al. (2005a) found that 80% of the variation in carcass income was explained by HCW, marbling score, and USDA YG (HCW accounted for 51% of the variation in YG). Further, Bishop et al. (2002) reported that HCW, LMA, marbling score, and BF depth accounted for 57, 28, 6, and 3%, respectively, of carcass value. As expected, carcass weight was the primary driver of variation in carcass income.

Causes of variation in RFI and RFI_C

Metabolic and compositional differences between animals have been shown to be significant sources of variation in feed efficiency (Basarab et al., 2003; Nkrumah et al., 2004a; Herd and Arthur, 2009). Increases in R^2 in the current study due to body composition are presented in Table A-14. Trial, ADG and $BW^{0.75}$ accounted for 70.4% of the variation in DMI (e.g. RFI). Lancaster et al. (2009b) found that an equation for DMI which included ADG, mid-test $BW^{0.75}$, BF gain, LMA gain, and final BF depth accounted for as much as 83.7% of the variation in RFI. Gain in BF explained an additional 2% of the variation in DMI (Lancaster et al., 2009b), which corroborated evidence from Basarab et al. (2003). In this study, inclusion of final ultrasound BF thickness resulted in an increase in R^2 from 0.704 to 0.719.

Variation in DMI (e.g. RFI) could also be explained by feeding behavior traits in the current study. Variation in energetic costs of feeding activities (duration and frequency) may contribute to variation in RFI, as these activities are associated with standing and walking, and the energetic costs of ingesting feed (Lancaster et al., 2009b). In the current study, the inclusion of BV and meal behaviors resulted in R^2 increases over the base RFI model (Table A-15). Inclusion of meal duration, HD duration and meal frequency in the carcass-adjusted regression used to compute DMI for RFI_C in Lancaster et al. (2009b) resulted in an increase of the R^2 from 0.777 to 0.856 (35%). In the current study, BV duration accounted for 35% of the variation not accounted for in the base RFI model. In the current study, the inclusion of all significant feeding behavior traits in the RFI model accounted for an additional 44% of the variation in DMI not accounted for by ADG and mid-test $BW^{0.75}$, an increase in the R^2 value from 0.704 to 0.835 ($P < 0.001$).

Implications

Results from this study demonstrate that temperament is an economically relevant trait for feedlot cattle. Temperament could serve as a tool for producers to utilize in genetic selection of cattle, and in feedlot individual animal management protocols. The temperament of cattle has been shown to have significant implications for animal production efficiency and beef carcass quality and income. Temperament is easily measured at feedlot arrival by either subjective chute scoring or objective exit velocity measures, and would require little additional time or effort on the behalf of feeders to implement a temperament sorting system. The impact of temperament in different breeds and biological types of cattle suggests that selection or management of temperament in *Bos indicus*-influence cattle may yield greater improvement in targeted production-outcome variables than selection in *Bos taurus* cattle, due to greater amounts of variation and larger effects of excitable temperament in tropically-adapted breeds. However, all biological types of cattle appeared to show improvement in various economically relevant traits as temperament became less excitable.

Management systems that work toward incorporation of identifying temperament phenotypes at feedlot arrival to sort cattle into production-outcome groups and pens could reduce within-pen variation of economically important traits. Mitigation of the variation in production efficiency and carcass quality would enhance animal performance predictability and beef product quality and consistency. A system such as this could facilitate the use of technologies (e.g. implants, ionophores, and feed additives) for targeted production-outcome groups to improve overall production efficiency, reduce market risks, and optimize product quality. It may be prudent to judiciously use implants and feed additives in cattle with more excitable temperaments to improve feedlot performance, and likewise, restrict their use in calm cattle to allow for calm animals’ tendency for greater performance to be realized in a specific marketing scheme.

Further research considering the effects of temperament, measured by EV, and breed is necessary to elucidate the biological causes of the differences in production variables reported in the current study. In addition, the effects of feeding cattle pens grouped together by EV could be investigated, and interactions between temperament and pharmaceutical products (e.g. implants and beta-agonists) could also be evaluated.

CHAPTER III

SUMMARY

The livestock sector continues to face increasing demand for its products, as well as increasing cost of production and challenges to maintain environmental sustainability. Selection for efficient cattle with lower maintenance requirements and (or) improved efficiency is necessary to reduce the environmental impact of producing beef and input costs. Temperament of beef cattle has been linked to improved ADG ((Voisinet et al., 1997b; Llonch et al., 2016), DMI (Burrow and Dillon, 1997), and more favorable efficiency of gain (Petherick et al., 2002). In addition, calm-temperament cattle exhibited larger HCW and greater LMA (Nkrumah et al., 2007; Reinhardt et al., 2009), more BF depth (Cafe et al., 2011), and produced beef with lower WBS force scores (Behrends et al., 2008), which improved consumer acceptance (Miller et al., 2001).

The current study found that temperament can be used to reduce within-pen variation in ADG and DMI in a feedlot setting. Calm heifers were heavier at feedlot arrival and maintained a BW advantage for the duration of the trials. Calm cattle had more favorable ADG, DMI, and G:F ratios, but no difference was found in RFI or RFI_C between calm and excitable heifers. Further, temperament had an effect on BV and meal behavior, which are also indicative of DMI and ADG in feedlot cattle, such that calm cattle spent more time at the bunk and in meal events than excitable cattle. Ultrasound carcass traits differed between calm and excitable cattle, with calm heifers exhibiting greater final ultrasound BF depth and IMF than excitable heifers. Calm heifers exhibited larger carcasses with more BF depth and a tendency toward higher USDA quality grades than excitable heifers. Further, calm heifers had more tender beef at d-1 and d-14 post-mortem aging, which could result in premium rewards if the beef were marketed on a grid which rewarded tenderness. If a feedlot were capable of sorting cattle based on temperament on feedlot arrival into targeted production-outcome groups, there could be a reduction in within-group variance in production efficiency and carcass quality, thereby improving animal performance predictability and product consistency. In addition, the use of such a system could facilitate the use of technologies (i.e. implants, beta-agonists) for targeted production outcome groups to improve overall production efficiency, reduce market risks, and optimize product quality.

LITERATURE CITED

AMSA. 2015. Research guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of meat. American Meat Science Association., Champaign, IL.

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

Archer, J. A., E. C. Richardson, R. M. Herd, and P. F. Arthur. 1999. Potential for selection to improve efficiency of feed use in beef cattle: A review. Aust. J. Agric. Res. 50:147-161.

Arthur, P. F., J. A. Archer, and R. M. Herd. 2004. Feed intake and efficiency in beef cattle: Overview of recent Australian research and challenges for the future. Aust. J. Exp. Agric. 44:361-369.

Arthur, P. F., J. A. Archer, D. J. Johnston, R. M. Herd, E. C. Richardson, and P. F. Parnell. 2001. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. J. Anim. Sci. 79:2805-2811.

Bailey, J. C., L. O. Tedeschi, E. D. M. Mendes, J. E. Sawyer, and G. E. Carstens. 2012. Technical Note: Evaluation of bimodal distribution models to determine meal criterion in heifers fed a high-grain diet. J. Anim. Sci. 90:2750-2753.

Baker, S. D., J. I. Szasz, T. A. Klein, P. S. Kuber, C. W. Hunt, J. B. G. Jr., D. Falk, R. Richard, J. C. Miller, R. A. Battaglia, and R. A. Hill. 2006. Residual feed intake of purebred Angus steers: Effects on meat quality and palatability. J. Anim. Sci. 84:938-945.

Basarab, J. A., J. R. Brethour, D. R. Zobell, and B. Graham. 1999. Sorting feeder cattle with a system that integrates ultrasound backfat and marbling estimates with a model that maximizes feedlot profitability in value-based marketing. Can. J. Anim. Sci. 79:327-334.

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

Behrends, S. M., R. K. Miller, F. M. Rouquette Jr, R. D. Randel, B. G. Warrington, T. D. A. Forbes, T. H. Welsh, H. Lippke, J. M. Behrends, G. E. Carstens, and J. W.

Holloway. 2008. Relationship of temperament, growth, carcass characteristics and tenderness in beef steers. Meat Sci. 81:433-438.

BIF. 2016. Guidelines for uniform beef improvement programs, 9th revised edition. http://beefimprovement.org/content/uploads/2013/07/BIFGuidelinesFinal_updated0916.pdf.

Bishop, G. L., T. E. Lawrence, and T. H. Montgomery. 2002. Predicting beef carcass value. In: Plains Nutr. Council Conf., TAMU Res. Ext. Center, Amarillo, TX. Publication No. AREC 20-20. p 124.

Boleman, S. J., S. L. Boleman, R. K. Miller, J. F. Taylor, H. R. Cross, T. L. Wheeler, M. Koohmaraie, S. D. Shackelford, M. F. Miller, R. L. West, D. D. Johnson, and J. W. Savell. 1997. Consumer evaluation of beef of known categories of tenderness. J. Anim. Sci. 75:1521-1524.

Bruno, K. A., E. S. Vanzant, K. A. Vanzant, and K. R. McLeod. 2016. Relationships of a novel objective chute score and exit velocity with growth performance of receiving cattle. J. Anim. Sci. 94:4819-4831.

Burdick, N. C., R. D. Randel, J. A. Carroll, and T. H. Welsh. 2011. Interactions between temperament, stress, and immune function in cattle. Inter. J. Zoo. 2011.

Burrow, H. M., and N. J. Corbet. 2000. Genetic and environmental factors affecting temperament of zebu and zebu-derived beef cattle grazed at pasture in the tropics. Aust. J. Agric. Res. 51:155-162.

Burrow, H. M., and R. D. Dillon. 1997. Relationships between temperament and growth in a feedlot and commercial carcass traits of *Bos indicus* crossbreds. Aust. J. Exp. Agric. 37:407-411.

Burrow, H. M., G. W. Seifert, and N. J. Corbet. 1988. A new technique for measuring temperament in cattle. Proc. Aust. Soc. Anim. Prod. 17:154-157.

Cafe, L. M., D. L. Robinson, D. M. Ferguson, B. L. McIntyre, G. H. Geesink, and P. L. Greenwood. 2011. Cattle temperament: Persistence of assessments and associations with productivity, efficiency, carcass and meat quality traits. J. Anim. Sci. 89:1452-1465.

Carstens, G., C. Theis, M. White, T. Welsh, B. Warrington, R. Randel, T. Forbes, H. Lippke, L. Greene, and D. Lunt. 2002. Residual feed intake in beef steers: I. Correlations with performance traits and ultrasound measures of body composition. In: American Society of Animal Science, Western Section. p 552-555.

Cooke, R. F. 2014. Bill E. Kunkle Interdisciplinary Beef Symposium: Temperament and acclimation to human handling influence growth, health, and reproductive responses in *Bos taurus* and *Bos indicus* cattle. J. Anim. Sci. 92:5325-5333.

Cooke, R. F., D. W. Bohnert, B. I. Cappellozza, C. J. Mueller, and T. Delcurto. 2012. Effects of temperament and acclimation to handling on reproductive performance of *Bos taurus* beef females. J. Anim. Sci. 90:3547-3555.

Crockett, J. R., F. S. Baker, J. W. Carpenter, and M. Koger. 1979. Preweaning, feedlot and carcass characteristics of calves sired by continental, brahman and brahman-derivative sires in subtropical Florida. J. Anim. Sci. 49:900-907.

Crouse, J. D., L. V. Cundiff, R. M. Koch, M. Koohmaraie, and S. C. Seideman. 1989. Comparisons of *Bos indicus* and *Bos taurus* inheritance for carcass beef characteristics and meat palatability. J. Anim. Sci. 67:2661-2668.

Crowley, J. J., M. McGee, D. A. Kenny, D. H. Crews, R. D. Evans, and D. P. Berry. 2010. Phenotypic and genetic parameters for different measures of feed efficiency in different breeds of Irish performance-tested beef bulls. J. Anim. Sci. 88:885-894.

Cundiff, L. V. 1970. Experimental Results on Crossbreeding Cattle for Beef Production1. J. Anim. Sci. 30:694-705.

Curley, K. O., D. A. Neuendorff, A. W. Lewis, J. J. Cleere, T. H. Welsh Jr, and R. D. Randel. 2007. Functional characteristics of the bovine hypothalamic–pituitary–adrenal axis vary with temperament. Horm. Behav. 53:20-27.

Curley, K. O., J. C. Paschal, T. H. Welsh, and R. D. Randel. 2006. Technical note: Exit velocity as a measure of cattle temperament is repeatable and associated with serum concentration of cortisol in Brahman bulls. J. Anim. Sci. 84:3100-3103.

Durunna, O. N., Z. Wang, J. A. Basarab, E. K. Okine, and S. S. Moore. 2011. Phenotypic and genetic relationships among feeding behavior traits, feed intake, and residual feed intake in steers fed grower and finisher diets. J. Anim. Sci. 89:3401-3409.

Elzo, M. A., D. G. Riley, G. R. Hansen, D. D. Johnson, R. O. Myer, S. W. Coleman, C. C. Chase, J. G. Wasdin, and J. D. Driver. 2009. Effect of breed composition on phenotypic residual feed intake and growth in Angus, Brahman, and Angus × Brahman crossbred cattle. J. Anim. Sci. 87:3877-3886.

Fell, L. R., I. G. Colditz, K. H. Walker, and D. L. Watson. 1999. Associations between temperament, performance and immune function in cattle entering a commercial feedlot. Aust. J. Exp. Agric. 39:795-802.

Ferguson, D. M., D. Johnston, M. Burrow, and A. Reverter. 2006. Relationships between temperament, feedlot performance and beef quality. In: Australian Beef–the Leader Conference. p 161-165.

Fordyce, G., R. M. Dodt, and J. R. Wythes. 1988a. Cattle temperaments in extensive beef herds in northern Queensland. 1. Factors affecting temperament. Aust. J. Exp. Agric. 28:683-687.

Fordyce, G., M. Goddard, and G. Seifert. 1982. The measurement of temperament in cattle and the effect of experience and genotype. Proc. Aust. Soc. Anim. Prod 14:329-332.

Fordyce, G., M. E. Goddard, R. Tyler, G. Williams, and M. A. Toleman. 1985. Temperament and bruising of *Bos indicus* cross cattle. Aust. J. Exp. Agric. 25:283-288.

Fordyce, G., J. R. Wythes, W. R. Shorthose, D. W. Underwood, and R. K. Shepherd. 1988b. Cattle temperaments in extensive beef herds in northern Queensland. 2. Effect of temperament on carcass and meat quality. Aust. J. Exp. Agric. 28:689-693.

Fox, D. G., L. O. Tedeschi, and P. J. Guiroy. 2001a. A decision support system for individual cattle management. In: Proc. Cornell Nutr. Conf. Feed Manuf. p 64-76.

Fox, D. G., L. O. Tedeschi, and P. J. Guiroy. 2001b. Determining feed intake and feed efficiency of individual cattle fed in groups. In: Proc. Beef Impr. Fed. 33rd Ann. Res. Symp. Annu. Meet. p 80-98.

Francisco, C. L., R. F. Cooke, R. S. Marques, R. R. Mills, and D. W. Bohnert. 2012. Effects of temperament and acclimation to handling on feedlot performance of *Bos taurus* feeder cattle originated from a rangeland-based cow–calf system. J. Anim. Sci. 90:5067-5077.

Francisco, C. L., F. D. Resende, J. M. B. Benatti, A. M. Castilhos, R. F. Cooke, and A. M. Jorge. 2015. Impacts of temperament on Nellore cattle: physiological responses, feedlot performance, and carcass characteristics. J. Anim. Sci. 93:5419-5429.

Gibb, D. J., T. A. McAllister, C. Huisma, and R. D. Wiedmeier. 1998. Bunk attendance of feedlot cattle monitored with radio frequency technology. Can. J. Anim. Sci. 78:707-710.

Grandin, T. 1993. Behavioral agitation during handling of cattle is persistent over time. Appl. Anim. Behav. Sci. 36:1-9.

Haskell, M. J., G. Simm, and S. P. Turner. 2014. Genetic selection for temperament traits in dairy and beef cattle. Front. Gen. 5.

Hearnshaw, H., and C. Morris. 1984. Genetic and environmental effects on a temperament score in beef cattle. Aust. J. Agric. Res. 35:723-733.

Hebart, M. L., W. S. Pitchford, P. F. Arthur, J. A. Archer, R. M. Herd, and C. D. K. Bottema. 2004. Effect of missing data on the estimate of average daily feed intake in beef cattle. Aust. J. Exp. Agric. 44:415-421.

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

Herd, R. M., and P. F. Arthur. 2009. Physiological basis for residual feed intake. J. Anim. Sci. 87:E64-E71.

Herd, R. M., and S. C. Bishop. 2000. Genetic variation in residual feed intake and its association with other production traits in British Hereford cattle. Livest. Prod. Sci. 63:111-119.

Jackson, K. S., G. E. Carstens, L. O. Tedeschi, and W. E. Pinchak. 2016. Changes in feeding behavior patterns and dry matter intake before clinical symptoms associated with bovine respiratory disease in growing bulls. J. Anim. Sci. 94:1644-1652.

Johnston, D. J., A. Reverter, D. M. Ferguson, J. M. Thompson, and H. M. Burrow. 2003. Genetic and phenotypic characterisation of animal, carcass, and meat quality traits from temperate and tropically adapted beef breeds. 3. Meat quality traits. Aust. J. Agric. Res. 54:135-147.

Kharas, H. 2010. The emerging middle class in developing countries. OECD Publishing.

King, D. A., C. E. Schuehle Pfeiffer, R. D. Randel, T. H. Welsh Jr, R. A. Oliphint, B. E. Baird, K. O. Curley Jr, R. C. Vann, D. S. Hale, and J. W. Savell. 2006. Influence of animal temperament and stress responsiveness on the carcass quality and beef tenderness of feedlot cattle. Meat Sci. 74:546-556.

Koch, R. M., M. E. Dikeman, D. M. Allen, M. May, J. D. Crouse, and D. R. Campion. 1976. Characterization of biological types of cattle III. Carcass composition, quality and patability. J. Anim. Sci. 43:48-62.

Koch, R. M., L. A. Swiger, D. Chambers, and K. E. Gregory. 1963. Efficiency of feed use in beef cattle. J. Anim. Sci. 22:486-494.

Kononoff, P. J., P. J. Defoor, M. J. Engler, R. S. Swingle, S. T. James, H. M. Deobald, J. L. Deobald, and F. L. S. Marquess. 2013. Impact of a leptin single nucleotide polymorphism and zilpaterol hydrochloride on growth and carcass characteristics in finishing steers. J. Anim. Sci. 91:5011-5017.

Lancaster, P. A., G. E. Carstens, D. H. Crews, T. H. Welsh, T. D. A. Forbes, D. W. Forrest, L. O. Tedeschi, R. D. Randel, and F. M. Rouquette. 2009a. Phenotypic and genetic relationships of residual feed intake with performance and ultrasound carcass traits in Brangus heifers. J. Anim. Sci. 87:3887-3896.

Lancaster, P. A., G. E. Carstens, F. R. B. Ribeiro, L. O. Tedeschi, and D. H. Crews. 2009b. Characterization of feed efficiency traits and relationships with feeding behavior and ultrasound carcass traits in growing bulls. J. Anim. Sci. 87:1528-1539.

Link, D. J., L. K. Almas, M. S. Brown, and T. E. Lawrence. 2011. The beneficial impact of sorting heavy cattle at re-implant. In: 2011 Annual Meeting, Southern Agricultural Economics Association, Corpus Christi, TX.

Llonch, P., M. Somarriba, C. Duthie, M. J. Haskell, J. A. Rooke, S. Troy, R. Roehe, and S. P. Turner. 2016. Association of temperament and acute stress responsiveness with productivity, feed efficiency, and methane emissions in beef cattle: An observational study. Front. Vet. Sci. 3:43.

McDonagh, M. B., R. M. Herd, E. C. Richardson, V. H. Oddy, J. A. Archer, and P. F. Arthur. 2001. Meat quality and the calpain system of feedlot steers following a single generation of divergent selection for residual feed intake. Aust. J. Exp. Agric. 41:1013-1021.

Miller, M. F., M. A. Carr, C. B. Ramsey, K. L. Crockett, and L. C. Hoover. 2001. Consumer thresholds for establishing the value of beef tenderness. J. Anim. Sci. 79:3062-3068.

Nkrumah, J. D., J. A. Basarab, M. A. Price, E. K. Okine, A. Ammoura, S. Guercio, C. Hansen, C. Li, B. Benkel, B. Murdoch, and S. S. Moore. 2004a. Different measures of energetic efficiency and their phenotypic relationships with growth, feed intake, and ultrasound and carcass merit in hybrid cattle. J. Anim. Sci. 82:2451-2459.

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

Nkrumah, J. D., C. Li, J. B. Basarab, S. Guercio, Y. Meng, B. Murdoch, C. Hansen, and S. S. Moore. 2004b. Association of a single nucleotide polymorphism in the bovine leptin gene with feed intake, feed efficiency, growth, feeding behaviour, carcass quality and body composition. Can. J. Anim. Sci. 84:211-219.

Nkrumah, J. D., E. K. Okine, G. W. Mathison, K. Schmid, C. Li, J. A. Basarab, M. A. Price, Z. Wang, and S. S. Moore. 2006. Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. J. Anim. Sci. 84:145-153.

Northcutt, S., and B. Bowman. 2010. Docility genetic evaluation research. https://www.angus.org/Nce/Documents/ByThenumbersDocility.pdf.

O'Connor, S. F., J. D. Tatum, D. M. Wulf, R. D. Green, and G. C. Smith. 1997. Genetic effects on beef tenderness in *Bos indicus* composite and *Bos taurus* cattle. J. Anim. Sci. 75:1822-1830.

Peacock, F. M., A. Z. Palmer, J. W. Carpenter, and M. Koger. 1979. Breed and heterosis effects on carcass charateristics of Angus, Brahman, Charolais and Crossbred steers. J. Anim. Sci. 49:391-395.

Petherick, J. C., R. G. Holroyd, V. J. Doogan, and B. K. Venus. 2002. Productivity, carcass and meat quality of lot-fed *Bos indicus* cross steers grouped according to temperament. Aust. J. Exp. Agric. 42:389-398.

Pyatt, N. A., L. L. Berger, D. B. Faulkner, P. M. Walker, and S. L. Rodriguez-Zas. 2005a. Factors affecting carcass value and profitability in early-weaned Simmental steers: I. Five-year average pricing. J. Anim. Sci. 83:2918-2925.

Pyatt, N. A., L. L. Berger, D. B. Faulkner, P. M. Walker, and S. L. Rodriguez-Zas. 2005b. Factors affecting carcass value and profitability in early-weaned Simmental steers: II. Days on feed endpoints and sorting strategies. J. Anim. Sci. 83:2926-2937.

Reinhardt, C. D., W. D. Busby, and L. R. Corah. 2009. Relationship of various incoming cattle traits with feedlot performance and carcass traits. J. Anim. Sci. 87:3030-3042.

Reverter, A., D. J. Johnston, D. Perry, M. E. Goddard, and H. M. Burrow. 2003. Genetic and phenotypic characterisation of animal, carcass, and meat quality traits from temperate and tropically adapted beef breeds. 2. Abattoir carcass traits. Aust. J. Agric. Res. 54:119-134.

Richardson, E. C., R. M. Herd, V. H. Oddy, J. M. Thompson, J. A. Archer, and P. F. Arthur. 2001. Body composition and implications for heat production of Angus steer progeny of parents selected for and against residual feed intake. Aust. J. Exp. Agric. 41:1065-1072.

Sandelin, B. A., A. H. Brown, Jr., Z. B. Johnson, J. A. Hornsby, J. A. Hornsby, R. T. Baublits, and B. R. Kutz. 2005. Postpartum maternal behavior score in six breed groups of beef cattle over twenty-five years. Prof. Anim. Scientist 21:13-16.

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

Schmutz, S. M., J. M. Stookey, D. C. Winkelman-Sim, C. S. Waltz, Y. Plante, and F. C. Buchanan. 2001. A QTL study of cattle behavioral traits in embryo transfer families. J. Hered. 92:290-292.

Schwartzkopf-Genswein, K. S., D. D. Hickman, M. A. Shah, C. R. Krehbiel, B. M. A. Genswein, R. Silasi, D. G. Gibb, D. H. Crews, and T. A. McAllister. 2011. Relationship between feeding behavior and performance of feedlot steers fed barley-based diets. J. Anim. Sci. 89:1180-1192.

Schwartzkopf-Genswein, K. S., R. Silasi, and T. A. McAllister. 2003. Use of remote bunk monitoring to record effects of breed, feeding regime and weather on feeding behavior and growth performance of cattle. Can. J. Anim. Sci. 83:29-38.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1995. Relationship between shear force and trained sensory panel tenderness ratings of 10 major muscles from *Bos indicus* and *Bos taurus* cattle. J. Anim. Sci. 73:3333-3340.

Tedeschi, L. O., D. G. Fox, and P. J. Guiroy. 2004. A decision support system to improve individual cattle management. 1. A mechanistic, dynamic model for animal growth. Agric. Syst. 79:171-204.

Thomas, M., A. Brown Jr, and C. Rosenkrans Jr. 2012. Breed group effects for chute exit velocity as an indicator trait for temperament in weaned calves, University of Arkansas Department of Animal Science, Fayetteville, AK.

Tulloh, N. M. 1961. Behaviour of cattle in yards. II. A study of temperament. Anim. Behav. 9:25-30.

Turner, S. P., E. A. Navajas, J. J. Hyslop, D. W. Ross, R. I. Richardson, N. Prieto, M. Bell, M. C. Jack, and R. Roehe. 2011. Associations between response to handling and growth and meat quality in frequently handled *Bos taurus* beef cattle. J. Anim. Sci. 89:4239-4248.

UN. 2015. World Population Prospects 2015, Department of Economic and Social Affairs-Population Division.

USDA. 1997. Official United States standards and grades of carcass beef. https://www.ams.usda.gov/?dDocName=STELDEV3002979 Accessed Jun. 16, 2017.

Vasconcelos, J. T., and M. L. Galyean. 2007. Nutritional recommendations of feedlot consulting nutritionists: The 2007 Texas Tech University Survey. J. Anim. Sci. 85:2772-2781.

Veum, T. L., M. R. Ellersieck, T. L. Durham, W. R. McVickers, S. N. McWilliams, and J. F. Lasley. 1979. Response of Stress-Susceptible and Stress-Resistant Hamsphire Pigs to Electrical Stress I. Physiological and Biochemical Effects. J. Anim. Sci. 48:446-452.

Voisinet, B. D., T. Grandin, S. F. O'Connor, J. D. Tatum, and M. J. Deesing. 1997a. *Bos indicus*-cross feedlot cattle with excitable temperaments have tougher meat and a higher incidence of borderline dark cutters. Meat Sci. 46:367-377.

Voisinet, B. D., T. Grandin, J. D. Tatum, S. F. O'Connor, and J. J. Struthers. 1997b. Feedlot cattle with calm temperaments have higher average daily gains than cattle with excitable temperaments. J. Anim. Sci 75:892-896.

Welch, C. M., J. K. Ahola, J. B. Hall, G. K. Murdoch, D. H. Crews, L. C. Davis, M. E. Doumit, W. J. Price, L. D. Keenan, and R. A. Hill. 2012. Relationships among performance, residual feed intake, and product quality of progeny from Red Angus sires divergent for maintenance energy EPD. J. Anim. Sci. 90:5107-5117.

Whipple, G., M. Koohmaraie, M. E. Dikeman, J. D. Crouse, M. C. Hunt, and R. D. Klemm. 1990. Evaluation of attributes that affect longissimus muscle tenderness in *Bos taurus* and *Bos indicus* cattle. J. Anim. Sci. 68:2716-2728.

Williams, J. L., I. Aguilar, R. Rekaya, and J. K. Bertrand. 2010. Estimation of breed and heterosis effects for growth and carcass traits in cattle using published crossbreeding studies. J. Anim. Sci. 88:460-466.

Wolfger, B., C. J. Quinn, G. W. Torres, M. Taylor, and K. Orsel. 2016. Comparison of feeding behavior between black and Red Angus feeder heifers. Can. J. Anim. Sci. 96:404-409.

Wolfger, B., K. S. Schwartzkopf-Genswein, H. W. Barkema, E. A. Pajor, M. Levy, and K. Orsel. 2015. Feeding behavior as an early predictor of bovine respiratory disease in North American feedlot systems. J. Anim. Sci. 93:377-385.

Yeates, M., B. Tolkamp, D. Allcroft, and I. Kyriazakis. 2001. The use of mixed distribution models to determine bout criteria for analysis of animal behaviour. J. Theor. Biol. 213:413-425.

APPENDIX

Table A-1. Heifer diet ingredients and chemical analysis.

Item	
Ingredient	*As-fed basis %*
Dry rolled corn	73.7
Chopped sorghum-sudan hay	6.0
Cottonseed meal	6.0
Cottonseed hulls	6.0
Molasses	5.0
Mineral premix[*]	2.5
Urea	0.8
Chemical Composition	*Dry matter basis*
Dry matter, %	90.2
CP, % DM	12.6
NDF, % DM	20.3
ME, Mcal/kg DM	3.0

[*] Mineral Premix contained minimum 15.5% Ca, 2800 ppm Zn, 1200 ppm Mn, 12 ppm Se, 14 ppm Co, 30 ppm I, 45.4 KIU/kg Vit-D, 726 IU/kg Vit-E, 1200 ppm Tylan

Table A-2. Summary statistics (± SD) of performance, feed efficiency, feeding behavior, carcass ultrasound, and carcass traits for heifers (n = 415).[1]

Trait	Mean	SD	Min	Max
Performance traits				
Initial age, d	339.8	35.3	244.0	410.0
Initial BW, kg	280.5	35.9	165.7	390.8
Final BW, kg	387.6	49.5	245.5	560.0
Mid-test $BW^{0.75}$, kg	77.67	7.13	55.97	101.04
ADG, kg/d	1.53	0.32	0.44	2.66
DMI, kg/d	9.28	1.67	4.18	14.20
DMI, $g/BW^{0.75}$	119.4	16.9	67.0	164.3
Feed efficiency traits				
F:G	6.19	1.04	3.33	12.06
G:F	0.17	0.03	0.09	0.27
RFI, kg/d†	0.00	0.88	-3.63	2.62
RFI_c, kg/d†	0.00	0.87	-3.35	2.48
Residual gain, kg/d	0.00	0.23	-0.62	0.84
Bunk visit traits				
Head-down duration, min	41.96	19.95	3.80	101.26
BV frequency, events/d	64.97	19.72	26.01	126.30
BV duration, min/d	63.00	18.68	10.31	124.99
BV eating rate, g/min	164.61	53.88	57.54	647.58
Time-to-bunk, min	121.46	91.69	5.64	562.88
Meal traits				
Meal criterion, min	10.99	8.31	1.90	47.68
Meal frequency, events/d	9.27	4.52	2.67	27.39
Meal duration, min/d	138.80	36.77	54.00	286.88
Meal length, min/event	19.79	12.49	3.86	74.46
Meal size, kg/event	1.47	0.85	0.26	4.36
Meal eating rate, g/min	72.92	20.51	34.54	140.11
BV per meal, events/meal	8.33	3.99	2.36	24.81

Table A-2. – Continued.

Trait	Mean	SD	Min	Max
Carcass ultrasound traits				
Initial LMA, cm^2	44.22	7.43	27.74	80.65
Initial BF depth, cm	0.32	0.10	0.13	0.71
Initial IMF, %	3.23	0.93	1.19	6.20
Final LMA, cm^2	64.53	8.30	36.77	98.06
Final BF depth, cm	0.65	0.24	0.23	1.57
Final IMF, %	3.76	0.99	1.68	7.03
LMA gain, cm^2	20.43	6.08	1.29	42.58
BF gain, cm	0.33	0.19	-0.03	1.07
Carcass characteristics				
Hot carcass weight, kg	282.8	29.0	199.8	378.3
BF depth, cm	1.13	0.42	0.10	2.74
LMA, cm^2	74.13	7.81	58.06	109.68
KPH, %	2.24	0.57	0.50	7.50
USDA Yield Grade	2.75	0.60	0.92	4.72
Marbling score[2]	436	95	280	870
USDA Quality Grade[3]	401	44	290	557
WBS force, kg				
WBS force (1-d), kg	3.63	0.98	1.52	7.95
WBS force (14-d), kg	2.35	0.58	1.42	5.01
Temperament traits				
Initial REV (arrival & d 0), m/s	0.00	0.21	-0.53	0.72
Final REV (d 70), m/s	0.00	0.47	-0.86	3.52
Initial chute score (1-5)*	1.49	0.67	1.00	5.00
Final chute score (1-5)*	1.94	0.84	1.00	5.00

[1] $BW^{0.75}$ = metabolic mid-test body weight; F:G = feed to gain conversion; G:F = gain to feed conversion; BV = bunk visit; LMA = loin muscle area; BF = back fat; KPH = kidney, pelvic, and heart fat; USDA YG = USDA yield grade; WBS = Warner-Bratzler shear force

[2] 300 = Slight^{00}; 400 = Small^{00}; 500 = Modest^{00}; 600 = Moderate^{00}

[3] 300 = Select^{00}; 400 = Choice^{00}; 500 = Prime^{00}

*Chute scores were unavailable for the third trial.

†RFI was established using a regression of DMI on ADG and mid-test $BW^{0.75}$. RFI_C was established using a regression of DMI on ADG, mid-test $BW^{0.75}$, and final ultrasound backfat depth.

Table A-3. Effects of temperament and breed on performance and feed efficiency.[1]

	Temperament*			Breed					*P*-Value		
Item	Calm	Excitable	SE	Angus	Braford	Brangus	Simbrah	SE	Temp	Breed	Temp*Breed
Performance traits											
Initial age, days	332	331	5	335^{a}	330^{ab}	327^{b}	332^{ab}	3	0.87	0.05	0.18
Initial BW, kg	280.0	267.9	7.0	265.8^{a}	269.7^{b}	277.5^{abc}	282.8^{c}	4.7	0.001	0.001	0.85
Final BW, kg	391.6	367.8	9.2	383.6^{a}	361.1^{b}	384.5^{a}	389.4^{a}	6.2	0.001	0.001	0.6
Mid-test BW, kg$^{0.75}$	78.1	75.0	1.4	76.2^{ab}	74.6^{b}	77.3^{a}	78.1^{a}	0.9	0.001	0.001	0.7
ADG, kg/d	1.60	1.43	0.06	1.68^{a}	1.31^{b}	1.53^{c}	1.53^{c}	0.04	0.001	0.001	0.46
DMI, kg/d	9.41	8.72	0.30	9.52^{a}	8.36^{b}	9.25^{a}	9.12^{a}	0.20	0.001	0.001	0.09
DMI, g/MBW$^{0.75}$	119.9	115.4	3.4	124.0^{a}	111.5^{b}	118.1^{c}	116.9^{c}	2.3	0.001	0.001	0.01
Feed efficiency traits											
G:F	0.172	0.165	0.006	0.179^{a}	0.159^{b}	0.168^{c}	0.168^{c}	0.00	0.02	0.001	0.11
RFIp, kg/d	0.044	-0.009	0.205	0.162	-0.077	0.036	-0.053	0.139	0.34	0.32	0.003
RFIc, kg/d	0.034	-0.011	0.202	0.103	-0.168	0.070	0.040	0.137	0.40	0.13	0.001
Residual gain, kg/d	0.021	-0.104	0.085	0.143^{a}	-0.098^{b}	0.008^{c}	0.010^{c}	0.032	0.002	0.001	0.19

$^{a\text{-}d}$Means in the same row with unlike superscripts differ at $P < 0.05$.

*Temperament means were computed at mean initial REV (0.0 ± 0.21 SD m/s) -1 SD (Calm) and at mean initial REV +1 SD (Excitable).

†RFI was established using a regression of DMI on ADG and mid-test BW$^{0.75}$. RFI$_{C}$ was established using a regression of DMI on ADG, mid-test BW$^{0.75}$, and final ultrasound backfat depth.

Table A-4. Effects of temperament and breed on feeding behavior.

	Temperament*			Breed					*P*-Value		
Item	Calm	Excitable	SE	Angus	Braford	Brangus	Simbrah	SE	Temp	Breed	Temp*Breed
Bunk visit traits											
Head-down duration, min	40.4	36.7	3.6	42.5^{a}	35.0^{b}	42.6^{a}	34.0^{b}	2.40	0.05	0.001	0.01
BV frequency, events/d	66.39	64.26	3.05	63.88	64.42	65.21	67.76	2.05	0.11	0.15	0.47
BV duration, min/d	65.41	59.89	4.04	70.49^{a}	57.50^{b}	66.61^{a}	55.95^{b}	2.74	0.003	0.001	0.01
BV eating rate/ g/min	160.23	162.04	11.73	143.4^{a}	162.9^{a}	153.0^{a}	185.2^{b}	7.92	0.79	0.001	0.26
Time-to-bunk, min	134.0	150.6	13.5	134.5	145.3	144.5	145.2	9.04	0.09	0.69	0.28
Meal traits											
Meal frequency, events/d	10.17	10.57	0.76	9.34^{a}	10.92^{b}	10.97^{b}	10.25^{ab}	0.51	0.23	0.01	0.98
Meal duration, min/d	138.7	126.8	7.5	136.9^{bc}	123.0^{a}	141.6^{b}	129.3^{c}	5.05	0.002	0.001	0.06
Meal length, min/event	17.77	14.57	1.95	18.61^{a}	13.53^{b}	19.20^{a}	16.32^{a}	1.31	0.001	0.001	0.09
Meal size, kg/event	1.32	1.12	0.12	1.44^{a}	1.03^{b}	1.14^{bc}	1.28^{ac}	0.08	0.001	0.001	0.06
Meal eating rate, g/min	72.68	74.30	3.88	73.6^{ab}	79.9^{ab}	70.9^{a}	76.5^{b}	2.62	0.83	0.07	0.02
BV per meal, events/meal	7.58	6.77	0.61	7.61^{a}	6.58^{b}	6.69^{b}	7.81^{a}	0.41	0.001	0.00	0.58

*Temperament means were computed at mean initial REV (0.0 ± 0.21 SD m/s) -1 SD (Calm) and at mean initial REV +1 SD (Excitable).

$^{a\text{-}d}$Means in the same row with unlike superscripts differ at $P < 0.05$.

Table A-5. Effects of temperament and breed on ultrasound carcass characteristics.[1]

	Temperament *			Breed					*P*-Value		
Item	Calm	Excitable	SE	Angus	Braford	Brangus	Simbrah	SE	Temp	Breed	Temp*Breed
Carcass ultrasound traits											
Initial LMA, cm^2	42.91	43.76	1.35	41.93^{a}	42.16^{a}	44.58^{b}	44.67^{b}	0.90	0.33	0.001	0.94
Initial BF thickness, cm	0.30	0.30	0.02	0.31^{a}	0.33^{a}	0.31^{a}	0.25^{b}	0.01	0.49	0.001	0.88
Initial IMF, %	3.32	3.22	0.15	3.87^{a}	3.11^{b}	3.29^{b}	2.81^{c}	0.10	0.13	0.001	0.42
Final LMA, cm^2	64.33	63.96	1.70	64.52^{ac}	60.70^{b}	66.92^{a}	64.44^{c}	1.14	0.34	0.001	0.8
Final BF thickness, cm	0.66	0.61	0.05	0.72^{a}	0.67^{a}	0.67^{a}	0.49^{b}	0.03	0.02	0.001	0.98
Final IMF, %	3.91	3.68	0.17	4.69^{a}	3.61^{b}	3.84^{b}	3.05^{c}	0.12	0.001	0.001	0.37
BF gain, cm	0.36	0.32	0.04	0.41^{a}	0.34^{b}	0.36^{ab}	0.24^{c}	0.03	0.01	0.001	0.88
LMA gain, cm^2	21.46	20.21	1.34	22.56^{a}	18.42^{b}	22.31^{a}	20.04^{b}	0.90	0.03	0.001	0.62

[1] LMA = loin muscle area; BF = backfat depth; IMF % = intramuscular fat percentage.

$^{a\text{-}d}$Means in the same row with unlike superscripts differ at $P < 0.05$.

*Temperament means were computed at mean initial REV (0.0 ± 0.21 SD m/s) -1 SD (Calm) and at mean initial REV +1 SD (Excitable).

Table A-6. Effects of temperament and breed on carcass characteristics and value.[1]

	Temperament *			Breed					*P*-Value		
Item	Calm	Excitable	SE	Angus	Braford	Brangus	Simbrah	SE	Temp	Breed	Temp*Breed
Carcass Characteristics											
Hot carcass weight, kg	289.1	278.0	6.2	284.0^{a}	268.6^{b}	285.5^{a}	296.1^{c}	4.21	0.001	0.001	0.18
Back fat depth, cm	1.23	1.16	0.08	1.34^{a}	1.30^{a}	1.25^{a}	0.88^{b}	0.06	0.05	0.001	0.72
LMA, cm^{2}	75.06	73.74	1.67	74.87^{a}	69.83^{b}	74.81^{a}	78.07^{c}	1.13	0.09	0.001	0.74
KPH, %	2.29	2.27	0.13	2.25	2.22	2.32	2.35	0.09	0.55	0.299	0.29
USDA Yield Grade	2.86	2.76	0.13	2.92^{a}	3.00^{a}	2.87^{a}	2.45^{b}	0.09	0.07	0.001	0.69
Marbling	450	439	21	510^{a}	406^{b}	443^{c}	418^{bc}	11	0.17	0.001	0.25
USDA Quality Grade	408	402	10	433^{a}	387^{b}	405^{c}	395^{bc}	6.6	0.15	0.001	0.19
WBS force, kg											
WBS force (1 d), kg	3.42	3.70	0.22	3.35^{a}	3.75^{b}	3.44^{ab}	3.70^{b}	0.15	0.002	0.02	0.26
WBS force (14 d), kg	2.25	2.41	0.13	2.25	2.41	2.31	2.34	0.90	0.003	0.33	0.44
Carcass Value, $											
Carcass value, $/kg (Grid 1*)	4.61	4.58	0.05	4.69^{a}	4.48^{b}	4.60^{c}	4.62^{ac}	0.03	0.15	0.001	0.16
Income, $/animal (Grid 1)	1334	1278	40	1337^{ab}	1208^{c}	1306^{a}	1373^{b}	27	0.001	0.001	0.19
Carcass value, $/kg (Grid 2*)	4.67	4.63	0.05	4.75^{a}	4.53^{b}	4.65^{c}	4.68^{ac}	0.03	0.08	0.001	0.11
Income, $/animal (Grid 2)	1354	1292	38	1352^{ab}	1223^{c}	1330^{a}	1388^{b}	25	0.001	0.001	0.17

[1] LMA = loin muscle area; KPH = kidney, pelvic and heart fat WBS = Warner Bratzler shear force, 1-d and 14-d post-mortem aging.

[2] 300 = Slight^{00}; 400 = Small^{00}; 500 = Modest^{00}; 600 = Moderate^{00}.

[3] 300 = Select^{00}; 400 = Choice^{00}; 500 = Prime^{00}.

[a-d] Means in the same row with unlike superscripts differ at $P < 0.05$.

*Temperament means were computed at mean initial REV (0.0 ± 0.21 SD m/s) -1 SD (Calm) and at mean initial REV +1 SD (Excitable).

†Grid 1 was based on three-year average USDA premiums and discounts for carcass weight, USDA YG and QG. Grid 2 was the same, with an additional premium or discount for tenderness (Table A-15).

Table A-7. Phenotypic correlations between performance, feed intake, and feed efficiency traits in heifers.[1]

Trait	Age	ADG	DMI	G:F	RFI	RFI_C	RG	Initial REV
Initial BW	0.13*	0.41*	0.68*	-0.33*	0.00	0.01	-0.21*	-0.17*
Age		0.12*	0.02	0.22*	-0.06	-0.05	0.13*	-0.01
ADG			0.69*	0.46*	0.00	0.00	0.71*	-0.30*
DMI				-0.28*	0.52*	0.52*	0.00	-0.24*
G:F					-0.52*	-0.50*	0.90*	-0.14*
RFI						0.94*	-0.40*	-0.04
RFI_C							-0.40*	-0.04
RG								-0.19*

[1] G:F = Gain to feed ratio; RFI = residual feed intake; RFI_C = carcass-adjusted residual feed intake; RG = residual gain; Initial REV = average of arrival and d 0 relative exit velocities.

*Correlations are significant, $P < 0.05$.

Table A-8. Frequency of temperament classification across breed.[1]

Temperament Classification	Breed (%) Angus	Braford	Brangus	Simbrah	χ^2	*P*-value
Calm	35.94	23.93	34.96	30.63		
Moderate	40.63	43.59	34.15	35.14	6.46	0.3742
Excitable	23.44	32.48	30.89	34.23		

[1] Temperament classification was based on ± 0.5 SD from the mean initial REV of 0.00 ± 0.21

Table A-9. Frequency of USDA Quality Grade by breed.[1]

	Breed (%)					
Item	Angus	Braford	Brangus	Simbrah	χ^2	*P*-value
USDA Choice or greater	85.71	51.28	62.50	53.70	28.33	0.001
USDA Select or lower	14.29	48.72	37.50	46.30		
WBS ≤ 3.0 kg	12.7	25	19.49	22.64	3.23	0.2523
WBS > 3.0 kg	87.3	75	80.51	77.36		

[1] WBS = Warner-Bratzler shear force. Steaks with WBS ≤ 3.0 kg were tender.

Table A-10. Frequency of USDA Quality Grade and tenderness by temperament classification.[1]

	Temperament classification (%)				
Item	Calm	Moderate	Excitable	χ^2	*P*-value
USDA Choice or greater	63.49	62.34	55.47	6.21	0.1837
USDA Select or lower	36.51	37.66	44.53		
WBS ≤ 3.0 kg	92.74	90.2	80.16	10.55	0.0051
WBS > 3.0 kg	7.26	9.8	19.84		

[1] WBS = Warner-Bratzler shear force. Steaks with WBS ≤ 3.0 kg were tender. Temperament classification was based on ± 0.5 SD from the mean initial REV of 0.00 ± 0.21

Table A-11. Phenotypic correlations between temperament and performance and feed efficiency in heifers.[1]

Trait	Age	IBW	ADG	DMI	G:F	RFI
Arrival REV	-0.05	-0.12*	-0.27*	-0.18*	-0.15*	0.00
d 0 REV	0.02	-0.16*	-0.19*	-0.19*	-0.05	-0.07
Initial REV	-0.01	-0.17*	-0.30*	-0.24*	-0.14*	-0.04
d 70 REV	0.07	0.02	-0.02	0.00	-0.03	-0.01
Initial CS†	-0.27*	-0.27*	-0.23*	-0.30*	0.06	0.00
Final CS†	-0.36*	-0.39*	-0.31*	-0.45*	0.19*	-0.03

[1] REV = relative exit velocity (m/s); Initial REV = average of Arrival and d 0 REV; IBW= initial BW; RFI= residual feed intake; CS = subjective chute score.

*Correlations are different from zero at $P < 0.05$.

†Initial and final chute scores were not available for Trial 3.

Table A-12. Phenotypic correlations between performance and feeding behavior in heifers.[1]

Trait	Age	IBW	ADG	DMI	G:F	RFI
Bunk visit (BV) frequency, events/d	0.34*	-0.36*	-0.05	-0.17*	0.31*	0.24*
BV duration, min/d	0.08	0.13*	0.27*	0.48*	-0.15*	0.47*
Meal frequency, events/d	-0.23*	-0.43*	-0.29*	-0.41*	0.16*	0.02
Meal duration, min/d	0.31*	0.14*	0.36*	0.43*	0.03	0.33*
Meal length, min/event	0.42*	0.41*	0.40*	0.50*	-0.08	0.12*
Meal eating rate, g/min	-0.33*	0.43*	0.12*	0.32*	-0.32*	0.00
BV per meal, events/meal	0.55*	0.24*	0.29*	0.35*	0.02	0.16*
Head-down duration, min	0.47*	0.09	0.19*	0.31*	0.01	0.36*
Time-to-bunk, min	-0.44*	-0.07	-0.24*	-0.24*	-0.06	-0.18*

[1] IBW= initial BW; RFI= residual feed intake.

Table A-13. Phenotypic correlations between feeding behavior and temperament in heifers.[1]

Trait	BV Freq	BV Dur	Meal Freq	Meal Dur	Meal Length	Meal Intake	Meal eating Rate	BV eating rate	BV:Meal Ratio	HDD	TTB
Arrival REV	-0.07	-0.16*	0.03	-0.16*	-0.11*	-0.10	0.05	0.04	-0.09	-0.08	0.11*
d 0 REV	-0.03	-0.09	0.05	-0.11*	-0.13*	-0.12*	-0.01	0.00	-0.10*	-0.05	0.05
Initial REV	-0.06	-0.17*	0.05	-0.18*	-0.14*	-0.13*	0.04*	0.03	0.11*	-0.10*	0.09
d 70 REV	0.01	0.01	-0.02	0.02	0.10*	0.10	-0.02	-0.01	0.09	0.01	0.01
Initial chute score†	0.18*	-0.16*	0.28*	-0.20*	-0.33*	-0.35*	-0.10	0.02	-0.29*	-0.16*	0.26*
Final chute score†	0.31*	-0.19*	0.45*	-0.29*	-0.49*	-0.53*	-0.19*	-0.04	-0.40*	-0.19*	0.47*

Initial REV = average of arrival and d 0 relative exit velocities; BV = bunk visit; HDD = head down duration; TTB = time-to-bunk.

*Correlations are different from zero at $P < 0.05$.

†Initial and final chute scores were not available for Trial 3.

Table A-14. Variance in RFI accounted for by carcass ultrasound traits.[1]

Trait	Partial R^2	Cumulative R^2	*P*-value
Trial	0.300	0.300	0.001
$BW^{0.75}$	0.319	0.619	0.001
$BW^{0.75}$ + ADG	0.085	0.704	0.001
Base Model		0.704	
Ultrasound carcass traits			
Final BF thickness, cm	0.015	0.719	0.001

[1] RFI = residual feed intake; $BW^{0.75}$ = mid-test metabolic BW; BF = 12th rib backfat depth; IMF% = intramuscular fat; LMA = loin muscle area.

Table A-15. Variance in RFI accounted for by feeding behavior traits.[1]

Trait	Partial R^2	Cumulative R^2	*P*-value
Trial	0.300	0.300	0.001
$BW^{0.75}$	0.319	0.619	0.001
$BW^{0.75}$ + ADG	0.085	0.704	0.001
Base Model		0.704	
Feeding behavior			
BV duration, min/d	0.106	0.810	0.001
BV per meal, events/meal	0.015	0.825	0.001
Time-to-bunk, min	0.010	0.835	0.001

[1] RFI = residual feed intake; $BW^{0.75}$ = mid-test metabolic BW; BV = bunk visit.

Table A-16. Grid factors affecting carcass value.[1]

Item	Carcass mix (% of total HCW, kg)	Carcass grid adj. ($/100 kg)	Grid 1	Grid 2
Base carcass price		$468.11	--	--
USDA quality grade				
Prime	2.28%	$37.06	$0.85	$0.85
Top choice	17.70%	$9.19	$1.63	$1.63
Choice	41.47%			
Select	38.54%	$(19.67)	$(7.58)	$(7.58)
No roll/ Standard	0.00%	$(47.47)	$0.00	$0.00
USDA yield grade				
Yield grade 1	9.97%	$11.25	$1.12	$1.12
Yield grade 2	54.87%	$5.62	$3.08	$3.08
Yield grade 3	32.57%			
Yield grade 4	2.58%	$(24.53)	$(0.63)	$(0.63)
Yield grade 5	0.00%	$(38.74)	$0.00	$0.00
Other				
Hardbone	0.00%	$(75.52)	$0.00	$0.00
Over 30 months	0.00%	$(36.30)	$0.00	$0.00
Dark cutter	0.00%	$(74.96)	$0.00	$0.00
Dairy	0.00%	$(6.43)	$0.00	$0.00
Carcass weight				
< 249 kg	10.08%	$(53.18)	$(5.36)	$(5.36)
249 - 272 kg	23.12%	$(6.18)	$(1.43)	$(1.43)
272 - 408 kg	66.80%			
408 - 454 kg	0.00%	$(0.46)	$0.00	$0.00
454 - 476 kg	0.00%	$(33.07)	$0.00	$0.00
> 476 kg	0.00%	$(51.39)	$0.00	$0.00
Tenderness				
≤ 3.0 kg WBS	20.32%	$12.00		$2.44
3.0 - 4.9 kg WBS	79.41%			
> 4.9 kg WBS	0.27%	$(12.00)		$(0.03)
Avg. carcass grid value, $/100 kg			$459.78	$462.25

[1] QG and YG prices are based on 3-year averages (2014-2016). Adjustments, discounts, and premiums are expressed $ per 100 kg.

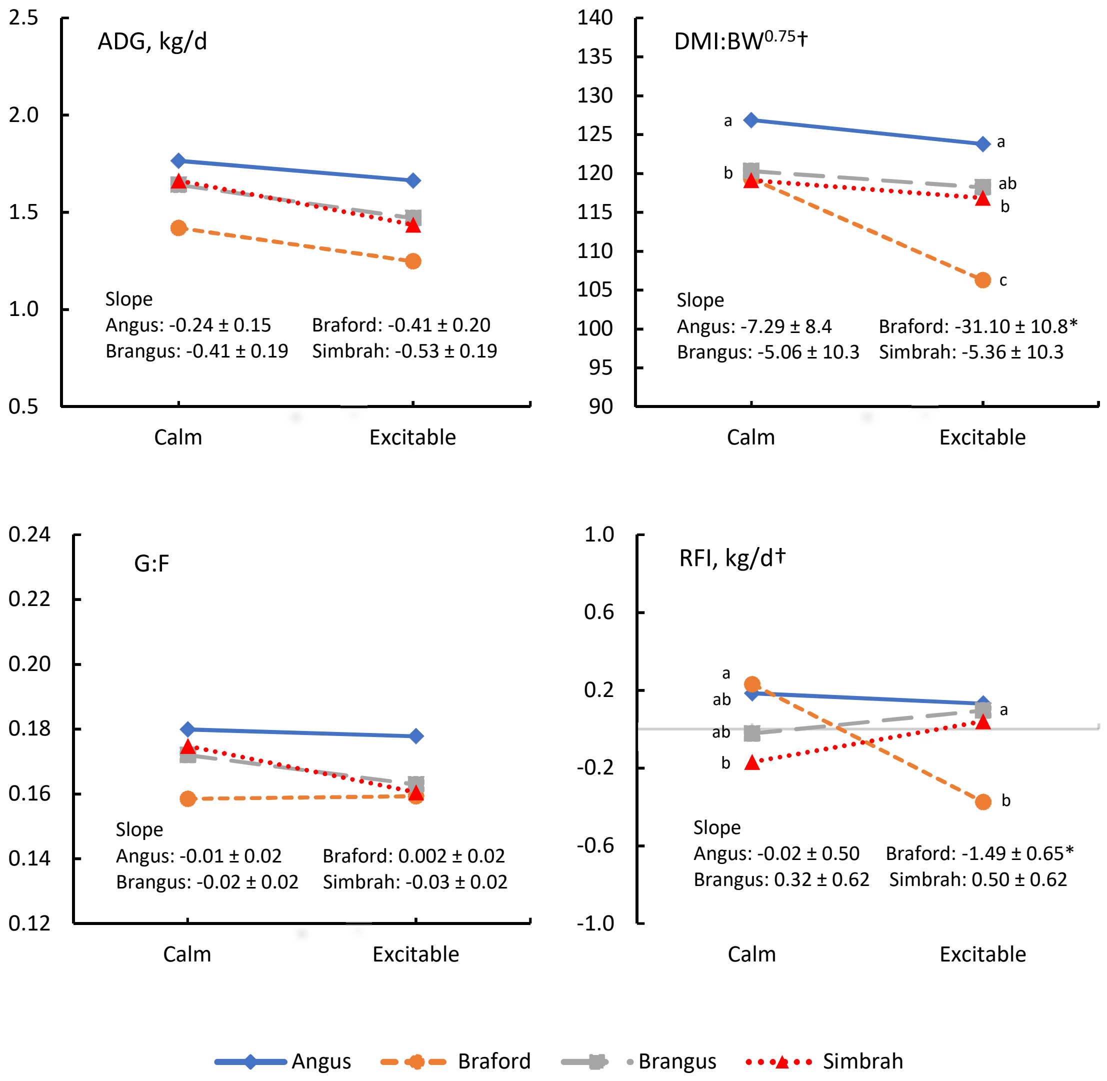

Figure A-1. Effects of temperament and breed on ADG, DMI:BW$^{0.75}$, G:F, and RFI. A temperament × breed interaction was observed for DMI:BW$^{0.75}$ and RFI (†; $P < 0.05$). Slope = initial REV covariate ± SE for each breed. Temperament means were established at ± 1 SD from the mean initial REV, and means with different superscripts differ at $P < 0.05$. Slopes of Braford, Brangus, and Simbrah heifers were compared to the slope of Angus, which was tested against the slope of the x-axis (zero). An asterisk indicates slopes different from Angus at $P < 0.05$.

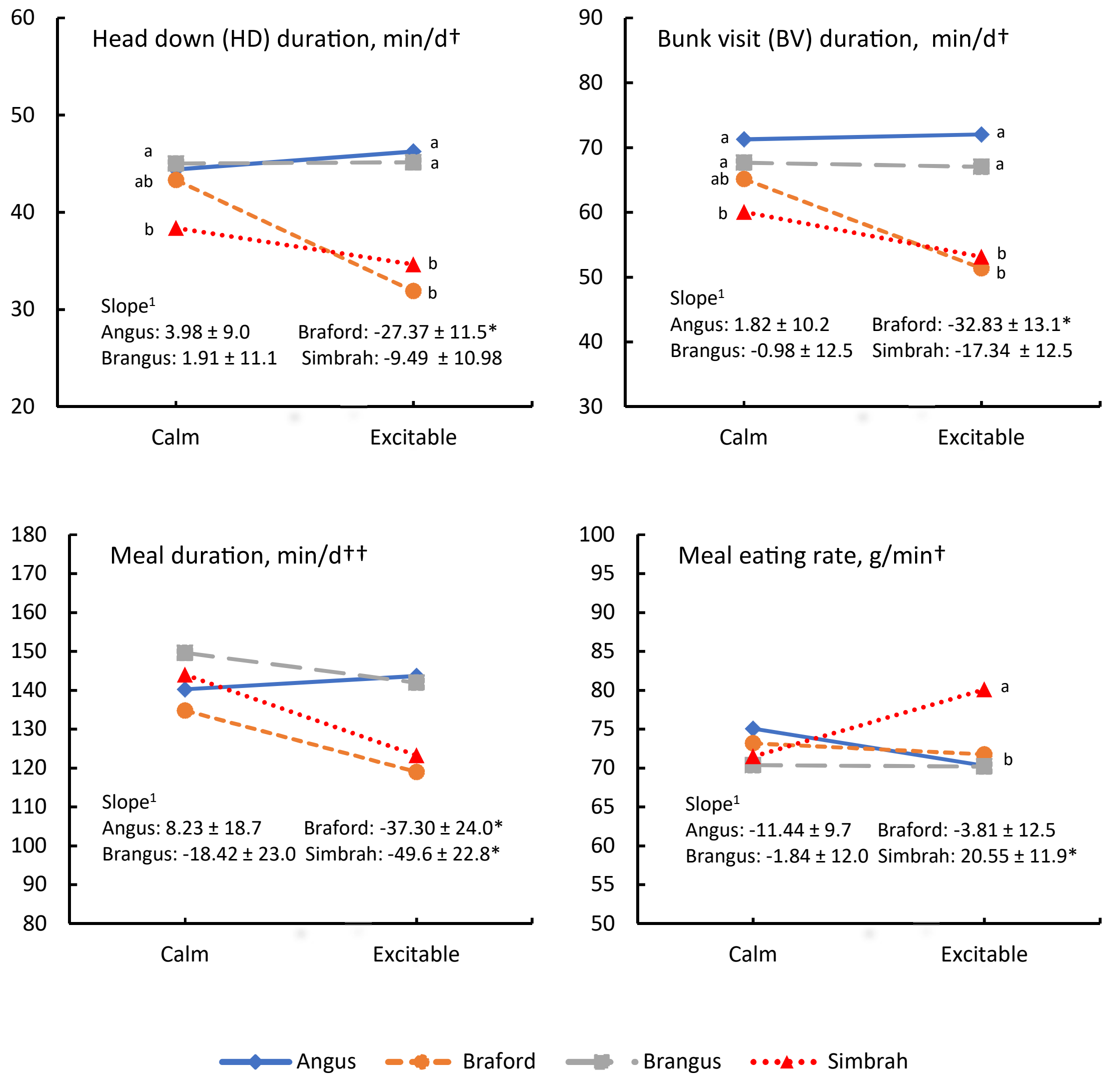

Figure A-2. Effects of temperament and breed on HD, BV duration, meal duration, and meal eating rate. A temperament × breed interaction was observed for HD duration, BV duration, meal eating rate (†; $P < 0.05$) and a tendency (††; $P < 0.10$) was observed for meal duration. Slope = initial REV covariate ± SE for each breed. Temperament means were established at ± 1 SD from the mean initial REV, and means with different superscripts differ at $P < 0.05$. Slopes of Braford, Brangus, and Simbrah heifers were compared to the slope of Angus, which was tested against the slope of the x-axis (zero). An asterisk indicates slopes different from Angus at $P < 0.05$.