The Effects of Days on Feed and Ractopamine HCL Administration on Growth and Carcass Traits of Yearling Heifers

by

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A thesis submitted to the Graduate Faculty of Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
August 6, 2011

Keywords: ractopamine, beef heifers, days on feed

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Abstract

Heifers comprise 30% of the total beef animals slaughtered in the United States yearly. However, heifers are less efficient and have lighter HCW than steers which affects the profitability of heifers. Beta adrenergic agonists increase production efficiency in steers but little is known about the effects of administering them to heifers. By increasing days on feed producers can increase marbling scores but decrease yield grades and increase inputs. Thus, the goals of this study were to examine the effect of RAC and days on feed on growth and carcass traits in growing heifers, to determine if either could reduce production costs. This study examined crossbred commercial yearling heifers (n=71 for carcass evaluation and n=67 for growth analyses, age = 397 ± 34 d, initial BW = 433 ± 34.9 kg) that were placed on ad libitum feed (DM = 89%, CP = 13.5%) for either 79 (n=15), 100 (n=15), 121 (n=16), 142 (n=16) or 163 (n=5) days for growth analyses or 79 (n=16), 100 (n=16), 121 (n=16), 142 (n=16) or 163 (n=7) days for carcass analyses. Days on feed (DOF) group assignments were stratified across initial weight and height. Individual birth dates and breed composition were known. A Calan System® (American Calan, Northwood, NH) was utilized to record daily feed intake. Body weights were recorded weekly. Thirty five days prior to harvest, one half of each DOF group were placed on Ractopamine-HCL (RAC) at a rate of 300 mg/hd/d (treatment phase).

Performance traits analyzed were overall gain, ADG, DMI, and DM feed efficiency (DMFE). Carcass traits included hot carcass weight (HCW), *longissimus dorsi* muscle area (LMA), adjusted 12th rib fat thickness (BF), kidney pelvic and heart fat % (KPH), marbling score (MS), and USDA Yield Grade (YG). During the treatment phase, performance traits were

recorded as treatment (TRT) gain, TRT ADG, TRT DMI, and TRT DMFE. Data were analyzed using general linear procedures of SAS and significance levels accepted at $P<0.05$. Independent variables included DOF, treatment, and breed composition. Covariates were initial weight or age at slaughter for growth analyses. Covariates for carcass characteristics included HCW, age at slaughter, and BF.

DOF affected post weaning growth and carcass characteristics more than feeding a beta-agonist for 35 days. Adjusting data to a common initial weight, DOF increased TRT gain and TRT DMI. Adjusting to a common age, DOF increased gain and ADG. Addition of RAC to the diet affected improved DMFE by 25% over control heifers during the treatment phase of the experiment (7.38 vs 9.82; $P<0.05$). RAC did not affect carcass characteristics, tenderness, or sensory evaluation. These data are consistent with published results of the effects of RAC on feedlot heifers. Breed was not a source of variation during the treatment phase for any performance trait. Breed had an effect on LMA, KPH, USDA YG, and MS.

Data from this study suggest heifers on feed longer than 100 or 121 d will not provide more salable product. Heifers fed longer than 121 days have improved MS, but significantly larger USDA yield grades. From this dataset, feeding yearling heifers 100 days is optimum. The administration of RAC to heifers at 300 mg/ hd /d be beneficial to producers by increasing the efficiency level of feedlot heifers and thus reducing feed costs.

Acknowledgements

The author would like to thank Dr. Lisa A. Kriese-Anderson. I am indebted to you for giving me the opportunity to work and continue my education at Auburn University. Dr. Kriese-Anderson's leadership, time, and guidance during my masters program have been essential to my success. If not for her giving me the chance to try, I would not be where I am today. I realize I have not been the golden student she was hoping for; however, she has greatly impacted my life, my hopes and dreams by giving me this amazing opportunity to further my academic development and personal growth.

The author would also like to thank Mr. Joshua Elmore for his patience, ability to listen, and help in solving situations; as well as, giving me opportunities to broaden my views and thoughts not only about the cattle industry in the southeast but in life. His friendship and guidance has not only been needed over years but very appreciated.

The author would like to convey appreciation to the numerous people in the animal science building that have all had a hand in the completion of my degree. The sense of family and acceptance of me has made life long impacts on my life. Thank you, Department of Animal Sciences, for your welcoming and your support and guidance. The faculty of the department has been there from the beginning helping and aiding in my success. A special thanks to Dr. Terry Brandebourg and Dr. Christy Bratcher for serving as members of my graduate committee.

The author would like to thank graduate students Cobie Rutherford, Kyle Grubbs, Suzanne Free, Ashley Bruce, Leanne Dillard, and Erin Hunter for their contribution to the project as well as the rest of the people that served on the sensory evaluation panel. I would like

to give a big thank you to the Lambert-Powell Meats Laboratory Staff. I would like to thank all other graduate and undergraduate students who, through friendship and cooperation, have made my master's program at Auburn University enjoyable.

Most importantly the author would like to thank her parents, Nancy and Larry Hittle, sister, Carie, and my husband, Gabe McNair, for their support, understanding the importance of this choice, and allowing me the opportunity to reach for my goals and dreams. Your pride, love, and belief in my abilities to succeed gave me the strength to not give up and reach for my dreams. Sis, if you had not set the bar so high, then I would not struggle so hard to reach it. Gabe, thank you for your sacrifices to allow me to reach this dream!

Thank you so much for your support!

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INTRODUCTION

Heifers comprise one-third of the yearly fed cattle production in the United States (Waggoner et al., 1990). Previous research has shown heifers have lower average daily gains (ADG) (Zinn et al., 1970b; Walker et al., 2006), are less efficient (Marlowe et al., 1958; Ray et al., 1969; Choat et al., 2003;) and have lighter hot carcass weights (HCW) (Choat et al., 2006; Zinn et al., 1970b) than steers. These factors contribute to feeder heifers having less value than their feeder steer counterparts. Meat quality is however similar between steers and heifers. Specifically, USDA quality grades (QG) were similar between fed steers and heifers (Choat et al., 2006; McKenna et al., 2002; Jones et al., 1990).

The rate of growth of the animal is important; however so are the variables which affect growth. Providing feed to cattle is the single largest expense in most commercial beef production enterprises. Feed costs represent approximately 66 and 77% of the total cost of gain in calf and yearling beef cattle finishing systems, respectively (Anderson et al., 2005). Hence, any improvement in gain or feed efficiency has the potential for increased profits due to reduction in input costs (Williams et al., 2006; Arthur et al., 2001).

In the past, genetic improvement of beef cattle has been aimed mainly at traits such as fertility and live weight. More recently, genetic improvement includes carcass and meat quality traits with little emphasis placed on reducing input costs. Feed efficiency can be described as the efficient use of energy consumed from the diet fed for maintenance and growth (Fox et al., 2002). Historically across the industry, the most common measure of efficiency has been feed conversion ratio (Allan, 2005). One means to reduce feed inputs is through improvement in feed

efficiency (Meyer et al., 2008). Variation in feed intake can be associated with variation in

maintenance requirements. The amount of energy needed to digest feed increases as feed intake

increases (Herd et al., 2000). Hicks et al., (1990) speculated that by controlling dry matter intake

(DMI), feed efficiency could be improved. The researchers examined three different regimens to

improve efficiency (Hicks et al., 1990). The three regimens included: 1) reducing the amount of

feed by a specific percentage, 2) regulating how much feed was fed at the beginning of a study

and then feeding ad libitum during the finishing period, and 3) limited feed during the entire

project to obtain a specific daily gain (Hicks et al., 1990; Zinn et al., 1986). Rossi et al., (2001)

used the afore mentioned approaches and found that feeding ad libitum during the treatment

period resulted in improved ADG and feed efficiency compared to ad libitum feeding.

Increased efficiency in the feedlot segment of the beef industry could lead to decreased

feedstuffs consumed and manure produced, along with lower feed costs. Use of beta adrenergic

agonists in the feedlot should also increase efficiency. Beta adrenergic agonists are

repartitioning compounds that redirect nutrient supplies away from fat deposition and toward

muscle growth (Walker et al., 2008). Beta adrenergic agonists are used to increase growth,

improve feed efficiency, and enhance lean tissue growth (Quinn et al., 2008). One such beta

adrenergic agonist, Ractopamine HCL (RAC), has been reported to improve ADG, feed

efficiency, carcass yield grade, HCW in feedlot heifers and steers, and also longissimus dorsi

muscle area (LM) and dressing percentage in feedlot steers (Crawford et al., 2006; Gruber et al.,

2007; Laudert et al., 2004; Schroeder et al. 2003a; Van Koevering et al., 1995; Walker et al.,

2006).

Consumers rank tenderness first in factors affecting the overall beef eating experience

(Choat et al., 2006; Savell et al., 1987; Smith et al., 1987). However, beef products are not

always found to be acceptable to the consumer (Choat et al., 2006). Various strategies to decrease the amount of unacceptable beef products have been suggested (Choat et al., 2006). Understanding factors affecting tenderness may help researchers overcome tenderness concerns. Some studies have shown tenderness is not influenced by sex of animal (Gracia et al., 1970; Zinn et al., 1970a; Prost et al., 1975). However, the factors of genetics (Wulf et al., 1996; O'Conner et al., 1997), age (Shackelford et al., 1995) and the use of growth implants (Platter et al., 2003) do influence tenderness of beef.

Increasing days fed to improve carcass marbling may reduce average daily gain and feed efficiency (Rossi et al., 2001; Van Koevering et al., 1995). Tenderness will only increase for a period of time on feed. Epley et al., (1968) reported 139 d, while 150 to 180d was reported by Zinn et al., (1970b). Van Koevering et al., (1995) reported that tenderness will then decrease due to maturity of the animal.

With the supplementation of beta adrenergic agonists into the diet causing an increase in lean muscle, the animal will reach slaughter weight faster and reduce the number of days on feed. This in turn will reduce feed input without affecting marbling or tenderness. Producers are able to decrease costs with more efficient animals while consumers are able to purchase beef products of the same quality.

REVIEW OF LITERATURE

BREED EFFECTS

Many studies have been conducted to evaluate beef breeds and crosses for various

economically important traits. Knowing, understanding, and utilizing breed differences can

increase producer profits. Numerous evaluations of breed differences have indicated no single

breed or breed type excels in all traits important to beef production (Wheeler et al., 2005; Rios-

Utrera et al., 2006).

Breed differences affect many important beef characteristics and the USDA Meat Animal

Research Center (MARC) has extensively studied biological differences in breeds for the past 40

years (Wheeler et al., 2005). Performance and carcass traits have been evaluated in seven

different cycles with Koch et al., (1976, 1979, 1982) and Wheeler et al., (1996, 2001, 2004,

2005).   Wheeler et al., (2005) most recently published the results of Cycle VII. The germplasm

evaluation project Cycle VII evaluated the 7 most common beef breeds in the United States

based on registration volume. Breeds included Angus, Red Angus, Charolais, Gelbvieh,

Hereford, Limousin, and Simmental. All carcasses were aged for 14 d.

Traits were adjusted to a constant age of 445 d at harvest. HCW of Angus and

Simmental sired calves were significantly heavier than HCW from Limousin and Gelbvieh sired

calves. With age as a covariate, the slowest growing calves were sired by Hereford, Limousin,

and Gelbvieh. The earliest maturing calves were produced by Angus, Red Angus, and Hereford

sires. These calves required fewer days of feed (DOF) to reach an acceptable fat thickness.

When data was adjusted to a common 12th rib fat thickness (BF), Continental sired calves had the

heaviest HCW compared to British sired calves. These results are different than those previously reported in past cycles of the germplasm evaluation project (Wheeler et al., 2005). In previous germplasm evaluation cycles examining these same breeds, Continental type cattle outperformed English type cattle. Utilizing expected progeny difference (EPD) values and selection pressure; breeds have reduced differences in growth rate and subsequently HCW.

British breeds have increased average HCW by 27% over the last 30 years. Charolais, Limousin, Gelbvieh, and Simmental breeds have also increased average HCW over the last 30 years (Wheeler et al., 2005). In the germplasm evaluation of Cycle VII, Continental breeds have less adjusted BF at a constant age or weight than British breeds. Generally, Continental breeds had the advantage over British breeds by demonstrating larger LMA.

Wheeler et al., (2005) also reported that when evaluating kidney, pelvic, and heart fat percentages, differences were found between breeds at a common age. Simmental and Angus sired calves had more KPH than all other breeds of sire except Red Angus and Gelbvieh. Hereford sired steers had less KPH than all other breeds except Charolais and Limousin. In addition, the Hereford breed had similar results when evaluated to a common weight. At a common fat thickness, Hereford sired steers had the lowest overall percentage of KPH.

Marbling scores in the Wheeler et al., (2005) study were higher for Red Angus and Angus sired calves evaluated both at a common age or fat thickness than other breeds. The data produced by carcasses from the Hereford breed tended to report lower MS than all other breeds. The data from the Hereford carcasses at a common fat thickness was not different than any other breed for USDA YG. Even though changes have been made genetically to all breeds during the past 40 years for growth rate and size, only small differences have been made in carcass characteristics.

Wheeler et al., (2005) also reported only slight differences were found in palatability traits across sire breeds. British breeds had smaller WBSF values than Continental breeds at a common BF. At a common marbling score, Angus and Red Angus had smaller WBSF values than all other breeds. Trained sensory panelists agreed with the WBSF results. Other extensive research has compared all of these breeds and all have reported similar results with generally non-significant differences between British and Continental breeds for LMA tenderness (Koch et al., 1976, 1979, 1982; Wheeler et al., 1996, 2001, 2004, 2005).

Knapp et al., (1989) compared differences between two breed types (English and Continental) and gender. They hypothesized that Continental steers would have the largest LMA followed by Continental heifers while English breeds of cattle would have the smallest LMA. Results from this study reported that Continental steers had the largest LMA area (P < 0.05). Continental heifers had less LMA than Continental steers but more LMA than English breeds of cattle. LMA from English steer and heifer carcasses were not different. English breed types produced carcasses with greater amounts of BF compared to carcasses produced by Continental breed types (Knapp et al., 1989). The influence over the last two decades of Continental European cattle breeds in cattle crossbreeding programs may have changed marbling and fat disposition in cattle (Lorenzen et al., 1993). From 1974 to 1993 cattle had heavier carcasses with a decline in amount of BF and USDA YG (Lorenzen et al., 1993).

Anderson et al., (2006) evaluated breed of dam effects on carcass traits across multiple purebred and crossbred steers and heifers. Five hundred and thirty-four steers and heifers were evaluated from three dam breeds (Hereford, Tarentaise, Hereford-Tarentaise cross) and six sire breeds (Hereford, Tarentaise, Angus, Piedmontese, Salers, and Charolais). Calves were backgrounded for 45 d averaging180 d of age and then placed in a feedlot. Animals were

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harvested at approximately 220 d of age and carcass data collected. Differences for all carcass

traits were found between steer and heifer carcasses except for BF and LMA. Fixed effects of

age of dam and sex of calf were not different for LMA (Anderson et al., 2006). However, fixed

effects of year of record, treatment (any differences in nutrition or management practices over

the 4 year study) nested within year, calf sire (due to no common sire across 4 years) nested

within year, and the sex by treatment interaction was significant for LM (Anderson et al., 2006).

Researchers have studied the effects of anabolic growth implants in cattle and have

analyzed the effects that occur in different breeds. O'Connor et al., (1997) conducted a study to

identify genetic strategies for improving beef tenderness in *Bos indicus* composite breeds of

cattle. The study utilized 575 steers and heifers ranging in age from 7 to 11 mo. Cattle originated

from different parts of the United States and production environments. *Bos indicus* influenced

cattle were obtained from Florida and Texas ranches. *Bos taurus* cattle originated from

Colorado, Idaho, Nebraska, and Wyoming ranches. Cattle were transported to Colorado where

they were fed a finishing diet. Steers were implanted with Synovex-S[®]. Heifers were implanted

with Finaplix-H[®] and fed melengestrol acetate (MGA). All cattle were re-implanted

approximately 120 d later with Finaplix-H[®]. All cattle were fed until 12th rib fat thickness

averaged 9 to 10 mm as determined by real-time ultrasound. When breeds were compared at a

common fat thickness, marbling scores were greatest for Red Brangus, followed by Braford, and

then Simbrah. These differences among the 3/8 *Bos indicus* composite breeds likely reflected

differences in genetic marbling ability among the three contributing *Bos taurus* breeds (Red

Angus, Hereford, and Simmental).

King et al., (2006) conducted a study to characterize differences in carcass traits between

breed groups of predominantly Angus, predominately *Bos indicus*, and half blood Angus X *Bos*

indicus cross cattle. There were differences among breed types for LMA. Families within each

breed type were extremely variable in LMA. In some cases, differences in LMA observed

between families within the same breed type were greater than differences between breed types

(King et al., 2006). Breed type was also different for USDA YG. This contradicts Knapp et al.,

(1989). In the Knapp et al., (1989) study, steer carcasses (n = 375) were comprised of English,

Continental, Holstein, less than 50% *Bos* indicus, or greater than or equal to 50% *Bos* indicus

breeds. No differences were reported for USDA YG across breed type for steer carcasses (Knapp

et al., (1989).

       Breed type was also a significant source of variation for USDA QG in the King et al.,

(2006) study. USDA QG was significantly affected by family breed type. MS was greater in

carcasses from heifers than steers in the King et al., (2006) study.

       Boles et al., (2009) evaluated effects of growth implants on carcass characteristics.

Continental sired (18 = heifers, 23 = steers; 20 = implanted, 21 = non implanted) and British

sired (18 = heifers, 16 = steers; 17 = implanted, 17 = non implant) calves were utilized in this

study. No implants were given before the animals entered the feedlot. This study reported that

anabolic growth implants, reduced MS by half a score compared with non-implanted control

cattle. British and Continental breed types were also evaluated in this study and steers and

heifers did not differ for MS (Boles et al., 2009).

       Knapp et al., (1989) included sensory evaluation in their study while investigating

different beef breed types. Means for taste panel attributes across cattle types were within

acceptable ranges (Knapp et al., 1989). However, frequency distributions of taste panel

tenderness scores showed Continental steers and heifers appeared to be more variable in

palatability than English cattle breeds (Knapp et al., 1989). Continental steers and heifers had a

higher percentage of unacceptable scores for overall tenderness (Knapp et al., 1989). Continental heifers were different from all others for the sensory evaluation of flavor (Knapp et al., 1989).

Other studies have indicated differences in tenderness among breed-groups (Shackelford et al., 1994). Marbling and tenderness are influenced by the genotype of the animal (Wulf et al., 1996). Genetic differences in tenderness and marbling have been found both among and within breeds of cattle (Koch et al., 1979; Crouse et al., 1989; Shackelford et al., 1994; Wulf et al., 1996). However, meat from *Bos indicus* cattle has been reported to be less tender than from *Bos taurus* cattle (Koch et al., 1982; Crouse et al., 1989).

SEX EFFECT OF CATTLE

Variation in performance and carcass characteristics between steer and heifer carcasses that goes beyond sex-influenced differences has been reported. Scientists have studied numerous factors to fully understand differences in performance and carcasses traits found between the sex classes. Normal physiological differences explain some growth and carcass variation seen; however, science has not been able to determine all differences found between steers and heifers. Being able to understand these differences will allow the beef industry to make optimum decisions. Multiple research studies have evaluated differences of performance and carcass characteristics by examining varying days on feed, breed differences, and growth promotants to find answers for differences observed between steers and heifers.

Performance characteristics are also known as growth traits. Performance characteristic differences between steers and heifers have been reported by many with conflicting results (Choat et al., 2003; King et al., 2006; Marlowe et al., 1958; Ray et al., 1969; Zinn et al., 1970a). Ray et al., (1969) listed two factors affecting growth rate of animals: 1) genetic potential of the

animal, and 2) the environment in which the animals were placed. In this four trial study that compared steer and heifer performance traits, seasonal differences had the biggest impact on variation in performance data.

In 1958, Marlowe et al., evaluated age, sex class, season of birth, and age of dam using 6,173 performance records of steers, heifers, and bulls. They found sex of calf influenced growth rate. Bull calves grew approximately 5% faster than steer calves and steer calves grew approximately 8% faster than heifer calves. Heifers were generally 11.4 to 30.9 kg lighter than steers when weighed at approximately 210 days of age.

ADG measures post-weaning growth in livestock. ADG is moderately to highly heritable in beef cattle with estimates ranging from 0.13 to 0.47 (Archer et al., 1997). Ray et al., (1969) completed a series of experiments to study the influences of season, sex class, and hormonal growth stimulants on feedlot performance. Steers were more efficient for gain than heifers and exhibited greater daily gains than heifers (Ray et al., 1969). Greater ADG was also found in 97 steers compared with 97 heifers (Choat et al., 2003). Initially, heifers were lighter at initiation of the project, coupled with lower ADG, resulting in lighter final weights compared to steers (Choat et al., 2003).

Other studies have disputed greater ADG in steers compared to heifers. King et al., (2006) found heifers (n = 257) had greater ADG than steers (n = 271). There were no reported differences between steers and heifers for weight on feed or ADG in a study conducted by Zinn et al., (1970a). The Zinn et al., (1970a) study evaluated 100 steers and 100 heifers from a West Texas ranch. Steers and heifers were evaluated for performance and carcass characteristics across multiple DOF up to 270 d. Differences were observed across DOF groups for steer and heifer weights off feed, except in DOF groups 60 and 90 and in DOF groups 240 and 270 (Zinn

et al., 1970a). ADG increased for animals fed 120 d or less (Zinn et al., (1970a). Increasing DOF to improve carcass marbling reduced ADG and feed efficiency as cattle neared finished body weight (Rossi et al., 2001).

Carcass characteristics of HCW, BF, LM, YG, QG, MS, maturity, and tenderness have economic impacts on beef carcasses. Scientists continue to evaluate these traits to decrease variability in the beef product and understand underlying biological processes. Data from several studies found carcass traits were significantly affected by sex of the animal (Zinn et al., 1970a; Marchello et al., 1970; Garcia-de-Siles et al., 1977; Murphey et al., 1985; Knapp et al., 1989; Jones et al., 1990; Lorenzen et al., 1993; Herring et al., 1994; Shackelford et al., 1995; Field et al., 1996; McKenna et al., 2002; Anderson et al., 2006; Choat et al., 2006; King et al., 2006; Boles et al., 2009).

In several studies, HCW of heifers was lighter than HCW of steers (Zinn et al., 1970a; Marchello et al., 1970; Jones et al., 1990; and McKenna et al., 2002). Zinn et al., (1970a) evaluated 100 steers and 100 heifers in West Texas. They found it would take an additional 45 days on feed for heifer carcasses to reach the same HCW as steer counterparts. More recently, results from the National Beef Quality Audit (NBQA) 2000, reported a 30 kg difference (P < 0.05) between HCW in steer and heifer carcasses (McKenna et al., 2002). The NBQA (2000) utilized 43,415 carcasses (67.9% steer; 31.4% heifer and 0.9% bullock carcasses) harvested at commercial U.S. packing plants. This data agreed with the finding of Jones et al., (1990) who also utilized carcasses in commercial harvesting facilities.

However, other studies found no differences in HCW between steer and heifer carcasses (Murphey et al., 1983; Choat et al., 2006). In the Murphey et al., (1985) study, data was collected in 7 packing plants across 3 states. They evaluated 129 steer and 80 heifer carcasses.

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Feeding steers and heifers to a common endpoint of 10 mm backfat also showed no differences in HCW between sex classes (Choat et al., 2006). The Choat study utilized 60 steers and 60 heifers fed a high concentrate diet.

BF is one of the major quantitative traits that affect carcass cutability in beef cattle. BF measurement is taken perpendicular to the outside surface of the carcass at a point ¾ of the distance of the length of the LMA from its chine bone side. An important factor in determining USDA YG comes from the adjusted amount of BF over the LMA of a carcass (Murphey et al., 1983). McKenna et al., (2002) reported heifers exhibited more BF than steers in the NBQA audit. King et al., (2006) also reported less BF on steer carcasses compared to heifer carcasses.

Choat et al., (2006) conducted 2 studies. BF was similar between steer and heifer carcasses in trial 1. However, heifer carcasses had greater BF compared with steer carcasses in trial 2. Knapp et al., (1989) also looked at different breed types and gender differences. Knapp et al., (1989) expected to find breed and gender differences for BF; however, no differences were found between heifers and steers.

Field et al., (1996) compared growth characteristics of virgin, spayed, and first calf heifers. In this study, there were no differences between groups of heifers for BF (Field et al., 1996). Shackelford et al., (1995) found similar findings using yearling heifers and first calf heifers. There were no differences in BF suggesting parity does not affect BF.

Saleable carcass product is a major factor of concern for packers and retailers today. The proportion of fat, bone, and muscle in a carcass affects beef carcass cutability and the amount of trimmable carcass fat plays a major role in the economic value of the carcass (Herring et al., 1994). Numerous studies have evaluated (KPH) in steers and heifers with mixed results. Anderson et al., (2006) and King et al., (2006) found heifer carcasses had more KPH than steer

carcasses. However, no significant differences in KPH percentage were reported between steer and heifer carcasses in other studies (Boles et al., 2009; Choat at al., 2006; Jones et al., 1990; McKenna et al., 2002; Murphey et al., 1985; and Shackelford et al., 1995).

Heifer studies were conducted to evaluate carcass characteristics across parity by evaluating virgin, spayed, and first calf heifers. Field et al., (1996) observed KPH percentage to be similar between virgin and first calf heifers. Spayed heifers produced carcasses with less KPH than virgin heifer carcasses. This data suggests removal of ovaries allows increased organ fat accumulation and potentially increases in USDA YG. These results agree with Shackelford et al., (1995). Shackelford et al., (1995) conducted a study to determine the effect of carcass maturity and the relationship of chronological age between yearling heifers and first calf heifers. Shackelford et al., (1995) also reported no differences in KPH between yearling heifers and first calf heifers.

Most of the higher priced beef cuts originate from the LMA. LMA is measured using a grid made up of 0.1 sq. in. units placed at the 12th and 13th rib juncture of the carcass. LMA normally ranges from 9 to 17 sq. in (BIF, 2002). Published literature reports are mixed in regard to LMA size differences between carcasses of steers and heifers.

Marchello et al., (1970) conducted two trials. Trial one used 32 steers and heifers from mixed breeds of cattle originating from Texas. They examined the influence of season, sex, and hormonal growth implantation on feedlot performance and carcass characteristics of cattle fed for 147 d. Neither trial detected differences in LMA between steer and heifer carcasses. Choat et al., (2006) also found no differences in LMA between steer and heifer carcasses. Cattle in the Choat et al., (2006) study were fed to an average of 10 mm fat over the 12th and 13th rib juncture.

King et al., (2006) and Anderson et al., (2006) also reported no differences in LMA for cattle of different sexes.

In the NBQA differences in mean LMA between steers and heifers were found (McKenna et al., 2002). Carcasses were evaluated from 30 different harvesting facilities from May to November 2000 and each collection period represented approximately 10% of each facilities production for that shift. Carcasses were examined for sex class, breed type, USDA YG, USDA QG, and defects. McKenna et al., (2002) reported steer carcasses possessed 0.5 cm^2 more LMA than heifer carcasses. This study also found LMA in general to decrease with increasing quality grade. Knapp et al., (1989) also found differences in LMA between steer and heifer carcasses.

Cutability of a carcass is expressed by USDA yield grade (YG), which is an estimate of boneless closely trimmed retail cuts. HCW, BF, LMA, and KPH are components used in the USDA YG prediction equation (Murphey et al., 1983). Studies have been conducted to determine if differences exist in USDA YG in beef cattle for differences caused by sex-class and breed differences (Murphey et al., 1983; Jones et al., 1990; McKenna et al., 2002; Choat et al., 2006; King et al., 2006; Knapp et al., 1989; Anderson et al., 2006).

Murphey et al., (1983) evaluated data relative to how sex class and degree of fatness affected the disposition of external fat. In this study, they analyzed data from 129 steers and 80 heifers collected in 7 packing plants in three states, but did not evaluate all of the carcass traits between sex classes. This study reported heifer carcasses contained greater amounts of BF, KPH, and lighter HCW than steer carcasses. Thus, heifer carcasses had lower cutability than steers. Even with heifers and steers depositing fat in like patterns variation was found between the sex classes of the carcasses. The physiological differences of fat distribution and amount

have to be taken into account. Knapp et al., (1989) evaluated 375 steer and heifer carcasses.

Results from that study agreewith the results of Murphey et al., (1983) both observed differences

in steer and heifer carcasses for YG. Knapp et al., (1989) study did find differences in USDA

YG between carcasses from steers and heifers.

The 2000 NBQA (McKenna et al., 2002) also found differences in YG between steer and

heifer carcasses. The study by Choat et al., (2006) agreed. Steer carcasses had lower YG than

heifer carcasses. Spayed heifer carcasses were also evaluated by Choat et al., (2006). YG from

spayed heifer carcasses were similar to YG values from steer carcasses, but lower than intact

heifers.

Anderson et al., (2006) did not report similar findings as King et al., (2006) but did agree

with Choat et al., (2006) and McKenna et al., (2002) studies. Carcasses from heifers had lower

USDA YG than carcasses from steers. This trial evaluated 534 steer and heifer carcasses with

known breed of dam and sire for each animal. Additionally fixed effects of age of dam and age

at harvest were sources of variation for YG in this study.

Jones et al., (1990) also evaluated sex-class differences in USDA QG and YG scores.

The 129 steers and 80 heifers in this study had large amounts of variation in conformation. All

animal carcasses were collected from 7 harvesting facilities in three states. Carcasses were

separated into USDA YG categories and analyzed by USDA YG and sex-class. Across all five

USDA YG steer carcasses had higher USDA YG than heifer carcasses (Jones et al., 1990). This

result was confirmed by NBQA results by McKenna et al., (2002).

King et al., (2006) reported contradicting results from the previous studies as that study

reported steer carcasses to have higher USDA YG than heifer carcasses. The USDA YG

LSmeans for 257 heifer carcasses was 3.21 which different from the USDA YG mean of 2.86

from 271 steer carcasses (King et al., 2006).

Graders evaluate the amount and distribution of intramuscular fat within the lean ribeye

at the 12th and 13th rib to determine a MS. In carcasses younger than 42 months of age, MS is

split into categories of standard, select, choice and prime. Each category is sub-divided into 100

subunits to express MS more precisely. Several studies found MS in heifer carcasses higher than

MS in steer carcasses (Shackelford et al., 1995; Field et al., 1996; O'Connor et al., 1997; Choat

et al., 2006; King et al., 2006). Results from 2000 NBQA (McKenna et al., 2002) substantiate

these experimental results analyzing 9,396 carcasses in 30 commercial United States harvest

facilities. Choat et al., (2006) in two studies found intact and spayed heifers produced carcasses

with greater MS than steer carcasses. MS also appears to be influenced by breed (Boles et al.,

2009; Field et al., 1996; O'Connor et al., 1997; King et al., 2006).

Garcia-de-Siles et al., (1977) compared differences in quality of steer and heifer carcasses

from similar breeds and management styles. Specifically this study evaluated carcasses by

common MS. This was an eight year study (1964-1972) that contained 437 steers and 412

heifers from two dam breeds and mated to three sire breeds. Age at harvest was a source of

variation of steer marbling scores. Steers exhibited a linear relationship with age and marbling

scores. Heifers did not show this same response. Heifers produced carcasses with increasing

MS and lower tenderness values as age increased.

A more recent study by Field et al., (1996) evaluated 53 Angus/Gelbvieh crossbred

heifers harvested after 100 d on a high concentrate diet. Average age at harvest (31, 33, or 35

months) and heifer status (virgin, spayed or heiferette) defined treatment groups. Each treatment

group consisted of 5 or 6 virgin heifers, 6 spayed heifers at 1 yr of age, or 6 heiferettes (calf

average age of weaning was 120 d). There was no differencefound in marbling score depending on maturity score.

Beef tenderness decreases with animal age (Prost et al., 1975). A (approximately 9-30 mo/age), B (approximately 30-42 mo/age), C (approximately 42-72 mo/age), D (approximately 72-96 mo/age), and E (approximately greater than 96 mo/age) maturity categories are part of the beef grading system due to the decrease in tenderness as chronological age increases (Field et al., 1997). Maturity categories are based to a large extent on the degree of bone calcification in the vertebral column. More specifically, the degree of the bone ossification in the sacral, lumbar, thoracic, and rib regions, and on color and texture of lean at the cut surface of the LM between the 12th and 13th ribs are the basis for carcass maturity scores (Field et al., 1997). Several factors, such as variability in calcium dependent protease activity of postmortem muscle as well as the increasing connective tissue strength, that increases in toughness as age increases is an affect of maturity (Field et al., 1997).

Shackelford et al., (1995) found a 10 fold greater variation in tenderness within a maturity category. Wide variations of carcass characteristics are found in all categories of maturity carcasses from cattle (Field et al., 1997; Wheeler et al., 1994). Not all findings have confirmed the influence of age on meat tenderness (Prost et al., 1975).

USDA QG is an overview category that is made up of several attributes of meat that affect the palatability. Marbling score within the LMA and category of maturity determine QG. When selling beef on a grid (price from quality not pounds of product), QG can economically impact the price received for the carcass.

USDA QG was evaluated by Zinn et al., (1970a) in carcasses serially slaughtered in 30 d increments from 30 to 270 DOF. Steers produced carcasses at 120, 180, and 210 DOF that were

higher for USDA QG than heifer carcasses at these DOF. Zinn et al., (1970a) found heifer

carcasses required 150 DOF to attain a grade of select but failed to reach choice grade even after

270 DOF.

McKenna et al., (2002) disagreed with the previous study results. The 2000 NBQA

found carcasses from heifers had higher QG than steer carcasses (McKenna et al., 2002).

Additionally, QG increased as carcass weights increased from less than 227 kg to 317 kg. As

carcass weights increased over 317 kg to greater than 454 kg only slight increases were observed

in QG. Increasing 12th rib fat thickness to 1.77 cm was correlated with an increase in USDA QG

(McKenna et al., 2002). King et al., (2006) findings were in agreement with the McKenna et al.,

(2002) study.

Evaluating steers and heifers (intact and spayed), in trial one, Choat et al., (2006)

reported sex-class differences in USDA QG. Spayed and intact heifer carcasses had higher

USDA QG than steer carcasses. However, no differences were reported in trial two between

steer and heifer carcasses for USDA QG.

Jones et al., (1990) looked at USDA QG across USDA YG categories. Eighty heifer and

129 steer carcasses within YG categories were evaluated with mixed results (Jones et al., 1990).

Steer carcasses exhibited higher QG than heifer carcasses within the USDA YG 1 category ($P <$

0.05). However, the opposite was observed within USDA YG 2 classification. Finally, no

differences were seen between carcasses of steers and heifers for QG when YG was classified as

3 or more.

Lack of consistent beef tenderness is a major problem facing the United States beef

industry. The 1990 NBQA revealed variation in beef tenderness was a primary concern of beef

retailers (Shackelford et al., 1995). Economic pressures have challenged United States livestock

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and meat industries to seek ways of producing meat products enabling consumers to receive maximum palatability benefits at a low cost (Morgan et al., 1991). The National Beef Tenderness survey and other studies have revealed tenderness as the single most important factor affecting taste or consumer perception of taste (Morgan et al., 1991; Shackelford et al., 1991).

Tenderness is the ease with which samples can be cut through with molars on first bite (Degeer et al., 2009). Several factors may influence meat tenderness. Factors include sex class, breed, maturity, environment such as climate conditions, disease level, management factors, and post-slaughter conditions such as length of time aging, enhancement, marinating, and mechanical tenderization. Other antemortem factors, such as genetics, growth implants, and age at slaughter also affect beef tenderness (Wulf et al., 1996; O'Connor et al., 1997; Platter et al., 2003 Shackelford et al., 1995; Choat et al., 2006). Additional beef attributes, such as meat color, flavor, aroma, tenderness, and method of cookery, play a collective role in consumer acceptance (Morgan et al., 1991). Numerous other variables have been related to tenderness, such as amount of intramuscular fat, sarcomere length, collagen content, size and type of muscle fibers, amount of connective tissue, and enzymatic activity involved in postmortem aging (Whipple et al., 1990).

Strategies such as postmortem aging and electrical stimulation have been shown to have positive effects on beef tenderness (Choat et al., 2006). Chilling rate of beef carcasses affects ultimate carcass pH (Wulf et al., 1996). However, if carcasses are chilled too quickly, tenderness is decreased (Wulf et al., 1996). Carcasses chilled too slowly will increase protein denaturation (Wulf et al., 1996). Postmortem aging either by dry aging or wet aging can increase tenderness values. Wulf et al., (1996) reported the percentage of tough beef will decrease as postmortem

aging days increase. Product enhancement such as mechanical tenderization, added enzymes, and marination (Vote et al., 2000) can all increase tenderness.

Despite many attempts, researchers have been unable to develop a mechanical method using uncooked muscle to successfully predict cooked meat tenderness (Timm et al., 2003). Meat science research has long used objective laboratory methods such as trained sensory panel and Warner-Bratzler shear force (WBSF) to analyze the palatability attributes of meat (Lorenzen et al., 2003). WBSF has been established as a standard for prediction of beef tenderness (Shanks et al, 2002). Numerous studies have evaluated various factors influencing WBSF values since K. F. Warner first suggested shear force was related to beef tenderness (Wheeler et al., 1996). Refinements in blade thickness, sharpness, the size, and shape of the hole in the shear blade have been made with the WBSF instrument. Most recently the WBSF instrument identified the combined effects of several cooking, coring, and shear factors have occurred to WBSF instrument to increase accuracy (Wheeler et al., 1994). The importance of standardizing core orientation and cooking conditions for WBSF values was demonstrated by Wheeler et al., (2001) and numerous variables that affect WBSF, including thawing of frozen steaks, sampling, aging, cooking, and coring have been characterized (Shanks et al., 2002; Wheeler et al., 1996). Standardized guidelines have been adopted by meat scientists and published (AMSA, 1995).

Animal health can also significantly affect tenderness of an animal. Morbidity has a negative impact on performance and carcass quality (Gardner et al., 1999). Morbidity caused lower ADG and increased percentage of carcasses producing less tender steaks (Waggoner et al., 2006). Waggoner et al., (2006) also documented unhealthy cattle had a reduced carcass value of $14.00 per 45.35 kg.

Tenderness decreases as final cooking temperature increases (Cover et al., 1962; Parrish et al., 1973; Cross et al., 1976; Wheeler et al., 1997 and Wheeler et al., 1999). Over-cooking has a negative impact on juiciness and overall acceptability. LMA tenderness decreases as end point temperature increases (Wheeler et al., 1999). A number of studies also show variation in initial steak temperature before cooking can impact the tenderness of the meat (Moody et al., 1978; Hostetler et al., 1982; Wheeler et al., 1997). A majority of research institutions are cooking meat to 71° C as is recommended by the American Meat Science Association guidelines (AMSA, 1995).

Miller et al., (2001) evaluated USDA select strip loin steaks and reported the transition from tender to tough beef occurred between shear force values of 4.3 to 4.9 kg . They further pinpointed the transition occurred at 4.6 kg. A WBSF value of 4.3 kg represents slightly tender with 4.9 kg equaling slightly tough in sampled steaks (Miller et al., 2001).

The effects of sex class on cooked beef steak tenderness are inconsistent.   Some studies have observed differences in tenderness between steers and heifers (Jeremiah et al., 1991 and Tatum et al., 2007). Multiple studies have specified beef from heifer carcasses tend to be tougher as measured by WBSF than steer contemporaries (Tatum et al., 2007; Choat et al., 2006; Maher et al., 2004; O'Connor et al., 1997; Wulf et al., 1996; Voisinet et al., 1997). However, several studies concluded sex class had no effect on cooked beef steak tenderness (Garcia et al., 1970; Prost et al., 1975; Tatum et al., 2007; Gruber et al., 2006).

Voisinet et al., (1997) reported heifers tend to produce a higher frequency of steaks that are more variable in tenderness values. This study reported, 33 of 111 heifer carcasses or 22.9% WBSF values high enough to be classified as tough and unacceptable for tenderness. Values from WBSF of 14 of 148 steer carcass steaks were classified in the tough category (9.5%) and

unacceptable. Maher et al., (2004) had similar findings. The Mahar et al., (2004) study utilized 81 steer and 81 heifer carcasses. However, Tatum et al., (2007) and Gruber et al., (2006) did not agree with the previous studies. Neither study found a difference in WBSF values of steaks aged for 28-d between steer and heifer carcasses.

The difference in tenderness between heifer and steer carcasses might be due to ovarian function in heifers. Intact heifers exhibited higher WBSF values than steers (Choat et al., 2006). However, no differences were observed between intact and spayed heifers. This finding might be attributed to the chronological age at which the ovaries were removed from the spayed heifers (250 days of age). Field et al., (1996) also reported no differences in tenderness between steaks from intact and spayed heifers. Additionally, no differences were found for tenderness values between yearling and first calf heifers (Field et al., 1996).

Postmortem aging of beef is known to improve beef tenderness (Wulf et al., 1996). Much research has been focused on identifying the mechanism by which meat becomes more tender with time. Fourteen or more days of aging has been reported to reduce differences in WBSF values between steers and heifers (O'Connor et al., 1997). Adjusting to a common MS or a common BF impacted the number of postmortem aging days needed to show significance (Choat et al., 2006). Within a common marbling score, WBSF did not differ between steer carcasses and intact heifer carcasses at 21 d postmortem. Steer carcasses produced steaks that had lower WBSF for both 7 d postmortem and 14 d postmortem than heifers in this study. This suggests heifer carcasses need an additional 7 days of aging to eliminate WBSF differences with steer carcasses. Choat et al., (2006) reported that at a common fat thickness was in agreement with O'Connor et al., (1997). At day 7 postmortem, steaks from steer carcasses had lower

WBSF values than steaks produced from heifer carcasses in this study. However, sex had no effect on WBSF, at 14 and 21 d postmortem.

Zinn et al., (1970b) reported differences for WBSF values of steaks in steer and heifer carcasses across DOF. Meanwhile, Anderson et al., (2006) found steer carcasses to have lower WBSF values than heifer carcasses. Prost et al., (1975) used 80 cattle from a lowland black-white breed from Poland to determine tenderness of beef in relation to individual muscles, ages, and sex of animals and carcass quality grades. *Psoas major, biceps femoris, Quadriceps femoris, Semitendinosus, Infraspinatus, Triceps brachii,* and *Extensor Capri radialis* muscle were evaluated by Prost et al., (1975). Prost et al., (1975) found heifers to produce carcasses with lower tenderness values for two muscles (*biceps femoris* and *Quadriceps femoris*). WBSF values taken from steer *Extensor Capri radialis* muscles were lower than the WBSF values measured from the same heifer muscles. However, when all muscles were combined, no differences in tenderness values were seen between steer and heifer carcasses. Knapp et al., (1989) also found no differences due to breed or sex-class for WBSF values.

Sensory evaluation is an objective measurement taken by trained individuals. Sensory evaluation measures qualitative aspects of a product including aroma, appearance, flavor, texture, aftertaste, and auditory attributes of a product. Thawed samples from each steak are cooked and evaluated by an 8 member trained panel to obtain an objective measurement (O'Connor et al.,, 1997). Panelists generally use a hedonic scale that is an 8 point structured rating scale to assign scores to each sample.

Measuring consumers' reaction to meat palatability is difficult because consumers' acceptance often is influenced by additional factors, such as price and nutrition (Lorenzen et al.,

2003). The Beef Consumer Satisfaction Study showed tenderness can be a major and contributing factor to consumers' perception of taste (Brooks et al., 2000).

A study was designed to determine if first calf heifers could be efficiently fed to produce Choice beef, by measuring feedlot performance and carcass traits (Reiling et al., 1996). Reiling et al., (1996) agreed with other researchers finding no differences in sensory attributes between A- and B-maturity carcasses despite differences in carcass maturity and age. Reiling et al., (1996) utilized heifer carcasses of approximately 24 mo of age which reported higher values in tenderness than all other months. Data from first calf heifers of approximately 36 mo of age reported higher values for juiciness, flavor intensity, and presence of off-flavors than other age groups. Sensory evaluation was done by an experienced sensory panel using a 15 cm continuous line scale with anchors at (0 = extremely tough) to (15 = extremely tender)) (Reiling et al., 1996).

Choat et al., (2006) evaluated beef palatability from beef of intact and spayed heifers as well as steers at common BF and MS endpoints. At a common BF, the sensory evaluation panel reported differences for amount of connective tissue between intact and spayed heifer carcasses. Intact heifers had less connective tissue than steers. Spayed heifer samples were intermediate in levels of connective tissue. Muscle fiber tenderness, amount of connective tissue, overall tenderness and flavor all showed significant differences within a common MS. Intact heifers produced carcasses that had lower values for muscle fiber tenderness, amount of connective tissue, and overall tenderness than steers. Spayed heifers were intermediate for these sensory traits, from either intact heifers or steers. A difference for flavor was found between steers and spayed heifers (Choat et al., 2006).

Field et al., (1996) reported sensory panel ratings as the percentage of incidence of loin steaks tenderness within treatments. A 12 cm continuous scale was used to rank tenderness with 0 = extremely tough and 12 = extremely tender (Field et al., 1996). The majority of first calf heifers in this study fell in an 8.9 or higher category for tenderness. Fifty percent of the intact heifers were in the 7 cm and higher rating. The majority of the spayed heifers fell between 5 and 8 cm on the 12 cm scale. Within each treatment group only 6 to 12 % of the steaks had ratings of 4.99 or lower (Field et al., 1996).

Shackelford et al., (1995) found no differences from sensory panel evaluation of carcass maturity on meat palatability. This evaluation was from 28 yearling heifers and 25 first calf heifers with known genetics that included purebred and composite breeds (Shackelford et al., 1995). All heifers originated from the (MARC). Yearling heifers were approximately 19 mo and first calf heifers averaged 31 mo of age. Chronological age was important to see what relationship it played on carcass maturity scores and meat palatability (Shackelford et al., 1995).

DAYS ON FEED (DOF)

The length of time an animal is fed a high concentrate diet affects the eating quality of the meat. Researchers have found that extending DOF increases HCW, BF, and USDA QG (Van Koevering et al., 1995; Zinn et al., 1970b; Hicks et al., 1987; Dolezal et al., 1982). These attributes can increase the value of the harvested cattle. Increasing DOF to gain benefits in HCW, BF, and QG tends to reduce ADG and feed efficiency (Rossi et al., 2001; Hicks et al., 1987; Van Koevering et al., 1995). The cattle industry could avoid unnecessary external fat condition by discovering optimum days on feed needed to produce consumer acceptable beef (Duckett et al., 1993). There is a linear increase in numerical USDA YG and subcutaneous fat thickness with increasing DOF (Greene et al., 1989; Williams et al., 1989; and May et al., 1992).

Williams et al., (1989) reported DOF increased total fat trim per carcass which led to trimming of retail cuts.

Zinn et al., (1970b) reported ADG increased as DOF increased up to 180 DOF. ADG increased at each weigh period through 120 DOF. No differences in ADG were seen from 120 to 180 DOF (Zinn et al., 1970b). There was no difference in ADG performance between feedlot steers and heifers in this study. Results of this study indicated an apparent interaction between DOF and animal age (Zinn et al., 1970b). After 180 DOF, animal age appeared to exert a greater influence than DOF. Zinn et al., (1970b) went further by reporting LMA tenderness started to decrease at about 400 days of age and was lower at 530 days of age.

Tatum et al., (1980) investigated the relationship between DOF and carcass characteristics within USDA QG on cooked beef palatability using 471 steers. Differences were found between 100, 130, and 160 DOF for maturity, MS, BF, and KPH. Cattle fed 100 d had less flavor desirability than cattle fed 130 or 160 d. Within USDA QG, steaks produced by cattle fed 100, 130, or 160 d differed little in palatability (Tatum et al., 1980). Sensory panelists were unable to detect any significant differences in tenderness due to DOF between USDA YG. Overall, Tatum et al., (1980) reported increasing feeding time from 100 to 160 days had a beneficial effect on flavor desirability, but did not affect juiciness, tenderness, or overall palatability.

However, Dolezal et al., (1982) found extending DOF beyond 100 days for steers and 90 days for heifers provided little additional palatability assurance. DOF for this project was set up in 30 d increments from 0 to 230 d. Steers (n = 326) and heifers (n = 68) of multiple breeds were evaluated. Dolezal et al., (1982) also found as DOF increased BF, MS, USDA YG, and USDA QG also increased. Carcasses from steers fed more than 100 d produced tenderness values

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higher than steer carcasses fed less than 100 d (Dolezal et al., 1982). However, steer carcasses at 100 DOF did not report differences in tenderness from steer carcasses fed 130, 160, 200, or 230 d (Dolezal et al., 1982). Heifers had similar results as the steers by not reporting any differences past 90 DOF for tenderness (Dolezal et al., 1982).

Duckett et al., (1993) found a linear response for DOF up to 196 d in traits of HCW, LM, BF, and USDA YG. There was also a quadric response for DOF in MS and KPH. No differences were seen after 112 DOF for MS and KPH. Conclusions made from this study reported an increase on DOF meant additional subcutaneous fat disposition without improving quality grades. Multiple researchers have found that little significant improvement occurs past 100 DOF (Zinn et al., 1970b; Tatum et al., 1980; Dolezal et al., 1982).

RACTOPAMINE HCL

Ractopamine is a phenethanolamine with beta adrenergic agonist properties (Watkins et al., 1990). Phenethanolamines, commonly called repartitioning agents, are compounds that alter how dietary energy intake is partitioned between lean and fat tissue. Human medicine has used phenethanolamine for many years. Researchers have studied leanness enhancing repartition agents of phenethanolamines for two decades in livestock species (Walker, 2008). This results in a favorable shift in the lean:fat ratio of growing animals (Baker et al., 1984; Harborth 2006; Jones et al., 1985; Watkins et al., 1990). Beta adrenergic agonists are commonly used in livestock production to accelerate growth by enhancing lean tissue accretion (Quinn et al., 2008). Ractopamine is one of many in a family of beta adrenergic agonists. Others include Cimaterol, Clenbuterol, and Zipaterol (Harborth, 2006). Zilpaterol is the only other beta adrenergic agonist currently approved for use in beef cattle in the United States (Walker, 2008).

All phenethanolamines share common features and must retain these features in order to have biological activity (Walker, 2008). The phenethanolamine compound acts as a generic class of substituted catecholamines that share some structural and pharmacological properties with epinephrine or norepinephrine which act on beta adrenergic receptors (Baker et al., 1984). Beta adrenergic agonists obtain their name from the beta adrenergic receptor to which they bind (Walker, 2008). Beta adrenergic agonists repartition nutrients toward decreased lipogenesis, increased lipolysis, increased protein accretion, decreased protein degradation or a combination of all these processes.

The livestock industry today is using beta adrenergic agonists for beef cattle, broilers, lambs, swine, and turkeys. Elanco Animal Health trademarked Ractoamine HCL (RAC) in swine as Paylean™ (See et al., 2004). In beef, Optaflexx™ is the trademark name for RAC (Elanco Animal Health, Greenfield, IN) and was the first orally active beta adrenergic agonist to be approved by the Food and Drug Administration (FDA) for beef cattle (Schroeder et al., 2003a).

Beta adrenergic agonists are not equally effective in all species of livestock (Moody et al., 2000). External factors such as diet, dose, treatment length, age, BW, sex, and genetics impact the biological response of an animal to a beta adrenergic agonist. A factor that can change the response of a beta adrenergic receptor agonist is the potential change in the receptor number. The three currently known sub-types of beta adrenergic receptors are beta one, beta two, and beta three (Harborth, 2006). Moody et al., (2000) suggested beef cattle and lambs had a larger response to phenethanolamines than swine especially with beta two agonists. Three subtypes of beta adrenergic receptor agonists are found in cattle, with beta-two adrenergic receptor agonists being the most abundant in skeletal muscle. RAC is believed to elicit its

growth-promoting response through the beta one adrenergic receptor (Smith et al., 1987; Moody et al., 2000; Sissom et al., 2007). Due to the beta one adrenergic receptor, RAC is most effective in swine followed by beef cattle and then sheep (Moody et al., 2000).

RAC is used to improve ADG and FE, while not affecting DMI in cattle (Laudert et al., 2005a; Schroeder et al., 2003a; Walker, 2006). Walker et al., (2006) reported adding 200 mg/hd/d of RAC to feedlot heifers increased ADG by 18% while not affecting DMI. These results were similar to Carroll et al., (1990) where ADG increased 11% when steers were fed 20 ppm RAC for 38 to 45 d. Preston et al., (1990) reported a 25% increase in ADG when feeding finishing steers 20 ppm RAC for 46 d. RAC also increased HCW (Crawford et al., 2006) and (BF) but has not been shown to effect USDA marbling scores (MS) (Schroeder et al., 2003a; Griffin et al., 2009). Carcass enhancement occurs when RAC is fed during the final 28 to 42 days on feed and can be fed at a rate up to 400 mg/hd/d. Laudert et al., (2005b) reported RAC increased LMA, improved G:F, with limited effects on USDA yield grade (YG) and quality grade (QG). Walker et al., (2006) along with Schroeder et al., (2003b) showed no response to RAC in feedlot heifers for dressing percentage, BF, LMA, MS, USDA YG, or USDA QG. There was no effect of RAC on KPH in feedlot steers or feedlot heifers (Schroeder et al., 2003a, 2003b; Laudert et al., 2004; Walker et al., 2008).

Griffin et al., (2009) completed two feedlot experiments to determine the effects of Melengestrol Acetate (MGA) and RAC on performance and carcass characteristics in heifers. The first study included 1,807 commercial British x Continental heifers either fed a high concentrate diet with the addition of 200 mg/ hd/ d of RAC for 36 d with 0.4 mg/ hd/ d of MGA or 0.4 mg/ hd/ d of MGA. The addition of RAC in the diet with MGA increased DMI by 0.17 kg/d and feed efficiency by 1.8% while ADG was not significant for the entire project.

Meanwhile during the treatment period, the treatment group of RAC and MGA increased ADG (P < 0.10) compared to the MGA heifers, increased DMI (P < 0.01) as well as improved feed efficiency (P < 0.05). Differences were also found when ADG and DMI were analyzed at a common carcass weight. RAC significantly improved ADG and G:F for the entire project. HCW increased by 1.3% when RAC and MGA were both added to the diet. Looking at only the treatment phase, differences between treatment groups were also found between gain (P < 0.01) and G:F (P < 0.01). Once again RAC had a limited impact on carcass characteristics. HCW was the only carcass characteristics that showed significance, with the treatment group of RAC and MGA having 3.3 kg heavier HCW (P < 0.01) than MGA heifers (Griffin et al., 2009).

The second experiment also analyzed commercial British and x Continental heifers located in the Panhandle of Texas (Griffin et al., 2009). Treatment groups were either feed a high concentrate diet with MGA (0.4 mg/ hd/ d) for the entire project or added RAC to the diet and MGA for the last 29 d (Griffin et al., 2009). DMI was not affected by treatment group for the entire project (Griffin et al., 2009). RAC and MGA did significantly impact gain (P < 0.01) and feed efficiency showed a 3.7% increase for the entire project. During the treatment phase of the study DMI was not affected but ADG increased (P < 0.01). Analyzing the data by adjusted carcass weight for the entire project found RAC and MGA heifers to increase (P < 0.05) gain by 0.05 kg/d and improve (P < 0.01) feed efficiency by 3.7% (Griffin et al., 2009). Heifer carcasses showed advantages to using RAC in the diet due to 3.2 kg heavier HCW (Griffin et al., 2009). LMA was greater for heifers fed RAC and MGA than MGA alone (P < 0.01) (Griffin et al., 2009). However, reduced scores for marbling were reported (P < 0.01) and yield grades (P = 0.11) were not affected when RAC was added to the diet (Griffin et al., 2009).

Generally, phenethanolamine effects decrease over time. This is due to either down regulation or desensitization of the beta adrenergic receptors (Moody et al., 2000). The response of RAC in the live animal is to increase rapidly at first. Over time, the live animal response to RAC plateaus, and then seems to decrease toward the end of the RAC feeding period (Dunshea et al., 1993 and Williams et al., 1994). Sissom et al., (2007) evaluated of RAC and DOF of heifer calves (282 ± 3 kg) found no (P > 0.10) interaction between RAC and DOF. As DOF increased, there was a decrease in ADG and G:F (P < 0.05) (Sissom et al., 2007). DOF did positively affect HCW, LM, BF, and MS, at an increasing rate as DOF increased (Sissom et al., 2007). DOF also positively affected USDA YG by declining as DOF increased (Sissom et al., 2007). Winterholler et al., (2007) was not in agreement with Sissom et al., (2007) this study did report effects of RAC and DOF interaction. However, Winterholler et al., (2007) utilized steers instead of heifers.

In general, phenethanolaminenes have the ability to reduce meat tenderness (Moody et al., 2000). Moody et al., (2000) reported that RAC and zilpaterol tend to affect meat tenderness less than other phenethanolamines in cattle and sheep. However, Moody et al., (2000) reported the decrease in tenderness due to RAC or zilpaterol could possibly be due to the degree of fatness of the animals and not the addition of a beta adrogenic agonist. With consumers demanding a consistent and acceptable eating experience, Schroeder et al., (2003b) evaluated the effects of feeding various levels of RAC (0, 100, 200, and 300 mg/ hd/ d) for the last 35 d prior to harvest on beef carcass characteristics and sensory properties. No differences were reported for pH levels or percent cooking loss between control and steaks from cattle fed RAC (Schroeder et al., 2003b). In addition of RAC to the diet did not affect (WBSF) values for RAC fed at a level of 100 or 200 mg/hd/d. When RAC was fed at 300 mg/ hd/ d, WBSF values were

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increased (P<0.05) over control WBSF values. However, all steaks still fell in the acceptable

tender category defined by the Millet et al., (2001). WBSF values obtained from cooked LM

steak core samples by Quinn et al., (2008) were not different for heifers fed control and RAC

diets (P> 0.41). Quinn et al., (2008) analyzed the most appropriate strategies for dosage or

duration of Ractopamine-hydrocholoride (RAC) administration to achieve optimal growth

response with heifers. Three hundred and two crossbred heifers of initial body weight of 479 kg

for 54 d were evaluated before splitting them into two groups of control and treatment (Quinn et

al., 2008). Heifers were fed 0 or 200 mg/ hd/ d of RAC for the last 28 d prior to harvest and

RAC had no significance for WBSF.

Schiavetta et al., (1990) and Wheeler and Koohmaraie (1992) observed lower WBSF

values in control animals compared with those fed beta agonists clenbuterol and $_L$-664,696,

respectively. Furthermore, similar increases in LMA toughness were observed with wethers fed

beta agonists $_L$-664,696 (Pringle et al., 1993). When RAC was fed to finishing steers at 300 mg/

hd/ d, meat samples from those fed RAC had significantly greater shear force than steers that

were not fed RAC (Avendano-Reyes et al., 2006).

An advantage for using phenethanolamines in the meat industry is that leanness is

achieved without decreasing the amount of juiciness of meat (Moody et al., 2000). Schroeder et

al., (2003b) reported no statistical differences were detected for juiciness, flavor, and off flavor

for any of the RAC treatments. No differences were reported for initial and sustained tenderness

(Schroeder et al., 2003b). Differences were found between control and treatment of 300 mg/ hd/

d for initial and sustained tenderness. Overall, the FDA concluded no differences would be

detected by the consumer for palatability as defined by juiciness, flavor, and tenderness from

feeding cattle RAC (Schroeder et al., 2003b).

The purpose of the current study was two-fold. The objectives of this experiment were 1) to examine the effect of growth and carcass characteristics due to the administration of Ractopamine HCL to a finishing diet, and 2) to examine optimal days on feed for maximum marbling without sacrificing carcass quality in crossbred yearling heifers.

EFFECT ON DAYS ON FEED AND RACTOPAMINE HCL ADMINISTRATION ON GROWTH AND CARCASS TRAITS OF YEARLING HEIFERS

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INTRODUCTION

Providing feed to cattle is the single largest expense in most commercial beef production enterprises, and thus any effort to improve the efficiency of feed use will reduce input costs (Arthur et al., 2001). Ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) was the first orally active phenethanolamine with an active beta adrenergic agonist to be approved by the Food and Drug Administration (FDA) for beef cattle (Schroeder et al., 2003a; Walker et al., 2006). RAC is fed the final 28 to 42 days on feed and can be fed up to 400 mg/ hd/ d (Schroeder et al., 2003a). Cattle administered ractopamine exhibited improved ADG and gain to feed ratios (G:F), while not affecting DMI (Laudert et al., 2005a; Schroeder et al., 2003a; Walker, 2008). Laudert and coworkers (2005b) reported increased *longissimus dorsi* muscle area (LMA) and improved G:F with limited effects on USDA yield grade (YG) and USDA quality grade (QG) in steers fed RAC. Increased HCW has been documented (Crawford et al., 2006) while not affecting marbling score (MS) in steers fed RAC (Schroeder et al., 2003a). However, there is data suggesting RAC affects steers and heifers differently (Schroeder et al., 2003a).

The purpose of this study was two-fold. The objectives were 1) to examine the effect on growth and carcass characteristics of yearling heifers administered Ractopamine HCL in a

finishing diet verses control heifers, and 2) to examine optimal days on feed for maximum

marbling without sacrificing carcass quality in crossbred yearling heifers.

MATERIALS AND METHODS

Animal Care and Use

All experimental procedures performed at Auburn University were approved by the

Auburn University Institutional Animal Care and Use Committee (AU-IACUC, PRN 2007-

1273).

Description of Data

Seventy-one commercial crossbred yearling heifers were utilized for this study. Only

sixty-seven heifers were used in the growth analyses due to complications. One heifer from 79

DOF group and 2 heifers from 163 DOF group were not trainable to their individual Calan gates

while 1 heifer in 142 DOF group calved during the project. Age (397 ± 34 d), genetic makeup,

birth date, vaccination program, weight (372.2-400.8, kg) and source were known for each

heifer. Heifers were purchased from seven commercial Alabama beef producers as a comingled,

weaned and backgrounded group. Sire breeds included Angus, Simmental, Charolais, and

composite ½ Angus x ½ Simmental, and ½ Simmental x ½ Angus. Dam breeds were comprised

of 16 different individual and combinations of Angus, Simmental, Charolais, Gelbvieh,

Limousin, Brangus, Santa Gertrudis, and Barzona.

Following purchase, heifers were placed on a summer perennial mix pasture

(bermudagrass: *Cynodon dactyloncl* and bahiagrass: *Paspalum notatum Flusge*) and fed soyhull

pellets (3.2 kg/ hd/ d) for 66 days. Heifers were transported to the Auburn University Beef

Cattle Evaluation (AUBCE) facility in late Fall 2007 where they remained for the duration of the

project.

Heifers were acclimated to the AUBCE facility during a 21 d warm up period. Under roof, the AUBCE facility consists of 8 pens with 12 Calan Gates® (American Calan, Northwood, NH) in each pen. Heifers had inside and outside access with inside pen dimensions of 9.1 meters wide by 10.2 meters long. Outside pen dimensions were 18.6 m at their widest point by 92.7 m long and divided into three 6.2 m strips. Heifers were allowed access to one strip per pen weekly. This allowed ground cover (common bermudagrass: *Cyndodon dactylon*) to be maintained for the duration of the project. Water was provided using automatic water troughs with one trough supplying water to two pens.

Upon arrival at AUBCE, heifers were individually revaccinated for $BVD/BSRV/PI_3$ /IBR, dewormed and randomly allocated into one of five days on feed (DOF) groups. DOF groups were stratified based on heifer initial weight and height (Table 1). The 5 DOF groups were defined as 79 (n=16), 100 (n=16), 121 (n=16), 142 (n=16), or 163 (n=7) d. Each DOF group was subdivided into 2 treatment groups. Half of each DOF group received 300 mg/ hd/ d of Ractopamine HCL (RAC, Elanco Animal Health, Greenfield, IN) for 35 d prior to slaughter. The remaining half of each DOF received 0 mg/ hd/ d of RAC. RAC was hand weighed and added to the morning diet daily for those receiving RAC. RAC was individually mixed into the top part of the feed. Heifers receiving 0 mg/ hd/ d RAC served as controls.

Heifers were fed 2% of their individual BW with the diet formulations shown in (Table 2) and hay (bermudagrass and bahiagrass) mix (0.56 kg/ hd/ d) during the 21 d training period. Each heifer was fed 0.5 mg/ hd/ d of melengestrol acetate (MGA) to suppress estrous. The diet was analyzed each month to ensure nutritional equality.

After 21 d of training, heifers were weighed and measured for height on two consecutive days to establish on-test weights and heights. Heifers were fed the diet ad libitum twice a day

and orts measured and recorded daily. No hay was fed during the test period. Heifers were weighed weekly throughout the test period.

Three heifers (DOF group 79, 142, 163) were not trainable to individual Calan Gates[®]. These heifers were fed as a group for the duration of the project and their feed data was removed from all growth analyses. Another heifer calved on day 68 (DOF group 163) of the project. Her data was also removed from all growth analyses.

Real time ultrasound measurements of 12th rib fat thickness (UBF) and *longissimus dorsi* muscle area (ULMA) were collected on the first day heifers went on test, 35 d prior to harvest, and 1 d prior to harvest using an Aloka 500 machine (Wallingford, CT) with a 17 cm linear probe. Measurements were taken by the same Ultrasound Guidelines Council (UGC) certified technician each time and interpreted by an UGC certified laboratory.

Carcass Data Collection and Sampling Methods

Feed was removed from heifers 24 hours prior to harvest and transported to the Auburn University Lambert-Powell Meats Laboratory. Heifers were harvested under USDA inspection. HCW, lung lesions, and liver abscesses were recorded prior to entering the cooler. Carcasses were ribbed between the 12th and 13th rib in order for carcass graders to record carcass traits for each animal (USDA, 1997). Carcass traits of 12th rib fat thickness (BF), LMA, percentage of kidney, pelvic, and heart fat (KPH), and MS were measured 24 hour postmortem by trained personnel. Strip loins from the right side of each carcass were also removed 24 h postmortem. Each loin section was placed in a vacuum-sealed bag (Cryovac, Simpsonville SC) and aged in the cooler at $4 \pm 2°$ C for 21 d.

Loins were removed from the cooler after the aging period and cut into individual 2.54 cm steaks. There were 7 steaks cut from each loin starting from the anterior end. Each steak

was labeled and placed in a vacuum-sealed bag (Cryovac, Simpsonville SC) and frozen at -20° C until subsequent analyses could be performed.

Warner-Bratzler Shear Force. (WBSF)

Warner-Bratzler shear force (WBSF) measurements were taken according to American Meat Science Association standards (AMSA, 1995). The third steak from the anterior end of the *longissimus dorsi* muscle was used in all WBSF analyses. Individual steaks were randomly removed from the freezer, and thawed for 24 h at 4 ± 2° C. Steaks were cooked using a clam shell style grilling method (Kerth et al., 2003). Two George Foreman (Model GRV120, Salton, Inc., Lake Forest, IL) grills were used to cook two steaks at a time until an internal temperature of 70°C was reached. An Electo-therm Digital Thermometer (Model TM99A, Cooper Instruments Corp., Middlefield, CT) was used to measure the internal temperature of each steak to 70° C before each steak was removed from the grill. Once cooked, each steak was placed on a Styrofoam tray, overwrapped with PVC film, and cooled for 24 h at 4 ± 2° C. Six cores (1.27 cm in diameter) were taken perpendicular to the muscle fiber orientation from each steak. Cores were analyzed with a Texture Analyzer (Model TA.XT2i, Stable Microsystems, Texture Technologies Corp., Scarsdale, NY) with a WBSF attachment. Each core measurement was taken using a Warner-Bratzler Probe and Guillotine Set. The probe was programmed to be lowered 30 mm after detection of resistance. The penetration speed was 3.3 mm/s with a post-test speed of 10 mm/s and a pre-test speed of 2.0 mm/s were used during the shearing. Each core was sheared once across the middle, perpendicular to the muscle fiber orientation, avoiding fat pockets. A single, peak shear force measurement (kg) was obtained for each core and an average shear force was determined for each steak.

Trained Sensory Evaluation

Trained panelists (n = 7) were selected based on previous experience and desire to participate in the sensory panel. Selected panelists were given instructions relative to sensory attributes and then presented training products representing the attributes to be evaluated on the panel. Panelists were trained according to procedures outlined by AMSA (1995). Frozen individual steaks were randomly chosen from the freezer and thawed for 24 h at $4 \pm 2°$ C, and cooked after being removed from the vacuum package, they were cooked using the procedures outlined by Kerth et al., (2003). When each steak reached 70°C internally, it was removed from the grill, trimmed of subcutaneous fat, cut into 1 x 1 x 1 cm cubes, and placed into serving trays. Trays were placed into a preheated to 65°C incubator until all samples were prepared.

During training and actual sensory analysis, panelists were seated in a room with dim red lighting, separated by partitions and from the sample preparation area. Panelists used room temperature distilled water and unsalted crackers for pallet cleansing. Each panelist evaluated two cubes from each steak. Each steak was evaluated for initial and sustained juiciness, initial and sustained tenderness, flavor intensity and off flavor. Each sensory characteristic was evaluated on a 9 point structured hedonic rating scale (Figure 1). An average was taken from the seven panelists for each sensory characteristic to obtain a measurement for each steak. No more than four steaks were evaluated at each taste panel session to avoid fatigue. Including the training period, taste panel was conducted daily for five weeks.

Statistical Analysis

Data were analyzed using the general linear models procedure of SAS (SAS Inst. Inc., Cary, NC, 2002). Main effects were separated using the PDIFF option of least squares means with a significance value set at P< 0.05. Analyzed performance traits included gain, average

daily gain (ADG), dry matter intake (DMI), and dry matter feed efficiency (DMFE). All performance traits were analyzed for the entire length of the project and separately for the treatment phase (35 d pre-harvest). Carcass traits analyzed were HCW, BF, LMA, KPH, YG, and MS. Fixed effects used in either performance or carcass trait analyses were DOF (79, 100, 121, 142, 163 d), treatment (RAC or control), and sire breed type (British, British – Continental, Continental, Continental – British). Dam breed types were not included in the model as a source of variation since there were 16 dam breed combinations. Because of the linear arrangement of days on feed, contrasts were constructed to test linear, quadratic and cubic effects for performance and carcass traits. WBSF and sensory evaluation panel traits were also analyzed using the same fixed effects included in the model.

Covariates of initial weight and age at slaughter were used for all live animal traits while adjusted BF, HCW, or age at slaughter were used to as covariates for carcass traits.

The model used was:

$$Y_{ijkl} = \mu + D_i + I_j + S_k + DI_{ij} + B_l + e_{ijklm}$$

μ = overall mean

D_i = fixed effect of DOF ($_i$ = 79, 100, 121, 142, 163)

I_j = fixed effect of treatment ($_j$ = RAC or control)

S_k = fixed effect of sire breed type

DI_{ij} = interaction between DOF and Treatment

B_l = Model covariates =

        Initial weight (Growth traits)

        Age at slaughter (Growth traits)

        BF (Carcass traits)

HCW (Carcass traits)

Age at slaughter (Carcass traits)

e_{ijklm} = random error term

RESULTS AND DISCUSSION

Performance Traits

Simple means and standard errors of initial heifer data are presented for treatment group (Table 1) and days on feed (DOF) groups (Table 3). In general, simple means of treatment groups and days on feed groups were similar across groups. One item to note is the 12th rib fat thickness (FT) for all heifer groups (Table 1). Heifers in this study began the trial with much more subcutaneous fat than desired.

Performance Trait Analysis

There was no significant interaction between treatment and DOF for any performance trait; therefore only main effect results are presented. Two analyses were performed on each growth trait. Each performance trait was analyzed for the entire length of the trial and then again for the last 35 days of the trial when RAC was administered. All performance traits were also analyzed with a covariate of initial weight on trial and again using age at slaughter.

Entire Trial

Initial Weight as Covariate

The main effects of treatment and sire breed type were not significant at $P<0.05$ for any performance trait when initial weight was used as a covariate across the entire length of the trial. However, DOF had a linear effect on GAIN and DMI ($P<0.05$; Table 4). As expected, GAIN increased as DOF increased. Heifers on feed 79 d gained the least amount of weight before slaughter, while heifers fed 163 d prior to slaughter gained the most amount of weight. Heifers

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fed 121 d had similar gains to heifers fed 100 d and 142 d. However, heifers fed 100 d and 142 d

had different gains from one another.

As expected, DMI increased linearly over DOF. As DOF increased, so did DMI of the

diet. Each DOF group was different for DMI (Table 4). However, even though GAIN and DMI

increased as DOF increased, ADG and DMFE were unchanged across groups. Heifers fed 142 d

and 163 d tended to have lower ADG, but it was not different compared to the other DOF

groups.

A study conducted by Van Koevering et al., (1995) reported similar results for ADG with

steers across days on feed when using off-truck weights as initial starting weights. They too

reported linear differences in final weight as DOF increased. They also observed no differences

in ADG or daily DMI (kg/d) across DOF groups. However, the steers in the Van Koevering et

al., (1995) study demonstrated a, cubic response for DMFE. Steers fed 119 d in the Van

Koevering et al., (1995) study were the most efficient, while steers fed 147 d were the least

efficient. Steers fed 105 or 133 d were similar, yet intermediate in their DMFE values.

Griffin et al., (2009) conducted a study most similar to the current study. They measured

growth and carcass traits in feedlot heifers in Nebraska and Texas for 133 d. All heifers in the

Griffin et al., (2009) study were fed MGA daily. RAC (200 mg/ hd/ d) was fed to half of the

heifers 29 d prior to slaughter. They analyzed growth traits for the entire length of the project

(133 d) using pen BW as a covariate. Heifers fed MGA daily and 200 mg/ hd/ d RAC for 29 d

had higher DMI and improved G:F ratios (P<0.05) than heifers just fed MGA. However, no

differences in ADG were observed between the RAC fed and non-RAC fed heifers in the Griffin

et al., (2009) study. However, when the Griffin et al., (2009) data was adjusted for HCW, there

were differences in ADG observed between the RAC fed and non-RAC fed heifers. No

differences were seen for the traits of DMI or G:F ratio when adjusted for HCW. Schroeder et al., (2003a) also reported differences between RAC- and non-RAC fed heifers for feed efficiency. The Schroeder et al., (2003a) study also reported differences in ADG between heifer groups.

Age at Slaughter as Covariate

When the model included age at slaughter as a covariate, DOF was again the only significant main effect in the model for performance traits of GAIN and ADG (Table 5). GAIN increased linearly as DOF increased. Adjusting the data for age at slaughter, heifers fed 79 d gained the least amount of weight prior to slaughter, while heifers fed 163 d gained the most amount of weight prior to slaughter. Heifers fed 121 or 142 d gained intermediate, but similar amounts of weight, but (P<0.01) more than heifers fed 100 d.

Heifers fed 79 d had significantly lower ADG compared to heifers fed 100 d. Heifers fed 121, 142 or 163 d were intermediate in ADG value, but not different than heifers fed either 79 or 100 d.

There were no differences between DOF groups for DMI, due to a large SD in the heifers fed 163 d. Intake certainly trended higher as days on feed increased. Although not significant, there tended to be differences for DMFE (P = 0.06) when adjusted for age at slaughter. The heifers fed for 79 d, and thus the youngest, were the least efficient. The heifers fed 100d were the most efficient. The remaining groups were intermediate in DMFE values. Van Koevering et al., (1995) observed a linear increase for final weight across DOF for steers when adjusted to a common carcass weight. Results from the Van Koevering et al., (1995) study were similar to the current study when data was adjusted to a carcass weight basis. ADG in the Van Koevering et al., (1995) study followed a quadratic trend with steers fed 118 d exhibiting the highest ADG and

steers fed 105 d having the lowest ADG. Steers fed 133 or 147 d were not different from steers

fed either 105 or 118 d. DMFE results for the steers in the Van Koevering et al., (1995) study

were similar to DMFE results found in the current study. Zinn et al., (1970b) reported ADG

increased as DOF increased up to 180 DOF. ADG increased at each weigh period through 120

DOF. No differences in ADG were seen from 120 to 180 DOF (Zinn et al., 1970b). Rossi et al.,

(2001) reported better growth traits for DMI (P < 0.01) and G:F (P < 0.02) for steers fed 163 d

than 203 d. Rossi et al., (2001) found steers fed 168 days to be more efficient than steers fed 203

days.

Treatment Period

Growth Analysis

During the 35 d treatment phase, there were no differences for GAIN, ADG or DMI

between heifers fed RAC and controls (Table 6) when using initial weight as a covariate.

However, heifers fed RAC tended to gain more and have greater ADG (P=0.08 and P=0.07) than

heifers not fed RAC. Age at slaughter was also used as a covariate during the 35 d treatment

phase but no differences were seen between treatment groups for any performance traits (results

not shown).

Most published studies have found differences in GAIN during the treatment phase when

beef animals were fed a beta-agonist (Griffin et al., 2009; Laudert et al., 2005a; Schroeder et al.,

2003a; Walker, 2008). Schroeder et al., (2003a) reported an improvement in gain of 3.6, 7.3, and

8.9 kg in heifers fed RAC at 100, 200, and 300 mg/hd/d, respectively compared to control heifers

fed 0 mg/hd/d RAC.

Griffin et al., (2009) also reported differences in GAIN between heifer treatment groups,

reporting RAC to increase total GAIN when adjusted to a common live weight or hot carcass

weight. Walker et al., (2006) also observed RAC to increase gain in heifers when adjusted to a common carcass weight.

Quinn et al., (2008) also found no differences in heifer ADG between control and RAC groups fed 200 mg of RAC /hd/d 28 d before slaughter. However, other studies have reported differences in ADG between animals fed RAC and fed no RAC. Schroeder et al., (2003a) observed an improvement ($P < 0.03$) in ADG with the addition of RAC into the diet for heifers. Heifers fed RAC at 100, 200, and 300 mg/ hd/ d had 8.0, 17.5, and 20.4 percent improvement in gain over control heifers, respectively. Schroeder et al., (2003a) observed a linear increase in ADG as dose increased for heifers and steers. Steers in the Schroeder et al., (2003a) study had significant differences ($P < 0.001$) in ADG depending on treatment group and even larger increases in ADG over heifers fed RAC. Steers fed RAC at 100, 200, and 300 mg/ hd/ d had 17.1, 19.6, and 25.7 percent increases in ADG over control steers, respectively. Walker et al., (2006) observed an 18 percent increase, in ADG for finishing heifers fed RAC compared to control heifers. Walker et al., (2006) reported an increase in the percentage of ADG to 25 percent when daily gains were calculated from carcass weights. Griffin et al., (2009) reported an increase in ADG with the addition of RAC to the feed when adjusted to live weight or HCW basis. Abney et al., (2007) reported similar results to the Schroeder et al., (2003a) study as steers fed RAC increased linearly for ADG when adjusted to a common body weight as compared to control steers.

Dry matter intake between heifer groups was also not affected by RAC when adjusted by the covariate of initial weight. This is in agreement with most published literature reports. Schroeder et al., (2003a) reported DMI was not affected for either steers or heifers when RAC

was added to the diet. This result was supported in three other studies utilizing heifers (Quinn et al., 2008; Walker et al., 2006; and Griffin et al., 2009).

DMFE, adjusted for initial weight, was the only performance trait affected by the addition of RAC to the diet during the 35 d treatment phase in this study. RAC fed heifers had better DMFE (P = 0.02) during the 35 d of treatment compared to the control heifers. Quinn et al., (2008) reported a trend for improved G:F for heifers fed RAC compared with heifers not fed RAC. Griffin et al., (2009) had conflicting results with G:F depending on the covariate used in the analysis. G:F, adjusted to live weight in the Griffin et al., (2009) study, was not different between RAC fed and control heifers. Adjusting to a common HCW, RAC fed heifers exhibited higher G:F ratios than control heifers. Laundert et al., (2005a) stated heifers fed RAC in their study were more feed efficient than heifers not fed RAC. Laundert et al., (2005a) reported both G:F and F:G values of heifers fed either 200 mg/ hd/ d or 0 mg/ hd/ d for 28 to 32 days before slaughter. F:G and G:F were better for heifers fed RAC compared to control heifers not fed RAC. Schroeder et al., (2003a) reported improvement of feed efficiency (P<0.03) on a pen basis for heifers fed RAC verses control heifers. In agreement with these previous findings, Gruber et al., (2007) and Winterholler et al., (2007) observed increased G:F in steers fed RAC for 28 days prior to slaughter.

DOF was a source of variation for GAIN and ADG for both covariate analyses during the treatment phase of the trial. Using either covariate, DOF exhibited a cubic effect on both GAIN and ADG (Table 7 and 8). Adjusting for either initial weight or slaughter, heifers fed 100 d gained the most weight with the highest ADG. Heifers fed 79 d or 142 d gained the least amount of weight with the lowest ADG. Sissom et al., (2007) reported ADG in heifers to decrease as DOF increased from 129 to 170 days during a final treatment period of 28 days on feed.

Winterholler et al., (2007) reported a decline in ADG across DOF during the treatment period of the last 28 days on feed. Steers fed 171 d were less efficient (P<0.01) than steers ADG fed 150 d during the treatment period. Abney et al., (2007) reported a quadratic effect across DOF for ADG for finishing steers. Steers fed for 35 days had a 14 % increase in ADG and were more efficient than steers fed RAC for 28 days. However there was not a increase in ADG when days were increased to 42 days.

DMI exhibited a decreasing linear pattern (P<0.05) across DOF during the 35 day treatment period with initial weight as the covariate (Table 7). Heifers fed 142 or 163 d ate significantly less feed than heifers fed 79, 100 or 121 d. DOF was not a source of variation for DMI when adjusted to a common age at slaughter (Table 8). However, results trended toward a linear decrease in DMI. Sissom et al., (2007) observed no differences in DMI for feedlot heifers as DOF increased during the last 28 days on feed. In the Winterholler et al., (2007) study, feed intake did decline as DOF increased but not significantly during the last 28 days in the treatment period. Abney et al., (2007) reported a quadratic increase in the treatment period across DOF for DMI in steers.

Dry matter feed efficiency was not affected across DOF groups during the treatment period with either covariate in the current study (Table 7 & 8). Other studies reported differences for DMFE across DOF. Abney et al., (2007) reported a linear increase in G:F ratio as days on feed increased during the last 28 days. Sissom et al., (2007) did not observe an interaction between RAC administrated and DOF. However, Sissom et al., (2007) did report a decrease in G:F as the number of days increased.

Sire breed type was not a source of variation for traits during the treatment period with either covariate. In a study utilizing swine, pig genetics did make a difference in performance

traits (Gu et al., 1991); however, Gruber et al., (2007) and the present study did not find differences in performance traits for cattle based on sire breed. This may be due to the decrease in variation in growth traits between cattle breeds the last 30 years once EPD values became commonly available.

Carcass Characteristics

The addition of RAC to the diet did not affect any of the carcass traits measured (HCW, BF, LMA, MS). Several other studies in the literature also reported no differences in carcass traits after the administration of RAC (Sissom et al., 2007; Schroeder et al., 2003a; Quinn et al., 2008; and Winterholler et al., 2007).

Of all carcass traits, HCW has been the trait most affected by the use of RAC pre-slaughter in the literature. (Schroeder et al., 2003a; Walker et al., 2006; Winterholler et al., 2007; Sissom et al., 2007; and Gruber et al., 2007). Schroeder et al., (2003a) observed a increase of HCW in heifers fed RAC and a similar response in steers with an increase in HCW of 5.6 kg of RAC fed steers over control steers. Meanwhile, Griffin et al., (2009) reported differences in both LMA and marbling score. Heifers fed RAC had a larger LMA than control heifers. However, this same study observed marbling score to be higher in control heifers over RAC heifers, finding a negative impact with the use of RAC on marbling scores.

DOF was a source of variation for several carcass traits in this study. Carcass traits were adjusted by either age at slaughter, hot carcass weight or carcass backfat (Table 9). HCW was only affected by DOF when adjusted to a common age at slaughter (P<0.05). A quadratic response was seen on HCW as DOF increased. HCW increased with each slaughter group until d 121 and then leveled off. Thus age played a factor in increasing HCW to a certain stage. This suggests heifers on feed longer than 121 d will not provide more amounts of salable product.

The results for HCW in this study contradicts many other studies where HCW increased as DOF increased (Van Koevering et al., 1995; Zinn et al., 1970b; Hicks et al., 1987; Dolezal et al., 1982; Sissom et al., 2007; Winterholler et al., 2007). Linear responses in HCW were reported previously by Zinn et al., (1970a) and Hicks et al., (1987). Sissom et al., (2007) observed a increase in steer HCW as DOF increased from 129 to 170 days. Similarly Winterholler et al., (2007) reported increases in HCW as DOF increased from 150, 171, to 192 days. Abney et al., (2007) also detected a linear increase in HCW as dose of RAC increased from 100 mg/hd/d to 200 mg/hd/d in steers. There was only a tendency ($P = 0.09$) for HCW to respond with the increase in RAC and DOF in a quadratic form (Abney et al., 2007).

LMA was not affected by the length of the feeding period or covariate (Table 9). Other studies previously reported LMA in steers and heifers increased as DOF increased (Sissom et al., 2007; Van Koevering et al., 1995; Winterholler et al., 2007)

BF was affected by DOF whether adjusted for age at slaughter or HCW. In essence, there was a cubic response for BF across days on feed (Table 9). Heifers fed 121 and 142 days had more BF than heifers fed 79, 100, and 163 days adjusted to a common age at slaughter. Results were similar when BF was adjusted to on a HCW basis. Heifers fed 79 or 100 d exhibited the least amount of BF in this study.

It is unclear why BF did not follow an expected linear increase as days on feed increased since a linear response for total gain was observed. The amount of BF each heifer exhibited at the beginning of the study may have affected final 12th rib fat thickness. Sissom et al., (2007) reported BF to increase linearly on carcasses as DOF increased. Meanwhile Winterholler et al., (2007) reported steers fed 150 days had the least amount of BF; significantly less than steers fed 171 days but similar to steers fed 192 days.

KPH was affected by DOF in the present study irrespective of covariate (Table 9). KPH followed a similar pattern observed in 12th rib fat deposition. Heifers fed 79 d exhibited the least amount of KPH compared to any other heifer group. When the data was adjusted to a common age, KPH deposition followed a quadratic response, where KPH leveled off after 100 DOF. When data was adjusted to either a common HCW or BF, KPH was cubic in nature across DOF with KPH decreasing after 142 d of feed. Since HCW and BF also decreased in the 163 d group, the results seen with KPH follow that same trend. This could again be the result of a smaller group of heifers fed 163 d.

Van Koevering et al., (1995) also reported a cubic response in KPH and suggested KPH reached a plateau value across DOF. Similar results in steers fed for 114 d or less had lower percentage of KPH than steers fed 125 d or greater were also reported by Hicks et al., (1987). Sissom et al., (2007) reported steer carcasses had less KPH as DOF increased. Winterholler et al., (2007) reported an increase in KPH percentage in steer carcasses fed 150 days compared to steer carcasses fed 171 days or 192 d

As expected, there were no differences for USDA YG across DOF when data was adjusted to a common BF or HCW. This makes sense since USDA YG is a calculated variable from HCW, LMA, BF and KPH. A minimum of 2 dependent variables adjusted for each covariate were similar in value across DOF. However, when the data was adjusted to a common age across DOF, a quadratic response was observed for USDA YG. Heifers fed 79 or 100 d had lower USDA YG compared to the other groups. Heifers fed 79 or 100 d, even with more than desired BF, still had an average USDA YG of less than 3.0. However, there was no difference in USDA YG in heifers fed 121, 142 or 163 d. Even heifers fed more than 100 d with large

amounts of BF and KPH had USDA YG averages of less than 4.0. This does speak to the amount of muscle in this set of heifers.

Van Koevering et al., (1995) reported more undesirable USDA YG values as DOF increased. Winterholler et al., (2007) reported USDA YG values increased in steer carcasses from 150 to 171 days on feed. However, USDA YG values were similar in steer carcasses fed either 171 or 192 days. Sissom et al., (2007) also reported an increase in USDA YG in steer carcasses as DOF increased. Heifers in this study produced carcasses with excellent marbling scores. Of the 71 heifers slaughtered, there was one standard carcass (d 79) and four select carcasses. All other carcasses had USDA QG of low choice or higher. There were no differences in MS in carcasses adjusted to a common age at slaughter across DOF. When carcasses were adjusted to a common HCW, MS increased linearly as DOF increased (Table 9). There was a cubic response in MS when carcasses were adjusted to a common BF. Sissom et al. (2007), Van Koevering et al. (1995), and Winterholler et al., (2007) were in agreement with the present study by observing MS to increase across DOF in steer carcasses.

Sire Breed Types

Several carcass traits were affected by sire breed type (Table 10) including LM, KPH, YG and MS. However, when data was adjusted to a common age at slaughter or BF, sire breed type did not affect HCW. These findings are similar to the study by King et al., (2006) which observed no differences in HCW across breed types. In contrast, Wheeler et al., (2005), in the cycle VII studies of the Germplasm Evaluation study, found Continental sired animals to have significantly heavier HCW than British sired animals when adjusted to at a common FT, MS, or fat trim. However, at a constant age, there were no differences in HCW between carcasses of Angus and Simmental sired steers. Gruber et al., (2007) also reported Continental sired steer

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carcasses had significantly heavier HCW than British or Brahman sired steer carcasses. Boles et al., (2009) also observed Continental steer and heifer sired carcasses to produce heavier HCW than British steer and heifer sired carcasses.

When adjusted to a common age at slaughter, LMA was not affected by sire breed types. However, differences were found when the data was adjusted to a common HCW or BF. Carcasses from Continental and British-Continental sired heifers were heavier than carcasses from British sired heifers when adjusted to a common HCW. However, adjusted to a common BF, only carcasses from Continental sired heifers were heavier than carcasses from British sired heifers. This is a bit puzzling since there were no differences in age at slaughter among sire breed types.

These findings are in agreement with several studies in the literature (Gruber et al., (2007), Wheeler et al., (2005), and Boles et al., (2009)). Gruber et al., (2007) reported carcasses produced by Continental-sired steers were larger than LMA of British and Brahman crossbred carcasses, respectively. At a common age, fat thickness, marbling score, and fat trim percent, Continental sire breeds had larger LMA than British sire breeds in Cycle VII of the Germ Plasm Evaluation study (Wheeler et al., 2005). However, Wheeler (2005) did not observe the same trend when adjusted to a common carcass weight. Boles et al., (2009) reported that British sired steers and heifers carcasses had significantly higher LMA that Continental steers and heifer carcasses.

Meanwhile BF was not affected among sire breed types when adjusted to a common age at slaughter or a common HCW. Previous research findings disagree. Gruber et al., (2007) observed carcasses from British sired steers to have more BF than Continental sired steer carcasses. Wheeler et al., (2005) reported at a constant age or weight, BF was significantly

higher for British sired carcasses than for Continental sire breeds. But, at a constant fat trim

percent, there were no sire breed differences in BF in the Cycle VII Wheeler et al.,(2005), study.

Sire breed type affected KPH, regardless of covariate. Carcasses from Continental-

British sired heifers exhibited more KPH than the other three sire breed types. Carcasses from

British-Continental sired heifers were intermediate in KPH value, while carcasses from British-

or Continental- sired heifers displayed the least amount of KPH. At a constant weight, Wheeler

et al., (2005) disagreed, finding breed sire type to be similar for KPH percentage in steer

carcasses. Gruber et al., (2007) also observed no sire breed differences for percentage of KPH.

When adjusted to a common age at slaughter, USDA YG was not affected by sire breed

types. Differences were reported at a constant HCW for USDA YG. Carcasses from

Continental sired heifer carcasses had lower USDA YG than carcasses from British sired heifers

at a constant HCW, while heifer carcasses sired by British-Continental bulls had similar USDA

YG with all other sire breed types. Meanwhile, USDA YG of carcasses from British-Continental

sired heifer was lower than USDA YG of carcasses from British- and Continental-British-sired

heifers, at a constant BF. Continental sired heifer carcasses had similar USDA YG as all other

sire breed types adjusted to a common BF. At a constant fat thickness and fat trim endpoints,

there were no differences among sire breeds in the Cycle VII study (Wheeler et al., (2005). At a

constant age and weight endpoints, Wheeler et al., (2005) observed British sire breeds to have

significant higher USDA YG. However, Boles et al., (2009) found steer and heifer carcasses

sired by British breeds to have lower USDA YG than Continental sired breeds at both common

age and weight endpoints.

At a constant age at slaughter and BF, the response for MS was the same across sire

breed types. MS was similar across carcasses sired by British and Continental bulls when

adjusted to a common age at slaughter or BF. Carcasses sired by Continental-British bulls had less MS than British and Continental sired carcasses with either covariate of age at slaughter or BF. Carcasses from British-Continental sired heifers were not different for MS from carcasses sired by Continental or Continental-British bulls at a constant age at slaughter or BF. When adjusted to a common HCW, British, British-Continental, and Continental sired heifer carcasses had similar MS. Similarities were also reported in MS with heifer sired carcasses of the composite breeds (Continental-British and British-Continental) at a constant HCW. These results disagree with the findings of Gruber et al., (2007). British sired steer carcasses had higher MS than Continental and Brahman sired steer carcasses (Gruber et al., 2007). Wheeler et al., (2005) reported at a constant age, weight, and fat thickness, MS was significantly higher for Angus steer carcasses than all other sire breeds. However, Wheeler and coworkers (2005) stated at a constant fat trim, Hereford sired steer carcasses tended to have the lowest MS of all other breeds.

Tenderness & Sensory Evaluation

RAC had no effect ($P>0.05$; Tables 11 and 12) on tenderness or sensory evaluation. This included tenderness values from WBSF and sensory traits of initial and sustained tenderness, initial and sustained juiciness, flavor intensity, and off-flavor analyses. Many other studies in the literature also found no tenderness differences in steaks from animals fed RAC. Quinn et al., (2008) reported WBSF to be similar for treatment (200 mg/hd / d) heifers verses control (0 mg/ hd/ d) heifers. Schroeder et al., (2004b) reported 100 or 200 mg/ hd/ d dosage of RAC administered to cattle had no effect on WBSF, but found an increase in WBSF when the dosage of RAC was increased to 300 mg hd $^{-1}$ d^{-1}. Avendano-Reyes et al., (2006) agrees with Schroeder et al., (2004b) study by reporting an increase in WBSF when steers were administered 300 mg/

hd/ d/ of RAC. Gruber et al., (2008) study contradicted the current study as well as Schroeder (2004b). Gruber et al., (2008) observed an increase in WBSF for steers fed 200 mg/ hd/ d compared to controls.

CONCLUSIONS

In this study, days on feed affected post-weaning growth and carcass characteristics in heifers more than feeding a beta-agonist 35 d prior to slaughter. Adjusting data to a common weight, as days on feed increased, total weight gain and dry matter intake increased. However, no differences were seen for either ADG or DMFE. Adjusting data to a common age, as days on feed increased, total weight gain increased. There were also differences in ADG. Heifers fed 100 d had greater ADG than heifers fed 79 d. Heifers fed 100 d produced carcasses that were leaner (12th rib fat and USDA YG) than heifers fed longer than 100 d. There were no differences in LMA among heifer groups. As heifers were fed longer, marbling score, regardless of covariate, increased although there was no group that did not produce a minimum of average choice carcasses. However, heifers fed 79 or 100 d did have lighter HCW than all other groups when adjusted for age. There were no HCW differences when adjusting to a common 12th rib fat. Data from this study suggest heifers on feed longer than 100 or 121 d will not provide more salable product. Heifers fed longer than 121 days have improved MS, but significantly larger USDA yield grades. From this dataset, feeding yearling heifers 100 days is optimum. Ultimately, it will depend on Select/Choice spread and discounts for USDA yield grades over 3.5.

The addition of RAC to the diet only affected DMFE for the last 35 d prior to harvest in these heifers. Heifers fed RAC had a lower dry matter F:G ratio. The highlight of this research project is the difference between control and treatment heifers DMFE values when adjusted to an

initial weight. RAC did not affect tenderness traits or sensory evaluation. It is unclear why the

heifers did not respond more favorably to the level of RAC administered as seen in other

published data. The large amount of subcutaneous fat levels that the heifers started the project

with should have increased the effects of RAC.

Table 1. Simple means and standard errors of initial traits for yearling, crossbred heifers by treatment group

| Trait | Treatment[1] | |
	Control	RAC
Number of heifers	36	35
Delivery Weight, kg	384.3 ± 11.8	386.4 ± 14.4
Delivery Height, cm	123.9± 0.2	125.2± 0.2
On-Test Weight, kg	431.8 ± 11.9	435.2 ± 14.0
On-Test Height, cm	125.2 ± 0.2	126.5± 0.2
On-Test 12th rib fat thickness, mm	10.4 ± 0.02	9.9 ± 0.03
Age, days	408 ± 5.9	395 ± 5.5

[1] RAC = Ractopamine HCL fed 300 mg/hd/d 35 day prior to harvest
Control = no supplement fed

Table 2. Composition of the diet fed to yearling heifers[1]

Ingredient	Percentage
Big Screen Corn	38.5
Wheat Midds	6.5
Corn Gluten Pellets	17.5
Dried Distillers Grain	9.5
Cottonseed hull pellets	10.0
Cottonseed hulls	5.0
Limestone	1.25
Soyhulls	6.5
Salt	0.5
Vitamins A,D,E	0.1
BICARB	1.0
Trace Minerals	0.1
Rumensin 80	0.019
Molasses	2.5
Fat	1.0

[1]As calculated: DM = 90.15%; CP = 13.66%, NDF = 32.17%, ADF = 15.72, NE_m = 1.48 Mcal/kg, NE_g = 0.76 Mcal/kg

Table 3. Simple means and standard errors of initial traits for yearling, crossbred heifers by days on feed

Traits	Days on Feed				
	79	100	121	142	163
Number of heifers	16	16	16	16	7
Delivery Weight, kg	383.9 ± 16.0	384.1 ± 18.2	388.2 ± 25.6	387.3 ± 20.4	380 ± 22.6
Delivery Height, cm	124.5 ± 0.3	124.5 ± 0.3	125.1 ± 0.4	124.5 ± 0.3	124.5 ± 0.4
On-Test Weight, kg	438.1 ± 15.8	433.6 ± 21.3	434.0 ± 24.7	433.1 ± 18.3	421.3 ± 16.9
On-Test Height, cm	124.5 ±0.3	125.8 ± 0.4	126.5 ± 0.5	124.5 ± 0.3	124.5 ± 0.5
On-Test 12th rib fat thickness, mm	10.2± 0.03	9.9 ± 0.03	10.4 ± 0.04	10.4 ± 0.05	9.9 ± 0.07
Age, days	396 ± 8.9	412 ± 9.8	394 ± 8.8	412 ± 6.4	386 ± 13.0

Table 4. Least squares means for postweaning traits across days on feed for the entire feeding with initial weight as covariate

Trait[1]	Days on Feed					P-value
	79	100	121	142	163	
Number of heifers	15	16	16	15	5	
GAIN, kg	98 ± 8.5^{a}	133 ± 8.3^{b}	151 ± 7.6^{bc}	156 ± 7.1^{c}	194 ± 13.8^{d}	< 0.01
ADG,kg	1.24 ± 0.1	1.32 ± 0.1	1.25 ± 0.1	1.10 ± 0.1	1.18 ± 0.1	0.25
DMI,kg	797 ± 37^{a}	1096 ± 36.1^{b}	1153 ± 32.9^{c}	1277 ± 30.7^{d}	1493 ± 60^{e}	<0.01
DMFE	8.3 ± 0.4	7.5 ± 0.4	7.7 ± 0.4	8.5 ± 0.3	7.9 ± 0.7	0.33

Data represent least squares means ± SEM
[a-e]Means in a row not bearing a common superscript differ, $P < 0.05$.
[1]GAIN = final weight minus initial weight
ADG = average daily gain
DMI = dry matter intake
DMFE = Dry matter feed efficiency defined as dry matter intake divided by gain

Table 5. Performance trait least squares means for entire length of trial with age at slaughter as a covariate across days on feed

			Days on Feed			
Item	79	100	121	142	163	P-value
Number of Heifers	15	16	16	15	5	
Gain,kg	88.87 ± 9.1^{a}	132.37 ± 7.9^{b}	151.13 ± 7.2^{c}	167.98 ± 7.9^{c}	200.91 ± 13.5^{d}	0.01
ADG, kg	1.14 ± 0.1^{a}	1.31 ± 0.1^{b}	1.25 ± 0.1^{ab}	1.21 ± 0.1^{ab}	1.25 ± 0.1^{ab}	0.01
DMI,kg	766.95 ± 44.6	966.31 ± 39.0	1148.64 ± 35.5	1309.63 ± 38.9	1494.23 ± 66.0	0.12
DMFE	8.77 ± 0.5	7.52 ± 0.4	7.70 ± 0.4	8.05 ± 0.4	7.53 ± 0.7	0.06

Data represent least squares means ± SEM
[a-c]Means in a row not bearing a common superscript differ, P < 0.05.
[1]Gain = final weight minus initial weight
ADG = average daily gain
DMI = dry matter intake
DMFE = Dry matter feed efficiency defined as dry matter intake divided by gain

Table 6. Performance trait least squares means for treatment 35 days pre-harvest using initial weight as a covariate

| Trait[1] | Treatment[2] | | P-value |
	Control	RAC	
Number of heifers	32	35	
Gain,kg	39 ± 2.7	43 ± 2.2	0.0762
ADG, kg	1.11 ± 0.1	1.24 ± 0.1	0.0743
DMI,kg	333 ± 10.4	318 ± 8.5	0.1547
DMFE	9.82 ± 1.07[a]	7.38 ± 0.8[b]	0.0205

Data represent least squares means ± SEM
[a,b]Means in a row not bearing a common superscript differ, P < 0.05.
[1]ADG = average daily gain
 DMI = dry matter intake
 DMFE = Dry matter feed efficiency defined as dry matter intake divided by gain
[2] RAC = Ractopamine HCL fed 300 mg/hd/d 35 day prior to harvest
        Control = no supplement fed

Table 7. Performance trait least squares means across days on feed 35 days pre-harvest using initial weight as a covariate

Trait[1]	Days on Feed					Contrast	P-value
	79	100	121	142	163		
Number of heifers	15	16	16	15	5		
Gain, kg	40.75 ± 3.2^{ab}	47.68 ± 3.1^{b}	43.11 ± 2.9^{b}	35.75 ± 2.7^{a}	40.90 ± 40.9^{ab}	Cubic	0.0443
ADG, kg	1.16 ± 0.1^{ab}	1.35 ± 0.1^{b}	1.23 ± 0.1^{b}	1.01 ± 0.1^{a}	1.14 ± 0.1^{ab}	Cubic	0.0352
DMI, kg	349 ± 12.4^{a}	336 ± 12.1^{ac}	336 ± 11.1^{ac}	306 ± 10.3^{b}	303 ± 20.2^{bc}	Linear	0.0249
DMFE	10.02 ± 1.2	7.24 ± 1.2	7.88 ± 1.1	9.77 ± 1.0	8.09 ± 2.0	---	0.2642

Data represent least squares means ± SEM
[a-c]Means in a row not bearing a common superscript differ, P < 0.05.
[1]Gain = final weight minus initial weight
ADG = average daily gain
DMI = dry matter intake
DMFE = Dry matter feed efficiency defined as dry matter intake divided by gain

Table 8. Performance trait least squares means across days on feed for 35 days pre-harvest using age at slaughter as a covariate

| Item | Days on Feed | | | | | Contrast | P-Value |
	79	100	121	142	163		
Number of Heifers	15	16	16	15	5		
Gain, kg	37.90 ± 3.6^a	47.24 ± 3.2^b	42.88 ± 2.9^{ab}	38.66 ± 3.2^a	42.04 ± 5.4^{ab}	Cubic	0.0525
ADG, kg	1.08 ± 0.1^a	1.30 ± 0.1^b	1.22 ± 0.1^{ab}	1.08 ± 0.1^a	1.16 ± 0.2^{ab}	Cubic	0.0451
DMI, kg	342.11 ± 15.1	333.54 ± 13.2	334.18 ± 12	313.91 ± 13.2	301.15 ± 22.5	---	0.1251
DMFE	10.56	7.22	7.86	9.22	7.55	---	0.1763

Data represent least squares means ± SEM
[a-c]Means in a row not bearing a common superscript differ, P < 0.05.
[1]Gain = final weight minus initial weight
ADG = average daily gain
DMI = dry matter intake
DMFE = Dry matter feed efficiency defined as dry matter intake divided by gain

Table 9. Carcass traits least squares means across days on feed 35 d before slaughter adjusted to 3 covariates of age at slaughter, hot carcass weight, and 12th rib fat

Trait	Days on Feed					Contrast	P-Value
	79	100	121	142	163		
HCW, kg $_{AAS}$	320.30 ±11.6 ^{a}	341.96 ± 10.1^{ac}	362.75 ± 9.4^{bc}	358.49 ± 10.2^{bc}	350.70 ± 15.4^{ac}	Quad	0.0378
HCW, kg $_{BF}$	330.00 ± 9.6	353.64 ± 9.4	355.00 ± 8.5	350.45 ± 8.2	352.73 ± 12.9	--	0.1561
LMA, cm^2 $_{AAS}$	86.90 ± 1.2	87.74 ± 1.0	88.64 ± 0.8	88.45 ± 1.0	84.90 ± 2.2	---	0.8933
LMA, cm^2 $_{HCW}$	88.36 ± 1.0	88.56 ± 0.8	87.02 ± 0.8	89.40 ±0.6	86.56 ± 1.6	--	0.9109
LMA, cm^2 $_{BF}$	83.54 ± 1.2	86.84 ± 1.2	88.97 ± 1.0	91.41 ± 0.8	87.09 ± 2.2	--	0.3339
12th Rib Fat, mm $_{AAS}$	16.20 ± 2.2^a	15.40 ± 2.0^a	24.10 ± 1.7^b	24.30 ± 2.0^b	20.00 ± 3.0^a	Cubic	0.0029
12th Rib Fat, mm $_{HCW}$	18.20 ± 1.7^{ab}	16.20 ± 1.7^b	22.80 ± 1.5^{ac}	24.30 ± 1.5^c	20.50 ± 2.5^{abc}	Cubic	0.0082
KPH % $_{AAS}$	2.38 ± 0.2^a	3.68 ± 0.1^{bc}	4.04 ± 0.1^b	3.61 ± 0.1^{bc}	3.34 ± 0.2^c	Quad	<0.0001
KPH % $_{HCW}$	2.57 ± 0.1^a	3.73 ± 0.1^{bc}	3.96 ± 0.1^b	3.55 ± 0.1^c	3.32 ± 0.2^c	Cubic	< 0.0001
KPH % $_{BF}$	2.49 ± 0.1^a	3.780 ± 0.1^{bc}	3.97 ± 0.1^b	3.52 ± 0.1^c	3.34 ± 0.2^c	Cubic	<0.0001
USDA Yield Grade$_{AAS}$	2.67 ± 0.3^a	2.94 ± 0.2^a	3.90 ± 0.2^b	3.86 ± 0.2^b	3.46 ± 0.4^{ab}	Quad	0.0111
USDA Yield Grade $_{HCW}$	3.07 ± 0.2	3.05 ± 0.2	3.74 ± 0.2	3.75 ± 0.2	3.45 ± 0.2	Quad	0.1191
USDA Yield Grade $_{BF}$	3.37 ± 0.1	3.62 ± 0.1	3.49 ± 0.1	3.29 ± 0.1	3.47 ± 0.1	---	0.2339
Marbling Score[1]$_{AAS}$	594 ± 31.8^{ab}	566 ± 27.6^{ac}	543 ± 25.7^a	637 ± 27.8^b	634 ± 42.0^{bc}	---	0.061
Marbling Score[1]$_{HCW}$	595 ± 30.4^{abc}	568 ± 27.6^{ab}	539 ± 26.1^b	642 ± 24.3^c	641 ± 39.9^{ac}	Linear	0.0179
Marbling Score[1]$_{BF}$	597 ± 29.6^{ab}	575 ± 28.9^{ab}	536 ± 26.2^a	636 ± 20.2^b	641 ± 39.7^b	Cubic	0.0245

Data represent least squares means ± SEM
[a-c]Means in a row not bearing a common superscript differ, P < 0.05.
[1]Marbling scores were determined by the USDA grading service using a scale of: traces = 200 to 299; slight = 300 to 399; small = 400 to 499; modest = 500 to 599; moderate = 600 to 699; slightly abundant = 700 to 799; moderate abundant = 800 to 899; and abundant = 900 to 999.
$_{AAS}$ Age at Slaughter covariate $_{HCW}$ Hot Carcass Weight covariate $_{BF}$ 12th Rib Fat thickness covariate

Table 10. Least squares means of sire breed types of crossbred yearling heifers using the covariates of age at slaughter weight, kg; hot carcass weight, kg; and 12th rib fat, cm.

Trait	Sire Breed Types				
	British	British-Continental	Continental	Continental-British	P-Value
HCW, kg $_{AAS}$	352.15 ± 5.7	337.57 ± 21.4	357.70 ± 8.8	339.95 ± 10.1	0.7740
HCW, kg $_{BF}$	349.09 ± 5.1	342.27 ± 18.9	362.73 ± 7.5	339.55 ± 8.9	0.1902
LMA, cm^2 $_{AAS}$	83.80 ± 2	93.67 ±4.4	88.85 ±0.8	83.22 ± 0.1	0.0988
LMA,cm^2 $_{HCW}$	83.54 ± 0.2^a	95.73 ± 3.6^b	88.69 ± 0.6^{bc}	84.04 ± 0.8^{ac}	0.0237
LMA,cm^2 $_{BF}$	83.94 ± 0.01^a	94.05 ± 0.09^{ab}	89.61 ± 0.01^b	82.70 ± 0.04^{ab}	0.0238
12th Rib Fat, mm $_{AAS}$	21.80 ± 1.0	18.70 ± 4.3	18.50 ± 1.7	20.80 ± 2.0	0.4684
12th Rib Fat, mm $_{HCW}$	21.80 ± 1.0	20.00 ± 3.8	18.20 ± 1.5	21.50 ± 1.7	0.2774
KPH % $_{AAS}$	3.16 ± 0.1^a	3.28 ± 0.3^{ab}	3.23 ± 0.1^a	3.97 ± 0.1^b	0.0025
KPH % $_{HCW}$	3.15 ± 0.1^a	3.35 ± 0.3^{ab}	3.18 ± 0.1^a	4.03 ± 0.1^b	0.0003
KPH % $_{BF}$	3.14 ± 0.1^a	3.31 ± 0.3^{ab}	3.26 ± 0.1^a	3.97 ± 0.1^b	0.0014
USDA Yield Grade $_{AAS}$	3.78 ± 0.1	2.75 ± 0.3	3.23 ± 0.1	3.72 ± 0.2	0.1461
USDA Yield Grade $_{HCW}$	3.75 ± 0.1^a	2.91 ± 0.5^{ab}	3.13 ± 0.2^b	3.85 ± 0.2^a	0.0347
USDA Yield Grade $_{BF}$	3.63 ± 0.1^a	2.98 ± 0.2^b	3.45 ± 0.1^{ab}	3.72 ± 0.1^a	0.0238
Marbling Score[1] $_{AAS}$	685 ± 15.6^a	530 ± 58.5^{bc}	631 ± 24.1^{ab}	560 ± 27.6^c	0.0119
Marbling Score[1] $_{HCW}$	657 ± 15.6^{ac}	535 ± 58.4^{bc}	633 ± 23.2^c	562 ± 27.7^b	0.0168
Marbling Score[1] $_{BF}$	656 ± 15.6^a	636 ± 58.0^{bc}	638 ± 23.1^{ab}	559 ± 27.2^c	0.0122

Data represent least squares means ± SEM
[a-c]Means in a row not bearing a common superscript differ, $P < 0.05$.
[1]Marbling scores were determined by the USDA grading service using a scale of: traces = 200 to 299; slight = 300 to 399; small = 400 to 499; modest = 500 to 599; moderate = 600 to 699; slightly abundant = 700 to 799; moderate abundant = 800 to 899; and abundant = 900 to 999.
$_{AAS}$ Age at Slaughter covariate $_{HCW}$ Hot Carcass Weight covariate $_{BF}$ 12th Rib Fat thickness covariate

Table 11. Warner-Bratzler shear force and sensory evaluation results due to treatment

Traits	Control	RAC	P-value
Warner-Bratzler Shear Force, kg	3.66 ± 0.08	3.54 ± 0.07	0.2939
Initial Juiciness	5.27 ± 0.08	5.36 ± 0.07	0.4508
Sustained Juiciness	5.12 ± 0.08	5.20 ± 0.07	0.4421
Initial Tenderness	5.34 ± 0.07	5.33 ± 0.06	0.8846
Sustained Tenderness	5.20 ±0.7	5.22 ± 0.06	0.8445
Flavor Intensity	4.90 ± 0.06	4.81 ± 0.05	0.2470
Off Flavor	1.91 ± 0.09	1.97 ± 0.08	0.6265

Data represent least squares means ± SEM
[a-c]Means in a row not bearing a common superscript differ, P < 0.05.

Table 12. Warner-Bratzler shear force and sensory evaluation results across days on feed

Traits	Days on Feed					P-value
	79	100	121	142	163	
Warner-Bratzler Shear Force, kg	3.62 ± 0.11	3.45 ± 0.10	3.49 ±0.10	3.81 ±0.11	3.6 ±0.17	0.2939
Initial Juiciness	5.22 ± 0.11	5.14 ± 0.10	5.16 ± 0.10	5.26 ± 0.11	5.79 ±0.17	0.4032
Sustained Juiciness	4.99 ± 0.11	5.00 ±0.10	5.07 ± 0.10	5.17 ± 0.11	5.59 ± 0.17	0.2105
Initial Tenderness	5.26 ± 0.09	5.23 ± 0.09	5.20 ±0.08	5.21 ± 0.09	5.79 ± 0.14	0.1088
Sustained Tenderness	5.11 ±0.10	5.07 ± 0.09	5.15 ± 0.09	5.20 ± 0.10	5.54 ± 0.16	0.2291
Flavor Intensity	4.73 ± 0.08	4.78 ±0.07	4.88 ±0.07	4.72 ± 0.08	5.17 ± 0.12	0.6388
Off Flavor	2.16 ± 0.13	1.85 ±0.12	1.91 ±0.11	1.98 ± 0.12	1.81 ± 0.19	0.7105

Data represent least squares means ± SEM
[a-c]Means in a row not bearing a common superscript differ, $P < 0.05$.

Figure 1. Trained sensory evaluation form

Name _____ Date _____ Time _____ Project _____

Sample No	Initial juiciness	Sustained juiciness	Initial tenderness	Sustained tenderness	Flavor intensity	Off Flavor	Off Descriptor
1							
2							
3							
4							
5							
6							
7							
8							

Juiciness	Tenderness	Flavor intensity	Off Flavor	Off Flavor descriptors
8 = Extremely juicy	8 = Extremely tender	8 = Extremely intense beef	8 = Extremely off flavor	8 = Metallic
7 = Very juicy	7 = Very tender	7 = Very intense beef	7 = Very off flavor	7 = Salty
6 = Moderately juicy	6 = Moderately tender	6 = Moderately intense beef	6 = Moderately off flavor	6 = Livery
5 = Slightly juicy	5 = Slightly tender	5 = Slightly intense beef	5 = Slightly off flavor	5 = Grassy
4 = Slightly dry	4 = Slightly tender	4 = Slightly intense beef	4 = Slightly off flavor	4 = Bitter
3 = Moderately dry	3 = Moderately tender	3 = Moderately intense beef	3 = Moderately off flavor	3 = Bloody
2 = Very dry	2 = Very tender	2 = Very intense beef	2 = Very off flavor	2 = Rancid
1 = Extremely dry	1 = Extremely tender	1 = Extremely intense beef	1 = Extremely off flavor	1 = Other

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