Influence of ractopamine hydrochloride and days on feed on feedlot performance and red meat yield in thin cull beef cows targeted for a lean market

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ABSTRACT: Thin, beef, cull cows [$n = 144$; initial body weight (**BW**) = 465.8 ± 56.9 kg, initial body condition score (**BCS**) = 2.13 ± 0.68] were serially slaughtered to evaluate the relationship between ractopamine hydrochloride (**RH**) administration and days on feed (**DOF**) on feedlot performance and carcass cutout value in a lean cow market. Cows were organized into a 3 × 2 factorial arrangement of treatments (48 pens, 8 pens per treatment, 3 cows per pen) and blocked by BW nested within pregnancy status. Treatment pens were top-dressed 400 mg per cow per day of RH (Actogain 45; Zoetis, Parsippany, NJ) for the final 28 d prior to slaughter to cows spending 28, 42, or 56 DOF. Pen served as the experimental unit, for all calculations. No RH × DOF interactions were detected ($P \geq 0.11$), indicating that despite a majority of compensatory gain occurring during the first 28 d of the trial, the magnitude of the RH response was not affected by DOF. Compared to controls, RH incited improvements in feedlot performance, but had a greater extent on carcass weight gain and efficiency. Specifically, RH improved average daily gain (**ADG**) by 13.7% ($P = 0.04$) and carcass ADG by 16.9% ($P = 0.02$) Cattle fed RH displayed a 15.5% improved gain to feed ratio ($P = 0.02$) and a 20% improved carcass gain to feed ratio ($P = 0.05$). Inclusion of RH in the finishing diet increased hot carcass weight by 4.5% ($P = 0.05$; 12.9 kg). However, supplementation of RH did not alter red meat yield ($P \geq 0.16$), but provoked a 11.1% improvement in lean maturity ($P < 0.01$). Evaluation of the main effect of DOF provided insight into the compensatory state of beef cull cows on a high-concentrate diet. Serial slaughter offal weights presented confounding results. With additional DOF, a numerical increase in liver weights ($P = 0.20$) suggested that organ tissue replenishment occurred throughout the trial, and cattle experienced compensatory gain during the entire feeding phase. In contrast, lung and heart weights were not altered, while kidney tended to decrease linearly ($P = 0.08$) despite additional DOF. Furthermore, extending DOF generated a linear increase in dry matter intake ($P < 0.01$) yet a tendency for a decline in ADG ($P = 0.10$), reinforcing the premise that most of compensatory gain occurred during the first 28 d of the trial. If thin (BCS ≤ 4), healthy candidates can be finished, feeders can reap the benefits of an additive relationship between compensatory gain and RH.

Key words: beta agonist, compensatory gain, cull cow, days on feed, ractopamine hydrochloride, serial slaughter

INTRODUCTION

Cull cow sales typically account for up to 20% of a cow calf enterprises gross revenue (NCBA, 2016), economic analyses suggest a near $70 loss for each non-concentrate fed cow sent to slaughter (Schnell et al., 1997). Customarily, producers sell cull cows at the nadir of their annual body weight (**BW**), most often following weaning, due to poor performance or reproductive inefficiency. The high metabolic demands of lactation in concert with nutrient restriction often cause fat and muscle tissue to be catabolized, lowering cull cow pay weight. This paradigm can also be viewed as an opportunity due to lower metabolic nutritional requirements and subsequent compensatory growth. The reduction of NE_m following nutrient deprivation has been attributed to viscera tissue catabolism (Burrin et al., 1989) and modified cellular ion pumping (Lobley et al., 1992). Not surprising, Freetly and Nienaber (1998) found that cull cows are often thin and can experience rapid growth on high-concentrate diets due to pronounced caloric economy and nitrogen retention.

Realimentation featuring high-energy diets has increased cull cow carcass red meat yields (Schnell et al., 1997). This lean tissue accretion may be further amplified with the supplementation of β-adrenergic agonists (**β-agonists).** More specifically, ractopamine hydrochloride (**RH**) has regularly improved the live performance and saleable carcass yields of young cattle (Pyatt et al., 2013; Howard et al., 2014). Although research has identified the effects of RH supplementation, given the variance in concentration, duration, sex, and age in studies, the repartitioning effects of protein and lipid metabolism vary greatly. Despite the response of cull cows to zilpaterol hydrochloride (Strydom and Smith 2010; Lawrence et al., 2011), no performance improvements of RH fed cull cows have been published (Carter et al., 2006; Dijkhuis et al., 2008; Holmer et al., 2009; Weber et al., 2012). Consequently, the purpose of this study was to evaluate the relationship between RH and compensatory gain in beef cull cows. Given this agenda, cows were serially harvested to extrapolate the arc of feedlot performance and red meat yield across varying days on feed (**DOF**) in order to ascertain the optimal duration for a lean market.

MATERIALS AND METHODS

All procedures of live animals were approved by the Texas Tech Institutional Animal Care and Use Committee (16051-05).

Cattle

A total of 203 mature beef cull cows were transported on five semi-loads to the Texas Tech Beef Center Teaching and Research Unit in New Deal, TX, on May 24, 2016. Eighty-three cows were sourced from a West Texas Ranch, 40 cows from a Wyoming sale barn, 40 from a Nebraska sale barn, and 40 from an Oklahoma sale barn. After arrival, cows were palpated by a professional embryologist to determine pregnancy status and projected length of gestation and scanned for carcass estimates [rib fat thickness (**FT**), ribeye area, and intramuscular fat percentage] by a Ultrasound Guidelines Council certified carcass ultrasound technician. Shrunk BW, body condition scores (**BCS**), chute disposition score, and general thriftiness notes were recorded on each candidate.

The 144 cows selected for inclusion were either nonpregnant or less than or equal to 4 mo bred, ranged in visual BCS from 2 to 4, scanned less than or equal to 6.35 mm of FT, appeared structurally sound, healthy, and not physically weak, and did not have unmanageable dispositions. Cattle were assigned a subjective chute score of 1 to 5, using the method outlined by Curley et al. (2006). Cows designated with chute scores 4 and 5 were precluded from use in the trial.

Experimental Design

Cows were stratified into a 3 × 2 factorial arrangement of treatments and blocked by pregnancy status (nonpregnant or ≤4 months bred) and BW nested within pregnancy status. A total of 8 blocks, with 5 representing open cows and 3 containing bred cows, were organized in 48 three-animal pens. Pens were randomly divided into treatments such that half of the cows on trial were fed 400 mg per cow per day of RH (Actogain 45; Zoetis, Parsippany, NJ) for the last 28 d, while the remaining half were designated as controls and received no RH. Cows were serially harvested after three feeding duration periods (28, 42, or 56 DOF).

Cattle Management

Prior to trial initiation all cattle were provided ad libitum access to round grass bale hay (WW-B. Dahl Bluestem; *Bothriochloa bladhii*) and water. On June 1, 2016 (day 1) cows designated to the study were reweighed individually and administered a trenbelone acetate–estradiol combination implant (Synovex Plus; Zoetis, Parsippany, NJ) and an oral

anthelmintic (Valbazeen; Zoetis, Parsippany, NJ). Cows were housed in soil surface pens (3 × 15.2 m) with 1 m of linear buck space per cow. Two diets were fed during the trial (Table 1). All pens were top-dressed with 0.45 kg of ground corn per cow per day during the final 28 d of each finishing period. This ground corn was a carrier for pens assigned to the RH treatment and was formulated to contain 400 mg per cow per day of RH (Actogain 45). No RH was included in the ground corn for pens designated to the control treatment.

On the first day of the study, cows were fed approximately 1.5% of their BW on an as-fed basis of the starter diet top-dressed over grass hay (2.3 kg hay per cow). Over a 5-d period cows were stepped up to increase intake of the starter diet to 2.0% of their BW on an as-fed basis, which was delivered over ground hay (2.3 kg hay per cow). The following 5 d served as a transition period as hay was excluded and the starter was blended with the finishing diet. The day 6 blend contained a 75:25 starter to finisher ratio on a dry matter (**DM**) basis, the day 7 blend contained a 60:40 starter to finisher ratio on a DM basis, the day 8 blend contained a 45:55 starter to finisher ratio on a DM basis, the day 9 blend contained 30:70 starter to finisher ratio on a DM basis, and the day 10 blend contained 15:85 starter to finisher ratio on a DM basis. From day 11 to trial completion, cows were offered 100% of the finisher diet. A clean bunk management system was utilized, where following two consecutive days of clean bunks cattle were offered an additional kilogram of feed (as-fed basis). Feed was delivered daily using a tractor-pulled Roto-Mix with a scale which measured within 0.45 kg. Daily feed records by pen were maintained and daily feed samples were collected and stored for DM analysis (forced-air oven for approximately 24 h at 100 °C). Weekly composite samples were analyzed for chemical composition (Servi-Tech Laboratories, Amarillo, TX) and presented in Table 1. Water troughs were cleaned twice weekly and a daily log was maintained to track health and monitor heat stress. No cows were treated for clinical signs of bovine respiratory disease through the duration of the study. On the day cattle were designated for harvest, prior to shipment cows were individually weighed and assigned a subjective BCS by the same trained evaluator that assessed them at the onset of the trial.

Postmortem Data Collection

Cattle in each serial harvest treatment were shipped on June 29, July 13, and July 27, 2016,

Table 1. Composition and analyzed nutrient content (DM basis) of diets fed during the experimental period

| Item | Diets[1] | |
	Starter[2]	Finisher[3]
Corn grain, steam flaked	0.00	50.00
Corn grain, cracked	15.00	0.00
Wet corn gluten feed[4]	52.00	27.90
Cotton burrs, ground	15.00	15.00
OW bluestem, fair	15.00	0.00
Limestone	2.00	1.50
Urea	0.00	0.45
Tallow	0.00	3.15
TTU supplement[5]	1.00	0.00
TTU supplement[6]	0.00	2.00
Analyzed composition[7]		
Dry matter, %[8]	70.60	75.20
Crude protein, %	15.90	14.60
Net energy for maintenance, Mcal/kg	1.76	1.91
Net energy for gain, Mcal/kg	1.15	1.27
Total digestible nutrients, %	73.94	78.93
Neutral detergent fiber, %	34.12	22.81
Fat, %	2.81	6.06
Calcium, %	0.92	0.74
Phosphorus, %	0.66	0.50
Potassium, %	1.31	0.94
Magnesium, %	0.34	0.24

[1]Treatment diets were top-dressed with a ground corn carrier (0.45 kg per cow per day) to contain no RH or RH (400 mg per cow per day; Actogain 45, Zoetis, Florham Park, NJ) for the final 28 d before slaughter.

[2]The starter diet was feed to all cows for the first 5 d of the trial. Cattle received a blend of the starter and finisher diet from days 6 to 10 (day 6 blend: 75:25 starter to finisher ratio on a DM basis, day 7 blend: 60:40 starter to finisher ratio on a DM basis, day 8 blend: 45:55 starter to finisher ratio on a DM basis, day 9 blend: 30:70 starter to finisher ratio on a DM basis, and day 10 blend: 5:85 starter to finisher ratio on a DM basis).

[3]The finisher diet was blended with the starter diet from days 6 to 10 and then fed exclusively to all cattle following day 11.

[4]Sweet Bran (Cargill, Dalhart, TX).

[5]Supplement composition (DM basis): 55.04814% ground corn, 40.000% NaCl, 1.9718% zinc sulfate, 0.825% Rumensin-90 (Elanco, Greenfield, IN), 0.506% Tylan-40 (Elanco), 0.500% Endox (Kemin Industries, Des Moines, IA), 0.3929% copper sulfate, 0.5% manganese oxide, 0.3149% vitamin E (500 IU/g), 0.25% selenium premix (0.2% Se), 0.1667% iron sulfate, 0.0198% vitamin A (1,000,000 IU/g), 0.0063% ethylenediamine dihydroiodide, and 0.0043% cobalt carbonate.

[6]Supplement composition (DM basis): 67.755% cottonseed meal, 15.000% NaCl, 10.000% KCl, 3.760% urea, 0.986% zinc sulfate, 0.750% Rumensin-90 (Elanco, Greenfield, IN), 0.506% Tylan-40 (Elanco), melengesterol acetate (MGA 200; Zoetis, Parsippany, NJ; 0.4 mg per cow per day), 0.500% Endox (Kemin Industries, Des Moines, IA), 0.196% copper sulfate, 0.167% manganese oxide, 0.157% vitamin E (500 IU/g), 0.125% selenium premix (0.2% Se), 0.083% iron sulfate, 0.010% vitamin A (1,000,000 IU/g), 0.003% ethylenediamine dihydroiodide, and 0.002% cobalt carbonate.

[7]Weekly composite samples were analyzed for chemical composition (Servi-Tech Laboratories, Amarillo, TX).

[8]Diet DM was calculated using weekly ingredient sample DM records.

respectively, for harvest at Preferred Beef (Booker, TX). At the time of harvest, the liver, kidney, lung, and heart were weighed and recorded by Texas Tech personnel. At 24 h postmortem, carcasses were cut open between the 12th and 13th rib interface by plant employees to enable data collection by a Texas Tech University Gordon W. Davis Meat Laboratory personnel. Measurements assessed and documented were hot carcass weight (**HCW**), loin muscle area (**LMA**), 12th rib **FT**, marbling score, lean maturity, and skeletal maturity. Calculated yield grade was derived according to the standards set forth by the USDA (1997). On the fabrication floor, the ribeye roll [Institutional Meat Purchase Specifications (**IMPS**); 109E], flats (IMPS 120), knuckle (IMPS 167), inside round (IMPS 168), eye round (IMPS 171C), strip loin (IMPS 175), sirloin top butt (IMPS 182), and tenderloin (IMPS 189) were weighed and recorded by a Texas Tech personnel. Additionally, a 2.5-cm-thick steak was removed from the anterior end of the strip loin. Steaks were vacuum packaged, frozen at 0 °C, and later used for analysis of proximate composition.

Prior to proximate analysis, steaks were thawed at 2 °C to 4 °C for 24 h, trimmed to remove exterior fat and connective tissue, and ground to obtain an approximate 200 g sample. Compositional analysis of fat, moisture, protein, and collagen was conducted using an association of official analytical chemists-approved (official method 2007.04; Anderson, 2007) near-infrared spectrophotometer (FoodScan 78800, FOSS, Laurel, MD).Fifteen independent readings were taken per sample and averaged for the final reported chemical value.

Statistical Analysis

Data generated from the study were analyzed as a nested analysis of variance with a 3 × 2 factorial arrangement of treatments using SPSS Statistics 25.0 (IBM; Armonk, NY). Pen was designated as the experimental unit for all computations. Factors used to calculate carcass ADG, carcass gain to feed ratio (**G:F**), and carcass ADG:live ADG were derived by applying a standard 44% dressing yield to the initial shrunk BW. This value was established under the consultation of Travis Herrod (Preferred Beef, Booker, TX, oral communication), who conveyed the plant average dressing yield for fresh weaned, thin cows that have not been fed a high-concentrate diet. Pen average carcass G:F was computed as carcass gain divided by daily dry matter intake (**DMI**). Both initial ultrasound and final carcass estimations of empty body fat were based on equations

developed by Guiroy et al. (2002). The effects of RH, DOF, and RH × DOF interaction were declared as fixed effects, whereas block was treated as a random effect in the model. Significance is discussed as ($P \leq 0.05$), while all ($P \geq 0.06$ to $P \leq 0.10$) are treated as tendencies.

Weights were shrunk 2% and 4% for all initial and final measurements, respectively. Initial weights were derived from averaging the measurements recorded during ultrasound (May 30, 2016) and pen assignment (June 1, 2016). All BCS scores were documented in a scale of 1 to 9, with each number subdivided into 1/3. With + denoting the top 1/3 and − denoting the bottom 1/3. For statistical analysis, these data were transformed to a 27-point scale. Following data analysis, figures were divided by 3 and reported on a 1 to 9 scale. To establish changes in red meat yield, raw weights for beef cuts where recorded and divided by HCW.

Economic computations were measured in US dollars. A compiled 3-yr (2014–2016) average live price reported from the Livestock Marketing Information Center of the USDA for lean and light cows was used to calculate initial value, while boning cow price was used for final value. Cost of gains was derived from 3-yr commodity price averages multiplied by pen feeding records. Transportation was priced at $2.33/km for a 22,500 kg semi-load, which was multiplied by 218 km (average distance reported by the 2016 National Beef Quality Audit) to calculate total transport expense. Yardage was calculated at $0.25 per cow per day. Expenses associated with death loss were determined by multiplying the compiled 3-yr average purchase price by the number of cows that died on trial, which was subsequently divided by the number of cows harvested. Interest cost was calculated by multiplying total expenses by 4.5% (Colton Long, Vice President, Commercial Lending Ag Texas, Amarillo, TX, oral communication). Implants were priced at $9.84 per pen and RH was priced at $1.92 per pen per day. Cost of gain was derived by dividing pen expenses by pen gain. Pen expenses and initial price were subtracted from final pen value to calculate net revenue.

Data analysis excluded 12 cattle that were dead or removed from the study. Five cows were found dead during the experiment, with a sixth cow euthanized under veterinarian orders. An additional six cows were removed from the study for lameness associated with foot rot. In each case, cows refused to consume concentrate diets, were extremely weak, and were losing ambulatory functions. These high-risk cows were treated for foot rot and in accordance with withdrawal protocols were

not eligible for harvest with their treatment groups. Deads and culls were removed from all calculations, pen values were averaged to a per animal basis to account for the removal of cattle. Two cows were either removed or died from each of the six treatments and no pen had more than one cow removed.

RESULTS AND DISCUSSION

The objectives of the study were 1) to evaluate the effects of the relationship between RH and compensatory gain in beef cull cows and 2) to determine the duration of the compensatory state in cull cows via varied DOF. No DOF × RH interactions were detected for any parameter ($P \geq 0.11$). Our initial belief was that RH could help extend the growth curve of cattle exiting the compensatory state, benefiting longer fed treatments and prompting an interaction. However, the data presented in Tables 2 and 7 suggest that longer fed treatments were not experiencing compensatory gain throughout the trial. The lack of any DOF × RH interaction infers that the compensatory state does not affect the magnitude of RH response. Accordingly, only the main effects will be discussed to address each of the stated objective.

Live Performance Traits

Trial performance means are presented in Table 2. Treatments fed RH documented a 13.7% increase in ADG (0.36 kg; $P = 0.04$) and a 16.9% increase in carcass ADG (0.34 kg; $P = 0.02$). With no difference in DMI observed ($P = 0.98$), RH supplementation translated to a 15.5% enhancement in G:F (0.034 units, $P = 0.02$) and outpaced controls by 20% in carcass G:F (0.035 units, $P = 0.05$). Suggesting that RH was successful at repartitioning nutrients to carcass tissues.

A recent meta-analysis of 16 trials evaluated the effect of RH supplementation in feedlot heifers (Pyatt et al., 2013). The consortium represented 12,342 heifers, with supplementation levels of RH including 100, 200, and 300 mg per animal per day, over the final 28 to 42 d prior to harvest. Recorded ADG were 7.8%, 15.7%, and 23.5% greater than negative controls, as RH inclusion increased from 100 to 200 and 300 mg per animal per day. A similar response was documented for G:F, as a 6.3%, 12.5%, and 18.8% increased efficiency compared to controls was observed in heifers supplemented with RH at 100, 200, and 300 mg per animal per day, respectively. In the present study, cows were supplemented with 400 mg per cow per day but responded comparably to heifers fed between 200 and 300 mg·per animal per·day. It is possible the slightly reduced response to RH observed in the current study is a result of the advanced age of the cattle on trial. Gonzalez et al. (2007) theorized that the mitigated response of cull cows to RH compared to traditional feedlot cattle was a function of reduced protein synthesis in older animals. The recruitment of quiescent satellite cells to fuse into established muscle fiber is the driving mechanism behind skeletal muscle growth (Collins et al., 2006). With maturation, satellite cell population decreases, as their activation potential diminishes. In fact, Gonzalez et al. (2007) estimated only 1% of total myonuclei are satellite cells.

Table 2. Feedlot and estimated carcass performance of cull beef cows finished over varied DOF[1] and fed RH

Item	DOF[2] 28	DOF[2] 42	DOF[2] 56	Days on RH[3] 0	Days on RH[3] 28	SEM[4]	P-values Linear[2]	P-values Quadratic[2]	P-values RH	P-values DOF × RH
Initial body weight, kg	463.0	467.8	466.7	466.9	464.8	7.74	0.85	0.86	0.90	0.73
Final body weight, kg	545.3	587.1	612.1	574.9	588.1	9.01	<0.01	0.63	0.44	0.9
Average daily gain, kg/d	2.94	2.84	2.6	2.61	2.97	0.09	0.1	0.71	0.04	0.44
Carcass average daily gain, kg	2.49	2.20	1.93	2.03	2.38	0.08	<0.01	0.95	0.02	0.94
Carcass transfer[5]	86.5	80.5	77.4	80.1	82.9	3.3	0.27	0.84	0.68	0.98
Dry matter intake, kg/d	11.36	12.39	13.29	12.35	12.34	0.33	<0.01	0.90	0.98	0.30
Gain:Feed	0.266	0.229	0.194	0.213	0.247	0.021	<0.01	0.74	0.02	0.30
Carcass Gain:Feed	0.23	0.182	0.147	0.169	0.204	0.009	<0.01	0.74	0.05	0.56

[1]Computations of carcass ADG, carcass G:F, and carcass ADG:live ADG were calculated by applying a 44% standard dressing percent to the initial BW to estimate initial HCW.

[2]Cows were fed a starter diet for 5 d, stepped up to the finishing diet from days 6 to 10, and then placed on the finisher diet for a total period of 28, 42, and 56 d before slaughter.

[3]Treatment diets were top-dressed to contain no RH (0 d) or RH (400 mg per cow per day; Actogain 45, Zoetis, Parsippany, NJ) for the final 28 d before slaughter.

[4]Pooled standard error of the treatment means (days on RH, $n = 24$ pens per main-effect mean; DOF, $n = 16$ pens per main-effect mean).

[5]Calculated as the ratio of carcass average daily gain:live average daily gain.

Across the spectrum of cull cow studies, there is little harmony concerning RH supplementation. Our findings contradict that of Allen et al. (2009), who saw no difference in performance or carcass characteristics of cull dairy cows supplemented with 312 mg per cow per day of RH for the final 32 d of a 90-d realimentation period. These findings echo the work of Holmer et al. (2009), who supplemented cull beef cows with 200 mg per cow per day of RH for the final 32 d of a 57-d finishing trial, and found no improvement in ADG. Indicating that RH may need to be supplemented at a rate greater than 350 mg per cow per day to manifest a performance response in cull cows.

Additionally, RH and control treatments were pooled to evaluate the main effect of DOF. As the feedlot period was extended, a linear decrease was observed for carcass ADG, G:F, and carcass G:F ($P < 0.01$), while live ADG portrayed a tendency for abatement ($P = 0.10$). Additional DOF also led to a linear increase in DMI and final BW ($P < 0.01$). Considered together, this would suggest that the majority of compensatory growth occurred during the initial 28 d of the experiment. Although the magnitude of response for compensatory gain fluctuates, a linear decrease in ADG and G:F is commonly observed as DOF is extended over a short period of time (Schnell et al., 1997; Funston et al., 2003; Sawyer et al., 2004; Weber et al., 2012). Reinforcing this narrative, carcass transfer measured as the ratio of carcass ADG:live ADG, numerically declined with additional time on feed, although the calculated values were not significant ($P = 0.27$). Underwhelming carcass transfer was surprising considering a linear increase in LMA and FT ($P \leq 0.01$, data presented in Table 4), while organ tissue failed to show clear growth trends throughout the trial (data presented in Table 7). Due to constraints on the harvesting floor, weights of gastrointestinal tracts were not captured. The cull cows utilized in the present study were extremely thin, displayed signs of muscle atrophy, and were most likely consuming a forage-based diet prior to trial initiation. Extremely high DMI may have activated accretion in the gastrointestinal tract, mitigating carcass transfer with additional DOF. This postulation is bolstered by the work of Matulis et al. (1987), who also recorded a linear increase in DMI and published a 53.6% increase in gastrointestinal tract weights, for cows fed 0, 28, 56, and 84 d. The authors noted that gastrointestinal weights outpaced HCW gains by 8% throughout the trial, which may explain the numerical decline in carcass transfer in the current study.

In both studies, the linear increase posted for DMI may be attributed to the deliberate adaptation process of transitioning cull cows from a forage to a high-concentrate diet. Additionally, the present study's FT measurements suggest that cows were not on feed long enough to trigger appetite suppression. It is also possible the increase in DMI was predicated by the compensatory state of the thin cull cows. Following dietary restriction, realimentation of cattle provokes higher plasma concentrations of insulin-like growth factor 1, inciting a physiological desire to increase intake (Yambayamba et al., 1996).

Continuously elevated DMI from 28 to 56 d under increasing heat loads was not expected. During the trial, high daily temperatures were measured and recorded by the Lubbock International Airport located 14 km from the Texas Tech Beef Research and Teaching Center. The average high daily temperature for each feeding period was 32.74 °C for days 0 to 28, 37.66 °C for days 29 to 42, and 37.0 °C for days 43 to 56. The average high temperature was 35.06 °C for the timeline of the entire trial. The results in the current study are surprising considering the findings of Strohbehn and Busby (2009), who noted in a 7-yr study that cull cows fed for a white cow market require an additional 6.7 d to reach targeted endpoints during summer months.

Body and Carcass Composition Parameters

A summary of the live and carcass composition data is presented in Table 3. Despite inciting favorable live gains, RH supplementation did not shift carcass composition or BCS by the end of the feeding period ($P \geq 0.45$). As anticipated, added DOF resulted in a linear increase for final BCS and empty body fat ($P < 0.01$). The strong linear response of these parameters, coinciding with additional DOF, upholds the observations of previous studies (Rathmann et al., 2012). Given many of the parameters used to estimate BCS are also objectively evaluated within the empty body fat equation, it is not surprising changes in both measurements are mirrored in the present study.

Carcass Traits

A summary of carcass trait means is presented in Table 4. In concert with the carcass ADG augmentation observed in Table 2, cows supplemented RH harvested with a 4.5% HCW enhancement (12.9 kg, $P = 0.05$). Greater HCWs are the result of numerical improvements dressing percent (1.24

Table 3. Estimated carcass and body composition of cull beef cows finished over varied DOF[1] and fed RH

	DOF[1]			Days on RH[2]			P-values			
Item	28	42	56	0	28	SEM[3]	Linear[1]	Quadratic[1]	RH	DOF × RH
Initial empty body fat,[4,5] %	22.15	22.39	22.00	22.04	22.32	0.15	0.70	0.33	0.36	0.14
Final empty body fat,[5] %	23.00	24.70	25.56	24.37	24.37	0.23	<0.01	0.28	0.45	0.88
Initial body condition score	2.11	2.19	2.05	2.17	2.07	0.09	0.60	0.26	0.28	0.63
Final body condition score	3.70	4.60	5.11	4.43	4.51	0.28	<0.01	0.25	0.61	0.30

[1]Cows were fed a starter diet for 5 d, stepped up to the finishing diet from days 6 to 10, and then placed on the finisher diet for a total period of 28, 42, and 56 d before slaughter.

[2]Treatment diets were top-dressed to contain no RH (0 d) or RH (400 mg per cow per day, Actogain 45; Zoetis, Parsippany, NJ) for the final 28 d before slaughter.

[3]Pooled standard error of treatment means (days on RH, $n = 24$ pens per main-effect mean; DOF, $n = 16$ pens per main-effect mean).

[4]Initial empty body fat was determined based upon ultrasound measurements recorded 2 d prior to trial initiation, using a standard 44% dressing percentage to estimate HCW.

[5]Empty body fat (%) = 17.76207 + (4.68142 × 12th rib fat) + (0.01945 × HCW) + (0.81855 × marbling score) − (0.06754 × LM area). The marbling score scale used was described by Guiroy et al. (2002) as follows: Standard = 3 to 4, Select = 4 to 5, low Choice = 5 to 6, average Choice = 6 to 7, high Choice = 7 to 8, low Prime = 8 to 9, and average Prime = 9 to 10.

Table 4. Carcass traits of beef cows finished over varied DOF[1] and fed RH

	DOF[1]			Days on RH[2]			P-values			
Item	28	42	56	0	28	SEM[3]	Linear[1]	Quadratic[1]	RH	DOF × RH
Hot carcass weight, kg	272.6	298.7	313.7	288.5	301.5	4.05	<0.01	0.43	0.05	0.7
Dressing percent	50.21	51.24	51.52	50.37	51.61	0.67	0.44	0.79	0.38	0.75
Loin muscle area, cm[2]	67.93	70.77	72.88	68.8	72.25	0.83	0.01	0.83	0.03	0.89
Loin muscle area, cm[2]/45.4 kg	11.46	10.88	10.63	10.99	10.99	0.13	0.01	0.54	0.99	0.98
12th rib fat, cm	0.33	0.51	0.6	0.45	0.5	0.03	<0.01	0.41	0.48	0.72
Calculated yield grade	2.17	2.41	2.48	2.3	2.41	0.04	<0.01	0.33	0.21	0.38
Marbling score[4]	2.65	3.29	3.68	3.27	3.14	0.10	<0.01	0.47	0.45	0.84
Skeletal maturity[5]	51.89	54.33	55.25	53.77	53.88	0.38	<0.01	0.27	0.88	0.63
Lean maturity[6]	26.26	26.75	26.16	27.81	24.96	0.49	0.93	0.61	<0.01	0.91
Liver score[7,8]		1.61	2.41	1.92	2.1	0.20			0.89	0.44

[1]Cows were finished for a period of 28, 42, and 56 d before slaughter.

[2]Treatment diets were formulated to contain no RH (0 d) or RH (400 mg per cow per day; Actogain 45; Zoetis, Parsippany, NJ) for the final 28 d before slaughter.

[3]Pooled standard error of treatment means (days on RH, $n = 24$ pens per main-effect mean; DOF, $n = 16$ pens per main-effect mean).

[4]3.00 = Slight00, 4.00 = Small00.

[5]10 to 19 = A Maturity; 20 to 29 = B Maturity; 30 to 39 = C Maturity; 40 to 49 = D maturity; 50 to 59 = E Maturity.

[6]10 to 19 = A Maturity; 20 to 29 = B Maturity; 30 to 39 = C Maturity; 40 to 49 = D Maturity; 0 to 59 = E Maturity.

[7]Liver scores were not collected on cattle harvested at 28 d.

[8]1 = Normal Liver; 2 = A− (1 to 2 small abscesses); 3 = A (2 to 4 small active abscesses); 4 = A+ (>4 small active abscesses).

units, $P = 0.38$) and final BW (13.2 kg, $P = 0.44$) prompted from RH inclusion. These figures suggest that RH successfully directed nutrients to carcass tissue accretion.

In growing cattle, RH has proved an effective tool for partitioning nutrients toward skeletal muscle deposition as opposed to adipose tissue accretion (McNeel and Mersmann, 1995; Mersmann, 1998). In the present study, cull cows supplemented RH cutout with 5.0% greater LMA compared to controls (3.45 cm[2], $P = 0.03$). A tendency for cull cows fed RH to display greater LMA was also reported by Harboth (2006). Surprisingly, the cull cows in the present study outperformed a recent meta-analysis of traditional feedlot heifers (Pyatt et al., 2013). Compared to controls, heifers supplemented with 300 mg per cow per day of RH harvested with a 6.40 kg heavier HCW and a 2.84 cm[2] greater LMA. Gonzalez et al. (2008) noted modest improvements in cull cow skeletal muscle fiber diameter and no changes in β_2-AR in response to RH supplementation at varying levels. However, the author theorized that RH inclusion needed to be greater than 300 mg per cow per day to cause an improvement in muscle cell size of beef cull cows.

Factors associated with quality grade were not negatively affected by RH inclusion. In fact, RH compelled a trade-off in quality factors, as

marbling scores were numerically reduced by 4.0% (0.13 units, $P = 0.45$), while lean maturity figures were improved by 11.1% (2.85 units, $P < 0.01$). These findings may be clarified by Holmer et al. (2009), who reported feeding RH for 35 d prior to slaughter produced carcasses with improved lean color compared to cows fed negative control diets. The authors proposed that RH supplementation caused rapid declines in pH which hastened protein denaturation and that greater protein turnover stimulated a dilution effect of myoglobin.

In response to extending DOF, linear increases were detected for LMA, marbling score, HCW, FT, and calculated yield grade ($P \leq 0.01$). Linear improvement of these parameters was also noted in serial slaughter studies conducted by Matulis et al. (1987), Schnell et al. (1997), and Sawyer et al. (2004), suggesting although the extent can vary, additional DOF is a precursor to carcass tissue accretion. Alternatively, LMA/45.4 kg responded to additional time on feed by decreasing linearly from 28, 42, and 56 DOF (11.46 cm^2, 10.88 cm^2, and 10.63 cm^2, $P = 0.01$). With the short feeding duration of the present trial, it is cogent to speculate that thin cull cows replenish muscle early in the feeding period and reach their genetic ceiling for lean tissue accretion rather quickly.

Chemical Composition

A summary of proximate analysis means is presented in Table 5. Inclusion of RH in finishing diets had no effect ($P \geq 0.38$) on loin muscle composition. Previous β-agonist studies have reported a reduction in collagen levels predicated by muscle fiber hypertrophy (Martin et al., 2014). In contrast, the present study's findings are congruent to the absence of a collagen response to RH observed by Strydom et al. (2009) in longissimus steaks from beef steers. The lack of a collagen response was not surprising

considering RH failed to generate an improvement in LMA/45.5 kg of HCW. Extending the duration of the finishing phase produced a tendency for a linear increase in percent fat ($P = 0.06$) but had no impact on any other parameter ($P \leq 0.23$). These results are in unison with a linear improvement of marbling scores ($P < 0.01$) with additional DOF in the current study.

Fabrication Yield

A summary of red meat yield means is presented in Table 6. Fabricated cuts were divided by carcass weight to determine if RH displayed an affinity to redirect nutrients to a specified area of the carcass. A RH response was not identified for any of the eight cuts recorded in this study ($P \geq 0.16$). Although RH was successful at increasing HCW (12.96 kg; $P = 0.05$) and did not alter FT, the data in Table 6 along with the ratio of LMA/45.5 kg of HCW indicate the β-agonist did not favor lean tissue accretion in locomotive muscles, which contradicts a previous study evaluating the saleable yield of carcasses from RH supplemented steers (Howard et al., 2014). Compared to negative controls, RH inclusion upgraded red meat yields by 0.61% and 0.86% for steers supplemented 300 or 400 mg per animal per day, respectively. Nearly half of the red meat yield improvement, precipitated by RH supplementation, was the result of cuts derived from the round (Howard et al., 2014).

Conversely, extending DOF provoked a linear decrease for cutout percentage of eye round (IMPS 171C; $P = 0.06$) with this trend continued for tender loin (IMPS 189; $P = 0.06$), inside round (IMPS 168, $P = 0.09$), and sirloin top butt (IMPS 182, $P = 0.10$). Supporting the hypothesis that thin cull cows replenish muscle tissue early in the feeding phase and subsequently only experience modest red meat accretion gains.

Table 5. Proximate analysis of percentage chemical fat, collagen, moisture, and protein of raw longissimus steaks from beef cows finished over varied DOF[1] and fed RH

Item, %	DOF[1]			Day on RH[2]		SEM[3]	P-values			
	28	42	56	0	28		Linear[1]	Quadratic[1]	RH	DOF × RH
Fat	3.58	4.02	4.39	4.15	3.84	0.17	0.06	0.92	0.38	0.41
Moisture	71.45	71.16	71.29	71.38	71.22	0.26	0.80	0.70	0.77	0.23
Protein	23.38	23.20	22.64	22.86	23.28	0.25	0.23	0.72	0.39	0.12
Collagen	1.59	1.62	1.68	1.61	1.65	0.08	0.64	0.97	0.78	0.11

[1]Cows were finished for a period of 28, 42, and 56 d before slaughter.

[2]Treatment diets were formulated to contain no RH (0 d) or RH (400 mg per cow per day; Actogain 45; Zoetis, Parsippany, NJ) for the final 28 d before slaughter.

[3]Pooled standard error of treatment means (days on RH, $n = 24$ pens per main-effect mean; DOF, $n = 16$ pens per main-effect mean).

Organ Characteristics

A summary of the means of organ characteristics is presented in Table 7. Supplementation of RH prompted reduced liver weights (0.705 kg, $P = 0.02$), which is noteworthy considering β-agonist fed cattle exceeded controls by 12.96 kg of HCW ($P = 0.05$) Although comprising of less than 2% of total BW, the energetic tax associated with the liver accounts for 24% of metabolic energy use (McBride and Kelly, 1990). The high-energy requirement is predicated by maintenance costs associated with the liver itself, as well as absorption and transportation of nutrients for use by other tissues. Furthermore, given gastrointestinal tract growth often exceeds live gain in cull cows (Matulis et al., 1987) and is highly correlated to liver weight (Johnson et al., 1990), RH ability to incite live weight gain, without increasing DMI, may account for the conservative offal tissue measurements and performance advantages registered in Table 2.

Response of viscera weights to additional time on feed produced confounding results. With additional DOF, liver and heart weights ($P = 0.20$; $P = 0.27$) numerically increased, lending credibility to the notion that compensatory gain occurred throughout the duration of the trial. These findings contradict the work of Matulis et al. (1987), who noted a quadratic effect of liver weights of implanted cull cows fed for 0, 28, 56, and 84 d. Suggesting a majority of compensatory gain occurs early in the finishing phase. Data in the present study also corroborate this claim, as kidney weights tended to decrease linearly ($P = 0.08$) implying restoration of catabolized tissue was completed prior to day 28. Often associated with a period of accelerated growth, following a state of dietary restriction, compensatory gain is commonly used to rapidly enhance ADG. It is well established that cattle entering a compensatory gain period will replenish organ mass attrition relatively early in the feeding phase (McBride and Kelly, 1990). Linear decreases in G:F, carcass ADG, and carcass G:F suggest that a majority of organ growth occurred during the first 28 d of the feeding period, enabling rapid tissue accretion to occur simultaneously. Although the duration of the trial was not long enough to achieve a quadratic response of performance parameters, static lung and

Table 6. Fabricated beef cuts presented as percentage of HCW of beef cows finished over varied DOF and fed RH

	DOF[1]			Days on RH[2]			P-values			
Item,[3] %	28	42	56	0	28	SEM[4]	Linear[1]	Quadratic[1]	RH	DOF × RH
109E, Rib eye roll	6.00	6.00	6.15	6.11	5.99	0.08	0.46	0.67	0.48	0.33
120, Flats	8.31	8.17	8.00	8.23	8.09	0.10	0.23	0.95	0.53	0.18
167, Knuckle	8.20	7.95	7.83	8.02	7.97	0.11	0.19	0.79	0.85	0.15
168, Inside round	13.91	13.25	13.23	13.68	13.26	0.16	0.09	0.35	0.19	0.36
171C, Eye round	3.74	3.63	3.48	3.65	3.58	0.05	0.04	0.83	0.44	0.18
175, Strip loin	6.45	6.55	6.41	6.53	6.41	0.09	0.86	0.52	0.50	0.38
182, Sirloin top butt	12.87	12.58	12.25	12.77	12.36	0.15	0.10	0.95	0.16	0.22
189, Tender loin	3.74	3.59	3.53	3.64	3.60	0.05	0.06	0.63	0.71	0.61

[1]Cows were finished for a period of 28, 42, and 56 d before slaughter.

[2]Treatment diets were formulated to contain no RH (0 d) or RH (400 mg per cow per day; Actogain 45; Zoetis, Parsippany, NJ) for the final 28 d before slaughter.

[3]Numbers denote the IMPS.

[4]Pooled standard error of treatment means (days on RH, $n = 24$ pens per main-effect mean; DOF, $n = 16$ pens per main-effect mean).

Table 7. Organ characteristics of beef cows finished over varied DOF[1] and fed RH

	DOF[1]			Days on RH[2]			P-values			
Item	28	42	56	0	28	SEM[3]	Linea[1]	Quadrati[1]	RH	DOF × RH
Liver, kg	8.666	8.958	9.070	9.261	8.556	0.129	0.20	0.74	0.02	0.53
Lung, kg	4.917	4.778	4.853	4.906	4.793	0.102	0.80	0.62	0.58	0.84
Heart, kg	2.468	2.591	2.585	2.577	2.526	0.032	0.27	0.32	0.93	0.82
Kidney, kg	1.657	1.602	1.483	1.601	1.569	0.039	0.08	0.70	0.96	0.77

[1]Cows were finished for a period of 28, 42, and 56 d before slaughter.

[2]Treatment diets were formulated to contain no RH (0 d) or RH (400 mg per cow per day; Actogain 45; Zoetis, Parsippany, NJ) for the final 28 d before slaughter.

[3]Pooled standard error of treatment means (days on RH, $n = 24$ pens per main-effect mean; DOF, $n = 16$ pens per main-effect mean).

Table 8. Net revenues (US dollars) for beef cows finished over varied DOF[1] and fed RH

Item, $	DOF[2]			Days on RH[3]		SEM[4]	P-values			
	28	42	56	0	28		Linear[2]	Quadratic[2]	RH	DOF × RH
Initial cow value	847.29	856.07	854.06	854.37	850.57	14.16	0.85	0.86	0.90	0.74
End live value	1,033.95	1,115.50	1,162.99	1,090.81	1,117.48	17.30	0.02	0.61	0.41	0.69
End carcass value	1,030.51	1,129.13	1,185.68	1,090.53	1,139.68	15.31	<0.01	0.43	0.05	0.70
Cost per kg live gain	2.00	1.73	1.75	1.87	1.79	0.06	0.07	0.23	0.50	0.92
Live revenue per cow	28.97	60.61	64.97	45.96	57.08	6.65	0.03	0.32	0.40	0.99
Carcass revenue per cow	25.54	74.24	87.67	45.68	79.29	14.78	0.09	0.57	0.26	0.81

[1]Cost assumptions: cow purchase price $1.83/kg and market live price at $1.90/kg (2014–2016 average price), carcass price at $3.78/kg (2014–2016 average price), feed cost at $8.46/45.5 kg of DM, implants $9.84/pen, RH at $1.92 per pen per day, death loss at 3% (five cows at average of 424.5 kg); transportation at $2.33/km for semi-truck with 39 cows for 218 km (average distance reported by the 2016 National Beef Quality Audit), interest rate at 1.73% (2014–2016 average short-term interest rate), yardage at $0.25/d.

[2]Cows were finished for a period of 28, 42, and 56 d before slaughter.

[3]Treatment diets were formulated to contain no RH (0 d) or RH (400 mg per cow per day; Actogain 45; Zoetis, Parsippany, NJ) for the final 28 d before slaughter.

[4]Pooled standard error of treatment means (days on RH, $n = 24$ pens per main-effect mean; DOF, $n = 16$ pens per main-effect mean).

decreasing kidney weights suggest cull cows most likely exited the compensatory state, relatively early within the experiment. It is also possible that continued liver weight growth was commensurate with increased DMI as DOF was extended. Regardless of the timing of offal mass gain, it is clear the feeding strategy used in the present study capitalized on lower metabolic requirements predicated by reduced organ weights.

Economic Impact

A summary of economic value means is presented in Table 8. Although RH supplementation led to a 15.6% improvement in G:F ($P = 0.02$), which helps offset the additional expense of the β-agonist, our findings suggest RH fed cull cows are more effectively marketed on a carcass basis. Numerically speaking, inclusion of RH in finishing diets led to a $11.12 increase in net revenue per cow when merchandized on a live weight basis ($57.08 vs. $45.96, $P = 0.40$), compared to exceeding controls by $33.61 on a carcass basis ($79.29 vs. $45.68, $P = 0.26$). Despite cows apparently achieving most of their compensatory growth during the first 28 d of the trial, longer fed treatments still linearly increased for live revenue per cow ($28.97 vs. $60.61vs. $64.97, $P = 0.03$) and displayed a tendency for linear carcass revenue per cow ($25.54 vs. $74.24 vs. $87.67, $P = 0.09$). Although the arc of live revenue per cow from days 42 to 56 appears to be approaching a quadratic ($P = 0.32$), linear net revenue values for extending the realimentation period to 56 d could provide market flexibility to deal with price fluctuations or varying optimal lean endpoint premiums/discounts. It is worth noting

the advanced age of the cattle on trial (all cows were E skeletal maturity), since it is established older cows are less efficient on high-concentrate diets (Sawyer et al., 2004). Collectively, suggesting that feeding cull cows for a lean market can be a solvent practice and that RH is a tool to augment economic gains.

Implications

Although it appears that the majority of organ and muscle mass attrition was replenished in the first 28 d of the feeding period, especially given that both live and carcass feed efficiency was maximized during this timeline. The magnitude of the RH response was not dependent on the duration of the finishing phase nor was it influenced by the timing of supplementation relative to the compensatory growth status of the animal. Compared to controls, RH incited improvements in feedlot performance but had a more profound impact on carcass gain and efficiency. Cutout data insinuates, RH did not redirect nutrients to a specific area of the carcass but promoted muscle accretion to achieve a 12.96 kg of HCW improvement over controls. Our economic findings suggest that feeding cow cull cows can be a lucrative enterprise and that RH can help exploit the compensatory gain and further augment profits.

LITERATURE CITED

Allen, J. D., J. K. Ahola, M. Chahine, J. I. Szasz, C. W. Hunt, C. S. Schneider, G. K. Murdoch, and R. A. Hill. 2009. Effect of preslaughter feeding and ractopamine hydrochloride supplementation on growth performance, carcass characteristics, and end product quality in market dairy cows. J. Anim. Sci. 87:2400–2408. doi:10.2527/jas.2008-1630

Anderson, S. 2007. Determination of fat, moisture, and protein in meat and meat products by using the FOSS FoodScan near-infrared spectrophotometer with FOSS artificial neural network calibration model and associated database: collaborative study. J. AOAC Int. 90:1073–1083.

Burrin, D. G., C. L. Ferrell, and R. A. Britton. 1989. Effect of feed intake of lambs on visceral organ growth and metabolism. Energy Metab. Proc. Symp. 43:103–106.

Carter, J. N., D. D. Johnson, T. A. Thrift, and J. L. Foster. 2006. Effects of feeding a βagonist on performance, carcass yield, quality, and economic value of cull cows. J. Anim. Sci. 84(Suppl. 2):130 (Abstract).

Collins, C. A. 2006. Satellite cell self-renewal. Curr. Opin. Pharmacol. 6:301–306. doi:10.1016/j.coph.2006.01.006

Curley, K. O., Jr., J. C. Paschal, T. H. Welsh, Jr., and R. D. Randel. 2006. Technical note: exit velocity as a measure of cattle temperament is repeatable and associated with serum concentration of cortisol in Brahman bulls. J. Anim. Sci. 84:3100–3103. doi:10.2527/jas.2006-055

Dijkhuis, R. D., D. D. Johnson, and J. N. Carter. 2008. Case study: feeding ractopamine hydrochloride to cull cows: effects on carcass composition, Warner Bratzler shear force, and yield. Prof. Anim. Sci. 24(6):634–638. doi:10.15232/S1080-7446(15)30915-3

Freetly, H. C., and J. A. Nienaber. 1998. Efficiency of energy and nitrogen loss and gain in mature cows. J. Anim. Sci. 76:896–905. doi:10.2527/1998.763896x

Funston, R. N., J. A. Paterson, K. E. Williams, and A. J. Roberts. 2003. Effects of body condition, initial weight, and implant on feedlot and carcass characteristics of cull cows. Prof. Anim. Sci. 19:233–238. doi:10.15232/S1080-7446(15)31410-8

Gonzalez, J. M., J. N. Carter, D. D. Johnson, S. E. Ouellette, and S. E. Johnson. 2007. Effect of ractopamine-hydrochloride and trenbolone acetate on longissimus muscle fiber area, diameter, and satellite cell numbers in cull beef cows. J. Anim. Sci. 85:1893–1901. doi:10.2527/jas.2006-624

Gonzalez, J. M., R. D. Dijkhuis, D. D. Johnson, J. N. Carter, and S. E. Johnson. 2008. Differential response of cull cow muscles to the hypertrophic actions of ractopamine-hydrogen chloride. J. Anim. Sci. 86:3568–3574. doi:10.2527/jas.2008-1049

Guiroy, P. J., L. O. Tedeschi, D. G. Fox, and J. P. Hutcheson. 2002. The effects of implant strategy on finished body weight of beef cattle. J. Anim. Sci. 80:1791–1800. doi:10.2527/2002.8071791x

Harboth, K. 2006. Potential management opportunities for cow/calf producers to maximize profit [PhD Diss.]. Manhattan: Kansas State University.

Holmer, S. F., J. W. Homm, L. L. Berger, J. K. McKeith, and J. Killefer. 2009. Realimentation of cull beef cows. I. Live performance, carcass traits and muscle characteristics. J. Muscle Foods 20:293–306. doi:10.1111/j.1745-4573.2009.00149.x

Howard, S. T., D. R. Woerner, D. J. Vote, J. A. Scanga, R. J. Acheson, P. L. Chapman, T. C. Bryant, J. D. Tatum, and K. E. Belk. 2014. Effects of ractopamine hydrochloride and zilpaterol hydrochloride supplementation on carcass cutability of calf-fed Holstein steers. J. Anim. Sci. 92:369–375. doi:10.2527/jas.2013-7104

Johnson, D. E., K. A. Johnson, and R. L. Baldwin. 1990. Changes in liver and gastrointestinal tract energy demands in response to physiological workload in ruminants. J. Nutrition 20:649–655. doi:10.1093/jn/120.6.649

Lawrence, T. E., C. A. Gasch, J. P. Hutcheson, and J. M. Hodgen. 2011. Zilpaterol improves feeding performance and fabrication yield of concentrate-finished cull cows. J. Anim. Sci. 89:2170–2175. doi:10.2527/jas.2010-3422

Lobley, G. E., P. M. Harris, P. A. Skene, D. Brown, E. Milne, A. G. Calder, S. E. Anderson, P. J. Garlick, I. Nevison, and A. Connell. 1992. Responses in tissue protein synthesis to sub- and supra-maintenance intake in young growing sheep: comparison of large-dose and continuous-infusion techniques. Br. J. Nutr. 68:373–388. doi:10.1079/bjn19920096

Martin, J. N., A. J. Garmyn, M. F. Miller, J. M. Hodgen, K. D. Pfeiffer, C. L. Thomas, R. J. Rathmann, D. A. Yates, J. P. Hutcheson, and J. C. Brooks. 2014. Comparative effects of beta-adrenergic agonist supplementation on the yield and quality attributes of selected subprimals from calf-fed Holstein steers. J. Anim. Sci. 92:4204–4216. doi:10.2527/jas.2014-7881

Matulis, R. J., F. K. McKeith, D. B. Faulkner, L. L. Berger, and P. George. 1987. Growth and carcass characteristics of cull cows after different times-on-feed. J. Anim. Sci. 65:669–674. doi:10.2527/jas1987.653669x

McBride, B. W., and J. M. Kelly. 1990. Energy cost of absorption and metabolism in the ruminant gastrointestinal tract and liver: a review. J. Anim. Sci. 68:2997–3010. doi:10.2527/1990.6892997x

McNeel, R. L., and H. J. Mersmann. 1995. Beta-adrenergic receptor subtype transcripts in porcine adipose tissue. J. Anim. Sci. 73:1962–1971. doi:10.2527/1995.7371962x

Mersmann, H. J. 1998. Overview of the effects of beta-adrenergic receptor agonists on animal growth including mechanisms of action. J. Anim. Sci. 76:160–172. doi:10.2527/1998.761160x

NCBA. 2016. Executive Summary of the 2016 National Market Cow and Bull Beef Quality Audit. National Cattlemen's Beef Association, Centennial, CO 80112.

Pyatt, N. A., G. J. Vogel, J. W. Homm, R. L. Botts, and C. D. Bokenkroger. 2013. Effects of ractopamine hydrochloride on performance and carcass characteristics in finishing heifers: 16-trial summary. J. Anim. Sci. 91(Suppl. 2):692–693 (Abstract 742).

Rathmann, R. J., B. C. Bernhard, R. S. Swingle, T. E. Lawrence, W. T. Nichols, D. A. Yates, J. P. Hutcheson, M. N. Streeter, J. C. Brooks, M. F. Miller, et al. 2012. Effects of zilpaterol hydrochloride and days on the finishing diet on feedlot performance, carcass characteristics, and tenderness in beef heifers. J. Anim. Sci. 90:3301–3311. doi:10.2527/jas.2011-4375

Sawyer, J. E., C. P. Mathis, and B. Davis. 2004. Effects of feeding strategy and age on live animal performance, carcass characteristics, and economics of short-term feeding

programs for culled beef cows. J. Anim. Sci. 82:3646–3653. doi:10.2527/2004.82123646x

Schnell, T. D., K. E. Belk, J. D. Tatum, R. K. Miller, and G. C. Smith. 1997. Performance, carcass, and palatability traits for cull cows fed high-energy concentrate diets for 0, 14, 28, 42, or 56 days. J. Anim. Sci. 75:1195–1202. doi:10.2527/1997.7551195x

Strohbehn, D. R., and D. W. Busby. 2009. A seven year summary of feeding cull market cows. Animal Industry Report: AS 655, ASL R2409. Available from https://lib.dr.iastate.edu/ans_air/vol655/iss1/32

Strydom, P. E., L. Frylinck, J. L. Montgomery, and M. F. Smith. 2009. The comparison of three β-agonists for growth performance, carcass characteristics and meat quality of feedlot cattle. Meat Sci. 81:557–564. doi:10.1016/j.meatsci.2008.10.011

Strydom, P. E., and M. F. Smith. 2010. Effects of duration of zilpaterol hydrochloride supplementation on growth performance, carcass traits and meat quality of grain-fed cull cows. Animal 4:653–660. doi:10.1017/S1751731109991479

USDA. 1997. United States standards for grades of carcass beef. Washington (DC): Agric. Market. Serv., USDA.

Weber, M. J., M. E. Dikeman, J. A. Unruh, J. R. Jaeger, L. Murray, T. A. Houser, and B. J. Johnson. 2012. Effects of sequential feeding of β-adrenergic agonists on cull cow performance, carcass characteristics, and mRNA relative abundance. J. Anim. Sci. 90:1628–1637. doi:10.2527/jas.2011-4285

Yambayamba, E. S., M. A. Price, and G. R. Foxcroft. 1996. Hormonal status, metabolic changes, and resting metabolic rate in beef heifers undergoing compensatory growth. J. Anim. Sci. 74:57–69. doi:10.2527/1996.74157x