DISSERTATION

EFFECT OF DIETARY BETA-AGONIST SUPPLEMENTATION ON LIVE PERFORMANCE, CARCASS CHARACTERISTICS, CARCASS FABRICATION YIELDS, AND STRIP LOIN TENDERNESS AND SENSORY TRAITS

Submitted by

Travis Steven Arp

Department of Animal Sciences

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Doctoral Committee:

Advisor: Keith Belk

Dale Woerner
J. Daryl Tatum
Dustin Pendell

ABSTRACT

EFFECT OF DIETARY BETA-AGONIST SUPPLEMENTATION ON LIVE PERFORMANCE, CARCASS CHARACTERISTICS, CARCASS FABRICATION YIELDS, AND STRIP LOIN TENDERNESS AND SENSORY TRAITS

Beef steers (n = 3,906) were fed at a commercial feed yard to evaluate the effects of beta-adrenergic agonist supplementation on live performance, carcass characteristics, carcass fabrication yield and strip loin tenderness and palatability. Steers were weighed and ultrasonic carcass measurements were collected for allocation into four feeding blocks. Within each block, approximately 100 steers were assigned two a pen that was assigned one of five treatments, including: No beta-agonist; Ractopamine hydrochloride (RH) fed at 200 mg/hd/d for the final 30 d of finishing (RAC200); RH fed at 300 mg/hd/d for the final 30 d of finishing (RAC300); RH fed as a 400 mg/hd/d top dress for the final 30 d of finishing (RAC400); and Zilpaterol hydrochloride (ZH) fed at 6.8 g/ton beginning 23 d before slaughter, with a withdrawal period starting 3 d before to slaughter (ZIL). The study design included eight replicates (pens) per treatment (two per block). Each feeding block was harvested on consecutive weeks. Each week, carcass parameters were measured and strip loin samples were collected from 18 carcasses per pen (720 total samples) for Warner-Bratzler and Slice Shear Force, and trained sensory analysis. Subsamples of eight carcasses per pen (320 total samples) were selected for whole carcass fabrication yield.

Final BW was not affected by treatment ($P = 0.2892$), but there was a tendency for cattle receiving βAA supplementation to be heavier compared to controls ($P = 0.0681$). Average daily gain and F:G ratio was improved with treatment of βAA ($P < 0.05$). Carcasses from the ZIL and RAC400 treatments had the heaviest HCW, and were significantly heavier than CON and

RAC200 treatments ($P < 0.05$). The ZIL treatment also recorded the highest dressing percent and carcasses had the largest LMA compared to all other treatments ($P < 0.05$). USDA yield grade and marbling score were reduced due to βAA supplementation ($P < 0.05$). Differences in marbling score reduced the frequency of carcass qualifying for the CAB premium in βAA treated cattle ($P < 0.05$), while also accounting for a decrease in the frequency of carcasses grading choice and an increase in the percentage of carcasses grading select for cattle receiving βAA supplementation compared to controls ($P < 0.05$). The percentage of YG1 carcasses was increased and the frequency of YG3 carcasses was decreased due to βAA treatment ($P < 0.05$). Treatment with dietary βAA elicited the greatest response in subprimal yield in cuts from the round. Zilpaterol treatment carcasses reported the highest total saleable yield, and were greater than all RAC treatments ($P < 0.05$). Warner-Bratzler and SSF was affected by treatment ($P < 0.05$), with an increase in shear force values with increased dose and potency of βAA's. Likewise, the percentage of steaks shearing greater than 4.4 and 20 kg for WBSF and SSF, respectively, was increased with βAA supplementation ($P < 0.05$). Tenderness attributes were ranked lower for steaks from βAA treatments by trained sensory panelists ($P < 0.05$). There were no differences detected by panelists for juiciness or beef flavor attributes.

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CHAPTER I

INTRODUCTION

Growth enhancement technologies have been widely used in livestock production for many years. For decades, they have been an integral part of the livestock feeding industry, and producers have continued to utilize these technologies to improve efficiency in cattle and hog feeding systems.

The current state of the livestock production and the economy has dictated an increased use of pharmacological agents to make beef and pork production more efficient and affordable. The recent economic recession, widespread drought, and consistent increases in input costs have had negative impacts on the margins cattle and hog feeders recognize when producing and selling livestock. Consequently, the hog industry, and more recently, the cattle feeding industry have increased utilization of beta-adrenergic agonists to improve the efficiency of production. While the use of Ractopamine hydrochloride (Paylean®, Elanco Animal Health, Greenfield, IN) has been used extensively in hog production since its approval by the Food and Drug Administration in 1999, similar pharmaceutical feed additives have only recently been implemented in commercial cattle feeding operations. Beta-adrenergic agonist use in fed cattle has substantially increased following the FDA approval of Ractopamine hydrochloride (Optaflexx®, Elanco Animal Health, Greenfield, IN) in 2003, and the approval of Zilpaterol hydrochloride (Zilmax®, Merck Animal Health, Summit, NJ) in 2006.

For decades, cattle producers have primarily used hormonal implants to enhance live animal growth in fed cattle. For over 50 years, estrogenic and androgenic hormone implants were widely used in the cattle feeding industry, and it is estimated that approximately 97 percent of feedlot cattle in the U.S. receive one or more implants during the finishing phase (Barham et

al., 2003; Tatum, 2006). There is a large body of literature that indicates the positive growth enhancement effects which implants impart on growing and finishing cattle and producers have extensively used implants to increase live body weight, improve average daily gain and feed efficiency, and reduce the number of days cattle are on feed (Apple et al., 1991; Duckett et al., 1997; Milton and Horton, 1996; Perry et al., 1991).

Likewise, there is a growing body of literature that indicates the positive response on growth and carcass characteristics that finishing cattle have to beta-adrenergic agonists. The use of both Ractopamine and Zilpaterol have shown to elicit similar improvements in live weight gain, average daily gain, and feed efficiency as those reported in hormone implants (Allen et al., 2009; Avendaño-Reyes et al., 2006; Beckett et al., 2009; Elam et al., 2009; Gruber et al., 2007; Kellermeier et al., 2009; Scramlin et al., 2010). In addition, these compounds have been reported to have profound effects on hot carcass weight, Longissimus muscle area and carcass cutability (Gruber et al., 2007; Hilton et al., 2010; Rathmann et al., 2009; Scramlin et al., 2010; Shook et al., 2009; Vogel et al., 2009). It is because of this that cattle feeders have drastically increased use of beta-agonists since their FDA approval, and a growing portion of the fed cattle population receive both a hormone implant, as well as a dietary beta-agonist supplement that is provided within the final 20 to 30 d of finishing.

While the efficacy of these compounds is well documented, so too are the negative effects on meat quality. The use of both Ractopamine and Zilpaterol has corresponded to increased toughness in meat from cattle given a dietary supplement of either compound (Avendañ0-Reyes et al., 2006; Garmyn et al., 2010; Gruber et al., 2008; Leheska et al., 2009; Woerner et al., 2011). Likewise, beta-agonists have been reported to decrease marbling scores,

while also negatively affecting the percentage of cattle qualifying for quality-based premiums (Kellermeier et al., 2009; Vasconcelos et al., 2008).

It is because of these factors that the use of beta-agonists has come under recent scrutiny. The positive effects of dietary beta-agonist supplementation has allowed cattle feeders to improve efficiency and packers to improve yields; however, packers also face the issue of lower quality carcasses and retailers are required to market products that could provide consumers with a less desirable eating experience. Researchers continue to analyze the effects of beta-agonist supplementation at different doses, potencies, and feeding periods, as well as differential effects on cattle of varying biological type. Determining the optimal dose, as well as the preferential cattle type for beta-agonist supplementation, will aid in optimizing the positive effects on growth while mitigating the negative effects on quality across the population at-large.

Currently, there is a considerable volume of literature detailing the effects of Ractopamine and Zilpaterol on live animal growth, carcass characteristics, and tenderness; yet, there are few studies which directly compare effects both compounds in a controlled study. Likewise, there are no known published studies evaluating the effect of Ractopamine on subprimal yield and carcass cutability in beef cattle. The objective of this study was to compare the effect of three different doses of Ractopamine hydrochloride and one dose of Zilpaterol hydrochloride to an implanted control on live animal growth, carcass characteristics, carcass fabrication yield, and strip loin tenderness and palatability.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Beef producers constantly strive to improve the productivity of cattle. Decreases in the size of the U.S. cattle herd over the past 15 years and rising cost of inputs has exacerbated the need to make the production of beef more efficient and affordable. As production enhancing technologies have evolved, cattle producers have used them to maximize efficiency from their cattle and improve profitability. Currently, there is an array of growth promoting technologies available, and feeders can combine steroid hormone implantation with β-adrenergic agonist (βAA) supplementation regimens to substantially improve feedlot cattle performance.

Cattle feeders have utilized steroidal implants in beef cattle for well over 50 years (Barham et al., 2003). Implantation of estrogenic and androgenic hormones improves growth efficiency of feedlot cattle by increasing final body weight, decreasing days on feed, and improving dry matter intake per kg of gain (Perry et al., 1991). Implants are still used in the majority of cattle on feed, and feeders often use different combinations of hormones and implant types to achieve maximal feed efficiency and growth from their cattle.

The efficacy of βAA on lean efficiency enhancement is widely recognized and has been a topic of research for more than three decades. However, βAA use in the cattle industry was limited until Ractopamine hydrochloride (RH) was approved by the Federal Drug Administration (FDA) in 1999 for use in swine and Zilpaterol hydrochloride (ZH) was approved in 2006 for use in cattle. The approval of both βAA‘s has allowed cattle feeders to combine growth promoting effects of steroidal implants with repartitioning agents, which increase growth and performance,

increase skeletal muscle accretion and improve overall carcass yield (Kellermeier et al., 2009; Parr et al., 2011; Perry et al., 1991).

Along with improvements in live weight and carcass gains, supplementation of cattle with βAA has come under scrutiny due to deleterious impacts on meat quality. Multiple studies (Gruber et al., 2008; Hilton et al., 2009; Kellermeier et al., 2009; Mehaffey et al., 2009; Vasconcelos et al., 2008) showed that feeding βAA reduces tenderness in steaks from the *longissimus* muscle (LM). Furthermore, βAA supplementation decreases quality grade and reduces the proportion of cattle grading choice (Beckett et al., 2009; Elam et al., 2009; Hilton et al., 2009; Kellermeier et al., 2009).

Supplementation of cattle with βAA is becoming more widespread in the beef industry. Yet, there is a necessity to better understand the biological type of cattle for which supplementation with βAA can be most advantageous. The positive and negative effects of βAA can be balanced by utilizing cattle which can reap the most benefit from live and carcass weight gains, but limit the reductions or consequences to consumer demand of reduced marbling score and tenderness. Data suggest that RH supplementation of cattle with a higher percentage British influence can provide the best combination of lean muscle gain and maintenance of carcass quality (Gruber et al., 2007; Gruber et al., 2008). Holstein and dairy type cattle also have been the subject of βAA research (Allen et al., 2009; Beckett et al., 2009; Garmyn et al., 2010; Vogel et al., 2009); objectives were to increase skeletal muscle mass and carcass yield.

Research on βAA mode of action, amount and duration of supplementation, and positive and negative effects on live performance and carcass parameters continues to be a major area of beef cattle and meat science research as βAA use becomes more widely implemented.

Growth Improvement in Livestock

A primary focus of beef production is using technologies to improve efficiency and decrease the cost of gain. While much progress has been made through genetic improvement in terminal livestock, beef producers have complimented that improvement with the adaptation of growth enhancement technologies. Anabolic growth implants have been utilized by beef producers for over 50 years to improve efficiency of fed beef cattle (Bruns et al., 2005). Use of naturally occurring steroid hormones, as well as the development of synthetic steroids, has offered cattle producers the opportunity to improve live animal performance, feed efficiency, and carcass yield (Perry et al., 1991).

More recently, the widespread use of βAA's have provided an additional method for improving beef cattle growth and carcass yield (Gruber et al., 2007; Kellermeier et al., 2009). Used as a feed additive, the use of two different commercial βAA improve growth beyond that of conventional implant strategies (Elam et al., 2009; Gruber et al., 2007).

Hormone Implants

The first growth promoting hormone approved for use in livestock was diethylstilbestrol (DES) in 1954 (Preston, 1999). However, this compound later was banned by the FDA in 1979 due to potential carcinogenic effects when used by humans, not in animals (Preston, 1999). Shortly after the approval of DES, estradiol benzoate (EB) and progesterone implants were approved for use in steers in 1956, and later in heifers in 1958 (Preston, 1999). The approval of zeranol, a synthetically derived estrogen, and trenbolone acetate (TBA), a synthetic androgen, followed in 1969 and 1987, respectively (Preston, 1999).

Estradiol benzoate, estradiol (E_2), and zeranol are the most commonly used estrogenic hormones, while TBA is the common androgen utilized in growth enhancement (Tatum, 2006). In the last two decades, combinations of E_2/EB and TBA in implants, in varying potencies and

under multiple release scenarios, are commonly used in fed beef cattle to enhance growth over single compound implant strategies (Preston, 1999; Tatum, 2006).

Normal growth in livestock is primarily controlled by estrogenic and androgenic hormones – estrogen and testosterone. Estrogen hormones act on the anterior pituitary to increase secretion of growth hormone (GH) or somatotropin, which then increases production of insulin-like growth factor I (IGF-I) from both the liver and locally in bone and skeletal muscle (Trenkle, 1997). Circulating GH binds to specified GH receptors on the liver to increase production of IGF-I, which is transported by IGF-I binding proteins to tissues and acts to increase protein accretion and stimulate long bone growth (Hossner, 2005). Insulin-like growth factor binds to a specified IGF-receptor and activates the PI3-Kinase pathway to increase protein accretion. In addition, increased IGF-I has been shown to increase satellite cell proliferation, which serves as the DNA content to increase muscle hypertrophy (Johnson et al., 1998). Comparatively, androgen hormones work directly on androgen receptors on muscle cells (Heitzman, 1979). While the mode of action is not well understood, it is expected androgens elicit a response through both an intracellular signaling cascade which stimulate protein accretion, while also blocking the potential catabolic effects of glucorticoid hormones, which have a similar affinity for androgen cell receptors (Wu, 1997). Additionally, testosterone is capable of aromatizing to estrogen in vivo, providing additional anabolic affects identical to the aforementioned mechanisms by which estrogens act (Wu, 1997). It is because of these independent mechanisms by which estrogens and androgens impart their physiological effects that estradiol and TBA are used in combination to produce additive anabolic affects in implanted cattle (Trenkle, 1997).

The use of combined anabolic implants affects animal growth in the same manner as those naturally occurring *in vivo*. Johnson et al. (1996) reported that steers implanted with a combined E_2 and TBA implant had 16 and 22 percent greater circulating IGF-I concentrations after 21 and 40 d of implantation, respectively. Furthermore, Johnson et al. (1998) reported that satellite cell cultures isolated from cattle receiving a combined E_2 plus TBA implant had a greater maximum cell fusion percentage than from cattle receiving no implant. Similar studies suggested that enhancement in circulating IGF-I was a primary response to hormone implantation that could be attributed to increased animal growth and improvements in skeletal muscle accretion (Dunn et al., 2003; Frey et al., 1995; Kamanga-Sollo et al., 2004)

Implant effectiveness in enhancing animal growth is well documented. Apple et al. (1991) reported that Holstein steers implanted with a TBA, zeranol, or combined EB and progesterone implant had higher average daily gains (ADG) for the first 56 d of implantation versus control steers. Similarly, Duckett et al. (1997) reported increases in ADG and dry matter intake (DMI) by feedlot steers given a single combined estrogen plus androgen implant. Additional literature shows that combination estrogen/TBA implants have an exacerbated effect on increased final body weight, ADG, DMI, and feed to gain ratio (F:G) compared to non-implanted cattle or those subjected to single implant strategies (Apple et al., 1991; Bruns et al., 2005; Duckett et al., 1997; Perry et al., 1991; Scheffler et al., 2003). Studies also reported increased hot carcass weight (HCW) and LM area (LMA) compared to cattle receiving no implant, and inconsistent effects on 12^{th} rib fat thickness (FT) and yield grade (Apple et al., 1991; Duckett et al., 1997; Perry et al., 1991; Scheffler et al., 2003).

While anabolic implants provide obvious benefit to live animal growth and carcass characteristics, their effect on carcass quality and beef tenderness have been questioned. Platter

et al. (2003) reported that cattle receiving differing lifetime implant strategies had lower marbling scores than cattle receiving no implant. The same study also reported a shift in the quality grade distributions of cattle, indicating a decrease in the frequency of carcasses grading upper two-thirds Choice and Prime using more aggressive implant strategies or a greater number of implants from weaning to finishing (Platter et al., 2003). Similar results were reported by Roeber et al. (2000) for feedlot cattle, in which case a decrease in marbling score was observed when combination implants or implant/re-implant strategies were used. Studies to determine effects of implants on tenderness have reported varied results. Multiple studies have reported no difference in Warner-Bratzler shear force (WBSF) values between steaks from non-implanted control cattle versus those receiving different single or combination implants (Beirman et al., 1999; Huffman et al., 1991; Milton and Horton, 1996); however, other studies have reported various implanting strategies having a deleterious effect on WBSF values compared to steaks from non-implanted cattle (Kerth et al., 2003; Pritchard et al., 2000; Roeber et al., 2000; Samber et al., 1996). Likewise, consumer acceptance of tenderness from steaks from implanted cattle versus non-implanted report conflicting results (Kerth et al., 2003; Roeber et al., 2000).

Implants remain the most widely used form of growth promotion in growing and finishing beef cattle due to their effectiveness and ability to improve production efficiency.

Beta-adrenergic agonists

Beta-adrenergic agonists are a multifaceted pharmacological agent utilized in both human medicine and livestock production. In human medicine, βAA are used as a bronchodilator to treat asthma, and to stimulate cardiac contraction strength and rate (Hossner, 2005). Alternatively, βAA are used in livestock to stimulate skeletal muscle growth, increase live and carcass weight gains and improve efficiency in cattle and swine.

Evaluation of the use of βAA started to build momentum in the 1970's and 80's with the use of clenbuterol, cimaterol, $L_{664,969}$, salbutamol and fenterol for use in livestock (Anderson et al., 2005; Mersmann, 1998). However, these compounds were never given FDA approval for commercial use in food producing animals. Clenbuterol is associated with adverse human health effects when tissues from those animals were consumed or inhalation of the compound during feed mixing. Several public health issues were associated with clenbuterol residues through the 1990's; hence, the use of the substance and associated βAA's were made illegal in the livestock industry. Ractopamine hydrochloride and ZH are the only βAA approved for use in livestock in the United States. Ractopamine (Paylean®; Elanco Animal Health, Greenfield, IN) was approved for use in swine in 1999, and later for cattle (Optaflexx®, Elanco Animal Health, Greenfield, IN) in 2003. Zilpaterol (Zilmax®; Merk Corp., Summit, NJ) was approved for use in cattle for many years in South Africa and Mexico, and later received FDA approval for use in cattle in the United States in 2006.

The catecholamines epinephrine and norepinephrine serve as biological βAA's in mammalian species, which bind to β-adrenergic receptors (βAR) to elicit a response on the sympathetic nervous system. These are of primary interest to human medicine, as they relate to bronchodilation and effect cardiovascular function (Mersmann, 1998). These hormones are inactivated and reabsorbed by specific uptake mechanisms to prevent the βAR from remaining active (Mersmann, 1998).

Beta-adrenergic agonists have the ability to bind to any of three βAR (β_1-AR, β_2-AR, or β_3-AR) which are present in most mammalian cells, but are present in different concentration depending upon the tissue and specie (Johnson, 2004; Mersmann, 1998). In skeletal muscle and lipid cells, β_1-AR and β_2-AR are the most common receptors, and have the greatest affinity for

pharmacological βAA (Mersmann, 1998). These receptors are members of the G_s protein coupled receptors. The βAR contain a seven membrane-spanning domain that forms loops on the cell membrane and are exposed on both the intra- and extracellular surface (Johnson, 2004). The physiological response to βAA is initiated when the βAA binds on the extracellular surface to the βAR, causing a conformational change to the receptor. This activates adenylate cyclase to synthesize cyclic-adenosine monophosphate (cAMP) from adenosine triphosphate (ATP). Cyclic AMP regulates the activity of protein kinase A (PKA), which is responsible for the phosphorylation of necessary enzymes involved in lipid and protein synthesis, as well as regulation of DNA transcription factors (Anderson et al., 2005; Johnson, 2004). Furthermore, PKA targets intracellular domains on the βAR to render it inactive.

In more general terms, βAA and the intracellular signaling cascade increases protein synthesis and decreases fat synthesis in livestock. It is because of this that βAA's are referred to as "repartitioning agents" due to repartitioning normal metabolic processes from synthesis of fat to synthesis of muscle. Beta-adrenergic receptors present on fat cells decrease lipid synthesis and increase lipid degradation; likewise, βAR present on muscle cells elicit a response which increases protein synthesis and a decrease in protein degradation (Anderson et al., 2005). When fed to ruminant livestock, it is suggested that the compound leaves the rumen intact, and is absorbed in the lower parts of the gastrointestinal tract; after which it enters the blood stream, is degraded in the liver, and is then delivered to the target tissues to elicit a response (Johnson, 2004).

Beta-Adrenergic Agonist Effects

It is widely understood that βAA supplementation improves live animal performance and efficiency, carcass weight and yield, and has negative effects on muscle tenderness and eating

quality. Efficacy varies depending upon βAA-type, animal age, cattle biological type, and if it is used in combination with other growth promoting strategies. The following section will highlight research focusing on varying βAA's used in cattle production and its effects on production traits and carcass characteristics.

Live Animal Performance

There are a multitude of recent studies investigating RH and ZH effects on cattle growth. Gruber et al. (2007) reported RH supplementation at 200 mg/hd/d increased final BW, ADG, and G:F ratio of Brahman, Continental, or British influenced cattle. Gruber et al. (2007), however, did not report a RH × breed effect, indicating that RH has no differential effect on cattle of differing biological types. Likewise, Abney et al. (2007) reported that RH supplementation improved final BW, ADG, and G:F ratio. Both Gruber et al. (2007) and Abney et al. (2007) indicated RH supplementation improved final BW by 7.3 and 5.9 kg, respectively; ADG was improved by approximately .2 kg/d. Abney et al. (2007) also reported a RH feeding duration effect when fed for 28, 35, and 42 d. Gains from RH supplementation were optimized at 35 d of feeding for final BW, ADG, and G:F ratio compared to shorter or longer feeding periods (Abney et al., 2007). Vogel et al. (2009) reported similar results feeding RH to calf-fed Holstein steers.

Comparatively, Quinn et al. (2008) reported minimal effects of treatment on live animal performance in feedlot heifers supplemented RH at 200 mg/hd/d. Allen et al. (2009) reported results similar to Quinn et al (2008) that live performance was not effected when feeding market dairy cows RH at 312 mg/hd/d. These results were attributed to the inherent variability associated with feeding market cows versus feedlot cattle that are more consistent in their biological type and age (Allen et al., 2009).

The majority of experiments assessing the effects of Zilpaterol on live animal performance have been conducted in the last five years due to the recent FDA approval for use in meat producing livestock. Early research conducted in Mexico indicated advantages for growth and performance feeding ZH in comparison to cattle receiving none (Avendaño-Reyes et al., 2006; Plascencia et al., 1999). A growing body of literature from the United States indicates ZH supplemented feedlot cattle possess similar growth and performance characteristics to those fed RH. A study published by Vasconcelos et al. (2008) reported minimal differences in final BW of steers supplemented ZH for the final 20, 30 and 40 d of finishing compared to steers fed no beta-agonist. The same study also reported that steers supplemented with ZH had significantly higher ADG and G:F ratio than steers fed no beta-agonist (Vasconcelos et al., 2008). In a similar study that evaluated ZH supplementation and duration of feeding, Elam et al. (2009) indicated that ZH supplementation increased final BW and improved ADG and G:F ratio versus non-supplemented steers. Elam et al. (2009) reported an 8, 9.3, and 10.8 kg increase in final BW when ZH is supplemented for the final 20, 30 and 40 d of the finishing period, respectively. In addition, other studies reported improvements in ADG and G:F ratio due to dietary ZH supplementation (Beckett et al., 2009; Montgomery et al., 2009; Scramlin et al., 2010).

Studies comparing efficacy of RH and ZH have resulted in varied results with respect to live animal growth and performance. Avandaño-Reyes et al. (2006) reported that ZH supplementation improved final BW, ADG and G:F ratio of beef steers versus those supplemented RH. Conversely, Scramlin et al. (2010) reported an advantage of 4.35 kg of final BW for RH supplemented beef steers over ZH supplemented steers, as well as increases in ADG and G:F ratio when supplemented with RH. Strydom et al. (2009) indicated that RH supplementation imparted significant increases in ADG and G:F in beef steers versus those

supplemented ZH, while also reporting an numerical advantage in final BW, albeit not statistically significant.

Carcass Characteristics

Original research investigating effects of βAA focused primarily on the compounds clenbuterol and cimaterol. Ricks et al. (1984) reported that cattle supplemented with with clenbuterol had lower 12th-rib FT, larger LMA, and lower numerical yield grade (YG). The study also reported changes in overall carcass composition due to clenbuterol supplementation, indicating an increase in percent protein and a decrease in percent fat due to treatment (Ricks et al., 1984).

More contemporary studies that evaluated effects of RH supplementation on carcass characterisitcs indicates improvements in carcass cutability and yield. Gruber et al (2007) reported an increase in HCW of 5.5 kg and larger LMA when steers were supplemented RH at 200 mg/hd/d. The results showed no difference in dressing percent, 12th-rib FT, or USDA YG (Gruber et al., 2007). However, RH did increase the percentage of YG2 and decrease the percentage of YG3 carcasses (Gruber et al., 2007). Likewise, RH did not affect the distribution of carcasses in respective USDA QG categories (Gruber et al., 2007). In a study analyzing effects of RH fed at 200 and 300 mg/hd/d to calf-fed Holstein steers, a study by Vogel et al. (2009) generated results similar to those reported by Gruber et al. (2007). Holstein steers that were supplemented with RH at 200 and 300 mg/hd/d had heavier HCW and larger LMA compared to control steers, while steers supplemented at 300 mg/hd/d had leaner 12th-rib FT (Vogel et al., 2009). In addition, steers supplemented 300 mg/hd/d of RH had lower a lower calculated YG, while steers supplemented RH at 200 mg/hd/d had lower marbling scores and a lower percentage of carcasses grading USDA Prime and Choice (Vogel et al., 2009). Similar

results were reported in studies comparing treatment with either RH or ZH (Avendaño-Reyes et al., 2006; Scramlin et al., 2010). A more exhaustive body of literature indicates improvements in carcass traits and yield in swine supplemented with RH at varying doses and potencies (Apple et al., 2004; Armstrong et al., 2004; Uttaro et al., 1993; Watkins et al., 1990).

Zilpaterol supplementation in finishing beef cattle has proven to be highly effective at improving carcass composition and yield. Vasconcelos et al. (2008) reported that ZH supplementation for the final 20, 30, or 40 d of finishing increased HCW, LMA, and decreased 12^{th}-rib FT and USDA YG in comparison to cattle receiving no βAA supplementation. These results were consistent with other studies investigating the effects of ZH on carcass characteristics and were indicative of the normal response in ZH supplemented beef steers (Elam et al., 2009; Kellermeier et al., 2009; Rathmann et al., 2009). A similar trend in improved HCW, LMA, and YG also were reported in calf-fed Holstein steers supplemented with ZH for differing lengths of time (Beckett et al., 2009; Garmyn et al., 2010).

An effect of ZH treatment of fed cattle that is not reported in RH literature was an improvement in dressing percent. Multiple studies reported a higher mean dressing percent in ZH fed cattle compared to controls, while also indicating a greater increase in HCW than in live weight (Beckett et al., 2009; Elam et al., 2009; Vasconcelos et al., 2008). There is no literature which supports a likely hypothesis for the reason behind the differential partitioning of nutrients between fat and lean tissues. Vasconcelos et al. (2008) reported a linear increase in lean tissue accretion with increased days of ZH supplementation with little variation in carcass fat between feeding periods. Further research is necessary to determine reasons for the disparity in live and carcass weights, as well as to determine what causes increases in dressing percent recognized via ZH supplementation, but not by feeding RH.

Carcass cutability and subprimal yields have been widely investigated in cattle supplemented with ZH, but there is currently no literature addressing differences in beef carcass yield due to RH supplementation. Kellermeier et al. (2009) indicated an increase in subprimal yield from nearly all fabricated carcass subprimals compared to controls. Carcass cutability studies analyzing both beef-type feedlot cattle and calf-fed Holsteins have reported increases in subprimal yield as well (Boler et al., 2009; Garmyn et al., 2010; Hilton et al., 2009; Rathmann et al., 2009). These results indicate the additional value added for packers due to larger subprimals – specifically higher value cuts from the rib and loin – due to Zilpaterol supplementation. The greatest effect of dietary ZH supplementation is recognized in cuts from the round (Shook et al., 2009). This is largely attributed to an increased concentration of Type IIa, glycolytic fibers, which are more responsive to βAA supplementation (Miller et al., 1988). Along with this, a study analyzing carcass composition of steers and heifers receiving dietary ZH supplementation reported steers and heifers had an increase in soft tissue protein percentage and weight, as well as an increased protein to bone ratio (Leheska et al., 2009).

Supplementation of ZH also has been shown to not only negatively affect marbling score, but also to cause a shift in the distribution of USDA quality grades in feedlot cattle. Kellermeier et al. (2009) reported a decrease in marbling score between ZH supplemented steers and controls of approximately 40 degrees. More importantly though, when compared to controls, ZH supplementation decreased the frequency of carcasses grading Premium Choice by nearly 17 percent (20% vs. 3.3%); decreased the percentage of carcass grading Choice by approximately 13 percent (36.67% vs. 23.33%); and increased the frequency of carcasses grading Select by nearly 20 percent (Kellermeier et al., 2009). A study conducted by Vasconcelos et al. (2008) reported results consistent with those of Kellermeier et al. (2009), to the extent that ZH

supplementation for 20, 30, or 40 d decreased the frequency of carcasses grading Choice and Prime by 16.1, 18.4, and 22 percent, respectively; the frequency of carcasses grading Select increased by 8.2, 9.8, and 19.8 percent, respectively. Vasconcelos et al. (2008) also reported that mean marbling score decreased by 31.1, 46.0, and 54.4 degrees for each feeding period. These results indicate that while ZH supplementation decreases marbling scores by less than half of a total marbling score, the deleterious effects on quality can drastically effect the distribution of carcasses receiving a quality based premium.

Tenderness and Palatability

The largest detriment of βAA supplementation is likely to be the consequential reduction in beef tenderness. A growing body of literature suggests that supplementation of βAA causes a decrease in objective tenderness measurements and are consistently rated less desirable by trained and consumer sensory panelists.

Studies to assess the effects of RH supplementation on postmortem tenderness have shown mixed results. In a study in which RH was supplemented at 200 mg/hd/d for the final 28 d of the finishing period, LM steaks from supplemented steers were on average 0.38 and 1.4 kg tougher for WBSF and SSF, respectively (Gruber et al., 2008). Furthermore, the study reported that 3, 7, 14, and 21 d of post mortem aging did not diminish the effect of RH supplementation (Gruber et al., 2008). The difference in tenderness was further recognized by trained sensory panelists, who rated steaks from RH supplemented cattle lower for tenderness and juiciness attributes (Gruber et al., 2008). Scramlin et al. (2010) reported that RH supplementation increased WBSF values at 3 and 7 d aging versus steaks from control carcasses; however, the disparity in tenderness was negated at the 14 and 21 d aging interval. These results agreed with Quinn et al. (2008) who reported no differences in WBSF values for LM steaks aged 14 d from

heifers supplemented 200 mg/hd/d of RH for the final 28 d of the finishing period. Boler et al. (2012) reported that steers supplemented with RH at 200 mg/hd/d for the final 28 d of the finishing period produced LM steaks with WBSF values that differed from control steers only at 4 d postmortem; however, steers receiving RH at 300 mg/hd/d for the final 28 d of the finishing period produced LM steaks that were tougher at 7, 14, and 21 d postmortem than both control and 200 mg/hd/d supplemented steers. At 28 d postmortem aging, steaks from cattle in the control, 200, and 300 mg/hd/d treatments did not differ (Boler et al., 2012). While these results vary, it appeared that increased post mortem aging for steaks from RH supplemented cattle provides the opportunity to mitigate negative effects on tenderness.

Zilpaterol supplementation in feedlot cattle has been shown to have more pronounced effects on beef tenderness. Leheska et al. (2009) reported that carcasses of steers and heifers supplemented with ZH for the final 20 and 40 d of finishing generated LM steaks with greater WBSF values than controls after 28 d post mortem aging. Zilpaterol supplementation for the final 20 d of finishing accounted for a 0.72 and 0.84 kg increase in WBSF in steers and heifers, respectively (Leheska et al., 2009). Likewise, trained sensory panelists rated steaks from carcasses of ZH supplemented steers significantly tougher than controls; while LM steaks from carcasses of ZH supplemented heifers tended to be rated tougher by trained panelists (Leheska et al., 2009). Rathmann et al. (2009) reported similar increases in WBSF values for steers fed dietary ZH for the final 20, 30, and 40 d of finishing. Increased time of ZH supplementation increased WBSF at 7, 14, and 21 d post mortem aging, and WBSF values for all feeding and post mortem aging periods exceed those from control carcasses (Rathmann et al., 2009). In the study conducted by Rathmann et al. (2009), a study by Miller et al. (2001) was cited for determination of tenderness thresholds. Miller et al. (2001) determined that at a WBSF of < 3.0 kg, 100 percent

of consumers found New York Strip steaks to be acceptable for tenderness (Miller et al., 2001). The study also determined at a WBSF value of 4.3 kg, 86 percent of consumers found steaks acceptable, and that 4.9 kg was a major point of distinction from consumers between tough and tender steaks (Miller et al., 2001). In the study published by Rathmann et al. (2009), frequency distributions for ZH vs. control treatments at each of the WBSF values referenced by Miller et al. (2001) showed that LM steaks from control carcasses had a significantly greater percentage of steaks at 3.0 and 4.3 kg of WBSF. Similarly, steaks from each of the three ZH treatments (fed for 20, 30, and 40 d) had a significantly greater percentage of steaks at or above the 4.9 kg threshold for toughness (Rathmann et al., 2009). Results from these studies are consistent with others that have evaluated tenderness from ZH supplemented cattle, and illustrate the profound effect dietary ZH has on postmortem tenderness and consumer acceptability (Avendaño-Reyes et al., 2006; Hilton et al., 2009; Kellermeier et al., 2009).

Combined Growth Technology Strategies

Anabolic implants and βAA's appear to enhance mammalian by independent mode of actions. While estrogenic hormones impose their function on skeletal muscle via increases in GH and IGF-I and androgenic hormones directly affect muscle cells via androgen receptors, it is expected that βAA act through βA-receptors found locally on skeletal muscle and lipid cells and produce an intracellular signaling cascade which increases protein synthesis and decreases lipogenesis (Johnson, 2004; Trenkle, 1997). Hence, it is hypothesized that independent responses would provide the opportunity to enhance growth to a degree that supersedes the normal response from implants or βAA individually.

Winterholler et al. (2008) compared steers receiving a combined TBA/E17β implant (120 mg TBA and 24 mg E17β) to steers receiving the same implant strategy in addition to dietary RH

at 200 mg/hd/d for the final 37 d of finishing and reported that there were no differences in final BW between the two treatments. Furthermore, while RH treated steers had a greater ADG for the final 37 d of finishing, ADG did not differ between treatments across the entire period on feed (Winterholler et al., 2008). Carcass characteristics also indicated that dietary RH supplementation did not significantly affect HCW, LMA, or 12th-rib FT; however, USDA YG and marbling score were decreased in cattle receiving dietary RH supplementation (Winterholler et al., 2008). Likewise, in a study published by Woerner et al. (2011), 73 steers and heifers received an initial TBA/E_2 implant (80 mg TBA and 16 mg E_2) at d 0 and a terminal TBA/E_2 implant (120 mg TBA and 14 mg E_2) at d 63 of feeding; the comparison treatment (n=74 steers and heifers) received the same two-implants strategy along with 200 mg/hd/d of dietary RH for the final 28 d of the finishing period (Woerner et al., 2011). Results indicated that RH supplementation had no effect on final BW, while ADG was improved only during the period of RH supplementation; however ADG over the entire test was not affected by dietary RH supplementation. Bass et al. (2009) reported that calf-fed Holstein steers administered differeing implanting strategies did not differ in final BW, ADG, HCW, or LMA compared to steers given identical implanting strategies in addition to 200 mg/hd/d of RH for the final 36 d of finishing.

Studies determining effects of ZH on beef steers, combined with various implant strategies have reported increases in live performance and carcass characteristics. Baxa et al. (2010) reported that a combined ZH and implant regimen provided additive effects on carcass characteristics. Steers fed dietary ZH (8.38 mg/kg (DM basis) for the final 30 d of the feeding period followed by a 3-d withdrawal before slaughter) in addition to a combined TBA/E_2 implant (120 mg TBA and 24 mg E_2) had the heaviest final BW, highest ADG and G:F ratio, the heaviest

HCW and largest LMA compared to steers only receiving the terminal implant, dietary ZH supplementation, or neither.

Research has been conducted to determine how both implants and βAA directly affect βA-receptors and IGF-I expression to determine reasons for disparities in growth enhancement. Multiple studies (Sissom et al., 2007; Baxa et al., 2010, Winterholler et al., 2007) reported increases in β_2-AR mRNA due to both dietary RH and ZH supplementation which was nearly 1,000 times greater than the concentration of β_1-AR mRNA expression. Literature suggests that RH has a selective affinity for β_1-AR (Mills, 2003), whereas ZH has a higher affinity for β_2-AR (Montgomery et al., 2009). It is feasible that the increased β_2-AR mRNA provides the impetus for an more pronounced growth response to dietary ZH used in combination with a hormone implant regimen compared to similar implant strategies using dietary RH. Additionally, literature indicate that steroid hormones can act through nongenomic actions, in which hormones work through second messenger systems such as cAMP signaling, similar to RH (Falkenstein et al., 2000). Estrogen administration also has been reported to reduce protein expression of the β_1-AR (Kam et al., 2004), which could mitigate RH responsiveness when used in combination with estrogenic implants.

Longissimus muscle tenderness also is affected due to combined implant/βAA strategies. Woerner et al. (2011) reported that steers and heifers supplemented with dietary RH in addition to a two-implant regimen generated LM steaks that were 0.23 kg tougher than at 28 d postmortem compared to those which did not receive dietary RH supplementation. Kellermeier et al. (2009) reported steers receiving both dietary ZH supplementation and a combined TBA/E_2 terminal implant generated LM steaks that were 1.2 kg tougher for WBSF values compared to those receiving only the combined implant. These negative additive effects of combined

implant/βAA strategies indicated the necessity for judicious use of growth enhancement technologies to mitigate the potential for reduction in consumer acceptance of retail product (Woerner et al., 2011).

Physiological Effects of Beef Tenderness

While it is widely recognized that βAA have deleterious effects on beef tenderness, there are various theories on the physiological modes of action which effect post mortem tenderness.

A generally accepted theory for the effects of βAA on beef tenderness is an effect of changes in muscle fiber diameter. Calkins et al. (1981) suggested that fiber type, and subsequently fiber diameter, is associated with beef tenderness. Type I, β-red, or slow twitch oxidative fibers are understood to have a smaller fiber diameter and higher concentrations were more associated with improved muscle tenderness (Klont et al., 1998). Likewise, Type IIa, α-white, or fast twitch glycolytic fibers are understood to have a larger fiber diameter and an increased concentration of these fibers are more associated with negative tenderness attributes; Type IIx, α-red, or intermediate fast twitch oxidative glycolytic fibers are intermediate to Type I and Type IIa fibers in fiber diameter (Klont et al., 1998). Research associating βAA with fiber type report a shift in fiber type, with decreased concentrations of Type I fibers and increased concentrations of Type II fiber types (Gonzalez et al., 2010; Gonzalez et al., 2009; Kellermeier et al., 2009). Gonzalez et al. (2009) reported that the *adductor, gracilis, Longissimus laborum, and vastus lateralis* muscles decreased in Type I fiber concentration while increasing in Type II fiber concentration due to dietary RH supplementation. However, the Type I and Type II fiber diameter was unchanged due to RH supplementation (Gonzalez et al., 2009). Baxa et al. (2010) reported no changes in concentration of Type I and Type IIa fibers due to dietary ZH

supplementation; however, an increase in concentration of Type IIx fibers was reported in ZH supplemented steers.

Differential effects on proteolytic enzyme activity due to βAA supplementation also have been studied to determine their effects on post mortem tenderness. The calpain system (m-calpain and μ-calpain) is generally recognized to improve post mortem tenderness due to the degradation of structural proteins (Goll, 1991). Likewise, calpastatin is an endogenous inhibitor of calpains, and increased concentration of calpastatin has been proven reduced beef tenderness (Goll, 1991). Hilton et al. (2009) reported no effect on μ- or m-calpain activity or calpastatin activity in steers supplemented with dietary ZH. Likewise, Rathmann et al. (2009) reported no effect on calpastatin mRNA abundance in steers supplemented dietary ZH. Walker et al. (2010) also reported that calpastatin mRNA expression was not effected by dietary RH supplementation at 200 mg/hd/d at day 14 or 28 of the feeding period. Studies which reported differences in calpain activity due to βAA supplementation involved supplementation of cattle with cimaterol, a βAA now banned by the FDA for use in livestock (Bardsley et al., 1992; Parr et al., 1992).

Considering the effect of βAA's on the proteolytic enzyme system are negligible, extended postmortem aging periods should have minimal effect on disparities in tenderness associated with βAA treatments. Gruber et al. (2008) reported that steaks from steers supplemented 200 mg/hd/d of dietary RH for the final 28 d of the feeding period had similar aging curves to steaks from control steers, and the difference in WBSF value between treatments was only slightly diminished from 3 to 21 d post mortem aging. These results were similar to those of Woerner et al. (2011), who determined that the effect of RH on LM WBSF was unaffected by postmortem aging out to 28 d. However, other studies evaluating the effect of postmortem aging on steaks from RH supplemented steers have reported that, while these steaks

had tougher WBSF values early in the postmortem aging period, by 21 d, the disparities in tenderness were largely diminished (Boler et al., 2012; Scramlin et al., 2010). Scramlin et al. (2010) reported that while tenderness was improved after a 21 d aging period, WBSF values for steaks from ZH supplemented steers was still significantly tougher after postmortem aging. These results were supported in other ZH studies (Brooks et al., 2009; Kellermeier et al., 2009; Rathmann et al., 2009), and indicated that, while the differences in tenderness between steaks from ZH supplemented steers and controls is diminished, ZH steaks are still considerably tougher after 21 d post mortem aging. Garmyn et al. (2010) determined that at a tenderness threshold of 4.6 kg WBSF, 100 percent of steaks from steers receiving no βAA supplementation were under the threshold value at 7, 14, 21, 28, and 35 d post mortem; by 35 d post mortem, 100 percent of steaks from ZH supplemented steers were also under the 4.6 kg threshold. More research is needed to evaluate the influence of extended postmortem aging periods on tenderness improvement for beef cattle supplemented with βAA past 21 d of aging.

Additional areas of research to determine βAA effects on postmortem tenderness have evaluated protein accretion and degradation. Proteins are continually degraded in skeletal muscle in the living animal, and rate of protein degradation versus protein accretion is related to an animal's ability to undergo muscle hypertrophy (Wheeler and Koohmaraie, 1992). Early research using the βAA $L_{644,969}$ reported that muscle protein degradation was only reduced after 3 weeks of supplementation, however, muscle protein accretion was increased after 1, 3, 5, and 6 weeks of supplementation (Wheeler and Koohmaraie, 1992). More contemporary studies agree with these findings, and have indicated that βAA supplementation has a greater effect on protein accretion compared to protein degradation (Gonzalez et al., 2008; Kellermeier et al., 2009; Leheska et al., 2009).

Conclusion

Growth enhancement technologies have been widely embraced in the livestock industry to improve growth, efficiency, and carcass traits. While hormonal implants have been utilized for decades in cattle production, recent advancements in dietary βAA supplements have offered swine and cattle producers the opportunity to further improve their production efficiency. Implanting strategies utilized intermittently during the growing and finishing phases in feedlot cattle have been reported to increase live weight, ADG, and feed efficiency, while also improving HCW, LMA, and FT (Apple et al., 1991; Bruns et al., 2005; Duckett et al., 1997; Perry et al., 1991; Scheffler et al., 2003). Likewise, dietary supplementation of βAA's has been shown to also improve live animal growth and have more profound effects on carcass traits and carcass cutability (Allen et al., 2009; Gruber et al., 2007; Hilton et al., 2010; Kellermeier et al., 2009; Leheska et al., 2009; Rathmann et al., 2009; Scramlin et al., 2010; Vasconcelos et al., 2008). However, the improvements in growth and carcass traits are accompanied by reduction in marbling score, and have been reported to reduce the frequency of carcasses qualifying for premiums in quality based grid marketing (Kellermeier et al., 2009; Vasconcelos et al., 2008). Furthermore, the most profound negative effect of both RH and ZH supplementation has been to reduce postmortem tenderness (Avendaño-Reyes et al., 2006; Gruber et al., 2008; Leheska et al., 2009; Quinn et al., 2008; Rathmann et al., 2009; Scramlin et al., 2010).

Growth enhancement technologies offer a tremendous amount of potential to cattle feeders, yet judicious use is required to mitigate deleterious effects on postmortem beef quality and eating quality. Further research is necessary to fully understand the physiological effects on beef tenderness. However, matching the biological type of cattle that are inherently more tender with βAA supplementation is vital to upholding consumer acceptance of beef from aggressive

growth promoting strategies. Cattle which inherently produce higher quality carcasses and more tender beef (e.g. greater British breed influence) are ideal subjects for more aggressive growth enhancement regimens. Similarly, faster growing breeds that produce inherently tougher beef (e.g. greater Continental or Brahman influence) should be limited to less aggressive implanting and dietary βAA supplementation as this can impart additive effects on increasing beef toughness.

Hormonal implants and βAA are, and will continue to be widely used in the cattle feeding industry. While their effectiveness is undeniable, optimizing animal growth, carcass traits, and beef quality is necessary for maintaining consumer preference for beef.

CHAPTER III

EFFECT OF DIETARY BETA-AGONIST SUPPLEMENTATION ON LIVE PERFORMANCE, CARCASS CHARACTERISTICS, CARCASS FABRICATION YIELDS, AND STRIP LOIN TENDERNESS AND SENSORY TRAITS

Materials and Methods

A study was conducted at a commercial feed yard in the Panhandle of Texas in which approximately 4,000 head of British × Continental crossbred steers were allocated to one of five experimental feeding treatments to determine the effect of beta-adrenergic agonist (βAA) supplementation on live animal performance, carcass characteristics, fabricated carcass subprimal yield, and strip loin tenderness and palatability.

Live Animal Phase

Upon initial receiving at the commercial feed yard, cattle were individually weighed, ear tagged with a unique individual identification, vaccinated with a modified live virus vaccine (Titanium® 3, Agri Labratories, St. Joseph, MO) and a clostridial bacterin toxoid (Vision® 7 with SPUR, Merck Animal Health, Summit, NJ), treated for internal parasites (Ivomec Plus®, Merial, Duluth, GA), and treated metaphlactically with Micotil® (Elanco Animal Health, Greenfield, IN). Steers also received an initial Component® TE-IS with Tylan (16 mg estradiol and 80 mg TBA; Elanco Animal Health, Greenfield, IN) or Ralgro® (26 mg Zeranol; Merck Animal Health, Summit, NJ) at initial processing, depending upon projected endpoint. At approximately 90 d before projected slaughter date, all steers were re-implanted with a Component TE-S implant (24 mg estradiol and 120 mg TBA; Elanco Animal Health, Greenfield, IN).

Approximately 60 d before the projected slaughter date, steers were transported from the commercial feeding facility to the company's research feed yard, also in the Texas Panhandle. Upon arrival, steers were provided access to drinking water and a moderate-concentrate mixed diet. The mean weight of steers upon arrival at the research feed yard was 484.6 ± 18.5 kg. Steers were weighed individually and ultrasonic carcass measurements were collected to determine projected terminal endpoint. This information was used to allocate 3,906 steers into four separate slaughter groups (blocks). Within each of the 4 blocks, cattle were randomly allocated to one of 5 treatment groups including: a negative control of cattle receiving no βAA (CON); cattle continuously fed 200 mg/hd/d of Ractopamine hydrochloride (RH; Optaflexx®, Elanco Animal Health, Greenfield, IN) for the final 30 d of the finishing period (RAC200); cattle continuously fed 300 mg/hd/d of RH for the final 30 d of the finishing period (RAC300); cattle continuously fed 400 mg/hd/d (top dress) of RH for the final 30 d of the finishing period (RAC400); and cattle fed Zilpaterol hydrochloride (ZH; Zilmax®, Merck Animal Health, Summit, NJ) at 6.8 g/ton of feed starting 23 d before slaughter and withdrawn 3 d before slaughter (ZIL). Within each block, each treatment was replicated twice (2 pens/treatment/block). In total, 40 pens of approximately 100 hd/pen were utilized for the trial.

Steers were immediately placed on a finishing ration after pen allocation. Block 1 steers were placed on to trial on January 31st and February 8th; block 2 steers were placed on trial February 9th; block 3 steers were placed on trial on February 21st and March 5th; and block 4 steers were placed on trial March 13th and March 21st. Detailed information on pens and dates of trial initiation are located in Appendix A. Steers were tagged with an identical pen identification tag before being allocated to treatment pen. Diets were formulated to meet or exceed National Research Council (1996) requirements for growing-finishing beef cattle at the research feed

yard's feed mill. Basal diets were mixed daily at the feed yard. Rations were mixed to contain 39.45% flaked corn, 25.18% dried distillers grains, 22.27% sweet bran blend, 7.01% corn silage, 2.50% cotton seed hulls, 2.08% tallow, and 1.60% water on a dry matter basis. Diets were formulated to contain the following nutrient dry matter composition: 73.92% dry matter, 16.94% crude protein, 21.14% crude fiber, and 8.00% fat. All cattle were fed their respective diets twice daily at 0700 and 1300 h. For steers receiving the RH treatments, a premix was included in the finishing ration to deliver 200 and 300 mg/hd/d for the final 30 d of the finishing period. Cattle receiving the RAC400 treatment were fed a portion of the basal ration at initial feeding, after which the remainder of the basal ration was delivered 30 min later, formulated to deliver 400 mg/hd/d of RH in an additional 2.5 kg/hd of feed. Diets were formulated on a dry matter (DM) basis to include 18.18 g/ton RH for the RAC200 treatment, 27.28 g/ton RH for the RAC300 treatment, 191.39 g/ton RH in the top dress for the RAC400 treatment, and 8.0 g/ton ZH for the ZIL treatment. Additionally, Rumensin® and Tylan® (Elanco Animal Health, Greenfield, IN) were added to basal diets at 30.0 and 8.0 g/ton DM, respectively. Diet samples were intermittently obtained directly from the feed bunks during the morning feeding. A portion of each sample was oven-dried at 100°C to monitor DM, while the remaining portion were retained and stored in a freezer. Retained samples were composited and submitted to a commercial laboratory for analysis of RH and ZH inclusion rates.

An employee from the research feedlot observed each pen of cattle daily during the study to assure proper functioning of water tanks, fences, and feed bunks. Cattle behavior also was noted during the study (i.e., bulling, appetite, health). Any sick or removal animals that did not return to the home pen within 24 h were removed from the study. Any steers that died during the

duration of the study were necropsied by a trained feed yard employee according to normal feed yard procedures. A list of removed and dead animals can be found in Appendix B.

Before initiation of the treatment period, pen weights were collected in the morning before feeding for each treatment replicate between 0400 and 0700 h. Weights for all treatments were collected on the same day; thus ZIL treatment pens were weighed eight days before ZIL treatment initiation. A weight was collected for each pen, after which steers were returned to their home pens and their respective treatment was delivered. Final pen weights were collected on the morning each block was shipped to slaughter. Cattle were fed their respective treatment diet, weighed, and subsequently loaded on to 15.2 × 2.5 m pot-belly trailers for transport to a commercial processing facility. Specific dates for treatment allocation, initiation, and shipment date can be found in Appendix A.

Harvest and Carcass Phase

Cattle were shipped to a commercial beef processing facility in the Texas Panhandle in four blocks beginning on April 18th, 2012 for four consecutive wk. Steers were harvested during the second plant shift on each Wednesday during the plant phase. Cattle were harvested using standard U.S. beef industry practices and USDA/FSIS inspection criteria.

Each treatment pen was harvested consecutively during the shift and the first and last carcass from each pen was identified and traced to an individual plant sequence number that was maintained throughout carcass data collection. Hot carcass weights (HCW) were automatically recorded by the plant at the end of the harvest line. Carcasses were tracked throughout the harvesting process and any rail-ins/rail-outs were recorded so as to maintain sequence traceability.

Carcasses were chilled for approximately 36 h. After carcasses were thoroughly chilled, each side was ribbed between the 12th and 13th ribs by plant personnel. Carcass data were collected from the in-plant carcass imaging system and was downloaded from the plant database. Carcass data that was collected included: Longissimus muscle area (LMA), 12th-rib fat thickness (FT), marbling score, and USDA yield and quality grade (YG; QG). Dressing percent (DP) for each pen was calculated by dividing the pen average of HCW by the pen live weight, and multiplied by 0.96 to represent a standard 4.0% pencil shrink.

Carcass Fabrication and Subprimal Yield

Carcasses were subsampled each week for whole carcass fabrication to determine subprimal yield. Before grading, the mean HCW for each pen was calculated and carcasses were identified that were ± 30 pounds from the pen HCW mean. During grading, two carcasses per pen within the given weight range were selected for each of four different fat thicknesses, including: Lean (< 0.32”); Low Average (0.33-0.44”); High Average (0.45-0.60”); and Fat (> 0.60”). The carcass fabrication selection matrix is listed in Appendix C. This resulted in eight carcasses per pen, 16 carcasses per treatment, 80 carcasses per week, and 320 carcasses over the duration of the study. Carcasses were fabricated during a separate shift each Saturday of the carcass phase. Trained plant personnel fabricated carcass primals and individual components were weighed and recorded by Colorado State University personnel, whom assured that each subprimal calculated a weigh back yield that did not exceed ± 2% of the total (98 to 102%). Each side was separated into the components listed in Appendix C. Weights were expressed as a percentage of chilled side weight, which was ascertained immediately before fabrication.

Warner-Bratzler and Slice Shear Force

Eighteen samples per pen were randomly selected during grading. The subsampling resulted in 36 samples per treatment per week, 180 samples per week, and 720 total samples over the duration of the study. Strip loin samples were cut from carcasses after grading and transported to Colorado State University in coolers chilled with ice. Samples were collected from both carcass sides; one side was used for shear force evaluation and the opposite was utilized for sensory evaluation. Side selection was randomized to represent an equal number of left and right carcass sides for tenderness and sensory evaluation. Upon arrival at the Colorado State University meat laboratory, the vacuum-sealed strip loin samples were aged for 14 d and subsequently frozen at -20°C. Once fully frozen, samples were cut into 2.5 cm steaks on a band saw, vacuum packaged and replaced into frozen storage. Upon conclusion of aging, samples were randomly assigned to a cooking day upon which Warner Bratzler Shear Force (WBSF) and Slice Shear Force (SSF) analysis was conducted. Steaks were thawed at 4°C for 24 h and cooked on an XLT Impingement Oven (BOFI Inc, Wichita, KS). A pre-cook temperature and weight, and post-cook temperature and weight were recorded. Steaks were cooked to a medium-well degree of doneness (68-71° C). A 1 cm slice was removed parallel to the longitudinal direction of the muscle fibers from the anterior portion of a freshly cooked steak for SSF evaluation. The measurement of SSF was conducted according to Shackelford et al. (1999) on an Instron Universal Testing Machine, Model 1011 (Instron Corporation, Canton, MA) using a slice shear force head at a cross-head speed of 500 mm/min. The remaining portion of the steak was allowed to cool to room temperature after which a minimum of five, 1 cm cores were removed parallel to the longitudinal orientation of the muscle fibers for WBSF analysis. Warner Bratzler shear force analysis was conducted according to AMSA guidelines (1995) on an Instron Universal Testing Machine, Model 1011 (Instron Corporation, Canton, MA) with a Warner-

Bratzler shear head at a cross-head speed of 200 mm/min. The core force for each of the 5 cores per steak was averaged to determine a single shear value for each steak.

Trained Sensory Panel Evaluation

Strip loin samples (720 total were subsampled) were collected from the opposite carcass side of carcasses selected for shear force evaluation. Steaks were aged, frozen, cut, and stored identically to steaks for WBSF and SSF evaluation. Twelve steaks were randomly assigned to one of 60 panels. Three panels were served per day to a minimum of six trained panelists. Steaks were cooked on an XLT Impingement Oven (BOFI Inc, Wichita, KS) to a medium-well degree of doneness (68-71°C). Steaks were then cut into 1 cm cubes, and two warm cubes per steak were fed to panelists. Panelists rated each steak by making a mark on a 15 cm unstructured line scale for the following attributes: myofibrillar tenderness, connective tissue tenderness, overall tenderness, juiciness, beef flavor intensity, butter/beef fat flavor, and any perceived off-flavors. Each line scale indicated a very low presence or desirability on the far left side and very high presence or desirability on the far right. A sample sensory ballot can be found in Appendix D. For each sample, panelist scores were averaged to determine a single value for each attribute.

Statistical Analysis

Analysis was conducted as a completely randomized block design. All variables were analyzed as a mixed model in JMP 9.0 (SAS Inst. Inc., Cary, NC) using pen as the experimental unit. Block (slaughter week) and treatment were utilized as a fixed effect in the model. The Student's t-test was used to test for differences among least squares means when the main effect of treatment was significant at a *P*-value less than 0.05.

For subprimal yield data, any carcasses that had a subprimal yield that exceeded the ± 2% weigh-back yield threshold were removed from the dataset before analysis. Subprimal yield was calculated as a percent of CSW.

Results and Discussion

Study Diet and Supplement Inclusion

Feed samples were collected and assayed regularly throughout the study for RH and ZH inclusion rates. Assay results indicated that RH inclusion rate averaged 13.5, 22.4, and 124.2 g/ton on an as fed basis for RAC200, RAC300, and RAC400 treatments, respectively. These samples averaged 108.9, 105.3, and 92.7% of the mean theory for RH inclusion on an as fed basis (acceptable limits are 75 to 125 percent). Results from ZH assays indicated that the average inclusion rate was 6.36 g/ton on an as fed basis, which averaged 93.33 percent of the mean theory (acceptable limits are 75 to 115 percent). Average per head consumption of RH for the CON and RAC treatments were 0, 192, 292, and 392 mg/hd/d. Average per head consumption of ZH for the ZIL treatment was 80 mg/hd/d.

Live Animal Performance

Live animal performance data are listed in Table 3.1. Upon initiation of the treatment phase, the average pre-treatment weight for all cattle on trial was 542.29 ± 2.72 kg, and did not differ among treatments ($P = 0.9164$). There was no effect on final BW due to treatment ($P = 0.2892$; Table 3.1). Average daily gain was affected by treatment ($P < 0.05$), and was improved via dietary supplementation of βAA. There were no differences between ZIL and all RAC treatments. The RAC200 treatment did not differ from controls. Dry matter intake was not affected by treatment ($P = 0.0575$), but tended to be decreased due to βAA supplementation. As

such, F:G ratio was improved due to treatment ($P < 0.05$), and was significantly lower for ZIL and all RAC treatment versus controls.

Present results were consistent with those of previous studies that revaluated the impact of RH and ZH supplementation. These studies reported substantial improvements in live animal performance due to dietary βAA supplementation (Avendaño-Reyes et al., 2006; Boler et al., 2012; Elam et al., 2009; Gruber et al., 2007). In a comparative study between the two βAA compounds, Scramlin et al. (2010) reported similar advantages in final BW and ADG for cattle supplemented with 200 mg/hd/d of RH for the final 33 d of feeding compared to those receiving 75 mg/hd/d of dietary ZH for 30 d; the study reported no differences in average daily feed intake or G:F ratio between the two βAA treatments (Scramlin et al., 2010). Alternatively, Avendaño-Reyes et al. (2006) reported conflicting results, reporting that steers supplemented with 60 mg/hd/d of ZH for 30 d had larger final BW and greater ADG than steers supplemented 300 mg/hd/d of RH for the same period. Results from the current study showed negligible differences in final BW, and ADG and F:G values indicated negligible differences between RH supplemented at any level compared to ZH.

Carcass Characteristics

Carcass results are summarized in Table 3.2 and 3.3. Hot carcass weight differed by treatment ($P < 0.05$). Increased dose and potency of βAA increased HCW, with ZIL treatment carcasses resulting in the heaviest HCW, which was similar to the RAC400 treatment. Dressing percent also was improved due to treatment with ZIL treatment cattle reporting a higher DP compared to all other treatments ($P < 0.05$); steers receiving the RAC300 and RAC400 treatment had a similar DP to steers receiving the CON treatment. Control steers and RAC200 steers generated carcasses with a similar DP. Mesenteric fat weights were measured to aid in

quantification of disparities in DP. There were no differences in mesenteric fat weights between treatments ($P = 0.8429$). Current βAA literature recognizes improvements in HCW due to dietary βAA supplementation, as well as the improvements in DP provided by ZH supplementation (Avendaño-Reyes et al., 2006; Elam et al., 2009; Gruber et al., 2007; Scramlin et al., 2010; Vogel et al., 2009). Current theories suggest a shift in protein metabolism from non-carcass components to carcass components (i.e., kidney, pelvic, heart fat, organ weight, and mesenteric fat); however, there are no studies which report differences to substantiate differences in dressing percent.

Longissimus muscle area differed due to treatment ($P < 0.05$), and was largest for carcasses from steers treated with ZIL compared to all other treatments. Steers receiving the RAC400 and RAC300 treatments had similar LMA, and were larger than steers receiving the RAC200 and CON treatments. There were no differences in 12^{th}-rib FT between treatments ($P = 0.8631$). It is generally recognized that both RH and ZH impart improvements on LMA in fed cattle (Avendaño-Reyes et al., 2006; Gruber et al., 2007; Kellermeier et al., 2009; Vogel et al., 2009; Woerner et al., 2011). However, previous studies have generated differing results on effects of βAA supplementation on FT and PYG. Scramlin et al. (2010) reported that carcass FT was not affected by RH supplementation at 300 mg/hd/d for the final 33 d of the feeding period; however ZH supplementation at 75 mg/hd/d for the final 33 d of the feeding period decreased carcass FT in the same study compared to RH and control treatment cattle. Vogel et al. (2009) reported that FT did not differ between controls and steers fed RH at 200 mg/hd/d for final 28 to 38 d of the feeding period; yet, steers supplemented RH at 300 mg/hd/d for the final 28 to 38 d of the feeding period generated carcasses with reduced 12^{th}-rib FT compared to controls and cattle fed RH at 200 mg/hd/d. Zilpaterol supplementation has been shown to decrease 12^{th}-rib FT

(Elam et al., 2009; Hilton et al., 2009); however several studies also have reported no effect on carcass FT due to ZH supplementation (Kellermeier et al., 2009; Montgomery et al., 2009; Parr et al., 2011). Supplementation level and duration of feeding of ZH was similar in each study, and there is little scientific information available to explain differences in carcass FT results.

USDA yield grade was improved due to treatment ($P < 0.05$; Table 3.2), and was lowest for carcasses from steers in the ZIL treatment compared to controls (2.70 vs. 2.98). USDA yield grade was similar for all RAC treatments. Treatment affected the frequency of YG1 and YG3 carcasses ($P < 0.05$; Table 3.3; Figure 3.2). Zilpaterol treatment of steers resulted in carcasses that were graded most frequently as YG1, and was a significantly higher frequency compared to all other treatments. Likewise, steers receiving ZH supplementation had the lowest frequency of YG3 carcasses ($P < 0.05$), and was a lower frequency compared to all other treatments. Gruber et al. (2007) reported a decrease in the frequency of YG3 and an increase in the frequency of YG2 carcasses due to RH supplementation. Comparatively, Boler et al. (2012) reported no difference in YG distribution due to dietary RH supplementation. Montgomery et al. (2009) reported that dietary ZH supplementation increased the frequency of carcasses with a numerical YG of 1.00-1.99 and 2.00-2.49, while also decreasing the frequency of carcasses with a numerical YG of 3.50-3.99 and 4.00-4.99. The results from Montgomery et al. (2009) are consistent with Elam et al. (2009) who reported increases in carcasses with a numerical YG less than 2.5, and a decrease in the frequency of carcasses with a numerical YG greater than 3.5.

Marbling score for carcasses differed by treatment ($P < 0.05$; Table 3.2) and was lower for steer receiving the ZIL treatment compared to steers in the control treatment (407.50 vs. 429.01). As a function of this, the frequency of carcasses qualifying for an Upper 2/3 Choice premium was decreased due to treatment ($P < 0.05$) and there was a tendency for the frequency

of USDA Choice carcasses to be decreased due to treatment ($P = 0.0973$) with steers receiving the ZIL treatment generating the lowest frequency (46.85%); treatment also had a tendency to increase the frequency of USDA Select carcasses ($P = 0.1076$), with steers receiving the ZIL treatment also having the highest frequency (50.43%). There was no treatment effect on carcass maturity (carcasses exceeding C-maturity; $P = 0.4555$) or on carcasses receiving a discount for heavy HCW greater than 950 lbs. or greater than 1050 lbs. ($P = 0.4448$ and 0.7283, respectively). Marbling score distributions for each treatment also are reported in Appendix E. Multiple studies have reported no difference in marbling score and quality grade distribution due to dietary RH supplementation of the live cattle from which these carcasses were derived (Boler et al., 2012; Gruber et al., 2007). However, Vogel et al. (2009) reported a reduction in marbling score and a reduction in the frequency of Holstein steers grading USDA Prime and Choice as well as an increase in the frequency of steers grading USDA Select due to RH supplementation of the live cattle. Studies assessing effects of dietary ZH supplementation on carcass quality have produced consistent results indicating a reduction in marbling score and general shift in the quality grade distribution to a higher frequency of carcasses grading USDA Select and a lower frequency of carcasses grading USDA Prime and Choice (Beckett et al., 2009; Elam et al., 2009; Montgomery et al., 2009).

Carcass Subprimal Yield

Effects of treatment on carcass fabrication yields are listed in Table 3.4. Total saleable yield differed by treatment ($P < 0.05$), and was highest for steers receiving the ZIL and RAC400 treatments. There were no differences between RAC200, RAC300, and RAC400 treatments. Likewise, total saleable yield was similar for steers receiving the CON, RAC200, and RAC300 treatments. The primary subprimals that were affected by treatment were located in the round

and sirloin. Treatment with βAA increased yield for the inside round, eye of round, shank meat, peeled knuckle, outside round, tri-tip, and quadriceps muscle group (ball-tip + peeled knuckle). Additionally, the strip loin, 91's trim, and bone differed by treatment ($P < 0.05$). All subprimals that had a significant treatment effect did not differ between steers that received the ZIL or RAC400 treatments, with the exception of the inside round; steers receiving the CON and RAC200 treatments did not differ for any subprimal yields. Likewise, all subprimals that differed by treatment had higher yields for subprimals derived from steers receiving the ZIL treatment compared to those receiving the CON treatment.

Various cutout studies evaluating the effects of ZH supplementation on carcass cutability have produced similar results as those in the current study, and have reported the most pronounced yield effect on subprimals from the round (Hilton et al., 2009; Kellermeier et al., 2009; Rathmann et al., 2009). Yield increases in the round have been primarily attributed to a higher portion of Type IIa, glycolytic fibers in the round that are more responsive to βAA effects (Miller et al., 1988). Rathmann et al. (2009) reported more pronounced effects of ZH supplementation compared to carcasses from control treatment steers on subprimal yield in the chuck with increases in the #114C chuck shoulder clod, #114F chuck shoulder tender, #116A chuck roll, and #116B chuck mock tender. Comparatively, Hilton et al. (2009) and Kellermeier et al. (2009) only reported subprimal yield differences in the shoulder clod and mock tender, which are consistent with the results from the current study. In comparison to studies conducted evaluating carcass cutout yield, carcass fabrication was conducted in large scale production facilities at faster line speeds, rather than at university meat laboratories; the subprimals were cut to plant specifications, rather than National Association of Meat Processors (NAMP) specifications or International Meat Purchasing Specifications (IMPS). While the

aforementioned studies yielded similar results to the current, differences in subprimal yield could be attributed to different cut specifications. Additionally, Rathmann et al. (2009), Hilton et al. (2009), and Kellermeier et al. (2009) pre-selected cattle and carcasses to represent uniform yield grade parameters for each treatment. The current study utilized a selection criterion which sorted carcasses into four different fat thickness groups for each treatment. Disparities in fat thickness could account for over-trimming of lean cuts and under-trimming of fatter cuts during normal in-plant fabrication processes, which could decrease differences between subprimals in the current study compared to those that are recognized in studies conducted outside large-scale beef production facilities.

Warner-Bratzler and Slice Shear Force

Results for objective tenderness evaluation are reported in Table 3.5. Warner-Bratzler shear force values differed by treatment ($P < 0.05$) and increased with increased dose and potency of βAA. Steaks from carcass of steers receiving ZIL treatment reported the highest WBSF values (3.95 kg) and were higher than all other treatments ($P < 0.05$). Warner-Bratzler shear force values were similar for RAC300 and RAC400 treatments, while WBSF for steaks from steers receiving RAC200 and CON treatments also were similar. The American Society for Testing and Materials (ASTM) has determined the WBSF threshold for tenderness claims in beef is 4.4. kg (ASTM, F2925-11). The percentage of steaks with a WBSF value exceeding 4.4 kg increased due to treatment ($P < 0.05$). The percentage of steaks shearing greater than 4.4 kg was nearly 20 percent greater in steaks from ZIL treatment carcasses compared to controls (22.34% vs. 2.50%). Steaks from steers receiving RAC200, RAC300, and RAC400 treatments had similar frequencies of steaks shearing greater than 4.4 kg.

Slice shear force values also differed by treatment ($P < 0.05$). Steaks from steers receiving the ZIL treatment had the highest SSF values, while steaks from steers receiving the RAC300 and RAC400 treatments were not different; steaks from steers receiving the CON and RAC200 treatments did not differ, as well. Similar to WBSF values, the ASTM SSF threshold for tenderness claims is 20.0 kg (ASTM, F2925-11). At this threshold, frequency of steaks shearing greater than 20.0 kg differed by treatments ($P < 0.05$). Steaks from steers receiving the ZIL treatment exceeded those from the control treatment that sheared greater than 20.0 kg by nearly 20 percent (25.10% vs. 5.66%); steaks from steers receiving the ZIL treatment also did not differ from steaks from steers receiving the RAC400 treatment. There were no differences between steaks from steers receiving RH supplementation at any dosage.

A multitude of studies have reported the negative effects of dietary βAA supplementation on postmortem tenderness (Boler et al., 2012; Gruber et al., 2008; Leheska et al., 2009; Rathmann et al., 2009). The current study evaluated tenderness only at 14 d postmortem and generated results similar to studies evaluating steaks from treated cattle at comparable aging periods. Ractopamine studies have reported that at 14-d steaks from RH supplemented cattle are tougher than controls (Boler et al., 2012; Gruber et al., 2008; Scramlin et al., 2010; Woerner et al., 2011); however there is literature that suggests postmortem aging in excess of 14 d reduces disparities in tenderness (Boler et al., 2012; Scramlin et al., 2010). Other studies have reported no effect of aging on improving tenderness in steaks from RH supplemented cattle compared to controls (Gruber et al., 2008; Woerner et al., 2011). Studies evaluating dietary ZH supplementation on postmortem tenderness have reported more pronounced reductions in tenderness, and showed no effect of postmortem aging on reducing tenderness differences compared to controls (Garmyn et al., 2010; Kellermeier et al., 2009; Rathmann et al., 2009).

There were no differences between treatments or contrasts in the percentage cook loss from steaks of carcasses used for objective tenderness measurements (Table 3.5).

Trained Sensory Panels

Results for trained sensory panel analysis are reported in Table 3.6. Each of the three tenderness attributes evaluated by trained panelists differed by treatment ($P < 0.05$). Steaks derived from steers receiving the CON treatment were the highest rated for myofibrillar, connective tissue, and overall tenderness and steaks from steers receiving the ZIL treatment were the lowest rated for all tenderness attributes. There were no differences between steaks from steers receiving the RAC400 treatment and ZIL treatment for connective tissue or overall tenderness; the two treatments did differ in the trained panelist ratings for myofibrillar tenderness. There were no differences between steaks from steers receiving the RAC200 and RAC300 treatments for each tenderness attribute; there were also no differences in panelists ratings for steaks from steers receiving the CON and RAC200 treatments for all tenderness attributes.

Treatment of steers with βAA caused no differences in juiciness ($P = 0.2455$), beef flavor ($P = 0.1265$), beef fat flavor ($P = 0.3314$), or off flavors ($P = 0.8876$) of steaks.

Gruber et al. (2008) reported that trained sensory panelists rated steaks from cattle fed dietary RH at 200 mg/hd/d lower for tenderness and juiciness compared to controls. Hilton et al. (2009) reported that trained panelists rated steaks from ZH treated cattle lower for tenderness, juiciness, and beef flavor. Garmyn et al. (2010) also reported that overall tenderness and sustained juiciness scores were reduced due to ZH supplementation, but found no differences in panelist rating for flavor attributes. Disparities in WBSF and SSF values between treatments should indicate differences in trained sensory panelist evaluation. In the current study, the shear

force and trained sensory panel results indicated the same trend in tenderness due to βAA supplementation of live cattle. It is recognized that βAA supplementation increases fiber diameter in skeletal muscle (Gonzalez et al., 2007; Kellermeier et al., 2009). Kellermeier et al. (2009) reported that, along with an increase in fiber diameter due to dietary ZH supplementation, strip loins from ZH treated cattle had a greater percent purge loss compared to controls. The additional purge loss reported in ZH studies (Kellermeier et al., 2009) could be a contributing factor to differences in juiciness and flavor. In the current study, cook loss was measured immediately after cooking; however, drip loss or purge before cooking or after the tempering period was not evaluated. Further evaluation of these factors could provide insight into the factors driving juiciness and flavor differences in other research.

Conclusions

Results of this study indicated that improvements in live animal performance and carcass traits occurred due to increased dose and potency of dietary βAA supplementation. Average daily gain and F:G ratio was improved in a manner consistent with contemporary Ractopamine and Zilpaterol literature (Gruber et al., 2008; Kellermeier et al., 2009; Montgomery et al., 2009). However, differences in final BW between treatments was not as pronounced as that reported in other βAA studies (Elam et al., 2009; Gruber et al., 2009; Kellermeier et al., 2009; Scramlin et al., 2010).

Steers receiving dietary ZH supplementation generated the heaviest HCW, highest DP, and largest LMA. Means separation indicated no differences between RAC treatments for HCW, DP, and LMA. USDA yield grade and marbling score were reduced due to βAA supplementation of live cattle. Reductions in marbling score due to treatment reduced the frequency of carcasses qualifying for an Upper 2/3 Choice premium. The percentage of YG1

carcasses was increased and the percentage of YG3 carcasses was decreased due to treatment, with carcasses from steers receiving the ZIL treatment having the highest frequency of YG1 and lowest frequency of YG3 carcasses.

Total saleable yield was improved with supplementation of βAA, and was highest for carcasses from steers receiving the RAC400 and ZIL treatments. Treatment with βAA's had the most pronounced effects on yield in subprimals from the round including: inside round, eye of round, shank meat, peeled knuckle, outside round, tri-tip, and quadriceps. Additionally, treatment improved yield for the strip loin, 91's trim, blade meat, and bone.

Steaks from steers supplemented with ZH had the toughest WBSF and SSF values, while also having the highest frequency of steaks shearing greater than 4.4 kg of WBSF. Beta-agonist treatment also increased the frequency of steaks shearing greater than 20.0 kg SSF in the RAC400 and ZIL treatments. For WBSF, SSF, and the frequency of steaks shearing greater than 4.4 and 20.0 kg, steaks from steers receiving the CON and RAC200 treatments did not differ. Similar trends were detected by trained sensory panelists, who rated steaks from cattle receiving the ZIL and RAC400 treatments tougher for myofibrillar, connective tissue, and overall tenderness than steaks from all other treatments.

This study supports literature indicating that the growth and carcass traits are improved via dietary βAA supplementation, but also reinforces the negative impact βAA's pose on meat quality and palatability. Additionally, results from this study demonstrated minimal differences in growth and carcasses characteristics between RH supplementation at higher concentrations (300 and 400 mg/hd/d) compared to ZH that was provided in steer diets at recommended label dosages (6.8 g/ton). Moreover, while ZIL treatment had a more pronounced effect on WBSF values, trained sensory panelists rated ZIL and RAC400 steaks similarly. Lower potencies of

RH are optimal to mitigate issues with quality, tenderness, and palatability, albeit with lesser effects on performance and carcass characteristics.

Cattle feeders have the opportunity to improve efficiency and carcass yield via the use of βAA's. Yet, this research underlines the importance of judicious use of growth enhancement technologies to optimize cattle growth and beef quality. Beta-agonist use should be matched with the biological type of cattle which will reduce issues with marbling and tenderness. Doing so will enhance growth and yield in lower performing cattle, and preserve quality and palatability in leaner, faster gaining breeds.

Table 3.1. Effect of Ractopamine hydrochloride and Zilpaterol hydrochloride supplementation of steers on live animal performance

	Treatment[1]						
Item[2]	CON	RAC200	RAC300	RAC400	ZIL	SEM	$P < F_{TRT}$
In Weight[3]	544.15	541.58	540.60	542.67	542.45	2.72	0.9164
Final Weight[4]	586.78	590.88	592.56	596.39	594.66	3.24	0.2892
ADG	1.42[b]	1.64[a]	1.73[a]	1.79[a]	1.74[a]	0.07	0.0059
DMI	9.89	9.60	9.73	9.83	9.63	0.13	0.0575
F:G	7.06[a]	5.88[b]	5.68[b]	5.60[b]	5.58[b]	0.25	0.0005

[a,b]Values in the same column that do not share a common superscript differ ($P < 0.05$).

[1]Treatments: CON = Control; RAC = Ractopamine hydrochloride (Elanco Animal Health, Greenfield, IN) fed at 200 or 300 mg/hd/d, or 400 mg/hd/d top dress ; ZIL = Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at 6.8 g/ton.

[2]Pen used as experimental unit.

[3]In Weight = pen weight collected before initiation of treatment calculated with 4% shrink.

[4] Final Weight = pen weight collected before shipment to slaughter with 4% shrink.

Table 3.2. Effect of Ractopamine hydrochloride and Zilpaterol hydrochloride supplementation of steers on subsequent carcass characteristics

	Treatment[1]						
Item[2]	CON	RAC200	RAC300	RAC400	ZIL	SEM	$P < F_{TRT}$
Hot carcass wt, kg	376.64[d]	376.00[c,d]	380.47[b,c]	382.91[a,b]	387.70[a]	1.89	0.0002
Dressing Percent	63.84[b,c]	63.64[c]	64.21[b]	64.21[b]	65.20[a]	0.14	< 0.0001
Mesenteric Fat, %	1.67	1.64	1.59	1.63	1.51	0.10	0.8429
LM area, sq. cm	84.71[c]	84.92[c]	86.32[b,c]	87.11[b]	91.38[a]	0.70	< 0.0001
12-rib fat, cm	1.13	1.09	1.11	1.10	1.06	0.04	0.8631
USDA yield grade	2.98[a]	2.95[a]	2.94[a]	2.92[a]	2.70[b]	0.07	0.0379
Marbling Score[3]	429.01[a]	416.02[a,b]	411.93[b]	419.94[a,b]	407.50[b]	4.91	0.0422

[a-d]Values that do not share a common superscript in the same row differ ($P < 0.05$).

[1]Treatments: CON = Control; RAC = Ractopamine hydrochloride (Elanco Animal Health, Greenfield, IN) fed at 200 or 300 mg/hd/d, or 400 mg/hd/d top dress ; ZIL = Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at 6.8 g/ton.

[2]Pen used as experimental unit

[3]Marbling score: 300 = Slight[00]; 400 = Small[00].

Table 3.3. Effect of Ractopamine hydrochloride and Zilpaterol hydrochloride supplementation of steers on subsequent Quality Grade and Yield Grade distribution

	Treatment[1]						
Item, %[2]	CON	RAC200	RAC300	RAC400	ZIL	SEM	$P < F_{TRT}$
Prime	0.40	0.14	0.50	0.25	0.13	0.21	0.6762
Upper 2/3 Choice[3]	13.73[a]	11.49[a,b]	8.69[b]	11.84[a,b]	3.08[c]	1.18	< 0.0001
Choice	57.55	51.82	48.66	52.61	46.85	2.80	0.0973
Select	40.22	45.62	48.92	45.17	50.43	2.74	0.1076
No Roll	1.31	2.03	1.79	1.30	1.83	0.44	0.6890
Hard Bone	0.52	0.39	0.13	0.66	0.76	0.26	0.4555
Heavy HCW							
> 950 lbs.	0.52	0.25	0.86	1.17	1.30	0.45	0.4448
> 1050 lbs.	0.00	0.00	0.12	0.12	0.13	0.09	0.7283
Yield Grade 1	6.38[b]	5.56[b]	6.33[b]	6.30[b]	11.89[a]	1.59	0.0497
Yield Grade 2	43.24	44.06	42.71	44.93	52.90	3.45	0.2332
Yield Grade 3	43.66[a]	44.57[a]	46.23[a]	44.57[a]	31.94[b]	3.44	0.0397
Yield Grade 4	6.59	5.67	4.73	4.21	3.27	1.37	0.4863
Yield Grade 5	0.14	0.14	0.00	0.00	0.00	0.09	0.5799

[a,b,c]Values that do not share a common superscript in the same row differ ($P < 0.05$).

[1]Treatments: CON = Control; RAC = Ractopamine hydrochloride (Elanco Animal Health, Greenfield, IN) fed at 200 or 300 mg/hd/d, or 400 mg/hd/d top dress ; ZIL = Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at 6.8 g/ton.

[2]Pen used as experimental unit.

[3]Upper 2/3 Choice = Greater than or equal to Modest[00].

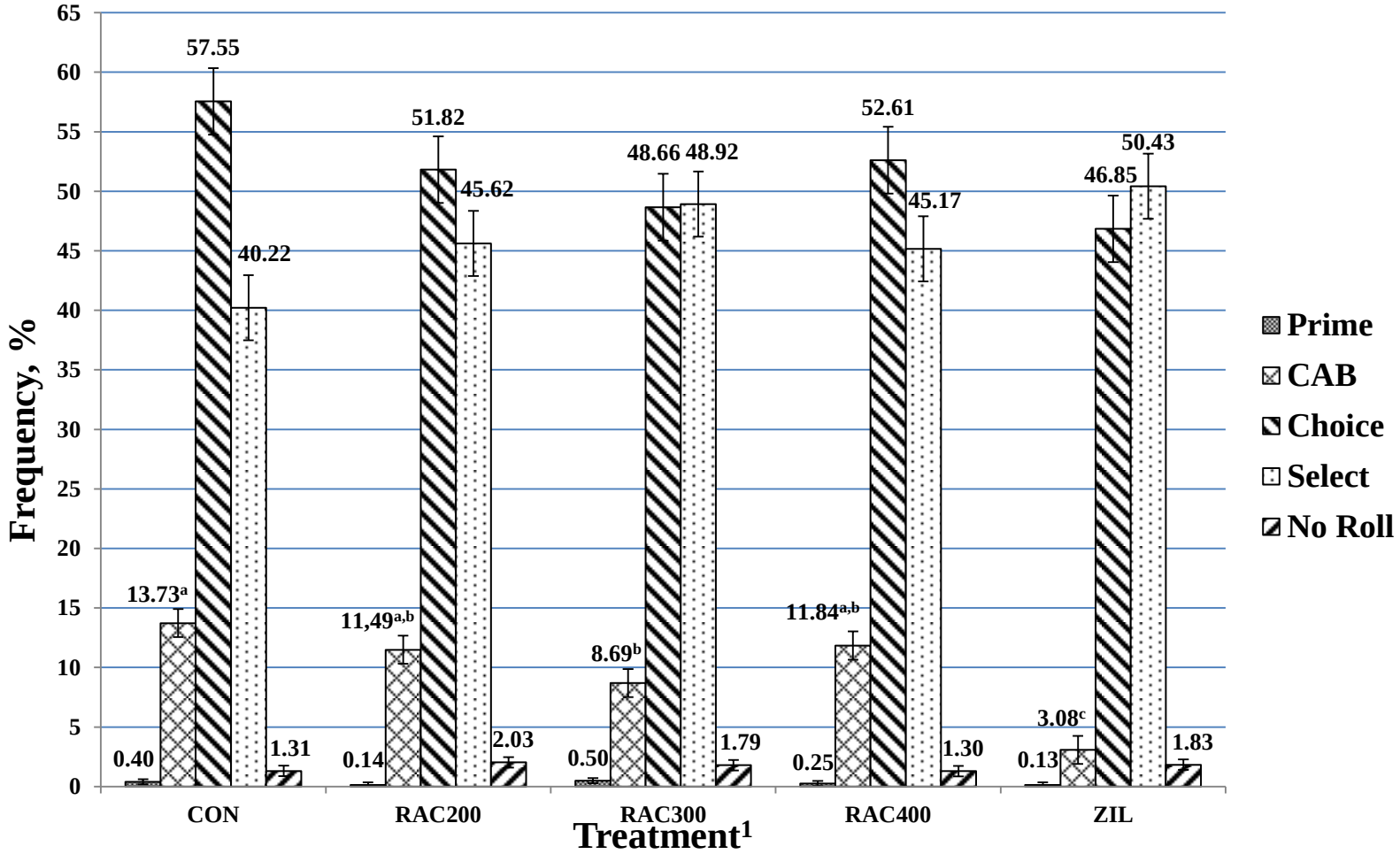

Figure 3.1. Effect of Ractopamine hydrochloride and Zilpaterol hydrochloride of steers on subsequent USDA Quality Grade distributions (values expressed as treatment mean frequency). [a,b]Least squares means (bars) not sharing a common superscript differ ($P < 0.05$). [1]Treatments: CON = Control; RAC = Ractopamine hydrochloride (Elanco Animal Health, Greenfield, IN) fed at 200 or 300 mg/hd/d, or 400 mg/hd/d top dress ; ZIL = Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at 6.8 g/ton.

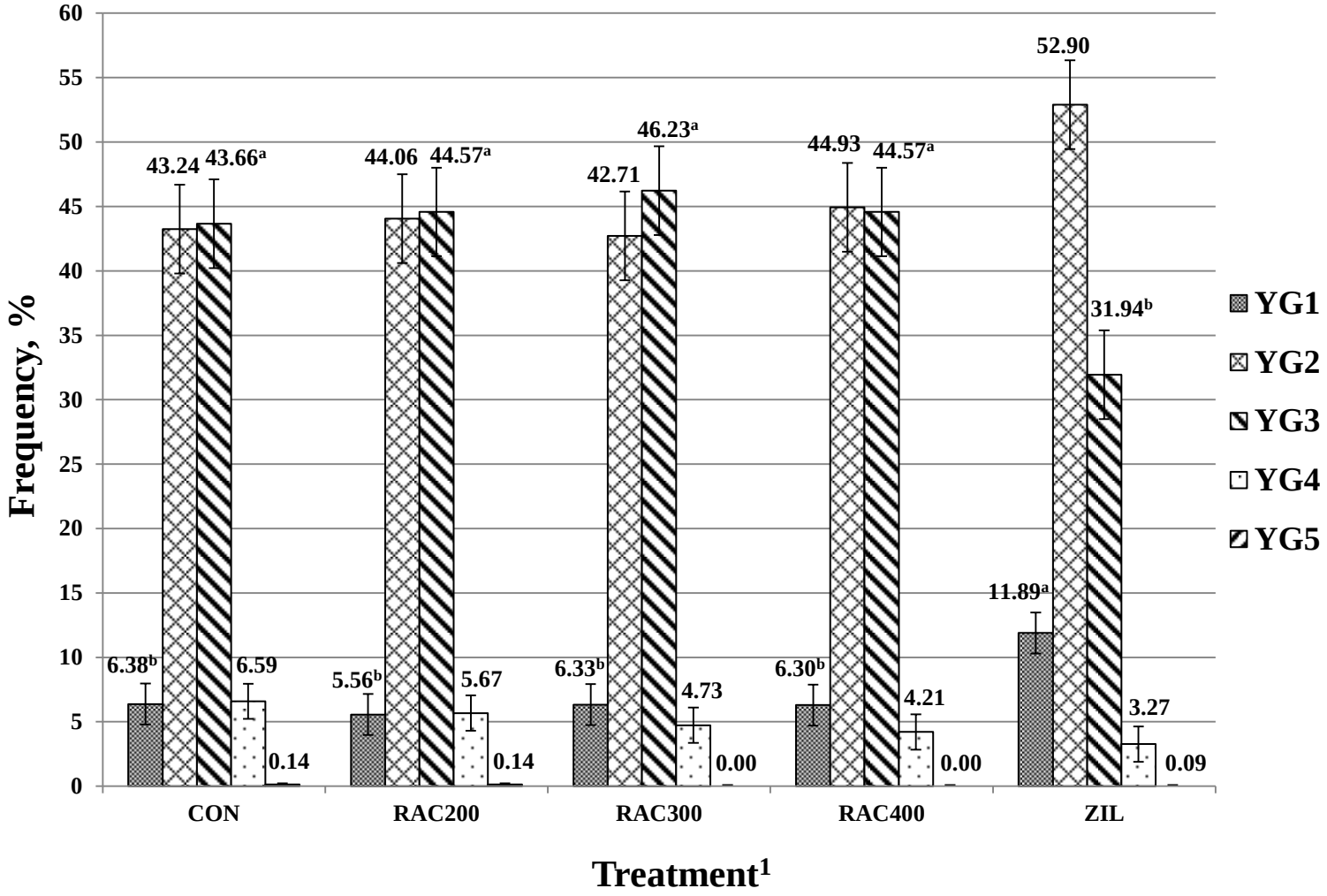

Figure 3.2. Effect of Ractopamine hydrochloride and Zilpaterol hydrochloride supplementation of steers on subsequent USDA Yield Grade distributions (values expressed as treatment mean frequency). [a,b]Least squares means (bars) not sharing a common superscript differ ($P < 0.05$). [1]Treatments: CON = Control; RAC = Ractopamine hydrochloride (Elanco Animal Health, Greenfield, IN) fed at 200 or 300 mg/hd/d, or 400 mg/hd/d top dress ; ZIL = Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at 6.8 g/ton.

Table 3.4. Effect of Ractopamine hydrochloride and Zilpaterol hydrochloride supplementation of steers on percent carcass yield of subprimal cuts from fabricated carcasses

	Treatment[1]						
Item[2]	CON	RAC200	RAC300	RAC400	ZIL	SEM	$P < F_{TRT}$
Chuck roll	5.89	5.84	5.84	5.86	5.83	0.07	0.9583
Chuck mock tender	0.86	0.88	0.88	0.89	0.90	0.01	0.1001
Chuck flat	0.47	0.47	0.47	0.45	0.45	0.01	0.3598
1 piece shoulder clod	4.55	4.62	4.60	4.64	4.69	0.04	0.1093
Teres major	0.21	0.21	0.22	0.22	0.22	0.00	0.1810
Pectoral muscle	0.62	0.65	0.66	0.63	0.64	0.02	0.4023
Bnls Chuck Short Ribs	0.45	0.46	0.45	0.45	0.45	0.01	0.8858
Ribeye roll	3.63	3.59	3.57	3.62	3.59	0.03	0.5701
Brisket, boneless	2.84	2.82	2.82	2.91	2.95	0.05	0.1752
Back ribs	1.05	1.03	1.02	1.03	1.01	0.01	0.1711
Inside round	5.68^{d}	$5.73^{c,d}$	$5.87^{a,b}$	$5.83^{b,c}$	5.96^{a}	0.05	0.0012
Eye of round	1.41^{c}	$1.44^{b,c}$	$1.51^{a,b}$	1.49^{a}	1.53^{a}	0.02	0.0005
Shank meat	1.18^{b}	$1.20^{a,b}$	1.22^{a}	$1.19^{a,b}$	1.22^{a}	0.01	0.0145
Knuckle, peeled	2.59^{b}	2.60^{b}	2.72^{a}	$2.67^{a,b}$	2.69^{a}	0.03	0.0474
Outside (flat) round	3.66^{c}	$3.70^{b,c}$	3.83^{a}	$3.76^{a,b}$	3.83^{a}	0.03	0.0001
Tenderloin	1.48	1.49	1.51	1.54	1.54	0.02	0.0526
Strip loin	2.88^{b}	2.98^{a}	$2.94^{a,b}$	2.95^{a}	2.98^{a}	0.03	0.0495
Top butt	3.17	3.16	3.19	3.18	3.20	0.03	0.8017
Short rib	1.35	1.34	1.36	1.33	1.33	0.01	0.2543
Flank	0.51	0.52	0.52	0.52	0.53	0.01	0.5559
Inside skirt	0.50	0.50	0.50	0.51	0.51	0.01	0.9578
Outside skirt	0.39	0.40	0.39	0.39	0.38	0.01	0.3430
Sirloin flap	0.87	0.91	0.89	0.91	0.89	0.02	0.4038
Tri-tip	0.76^{b}	0.78^{a}	0.79^{a}	$0.78^{a,b}$	0.81^{a}	0.01	0.0221
Ball-tip	0.62	0.62	0.60	0.63	0.66	0.03	0.6262
Blade meat	1.53^{b}	1.53^{b}	1.55^{b}	$1.57^{a,b}$	1.61^{a}	0.02	0.0255
Quadriceps	3.21^{c}	$3.22^{b,c}$	$3.32^{a,b,c}$	$3.29^{a,b}$	3.35^{a}	0.03	0.0021
50’s trim	3.65	3.54	3.55	3.56	3.52	0.05	0.3838
65’s trim	4.15	4.19	4.13	4.21	4.16	0.05	0.8100

Item[2]	Treatment[1]					SEM	$P < F_{TRT}$
	CON	RAC200	RAC300	RAC400	ZIL		
81's trim	5.56	5.74	5.61	5.64	5.67	0.06	0.2938
86's trim	3.10	3.14	3.20	3.15	3.20	0.03	0.0543
91's trim	4.01[a]	3.95[a,b]	3.99[a]	3.87[b]	3.91[a,b]	0.03	0.0174
Fat Tissue	14.63	14.47	14.21	14.08	14.10	0.24	0.4175
Bone	16.26[a]	15.96[a,b]	16.09[a]	16.03[a]	15.61[b]	0.12	0.0091
Total Saleable Yield	70.20[c]	70.61[b,c]	70.75[b,c]	70.90[a,b]	71.37[a]	0.23	0.0210

[a,b,c]Values that do not share a common superscript in the same row differ ($P < 0.05$).

[1]Treatments: CON = Control; RAC = Ractopamine hydrochloride (Elanco Animal Health, Greenfield, IN) fed at 200 or 300 mg/hd/d, or 400 mg/hd/d top dress ; ZIL = Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at 6.8 g/ton.

[2] Weight expressed as a percent of chilled side weight; subprimals cut to plant specification. Pen used as the experimental unit.

Table 3.5. Effect of Ractopamine hydrochloride and Zilpaterol hydrochloride supplementation of steers on subsequent steak Warner-Bratzler and Slice Shear Force measurements

	Treatment[1]						
Item[2]	CON	RAC200	RAC300	RAC400	ZIL	SEM	$P < F_{TRT}$
WBSF, kg	3.36^{d}	3.50^{c,d}	3.61^{b,c}	3.65^{b}	3.95^{a}	0.05	< 0.0001
> 4.4 kg, %	2.70^{c}	7.65^{b,c}	8.38^{b,c}	13.33^{b}	22.37^{a}	2.20	< 0.0001
SSF, kg	14.61^{d}	15.34^{c,d}	15.93^{b,c}	16.92^{b}	18.13^{a}	0.37	< 0.0001
> 20 kg. %	5.56^{c}	13.33^{b,c}	13.86^{b,c}	23.07^{a,b}	25.07^{a}	3.92	0.0071
Cook Loss, %	18.50	18.88	19.06	19.16	19.70	0.47	0.4923

[a-d]Values in the same column that do not share a common superscript differ ($P < 0.05$)

[1]Treatments: CON = Control; RAC = Ractopamine hydrochloride (Elanco Animal Health, Greenfield, IN) fed at 200 or 300 mg/hd/d, or 400 mg/hd/d top dress ; ZIL = Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at 6.8 g/ton.

[2]Pen used as the experimental unit.

Table 3.6. Effect of Ractopamine hydrochloride and Zilpaterol hydrochloride supplementation of steers on subsequent trained sensory panel attributes of Longissimus muscle samples derived from carcass of a subsamples of those steers

	Treatment[1]						
Trait[2,3]	CON	RAC200	RAC300	RAC400	ZIL	SEM	$P < F_{TRT}$
Myofibrillar	9.96[a]	9.64[b]	9.39[b,c]	9.11[c]	8.74[d]	0.10	< 0.0001
Connective Tissue	9.69[a]	9.45[a,b]	9.17[b,c]	8.94[c,d]	8.67[d]	0.12	< 0.0001
Overall Tenderness	9.72[a]	9.43[a,b]	9.17[b,c]	8.91[c,d]	8.62[d]	0.11	< 0.0001
Juiciness	8.27	8.21	8.17	8.13	8.13	0.07	0.2455
Beef Flavor	9.15	9.10	9.09	8.89	9.02	0.07	0.1265
Beef Fat Flavor	7.51	7.44	7.34	7.33	7.37	0.07	0.3314
Off Flavors	0.23	0.18	0.19	0.19	0.20	0.03	0.8876

[a-d]Values that do not share a common superscript in the same row differ ($P < 0.05$).

[1]Treatments: CON = Control; RAC = Ractopamine hydrochloride (Elanco Animal Health, Greenfield, IN) fed at 200 or 300 mg/hd/d, or 400 mg/hd/d top dress ; ZIL = Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at 6.8 g/ton.

[2]Pen used as experimental unit.

[3]Sensory panel scales: tenderness (1 = extremely tough, 15 = extremely tender); juiciness (1 = extremely dry, 15 = extremely juicy); Flavors (1 = no presence, 15 = very strong presence).

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APPENDIX A

Table A.1. Experimental dates

Pen	Allocation Date	Treatment Initiation	Withdrawal Date	Ship Date
1A	1/31/12	3/19/12		4/18/12
2A	1/31/12	3/19/12		4/18/12
3A	1/31/12	3/19/12		4/18/12
4A	1/31/12	3/26/12	4/15/12	4/18/12
5A	1/31/12	3/19/12		4/18/12
6A	2/8/12	3/19/12		4/18/12
7A	2/8/12	3/19/12		4/18/12
8A	2/8/12	3/19/12		4/18/12
9A	2/8/12	3/26/12	4/15/12	4/18/12
10A	2/8/12	3/19/12		4/18/12
1B	2/9/12	3/26/12		4/25/12
2B	2/9/12	3/26/12		4/25/12
3B	2/9/12	4/2/12	4/22/12	4/25/12
4B	2/9/12	3/26/12		4/25/12
5B	2/9/12	3/26/12		4/25/12
6B	2/9/12	3/26/12		4/25/12
7B	2/9/12	3/26/12		4/25/12
8B	2/9/12	3/26/12		4/25/12
9B	2/9/12	3/26/12		4/25/12
10B	2/9/12	4/2/12	4/22/12	4/25/12
1C	3/5/12	4/2/12		5/2/12
2C	3/5/12	4/2/12		5/2/12
3C	3/5/12	4/2/12		5/2/12
4C	3/5/12	4/9/12	4/29/12	5/2/12
5C	3/5/12	4/2/12		5/2/12
6C	2/21/12	4/2/12		5/2/12
7C	2/21/12	4/2/12		5/2/12
8C	2/21/12	4/9/12	4/29/12	5/2/12
9C	2/21/12	4/2/12		5/2/12
10C	2/21/12	4/2/12		5/2/12
1D	3/20/12	4/9/12		5/9/12
2D	3/20/12	4/9/12		5/9/12
3D	3/20/12	4/9/12		5/9/12
4D	3/20/12	4/9/12		5/9/12
5D	3/20/12	4/16/12	5/6/12	5/9/12

6D	3/13/12	4/9/12		5/9/12
7D	3/13/12	4/16/12	5/6/12	5/9/12
8D	3/13/12	4/9/12		5/9/12
9D	3/13/12	4/9/12		5/9/12
10D	3/13/12	4/9/12		5/9/12

APPENDIX B

Table A.2. Animal Accountability by Pen

Pen	Block	Treatment[a]	Initial Head Count	Deads	Removals	Final Head Count
01A	1	CON	99	0	1	98
02A	1	RAC200	99	0	1	98
03A	1	RAC300	103	0	0	103
04A	1	ZIL	100	0	0	100
05A	1	RAC400	102	1	0	101
06A	1	RAC400	104	1	2	101
07A	1	CON	104	0	1	103
08A	1	RAC200	103	1	0	102
09A	1	ZIL	106	0	2	104
10A	1	RAC300	103	1	0	101
01B	2	RAC400	101	0	0	101
02B	2	RAC200	100	1	0	99
03B	2	ZIL	99	1	1	97
04B	2	RAC300	101	0	1	100
05B	2	CON	100	0	2	98
06B	2	RAC200	96	0	0	100
07B	2	RAC400	93	0	1	92
08B	2	CON	92	0	0	92
09B	2	RAC300	95	0	1	94
10B	2	ZIL	93	0	0	93
01C	3	RAC400	93	0	2	92
02C	3	CON	92	0	0	92
03C	3	RAC300	93	0	0	93
04C	3	ZIL	93	0	0	93
05C	3	RAC200	91	1	0	90
06C	3	CON	100	0	0	100
07C	3	RAC400	103	1	0	102
08C	3	ZIL	102	1	3	98
09C	3	RAC300	103	0	0	103
10C	3	RAC200	104	0	2	102
01D	4	RAC400	96	0	0	96
02D	4	RAC200	98	0	1	97
03D	4	RAC300	94	0	1	93
04D	4	CON	97	0	0	97
05D	4	ZIL	96	0	0	96
06D	4	RAC200	91	1	0	90
07D	4	ZIL	91	0	0	91
08D	4	RAC400	91	0	0	91
09D	4	CON	92	1	0	91
10D	4	RAC300	94	0	0	94
Study Totals			3907	11	22	3878

[a]Treatments: CON = Control; RAC = Ractopamine hydrochloride fed at 200 or 300 mg/hd/d, or 400 mg/hd/d top dress ; ZIL = Zilpaterol hydrochloride fed at 6.8 g/ton.

Table A.3. Summary of Cattle that Died or were Removed During Study

Pen	Treatment[a]	EID	Date	Death or Removal	Diagnosis
01A	CON	982000000974001	4/9/12	Removal	Abscess
02A	RAC200	900086000756350	3/27/12	Removal	Buller
05A	RAC400	900086000770449	3/22/12	Dead	Digestive
06A	RAC400	982000174096124	3/20/12	Removal	SEP
06A	RAC400	982000054504743	3/23/12	Removal	Bloat
06A	RAC400	982000174096154	4/8/12	Dead	Abscess
07A	CON	3005889881	3/19/12	Removal	Bloat
08A	RAC200	982000170039801	4/4/12	Dead	Abscess
09A	ZIL	985152002875883	3/25/12	Removal	SEP/Eye Injury
09A	ZIL	900086000770479	3/25/12	Removal	Bloat
10A	RAC300	No EID	3/25/12	Dead	Digestive
10A	RAC200	3000848544	4/25/12	Removal	Cripple
02B	RAC200	982000200112099	4/10/12	Dead	Digestive
03B	ZIL	982000200112104	4/2/12	Removal	Abscess
03B	ZIL	985152002875964	4/9/12	Dead	Other
04B	RAC300	982000156402356	4/4/12	Removal	Fat Pneumonia
05B	CON	982000173357947	4/2/12	Removal	Cripple
05B	CON	982000133940373	4/8/12	Removal	Cripple
07B	RAC400	982000133937113	3/28/12	Removal	SEP
09B	RAC300	982000156404005	3/29/12	Removal	Buller
01C	RAC400	900086000760437	4/2/12	Removal	Hard Breather
01C	RAC400	900086000832962	4/30/12	Removal	Abscess
05C	RAC200	985152002877642	4/6/12	Dead	Digestive
07C	RAC400	982000054148714	4/7/12	Dead	Digestive
08C	ZIL	900086000765579	4/2/12	Removal	SEP
08C	ZIL	900086000760197	4/7/12	Removal	Fat Pneumonia
08C	ZIL	900086000755913	4/10/12	Dead	Digestive
08C	ZIL	982000061872358	4/23/12	Removal	Buller
10C	RAC200	900086000763156	4/2/12	Removal	SEP
02D	RAC200	900086001053132	4/27/12	Removal	Fat Pneumonia
03D	RAC300	900086000758498	5/2/12	Removal	Fat Pneumonia
06D	RAC200	982000127908335	4/17/12	Dead	Digestive
09D	CON	982000133605682	4/26/12	Dead	Digestive

APPENDIX C

Table A.4. Carcass fabrication selection matrix

	Hot Carcass Weight
Average Backfat	**Replicate Mean ± 30 lbs**
Lean (< 0.32”)	n = 2
Low Average (0.33 - 0.44”)	n = 2
High Average (0.45 - 0.60”)	n = 2
Fat (> 0.60”)	n = 2

Table A.5. Fabrication Item List

Chuck/Brisket	Rib/Plate	Loin/Flank	Round
Chuck Initial Wt.	**Rib Initial Wt.**	**Tenderloin Initial Wt.**	**Inside Round Initial Wt.**
SM Chk eye, 1x1	Rib Lipon, 2x2	Tenderloin	Inside Round 1/4" Inside round
Scottie/Mock tender	Rib Butterfly blade meat	Tenderloin 50's	Inside Round Aitch bone
Chuck flat	Rib Backribs	Tenderloin Tissue	Inside Round 65's
Subscap	Rib Cartilage	**Strip Loin Initial Wt. (including chine)**	Inside Round Tissue
Paddle bone	Rib Chine/Feather bones	Strip Loin Bnls Strip loin, 1x0	**Knuckle Initial Wt.**
Neck bones	Rib Backstrap	Strip Loin Bones (Chine, flat, feather, button, & rib)	Knuckle Peeled
Chuck Backstrap	Rib 50's	Strip Loin Tissue	Knuckle bone
Chuck Cartilage	Rib Tissue	**Top Butt Initial Wt.**	Knuckle 65's
Chuck Neck Cap	**Navels Initial Wt.**	1 pc Top Butt	Knuckle Tissue
Chuck Neck trim	Navels 11" Navel	Butt bone/Pin Bone	
Chuck 93% Chuck	Navel 65	Top Butt Sirloin-86's	**Eye of Round Initial Wt.**
Chuck 81% Chuck	Navel bones	Top Butt Tissue	Eye of Round
Chuck 65's	Navels Finger meat	**Loin Tail Initial Wt.**	Eye of Round Round 86's
Chuck Fish Fat	Navel 50’s	Loin tail - 81	Eye of Round Tissue
Chuck Tissue	Navel Tissue	Loin Tail Tissue	**Round Flat Initial Wt.**
Clod Initial Wt.	**Short Rib Initial Wt.**	Loin Tail Bones	Round Flat
1 pc Clod	Short Rib 11" Short ribs	**Flank Initial Wt.**	Round Flat Heel
Clod Teres major	Short Rib Bones	Flank	Round Flat Rat muscle
Clod Blade meat	Short Rib Rectangular Blade meat	Flank 50's	Round Flat Cartilage
Clod Chuck - 81's	Short Rib L-shape	Flank Tissue	Round Flat Round 86's
Clod 65's	Short Rib Finger meat (81's)	Flank Skin	Round Flat 65's
Clod Tissue	Short Rib Baby Bones 81	Rose meat	Round Flat Tissue
Pectoral/Foreshank Initial Wt.	Short Rib 50's	**Hanging Tender Initial Wt.**	**Hindshank Initial Wt.**
Pectoral	Short Rib Tissue	Hanging Tender Diaphram/fat	Hindshank Peeled Shank
Foreshank		Hanging tender	Hindshank Bones
Pectoral/Foreshank Bones		**Skirts Initial Wt.**	Hindshank Skin
Pectoral/Foreshank Tendons		Inside Skirt	
Pectoral/Foreshank Chuck - 81's		Outside Skirt	
Pectoral/Foreshank Tissue		Skirt Skin	
CSR Initial Wt.		Diaphragm	
CSR BCSR		Skirt Tissue	

CSR Bones		**Flap Initial Wt.**	
CSR Chuck - 81's		Flap	
CSR Tissue		Flap Tissue	
Brisket Initial Wt.		**Bottom Butt Initial Wt.**	
Brisket Bnls Brisket		Tri-tip	
Brisket bone		Ball-tip	
Brisket Finger meat		Bottom Butt Tissue	
Brisket 50's			
Brisket Tissue			

APPENDIX D

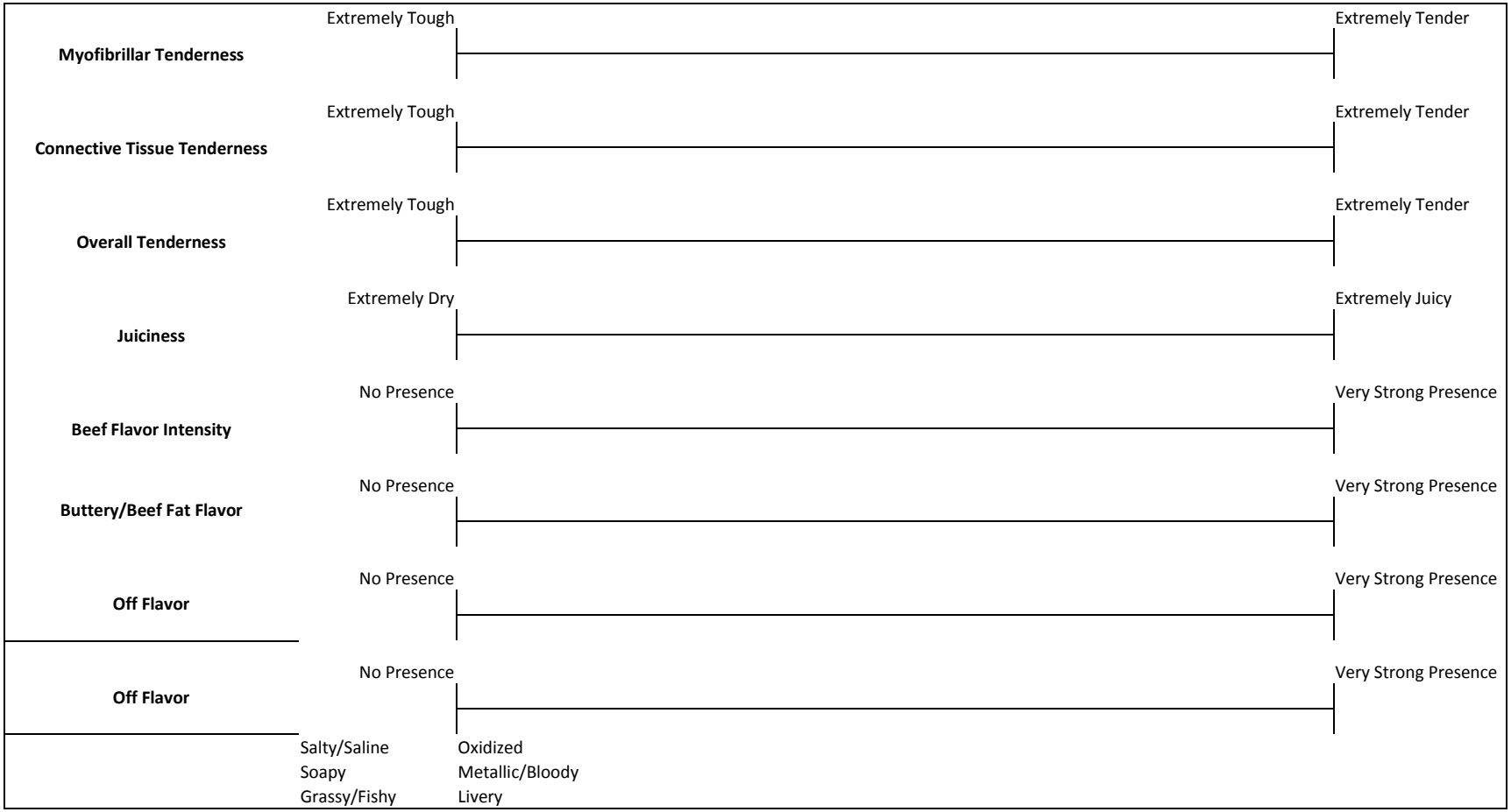

Figure A.1. Sample Sensory Ballot

APPENDIX E

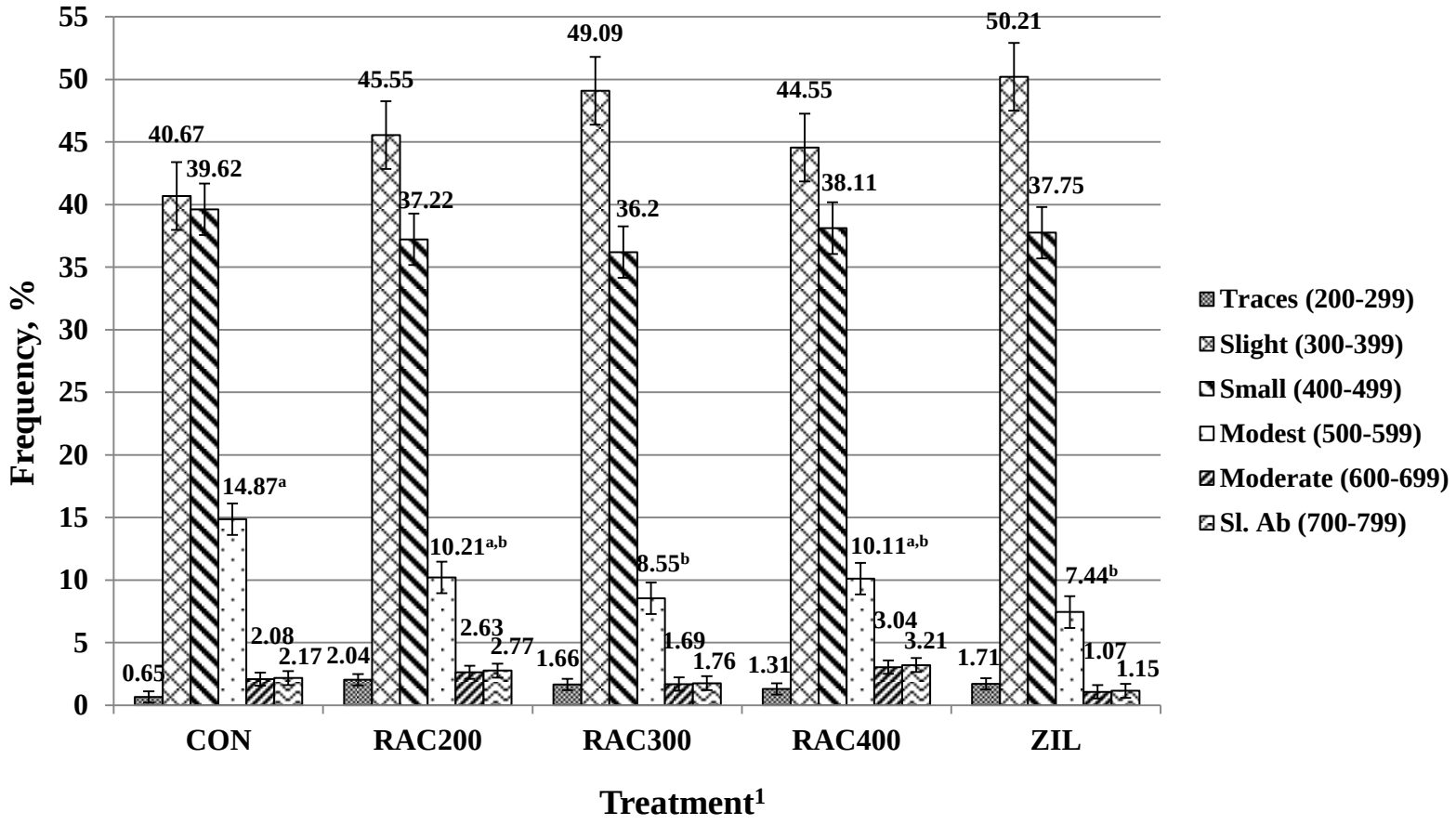

Figure A.2. Effect of Ractopamine hydrochloride and Zilpaterol hydrochloride of steers on subsequent marbling score distribution (values expressed at treatment mean frequency)**.** [a,b]Least square means (bars) lacking a common superscript differ ($P < 0.05$). [1]Treatments: CON = Control; RAC = Ractopamine hydrochloride (Elanco Animal Health, Greenfield, IN) fed at 200 or 300 mg/hd/d, or 400 mg/hd/d top dress ; ZIL = Zilpaterol hydrochloride (Merck Animal Health, Summit, NJ) fed at 6.8 g/ton.