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Influence of Production System on Animal Performance, Carcass Characteristics, Meat Quality, Environmental Impacts, Production Economics, and Consumer Preference for Beef

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INFLUENCE OF PRODUCTION SYSTEM ON ANIMAL PERFORMANCE, CARCASS CHARACTERISTICS, MEAT QUALITY, ENVIRONMENTAL IMPACTS, PRODUCTION ECONOMICS, AND CONSUMER PREFERENCE FOR BEEF

BY

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This dissertation is approved as creditable and independent investigation by a candidate for the Doctor of Philosophy in Animal Science degree and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this does not imply that conclusions reached by the candidate are necessarily the conclusions of the major department.

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This dissertation is dedicated to:

my parents Carol and Kenneth Webb, my grandparents Jean and Eugene Woodworth, and my dear friends and family members who have encouraged a passion for agriculture, the desire for continuous improvement, the aspiration to contribute to my community and the beef industry, and the goal of empowering others while striving to serve as a role-model for future agriculture enthusiasts.

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ABSTRACT

INFLUENCE OF PRODUCTION SYSTEMS ON ANIMAL PERFORMANCE, CARCASS CHARACTERISTICS AND MEAT QUALITY, ENVIRONMENTAL IMPACTS, PRODUCTION ECONOMICS, AND CONSUMER PREFERNCE FOR BEEF

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The overall objective of this study was to determine if the level of growth promotant technology used among production systems influence animal and carcass performance, meat quality, production economics, the environmental impact, and determine consumer preferences and perception. Angus × Simmental steer calves (*n* =120) were stratified by birth date, birth weight, and dam age in a completely randomized design and assigned to one of four treatments: 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated (NHTC, fed monensin and tylosin); 3) implant (IMPL, administered a series of three implants), and 4) implant plus fed a beta-agonist (IMBA, administered the same implant strategy as IMPL plus, fed ractopamine-HCI for the last 30 d prior to harvest). Animal weight, production expenses, and environmental factor data were collected from the production segments including: cow-calf, backgrounding, and finishing. During the finishing segment, animal feed intake, average daily gain (ADG), and efficiency was obtained. Carcass meat quality and yield performace was assessed. Striploins were collected for analyses post fabrication. Steaks were designated to specific postmortem aging periods, utilized for Warner-Bratzler shear force (WBSF), crude fat, and consumer sensory analyses. The consumer analyses

evaluated beef production system information undisclosed and disclosed or simiply, without and later with information to assess palatability only, perception only, and perception plus palatability among untrained consumer panelists.

IMPL had the greatest ($P < 0.01$) ADG and gain to feed (G:F). The final calculated body weight and hot carcass weight was similar ($P > 0.05$) and heavier ($P < 0.01$) for IMPL and IMBA in comparison to NA and NHTC, which were similar ($P > 0.05$). The actual branded carcass value was similar ($P > 0.01$) for NA and IMPL and greater ($P < 0.05$) than NHTC and IMBA, which was similar ($P > 0.05$). Excluding the cost of the calf, production costs were similar ($P > 0.05$) and lowest ($P < 0.05$) for NA and IMPL, NHTC was intermediate ($P < 0.05$), and IMBA had the greatest ($P < 0.05$) production cost. Net return was similar ($P > 0.\ 01$) between NA and IMPL, which was greater ($P < 0.01$) than NHTC and IMBA, which were similar ($P > 0.01$). In the environmental analysis, IMPL reduced GHG (CO_2e/kg HCW) emissions by 8%, energy use (MJ/kg HCW) by 6%, water use (kg H_2O/kg HCW) by 6%, and reactive N loss (g N/kg HCW) by 6%. The IMBA reduced GHG emissions by 7%, energy use by 3%, and reactive N loss by 1%.

Meat quality analyses for marbling score and crude fat among NA and NHTC did not differ ($P > 0.05$) but were greater ($P < 0.05$) than IMPL and IMBA, which were similar ($P > 0.05$) and lower in crude fat. Steaks from NA and NHTC did not differ ($P > 0.05$) for WBSF though were more tender ($P \leq 0.05$) than IMPL and IMBA, which were similar ($P > 0.05$) and tougher ($P \leq 0.05$). During the Undisclosed without Meat panel, NA was most preferred ($P \leq 0.05$) and IMBA was least preferred ($P \leq 0.05$) while NHTC and IMPL were intermediate and similar ($P > 0.05$). All samples differed ($P \leq 0.05$)

during the Disclosed with Meat panel where, NHTC was most preferred followed by NA, IMPL, and IMBA. Despite improvements from use of monensin, tylosin, growth promoting implants with and without ractopamine HCl, cattle within IMPL and IMBA resulted in greater animal and carcass weights, were most effective at minimizing the environmental impact, and improved producer net return (IMPL only). However, consumers may have detected reductions in tenderness and palatability as IMPL and IMBA were least preferred. Consumers preferred the palatability of meat raised with judicious use of antimicrobials and antibiotics to ensure animal health when production information was disclosed (NHTC).

CHAPTER I

Review of Literature

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INTRODUCTION

As of January 2016, there are approximately 13.1 million fed cattle in the US (NCBA, 2016) and it is estimated that 95% are implanted with growth hormones (Campiche, et al. 2004) and 60% - 80% are provided a beta-andrenergic agonist (Chichester, 2017). These technologies along with monensin and tylosin are commonly utilized in beef production because collectively they repeatedly demonstrate prevention of digestive ailments and improved animal growth, body weight gain, feed efficiency, hot carcass weight, and carcass yield (Bergen and Bates, 1983; Goodrich et al., 1984; Schanbacher, 1984; Bartle et al., 1992; Nagaraja and Chegappa, 1998; Platter et al., 2008; Stackhouse et al., 2012; Johnson et al., 2014; Johnson and Beckett, 2014). With a growing world population that is expected to reach over 9 billion by 2050 and an increasing gross domestic product, more people will demand meat (AgMRC, 2012; Gerbens – Leenes et al., 2013). In order to feed a larger and wealthier population, net food production must increase by 70% (FAO, 2009). Use of growth promotant technologies have provided more efficient meat production for over 50 years while offering producers an economic benefit and consumers an economically affordable product (Lawrence and Ibarburu, 2007; Machen, 2010; Johnson et al., 2013). These technologies also have environmental benefits as they have been shown to mitigate NH_3

and greenhouse gas emissions (Stackhouse et al., 2012) however, this is not well understood by consumers. Beef purchasers are demanding specific credence attributes related to animal raising and management practices that are less efficient (Caswell and Mojduszka, 1996; Umberger et al., 2009), but marketed with a social benefit. These demands include a growing segment of beef that is raised without growth enhancing technologies and without use of antibiotics (Sparling, 2001; Perrone, 2012). Given the dichotomy between providing more beef with improved resource management versus the consumer demand to decrease growth promotant technology, it is critical to understand the influence of production systems on meat quality and palatability, consumer preferences, and measures of sustainability (Platter et al., 2003; Mathews and Johnson, 2013).

Growth Promotant Technologies Used in Beef Production

Anabolic Steroids

Current Use

Anabolic steroids cause a growth promoting effect responsible for the morphological, physical, behavioral, and biochemical changes that occur during growth and development (Raun and Preston, 1997). This growth promoting effect shifts the transfer of nutrients consumed more directly to muscle development and bone deposition (Zobell et al., 2000). Due to this efficiency, anabolic steroids have been commercially available for over 50 years and used widely in all segments (suckling, growing, and finishing) of beef production (Preston, 1999; Bruns et al., 2005). Anabolic steroids are administered as implants to improve feed efficiency (5-15%) and weight gain (10-30%)

from weaning to finishing and yield more (5 - 8%) carcass weight (Perry et al., 1991; Preston, 1999; Nichols et al., 2002; Pritchard, 2008).

Endogenous hormones (estradiol, progesterone, and testosterone) are naturally occurring (Kerr and Hobbs, 2002) though, exogenous or synthetic hormones can be administered to cattle. The endogenous hormones are derived from the testes, pancreas, adrenal cortex, thyroid, adenohypophysis, and ovaries (Lone, 1997) whereas, the exogenous hormones (trenbolone acetate, melengestrol acetate) are produced to emulate the binding affinity of protein receptors like endogenous hormones. Anabolic steroids are considered either estrogenic (estradiol, progesterone, and zeranol) or androgenic (testerosterone and trembolone acetate) compounds (Preston, 1999; Stewart, 2013). Once administered, there is no withdrawal because the compound is absorbed into the bloodstream and metabolized by the liver, so the meat products are recognized as safe (Zobell et al., 2000; Pritchard, 2008). If residue testing is desired, the hepatic tissue (liver and kidneys) would have the greatest detectable level of the steroid (Lone, 1997). It is understood that implanted cattle produce beef with slightly elevated hormone levels (Lone, 1997). A 3 oz. serving of beef from an implanted cow contains 1.9 estrogen nanograms and is much less than a pregnant woman (90,000,000 estrogen nanograms produced /d), a non-pregnant woman (5,000,000 estrogen nanograms produced/d), an adult male (100,000 estrogen nanograms produced/d), and a pre-pubertal child (40,000 estrogen nanograms produced/d; Preston, 1997). In fact, if an animal was administered 10 times the manufacture's recommended amount, estrogen produced in beef would be only $1/1000^{th}$ of the endogenous level of a pre-pubertal girl (Johnson and Beckett, 2014). Further, the Joint Expert Committee on Food Additives (JECFA) of the World Health

Organization (WHO) and the Codex Committee on Residues of Veterinary Drugs in Food conclude there is no evidence of health risk associated from the consumption of beef produced with anabolic steroids (Kerr and Hobbs, 2002).

Application and Transfer of Steroid into the Animal

Anabolic steroids can be delivered in many implant matrices including a compressed pellet, an impregnated polymer or, a compressed pellet with a time-release exterior coating (Preston, 1999; Pritchard, 2008). For an implant to achieve a response over a period of time, the carrier matrix dissolves slowly and releases the steroid into the blood stream (Bartle et al., 1992). There are two efficient carrier matrixes that impact the payout period of the implant. The first, with a slower release rate (60 – 80 d) is lactose based and the second with a faster release rate is cholesterol (Istasse et al., 1988; Bartle et al., 1992; Preston, 1999). The US Food and Drug Administration (FDA) only allows implants to be injected into the ear because it is removed from the head and discarded at slaughter (Zobell et al., 2000; Gadberry, 2008; Pritchard, 2008; Stewart, 2013). Improper implanting techniques can crush an implant, which may inadvertently cause negative side effects such as: raised tail heads, udder development, bulling, and vaginal or rectal prolapses (Pritchard, 2000; Zobell et al., 2000). When administered, implants should be given subcutaneously in the middle third of the cartilaginous ridge of the ear (BQA, 2010). In addition to proper implantation, sanitation of the implant needle is important. A common sanitizer used to prevent the contamination and spread of coliform bacterial from fecal matter is Nolvasan (chlorhexidine acetate; Zobell et al., 2000).

Mechanism of Action

Anabolic steroids function predominantly on the ruminants' metabolism by stimulating the growth hormone (GH) to ultimately increase insulin growth factor – 1 (IGF-1) and corresponding hepatic tissue receptors. Insulin-like growth factor-1 is a somatotropin (ST)-dependent anabolic peptide that stimulates the proliferation and differentiation of muscle cells (Florini et al., 1991). Somatotropin not only regulates IGF-1 but also the action of insulin like growth factor binding proteins (IGFBP; Baxter, 1991; Thomson et al., 1996). Research has determined that implantation of TBA + estradiol-17β (E_2) increases serum IGF-1 concentrations and circulating concentrations of IGFBP in comparison to non-implanted cattle (Johnson et al., 1996b; Preston, 1999).

After implantation, the size of the pituitary and the number of acidophils increase (Nichols et al., 2002). An acidophil is a chemical substance that affects metabolic functions (anabolism and catabolism) resulting in greater nitrogen retention and body fat utilization (Lone, 1997). The anabolic effect of growth promoting hormones in ruminants occurs very fast. It has been determined that post administration, cellular changes signal the anterior pituitary to cause animal growth and carcass differences within 7 - 40 d (Preston, 1999). These responses are due to circulating hormones in the blood that increase the size of the anterior pituitary, acidophilic vessels, GH secretion and circulation, and insulin response (Preston, 1999). The stimulated GH causes protein accretion without any apparent effects on protein degradation (Hart and Johnson, 1986). Additionally, stimulation of GH inhibits GLUT4 from causing lipogenesis so that adipose can be mobilized and glucose can be conserved for lean tissue accretion. Stimulated GH actively passes through the lipophilic outer cellular membrane and binds to the designated protein receptor inside of the cell nucleus (Johnson, 2015). Once stabilized in

the nucleus by co-activator enzymes, RNA polymerase up-regulates gene transcription (Johnson, 2015). Appreciable growth is achieved due to promotion of myogenic differentiation and inhibition of adipogenic differentiation (Johnson, 2015). Ultimately lean accretion occurs from hypertrophy of satellite cells located in the nuclei between the sarcolemma and basement membrane (Dayton and White, 2014; Jiang and Ge, 2014). In postnatal muscle tissue, satellite cells are quiescent until degradation occurs causing signaling for proliferation and differentiation. The myoblasts fuse and generate myofibers to provide addition DNA resulting in more protein synthesis (Dayton and White, 2014; Jiang and Ge, 2014). Lean accretion occurs because of a net increase in DNA to protein ratio from the recruitment of satellite cells and nuclei between the sarcolemma and the basement membrane. The accretion of satellite cells causes muscle hypertrophy or enlargement of existing muscle fibers and fusing of myotubes.

Historical Use in Beef Production

Although implanting has been approved for more than 50 years, only 33% of cow-calf producers utilize the technology nationwide (Stewart, 2013). In 1956, the first estradiol based implant was introduced for use in steers (Synovex-S; Lone, 1997). In 1969, zeranol (Ralgro) became the first estrogen like implant approved for both sexes (Lone, 1997). Almost twenty years later in 1987, trenbolone acetate (TBA) became an approved androgenic implant (Zobell et al., 2000). In 1991, the FDA approved the combination implant (TBA and E_2) to provide synergistic effects and ultimately increase rate of gain and lean tissue deposition more than a single steroid (Bruns et al., 2005, Scheffler et al., 2003).

Effects of Anabolic Estrogens

Estrogen, the female sex hormone, has a cyclopentanoperhydro-phenanthrene ring containing18-C (phenolic A-ring; Lone, 1997). Estradiol causes protein deposition by secreting ST from the anterior pituitary and increases secretion of IGF-1 from the β-cells of the pancreas (Trenkle and Marple, 1983; Zobell et al., 2000). Estrogenic compounds interact with the estrogen cytosolic proteinous receptor causing binding inside of the nucleus (Johnson, 2015). The accelerated protein deposition is due to increased ST and insulin circulation from the pituitary and β-cells (Johnson, 2015). Synthetic E_2, Zearalenone (ZEA) is a nonsteroidal estrogenic metabolite found in natural products known as β-resorcylic acid lactones isolated from a number of cereal crops including: maize, barley, oats, and wheat (Lone, 1997; R.L. Preston, 1999). Zearalenone acts by binding to the E_2 receptors in the cytosol and nucleus. Reduction of ZEA produces a mixture of 7α and 7β-zeralenols containing at least 98% 7α –diastereoisomer, sold commercially as zeranol (Ralgro - Tradename; Merck Animal Health, Madison, NJ; Lone, 1997). Ralgro is an estrogenic implant that is classified as "estrogen like" containing 36 to 72 mg per dose (Johnson, 2015). The direct mode of action of estrogen is less understood than androgens.

Effects of Anabolic Androgens

Androgens have 19-C and contain an oxygen at C-3 and -17 (Lone, 1997). Unlike estrogenic steroids, the androgens do not stimulate the production of ST but increases the circulatory levels of IGF-1 (ZoBell et al., 2000). Androgens decrease muscle protein breakdown by occupying the corticosteroid cell receptor (Preston, 1999). Androgen receptors are unique because they work with direct muscle cellular receptors (Herscher et al., 1995). Androgens cause lean muscle accretion from pregnenolone biosynthesis in the

leydig cells (Lone, 1997). Androgens directly effect skeletal muscle and are often referred to as "true anabolic compounds" because androgenic enzymes cannot convert testosterone to dihydrotestosterone as their action is not mediated like estrogens (Lone, 1997). The anabolic activity of testosterone has a 3 - 5 fold response compared with the 8 - 10 fold response of TBA (Preston, 1999).

Effects of Trenbolone Acetate

The most potent anabolic steroid is TBA, a synthetic androgen compound known to decrease protein degradation (or muscle turnover). Moreover, TBA works synergistically with E_2 and testosterone to ultimately increase IGF circulation. Trenbolone acetate increases the rate of protein synthesis while slowing protein degradation resulting in a greater net increase of protein deposition (Dayton and White, 2014; Duckett and Pratt, 2014; Johnson, 2015). Trenbolone acetate is an excellent growth promotant on heifers (ADG $\geq$ 20%) but causes marginal effects on steers (ADG $\leq$ 5%; Dayton and White, 2014; Duckett and Pratt, 2014; Johnson, 2015). Trenbolone acetate inhibits the thyroid gland circulation of T_4 and T_3 hormones. These effects are dose dependent, the lower the dose the more anabolic while higher doses are more catabolic (biphasic response; Lone, 1997). At the cellular level, thyroid hormones may have dual action including long-term increases in protein synthesis through the transcriptional processes and short-term effects on energy metabolism through activation of respiratory enzymes in the mitochondria (Lone, 1997).

Combinational Anabolic Steroids and Re-implantation

When E_2 is combined with TBA, the gain efficiency and leanness effect is synergistic (Preston, 1999). As mentioned, lower doses of TBA increase protein synthesis

by causing the glucocorticoid receptor to reduce the catabolic effects of protein degradation (Trenkle, 1983; Buttery and Sinnett-Smith, 1984; Muir, 1985). Research has determined that post administration, hormone blood levels peak then gradually decline over time (Preston, 1999) during the payout period. Re-implantation is generally scheduled to coincide with the declining hormonal level (Lone, 1997; Zobell et al., 2000) to provide an additive response from the previous implant (Preston, 1999). A "biphasic" concentration pattern of two GH curve components result from the initial and secondary concentration of GH circulation (Preston, 1999).

Anabolic Steroid Effects on Live Performance

Performance of a Calfhood Zeranol Implant

Zeranol, an estrogenic steroid provides minimal growth effects on heifers but is a well documented growth promotant for steers (Duckett and Pratt, 2014; Johnson, 2015). Calfhood research trials have shown that implanting nursing beef calves with Ralgro improved daily gains (4 - 6%) at weaning and resulted in more BW gain (6.8 - 13.6 kg; Selk, 1997; Gadberry, 2008; Stewart, 2013; Dunn, N.D.). A study conducted by Pritchard (1981) concured; calves implanted with Ralgro were heavier (9 kg at 150 DOA) and remained heavier (16 kg heavier at 205 DOA) at weaning versus non-implanted calves. McReynolds (1979) also found a similar result for suckling calves after comparing 18 different implant sequences of Ralgro and Synovex-S during the suckling, growing, and finishing segment. Though McReynolds (1979) found calves implanted with Ralgro at suckling to have a negative finishing performance. More recently, research conducted by Webb et al. (2017) determined suckling calves implanted with Ralgro at 60 DOA (at branding) or 120 DOA (at pre-weaning) did not improve final animal or carcass

performance compared with a non-implanted control. An economic analysis conducted by Zimmerman (2012) used Superior Livestock Auction data to compare the value of different calf programs and discovered weaned steer calves with certified health programs sold between $3 – $5 more per cwt. versus implanted calves that were discounted more than $2 per cwt.

Performance of a Combination and Re-Implantation of a Terminal Combination Implant

Historically research has found combination (TBA/E_2) implants to increase growth rate (20%) and feed efficiency (15%) compared with a non-implanted control (Schanbacher, 1984; Bartle et al., 1992). Though there are different combination potencies that can be used dependent upon factors such as breed, sex, and estimated days on feed (DOF; Johnson and Beckett, 2014). For example, a large-frame Continental animal likely requires a lower dose of TBA/E_2 to provide adequate anabolic steroids to achieve weight gain without causing quality grade (QG) to be negatively impacted whereas, a smaller-framed British animal is likely to experience a greater benefit from a higher dose of TBA/E_2 to improve weight gain, feed efficiency, body size, and not negatively impact QG because of the breed's propensity for greater deposition of marbling (Johnson and Beckett, 2014). Surprisingly given the vast amount of literature on TBA/E_2, specific data directly evaluating animal performance using Revalor-IS is limited. Johnson et al. (1996a) used a moderate potency combination implant containing 120 mg TBA and 24 mg E_2 on finishing steers with a similar payout (100 – 140 d) duration as Revalor-IS. Crossbred steers were evaluated at 3 time periods to represent either the maximum growth response to the implant (d 0 - 40), the recommended slaughter time by the manufacturer (d 41 - 115) or, advanced time of the payout period (d

116 - 143). Collectively, implanted steers improved ADG by 18% and feed efficiency by 13% between d 0 - 40 post implantation versus a non-implanted control. Though, dry-matter intake (DMI) was not influenced. During the second period (d 41 to 115) ADG was still effectively greater (24%) than the control, though feed efficiency and DMI only exhibited a trend. The final period (d 116 – 143) resulted in no differences in animal performance indicating that the greatest advantages from the combination implant occurred during a typical feeding period (d 0 and 115).

Overall, it is well established that cattle administered a combination implant containing a high potency TBA and a low to moderate E_2 have improved ADG, feed efficiency, muscle accretion, and result in increased box beef value (Johnson et al., 1996a; Foutz et., 1997; Scheffler et al., 2003). Parr et al. (2011; in experiment 1) implanted steers with Revalor-IS followed by Revalor-S (cumulatively administered 200 mg TBA and 40 mg E2) at d 68 - 74 of the initial payout period. For this experiment, final carcass adjusted BW was greater (11 kg) and gain to feed (G:F) was improved for the combination compared with a single Revalor-S implant (120 mg TBA and 24 mg E_2). Although DMI did not increase in Parr et al. (2011), DMI is often greater in implanted cattle (Rumsey et al., 1992). Historically in a consecutive re-implantation strategy, TBA/E_2 improved ADG 10 - 30% and BW gain 5 – 15% compared to a single combination implant (Duckett et al., 1997; Preston, 1999). From a management aspect, it is important to consider the duration of time on feed and the plane of nutrition because implants promote lean muscle deposition and cattle tend to take longer DOF to achieve the same marbling as non-implanted cattle (Johnson and Beckett, 2014). Further, Parr et al. (2011) recommended that re-implantation should occur just after the initial implant

decline to optimize ADG, G:F, and moderates negative effects on QG. Waiting too long to re-implant hinders cattle performance and re-implanting too soon enhances cattle performance at the expense of QG. Other factors that may influence timing of re-implantation include cattle type, BW, caloric intake, cattle handling, and environmental conditions (Parr et al., 2011). After review of the literature, it is apparent that most research has either not indicated how harvest date was decided upon or utilized DOF as a constant variable, which is not a reflection of body composition. Research is needed evaluating the use of two consecutive TBA/E_2 implants that are specifically Revalor-IS and Revalor-200 to better estimate animal performance outcomes.

Beta-Andrenergic Agonist, Ractopamine HCI

Current Use

The theory of adrenotropic receptors action on catecholamines repartitioning lipid to protein was first introduced by Ahlquist (1948). In the biomedical community, tremendous interest has revolved around the production of andrenergic molecules that bind to bronchial-tracheal musculature to relieve human asthma. Beef production in North America also utilizes andrenergic molecules as a supplement in a majority (60% - 80%) of cattle finishing diets (Chichester, 2017). Johnson et al. (2014) describes beta-adrenergic agonists (β-AA) as, "receptor-mediated enhancers of protein synthesis and inhibitors of protein degradation." The supplementation of β-AA can be added as a top-dress, complete mixture, or a liquid feed (Ricks, 1984; Elanco, 2011). The use of β-AA in feeedyards promotes live weight gain, heavier BW, greater feed efficiency, increased hot carcass weight (HCW), and a improved dressing percentage (DP; Platter et al., 2008; Elanco, 2011; Johnson et al., 2014). There are two adrenergic repartitioning agents

approved by FDA for use in finishing beef cattle: 1) zilpaterol HCI (Zilmax – Tradename, Merck Animal Health, DeSoto, KS (ZH)) and 2) ractopamine HCl (Optaflexx – Tradename, Elanco Animal Health, Greenfield, IN (RH)). Though in August 2013, Merck Animal Health voluntarily removed ZH from retail commerce. Therefore, this discussion will focus on RH which was first approved by FDA in 2003 and is approved for supplementation of 70 - 430 mg $\bullet$ hd^{-1} $\bullet$ d^{-1} during the final 28 - 42 d of the feeding period prior to harvest (Platter et al., 2008; Elanco, 2011). Additionally, there is no withdrawl period when feeding RH therefore, cattle can be harvested immediately (Elanco, 2011).

Mechanism of Action

Observed differences in animal performance and carcass composition are complex to understand and not fully understood (Johnson et al., 2014). Supplementation of β-AA can be influenced by species, available cellular receptor type, animal age, feed intake, and diet (Mersmann, 1998; Johnson et al., 2014). The β-AA organic molecule functions because of the corresponding beta-andrenergic agonist receptors (β-AAR) that exist in mammalian cells (Mersmann, 1998). Though the animal response to β-AA are dependent upon the number of receptors available for activation (Mersmann, 1998). In mammalian cells, the β-AAR availability varies among anatomical location within specie (Mersmann, 1998). In bovine adipose, transcripts for β_1-AAR, β_2-AAR, and β_3-AAR exist (Casteilla et al., 1994). Though β_3-AAR is the predominant transcript found in brown adipose of fetuses and is greatly reduced after thermogenesis (Casteilla et al. 1994). The β-AAR have more than 400 amino acids and seven hydrophobic transmembrane domains that anchor the receptor to the plasma membrane (Mersmann,

1998: Johnson et al., 2014). Once anchored, catecholamines, norepinephrine and the biosynthesized epinephrine cause a physiological increase in muscle and reduce lipid (Mersmann, 1998). Both norepinephrine and epinephrine stimulate α- and β-AAR (β_1-AAR, β_2-AAR: Johnson et al., 2014) as they are both members of G protein-coupled receptors (GPCR). Though α-AAR do not exist in cell membranes of adipose tissue in beef cattle therefore, this regulation is not meaningful to adipose tissue metabolism (Johnson et al., 2014). Norepinephrine, is responsible for the catecholamine sympathetic nervous system neurotransmitter molecule and is more potent on β_1-AAR. Ractopamine HCl functions more effectively on these β_1-AAR (Garmyn and Miller, 2014) though unfortunately only a small population (1% to 4%) of β_1-AAR mRNA are present in bovine tissue (Johnson et al., 2014). Epinephrine secreted from the adrenal medulla circulates in serum at lower concentrations to promote β_2-AAR (Mersmann, 1998), which are abundant in skeletal (99%) and adipose (90%) tissues of cattle. Further, type II, glycolytic muscle fibers are most responsive to β_2-AAR stimulation by ZH. Consequently, ZH is more effective than RH at increasing the cross-sectional area of muscle (Johnson et al., 2014).

Beta-andrenergic agonists (β-AA) function as repartitioning agents by reducing lipogenesis, protein degradation, and simultaneously increasing lipolysis and protein synthesis (Ricks et al., 1984; Johnson et al., 2014). Specific to RH, muscle protein accretion is because of increased protein synthesis but has no influence on the rate of protein degradation (Johnson et al., 2014). This is due to a series of events that occur once the β-AA binds to the β-AAR and activates G_s proteins, which in turn, elevates

adenylyl cyclase (enzyme producing cyclic adenosine monophosphate, cAMP; Mersmann, 1998; Johnson et al., 2014). The G_s proteins disassociate and with ATP, initiate the cAMP response element binding protein (CREB) and Protein Kinase A. Once bound, a catalytic subunit causes phosphorylation of enzymatic proteins and activation of enzymes such as hormone sensitive lipase (HSL) a rate limiting enzyme for adipocyte triacylglycerol degradation (Mersmann, 1998). Other enzymes become inactivated once phosphorylated (acetyl-CoA carboxylase, a rate limiting enzyme for long-chain fatty acid biosynthesis (Mersmann, 1989). After supplementation, adipose tissue has an increased lipolytic rate (Mills and Mersmann, 1995) and elevated plasma nonesterified fatty acid concentration (Eisemann et al., 1988). However if chronic or long-term exposure (greater than 42 d) occurs, the response is halted due to internalization or loss of the cell surface receptor (Eisemann et al., 1988; Hausdorff et al., 1990). Limited evidence suggests that β-AA increase muscle and reduce lipid via somatotropin, which has no structural relationship to β-AA (Mersmann, 1998). Unlike anabolic steroids that increase muscle mass through hypertrophy, the β-AA has hypertropic effects restricted to skeletal and cardiac muscle (Reeds and Mersmann, 1991).

The general function of a β-AA is to use stored triglycerides within adipose tissue as circulating energy substrates for partitoning of muscle (Etherton and Meserole, 1982; Ricks, 1984; Moody et al., 2000). This results in an increase in protein synthesis at the expense of lipolysis. Use of β-AA increases the amount of mRNA transcribed in skeletal muscle proteins with β_1 or β_2-AAR and myosin heavy chain IIX (Johnson et al., 2014). Ultimately, β-AA cause an up-regulation of myofibrillar protein gene transcription (Johnson et al., 2014). The net result is an increase in protein:DNA ratio as the muscle

responds with promotion of protein synthesis and a minimal reduction of protein degradation while adipose is used as an energy substrate. Supplementation of RH is not as prolific as ZH for inhibiting protein degradation (Moody et al., 2000; Johnson et al., 2014).

Live Performance

During finishing, β-AA have been shown to promote ADG, final BW, and G:F (Moloney et al., 1991; Schroeder, 2004; Laudert et al., 2005; Avendaño-Reyes et al., 2006; Platter et al., 2008; Elanco, 2011; Johnson et al., 2014). In a summary of six studies supplementing RH, ADG and G:F increased by 17.4% and 15.9%, respectively (Laudert et al., 2005). Scramlin et al. (2010) fed crossbred steers RH at 200 mg • hd^{-1} • d^{-1} for 33 d compared with a non-supplemented control. The crossbred steers fed RH had a .23 kg greater ADG than CON and resulted in a heavier (7 kg) final BW. However, Scramlin et al. (2010) did not detect ($P > 0.05$) an improvement in average daily feed intake (ADFI) or G:F ratio. Unlike ZH, RH has been shown to be less effective at reducing ADFI. Some β-AA such as clenbuterol are hypothesized to reduce ADFI because of excessive stimulation of the central nervous system which suppresses rumen motility (Graham et al., 1982). In a separate study, Strydom et al. (2009) fed Bonsmara steers RH at 30 ppm for 30 d prior to harvest and determined no difference ($P > 0.05$) in final BW or HCW even though RH steers had a greater ADG (.5 kg) than control (CON). These results indicate some inconsistencies when supplementing RH perhaps due influences of breeds or environmental conditions. Consistent with Scramlin et al. (2010), Strydon et al. (2009) reported no difference in ADFI (CON, 13.3 vs. RH, 13.2; $P > 0.05$). In contrast, Avendaño-Reyes et al. (2006) supplemented crossbred cattle with 300 mg • hd^{-1} • d^{-1} of

RH compared with a non-supplemented CON 33 d prior to harvest. Steers fed RH consumed less (P = 0.03) DM than CON (8.37 kg vs. 8.51 kg, respectfully). However, similar to the previous studies, there was an improved G:F ratio (RH, 0.248 kg vs. CON 0.015 kg). In a summary of ten trials conducted across the US, Schroeder (2004) concluded ADG, final BW, and G:F were improved by 26%, 20%, and 20.5%, respectively. Unique to β-AA there is no effect on frame score and bone growth (Schroeder, 2004). In review of these research studies, determination of how the terminal harvest endpoint was decided upon is limited in the information provided. Harsh et al. (2015) indicated harvest d (d 84) and a visual appraisal was conducted but specifically the deciding factor was not illustrated. Providing a repeatable method for designating terminal endpoint may eliminate some inconsisitencies in animal performance results among studies. Further, some studies (Garmyn et al., 2014) do not provide sufficient information about animal management procedures other than the supplemented treatment. Having available information about animal production methods, breed, and the environment is helpful when interpreting results as these factors may influence treatment outcomes. Overall, use of RH appears to provide positive outcomes for animal performance.

Monensin and Tylosin

Current Use

Monensin (Rumensin 90 – Tradename, Elanco Animal Health, Greenfield, IN) is an oral ionophore fed to cattle during backgounding and/or finishing to improve G:F and reduce the incidence of digestive ailments such as coccidiosis (Stackhouse et al., 2012; Elanco, 2017a). Monensin has been approved by the FDA since 1975 and can be used in

a complete feed between 5 - 40 g/ton to provide 50 - 480 mg • hd^{-1} • d^{-1} for improved G:F and fed between 10 - 40 g/ton to provide a maximum of 480 mg • hd^{-1} • d^{-1} to manage coccidiosis in the feedyard (Elanco, 2017a). Monensin enhances G:F, DM digestibility, reduces DMI, lactic acid production, bloat, heat production, assists with coccidiosis management, and may reduce methane loss (Goodrich et al., 1984).

Tyslosin (Tylan 40 – Tradename, Elanco Animal Health, Greenfield, IN) is a feed-grade therapeutic antimicrobial fed to cattle during finishing to reduce the incidence of liver abscesses (Elanco, 2017b) because clinical signs are often not exhibited (Nagaraja and Chegappa, 1998). It is well accepted that ruminal lesions are the predisposing factor for liver abscesses (Jensen et al., 1954) because of the sudden transition to high-energy feeding patterns during finishing that initiate the colonization of *Fusobacterium necrophorum* and *Aracanobacterium pyogenes* anerobic bacteria causing liver abscesses. Liver abscesses are the direct result of feeding practices therefore, feedyard cattle tend to be the primary segment affected as the incidence of liver abscesses range from 12 - 32%. Nagaraja and Chegappa (1998) conducted a review of liver abscesses occurring from feedyard cattle and found therapeutic use of tylosin to reduce liver abscesses by 40 - 70%. Additionally, liver condemnations can cause postmortem economic losses at the beef packing plant in the form of decreased carcass yield and liver abscesses can impact antemortem economics from reductions in animal intake, ADG, and feed efficiency (Nagaraja and Chengappa, 1998). The macrolide tylosin can be supplied between 60 - 90 mg • hd^{-1} • d^{-1} to mitigate the presence of the anaerobic bacteria, previously described (Elanco, 2017b).

Mechanism of Action

The well documented mode of action of monensin is the alteration of volatile fatty acid (VFA) production so there is decreased acetate and butyrate to propionate ratio in the rumen (Schelling, 1984). The VFA alteration caused by increased proprionate is due to a cell membrane leak because of a leaking cellular NA+ K pump. This leak is causesed by a depression of Gram-positive bacteria and a proliferation of Gram-negative bacteria (Goodrich et al., 1984). Elevated propionate increases gluconeogenesis and body glucose turnover (up to 14%) allowing greater energy to be released from feedstuffs through greater levels of glucose while reducing the amount of amino acids (AA) used for glucose synthesis and thus, results in a protein sparing effect (Schelling, 1984). Propionate is also more efficient because it requires a lower heat of fermentation and allows more protein into small intestine (SI) for digestion and absorption.

The description of the mode of action for tylosin is rare, though it is well agreed upon that Gram-negative anaerobic bacteria (*Fusobacterium necrophorum* (the primary etiologic agent) and *Aracanobacterium pyogenes)* as mentioned, cause liver abscesses and are most inhibited by Tylosin compared with four other antimicrobials (bacitracin methylene disalicylate, chlortetracycline, oxytetracycline, and virginiamycin; Nagaraja and Chengappa, 1998). The anaerobic bacteria thrive on lactic acid as an energy substrate in the rumen and tylosin effectively stabilizes rumen bacteria and reduces lactic-acid production in the rumen. Consequently, tylosin inhibits both rumen bloat (acidosis) and these anaerobic bacteria from causing ulcerative lesions and strain on the liver, resulting in liver abscesses.

Live Performance

As previously mentioned, monensin improves ADG, DMI, and G:F regardless of animal sex or weight and is why monensin is a widely accepted growth promotant in the cattle feeding industry (Goodrich et al., 1984; Schelling, 1984). Further, cattle provided diets high in carbohydrates are most noted to have reduced DMI and improved G:F whereas, when roughage is high improvements in ADG are most notable (Stock et al., 1995). Monensin has been studied in cattle that have received anabolic steroids, Goodrich et al. (1984) summarized 7 trials utilizing implanted (zeranol, progesterone-estradiol or, testosterone-estradiol) steers and heifers and consistently found improvements in ADG and G:F from use of monensin. It is apparent that research specifically testing the combination of monensin, Revalor-IS and -200, and RH is limited or simply, the management detail is not transparently provided.

In regard to improvements in animal performance from use of tylosin, it is logical to speculate that if a large portion of the liver tissue were damaged due to abscesses the liver would function with much less efficiency and inhibit animal performance. In a meta-analysis conducted by Wileman et al. (2009) cattle receiving tylosin had an 8% risk of developing a liver abscess compared with cattle that were not fed tylosin and had a much greater (30%) risk of abscess development. Further, research has shown repeatedly that feeding tylosin improves ADG, G:F, and increases DP in comparison to cattle not fed tysosin in the feedyard (Brown et al., 1975; Vogel and Laudert, 1994). As mentioned earlier, economics should be considered if not effectively supplementing tylosin because of potential negative outcomes on cattle health, feed intake, ADG, G:F, and carcass yield grade (YG; Nagaraja and Chengappa, 1998; Stackhouse et al., 2012).

Growth Promotant Technology Effects on Carcass Performance

Anabolic Steroid Administration and Ractopamine HCI Use on Cutability

The USDA YG for beef carcasses range from 1 to 5 and are calculated based upon correction factors for HCW, ribeye area (REA), 12th rib fat thickness (FT), and percent pelvic, kidney, and heart fat (KPH) to predict the estimated percentage of boneless, closely trimmed, retail cuts (% BCTRC). Fatter carcasses are stamped with a higher numerical USDA YG and USDA YG 4 and 5 can receive discounts at the packing plant. The distribution of YG 1 through 5 is: 1, >52%; 2, 52.3%-50%; 3, 50.0% - 47.7%; 4, 47.4% - 45.4%; and 5, <45.4%. The 2011 National Beef Quality Audit (NBQA) found the mean YG to be 2.86 and the YG distribution to be: YG 1, 15.7%; YG 2, 41.0%; YG 3, 33.8%; YG 4, 8.5%; and YG 5, 0.9% (Gray et al., 2011).

Anabolic steroids have been proven as a consistent technology to reduce FT, percent KPH, and USDA YG while increasing HCW and ultimately mitigate the occurrence of USDA YG 4 and 5 (Kuhl, 1992; Preston, 1999, Johnson, 2015; Bruns et al., 2005, Pritchard, 2008; Kuhl, 2002; Bruns et al., 2008). Research conducted by Bruns et al. (2008) determined implanted cattle were 8% leaner than non-implanted cattle. Additionally, Duckett et al. (1997) reviewed 77 research trials and determined that a single combination implant improved steer HCW and REA. Though Duckett et al. (1997) discovered an inverse relationship between a larger REA and a corresponding smaller marbling score. In meat science, this phenomenon is known as the “dilution effect” which occurs when REA increases and marbling score diminishes due to hypertrophy of skeletal muscle (Duckett et al., 1999). In a separate lifetime analysis conducted by Duckett and Andrae (2001), implanting during the suckling, grazing, and finishing period resulted in an increased value of $93 per animal and reduced the cost of beef production. Similarly,

Reinhardt (2007) determined that a stair-step implant program maximized YG value ($85.68) on the rail compared to non-implanted carcasses. Re-implanting generally improves performance of cattle when sufficient nutrition is available (Pritchard, 2008; McCollum, N.D.). Overall, anabolic steroids generally improve animal performance in each segment of beef production however, a better understanding of the implications on carcass quality and skeletal maturity are needed to overcome quality and tenderness challenges (Perry et al., 1991; Preston, 1999; Duckett and Andrae, 2001; Jones et al., 2012).

In addition to providing anabolic steroids to improve postmortem efficiency, it is well documented that supplementation of β-AA generally increases HCW, DP (1-2%), and reduces FT (Platter et al., 2008; Elanco, 2011; Boler et al., 2012, Johnson et al., 2014). Given the anticipated carcass performance advantage, it is recommended that cattle supplemented β-AA be marketed on a carcass basis to increase returns from the grid marketing system (Maxwell, 2014). In review of research supplementing β-AA, Johnson et al. (2014) found an increase in LM diameter (by 6% to 40%) in comparison to a unsupplemented control. In contrast, when feeding RH Schroeder (2004) found no influence on LM diameter. Perhaps RH supplementation is less consistent at ensuring a positive response. To further illustrate, Garmyn et al. (2014) fed British steers RH at 308 $mg \bullet hd^{-1} \bullet d^{-1}$ for 28 d and determined there was no significant difference in HCW, FT, percent KPH, YG, or marbling score. Though Garmyn et al. (2014) discovered a .3 cm^2 REA increase in supplemented RH carcasses. This result is inconsistent with Avendaño-Reyes et al. (2006) that supplemented RH and found no influence on REA but a heavier HCW and a lower numeric YG ($P < 0.05$). Strydom et al. (2009) also found

inconsistencies when supplementing with RH in comparison to a CON as there were no influences on USDA YG, FT, REA or, KPH. In contrast, Schroeder (2004) reported an increase in HCW by 8.3 kg although LM area was not influenced ($P = 0.132$). In review, supplementing RH at a low dosage may not dramatically improve carcass performance. As previously described, some of these inconsistencies and/or lack of response may be due to the RH binding affinity for β_1 receptors that are less abundant. To be able to make producer recommendations and have an accurate comparison among growth promoting technologies, an effective control is needed.

Anabolic Steroid Administration and Ractopamine HCl Use on Marbling

To predict carcass quality and assess the value of beef, the USDA-AMS provides a voluntary service to apply USDA QG at beef packing plants. The USDA-AMS Meat Grader and/or approved video image analysis (VIA) system evaluates carcasses for intramuscular fat (IMF) or marbling, a known predictor for eating satisfaction in cooked beef (Hankins and Ellis, 1939; Cole and Badenhop, 1958). Marbling is a palatability-indicating characteristic and combined with physiological maturity (vertebral ossification, size and shape of the ribs, and color and texture of the LM at the 12th rib) a USDA QG (USDA Prime, USDA Choice, USDA Select) is assigned (Acheson et al., 2014). Acheson et al. (2014) proposed that USDA QG assignment would be as effective if only marbling was used as the determining factor. Beef consumers rely on marbling because of its bulk density or lubrication effect that provides cooking insurance and ensured palatability (Savell and Cross, 1988). The theory behind the lubrication effect is that marbling present around muscle fibers lubricates the fibrils and results in a juicy beef eating experience (Savell and Cross, 1988). Thus, marbling level is an important part of

QG determination. As marbling scores increase from Practically Devoid to Moderately Abundant, the likelihood of an enjoyable beef eating experience increases (Smith et al., 1985; Emerson et al., 2013).

The administration of anabolic steroids has been well documented to decrease marbling scores and consequently result in fewer carcasses grading USDA Choice or, be stamped a lower USDA QG (Kuhl, 1992; Bartle et al., 1992; Foutz et al., 1997; Preston, 1999; Platter et al., 2003; Bruns et al., 2005; Pritchard, 2008; Johnson, 2015). In a review of 37 trials examining steers administered an anabolic steroid while on a finishing diet, Duckett et al. (1996) detected mean reductions in marbling (24%) and carcasses grading USDA Choice (14.5%). Belk and Cross (1988) also found anabolic steroids to compromise USDA QG and increase the incidence of dark cutters. In contrast, some studies have found no difference even using successive implantation protocols (androgenic, estrogenic, and combinations) on deposition of IMF or beef tenderness (Nichols et al., 2002; Gerken et al., 2014). Duckett et al. (1999) found implanting to minimally reduced marbling score by one-half a marbling degree and re-implanting did not alter marbling scores. Gerken et al. (2014) evaluated *bos indicus* steers using a single implant of either E_2, TBA or, a combination (E_2 and TBA) and reported little affect on the IMF deposition. Other research agrees, implants have no negative affect on marbling score nor USDA QG (Johnson et al., 1996a; Scheffler et al., 2003, Smith et al., 2007).

Feeding cattle 200 mg RH mg $\bullet$ hd^{-1} $\bullet$ d^{-1} has been shown to decrease marbling score minimally (10%) compared with an non-supplemented control (Winterholler et al., 2006; Gruber et al., 2007). It is understood that cattle specie can influence marbling deposition and to evaluate RH use further, Gruber et al. (2007) compared carcasses from

English, Continental, and Brahma-cross cattle and only found a tendency ($P = 0.07$) for marbling reduction yet, this did not translate to an adverse influence on QG. Also, cattle specie did not influence marbling score suggesting that genetics for low (Brahma-cross) and high (English) propensities for IMF development were not affected by RH. In some contrast, Boler et al. (2012) reported no difference in USDA QG among RH carcasses however, carcasses supplemented with 300 vs. 200 mg RH $\bullet$ hd^{-1} $\bullet$ d^{-1} had numerically fewer USDA Choice carcasses and the higher supplementation rate produced more USDA select carcasses. Overall, a wide spectrum of studies (Schroeder et al., 2003; Laudert et al., 2005; Schroeder et al., 2005; Greenquist et al., 2006) have found little to no difference when supplementing RH on marbling score that translate to a reduced QG (Gruber et al., 2007; Boler et al., 2012).

Anabolic Steroid Administration and Ractopamine HCl Use on Tenderness

Beef tenderness, juiciness, and flavor have been described as the three components that contribute to consumer beef palatability and drive purchase decisions (Reicks et al., 2011). Repeatedly data has demonstrated that tenderness is the most critical factor to beef palatability and consumer satisfaction (Miller et al., 2001; Savell et al., 1987). It is understood that there are several factors (decreased proteolytic activity, reduced protein degradation, decreased collagen solubility, and decreased sarcomere length) that decrease meat tenderness (Geesink et al., 1993; Vestergaard et al., 1994). As previously mentioned, the USDA QG system utilizes physiological maturity to estimate animal age-related differences that influence meat tenderness. Research has shown that QG and beef tenderness are related and propose that QG influences objective measures of beef tenderness (Smith et al., 1985; Gruber et al., 2007, and Garmyn et al., 2011).

Though other studies did not find a relationship between carcass maturity and beef tenderness when maturity groups were restricted to only include carcasses from grain-fed animals (Miller et al., 1983; Field et al., 1997).

In regard to implantation, some studies have found no difference in the use of successive implantation (androgenic, estrogenic, and combinations) on the tenderness of beef (Nichols et al., 2002; Gerken et al., 2014). Whereas, other research confirms that the use of implants increases steak toughness (Morgan et al., 1997; Roeber et al., 2000). However, administration of exogenous estrogenic steroids may impart a significant influence on skeletal maturity. This is due to the influence of hyperestrogenism, or the acceleration of maturity as a result of the additive effects of estrogen. This may cause cattle that are less than 30 mo to be classified as B maturity and receive a carcass discount ($20 - $50/ cwt.; Acheson et al. 2014). Other concerns when administering anabolic steroids is an increase in objective measures of mean WBSF value and the potential to translate this effect into less desirable consumer tenderness ratings (Platter et al., 2003). In contrast, consumer acceptance ratings have been found to be similar for cattle successively implanted 2, 3, 4, or, 5 times (Platter et al., 2003). Roeber et al. (2000) evaluated steaks produced from cattle receiving combination implants and discovered steaks were not considered tough based upon WBSF values. In contrast, Foutz (1997) determined steers implanted with various combinations of steroids tended to produce steaks with greater WBSF values than steaks from a non-implanted control. Nichols et al. (2002) summarized 19 studies evaluating single and successive implantation and confirmed the inconsistent results between WBSF values and consumer panelist responses.

However, trained sensory panelists have been unable to detect differences in tenderness between implanted and non-implanted steers (Apple et al., 1991; Gerken et al., 1995). Research has also shown that extended postmortem aging (21 d to 28 d) mitigates the effect of implanting such that implanted treatments were considered as tender as a non-implanted control after a sufficient aging period (Schneider et al., 2007; Igo et al., 2011). However, a 14 d postmortem aging period was not effective at improving consumer tenderness acceptability of Select steaks from cattle implanted cumulatively with TBA and E_2 compared with steaks from a non-implanted control (Igo et al., 2011). In contrast, some studies (Belk and Cross, 1988; Duckett et. al., 1996; Pritchard, 2000) indicate that implants have minimal influences on beef tenderness and both Igo et al. (2011) and Hutcheson (2008) agree that implant treatment effects can be mitigated with greater postmortem aging. The consistent use of implants for more than 50 yrs is likely due to consistent animal performance benefits and research has shown that when appropriate implant strategies are utilized impacts on meat quality are minimized (Bruns et al., 2005). Anabolic implants improve animal performance at each segment of production, however a better understanding of the implications on carcass quality and skeletal maturity are needed to improve tenderness of beef aged < 14 d and mitigate tenderness challenges at the retail case (Perry et al., 1991; Preston, 1999; Duckett and Andrae, 2001; Jones et al., 2012).

It has been repeatedly established that beef tenderness can be negatively impacted by supplementing cattle with RH (Avendaño-Reyes et al, 2006; Gruber et al., 2007; Strydom et al., 2009; Scramlin et al., 2010; Boler et al., 2012; Arp et al., 2013). Though some studies (Schroeder et al., 2003; Arp et al., 2013) that supplemented steers with 200

mg RH• hd^{-1} • d^{-1}did not negatively influence meat tenderness. Though higher dosages (300 mg RH• hd^{-1} • d^{-1}) have resulted in greater WBSF values than a non-supplemented control. It is understood that the length of postmortem aging (28 - 42 d) and dosage level of RH can influence meat tenderness (Garymn et al. 2014). Johnson et al. (2014) reported supplementation of ZH 30 d prior to harvest increased the concentration of myosin heavy chain IIX in bovine skeletal tissue. Wheeler and Koohmaraie (1992) also found supplementation of β-AA to cause fractional protein degradation and cause an increase in calpastatin activity (Killefer and Koohmaraie, 1994). In a study evaluating cull cows that received a terminal combination implant and RH, type I fiber diameter was increased due to supplementation while type II was not influenced (Gonzalez et al., 2007). Woerner et al. (2011) evaluated the combination of providing an initial and terminal implant then, supplemented calf-fed steers and heifers 200 mg RH • hd^{-1} • d^{-1}. Overall, WBSF values were not influenced by the initial or terminal implants however, RH supplementation increased mean WBSF value by 0.23 kg, which tended to cause a loss in predicted consumer acceptance. This increase in toughness may be due to the effects of β-AA on postmortem tenderization described by Goll (1997) and illustrated by Strydom (2009) causing greater calpastatin activity and potentially new collagen cross-links (Roy et al., 2015).

Negative influences from RH supplementation on steak tenderness are debatable but regardless, any challenges have been described as minimal and manageable with adequate postmortem aging (Gruber et al., 2007; Strydom et al., 2009; Scramlin et al., 2010; Boler et al., 2012; Garymn et al., 2014). Scramlin (2010) and Garmyn (2014) found aging 14 d or more to mitigate differences in tenderness. In fact, Garymn (2014)

noted an interaction between β-AA supplementation and aging, where RH had a greater response to 21 d aging and consequently resulted in the lowest WBSF values compared with the control. Garmyn and Miller (2014) concluded that although objective measures of steak tenderness may occur, differenes in tenderness may not translate into a detection by a sensory panel. Therefore, consumers may be inconsistent in detection of differences in objective tenderness which may be due to the sample population tested, the aggressiveness of the implant protocol or, the level of RH supplementation.

The ability for beef consumers to consistently detect influences on sensory attributes is not conclusively proven and may be dependent upon factors influencing the sample population. Given considerable variation in outcomes for palatability indicators, this necessitates further exploration for improved management practices from a common sample population. Even though postmortem aging may provide a solution, according to the 2010 National Beef Tenderness Survey more than one-third of beef marketed at retail was not aged more than 14 d (Guelker et al., 2013). Given potentially limited postmortem aging at retail, reports investigating the influence of several technologies (i.e. implants, beta-agonists) or the lack of technology use (i.e. NA, NHTC) on beef tenderness from the same study are limited.

Monensin and Tylosin Use on Cutability, Marbling, and Tenderness

Specific data evaluating monensin on carcass performance is limited, though in regression models Goodrich et al. (1984) found monensin to decrease DP, FT, and marbling score. Montgomery et al. (2009) determined that when monensin and tylsosin were fed in combination with ZH, withdrawn from the diet 35 d prior to harvest that YG decreased more than when feeding ZH alone without ever supplementing monensin and

tylosin. Continuously feeding both components with ZH moderated negative effects of carcass quality. Feeding ZH decreased marbling score but withdrawal of monensin and tylosin caused marbling score to decrease further (Montgomery et al., 2009). This effect was substantial enough to influence USDA QG. Upon withdrawal, the number of Premium Choice carcasses decreased. Though tenderness was not evaluated in this publication, an extension of this project conducted by Hilton et al. (2009) determined withdrawal did not substantially harm carcass performance but improved some sensory characteristics. There was a tendency for decreased carcass protein percent upon withdrawal but no influence on expression of calpain and calpastatin, which also translated into no influences on objective measures of WBSF. As a positive impact of feeding monensin and tylosin until the terminal endpoint, consumer sensory ratings for juiciness were improved, though no other palatability attributes were affected.

Panelist Attribute Ratings

Tenderness

The North American beef industry has adopted the use of anabolic steroids as a management practice to improve growth and reduce cost of gain (Roeber et al., 2000; Igo et al., 2011). There are many different implant strategies that can be used, though the administration of TBA in particular (Barham et al., 2003) may compromise beef quality grades (Belk and Cross, 1988). Given that the majority of cattle are implanted (Campiche et al., 2004) evaluating the subsequent effects on subjective measures of eating satisfaction to understand the influence on beef palatability is important (Wheeler et al., 1997). General consumer sensory evaluations have determined that non-implanted steaks are more desirable for tenderness than steaks from implanted steers (Roeber et al., 2000;

Barham et al., 2003; Platter et al., 2003; Gruber et al., 2008; Igo et al., 2011). Moreover, aggressively implanting cattle (1 – 5 times) can reduce sensory tenderness ratings (Roeber et al., 2000; Platter et al., 2003; Barham et al., 2012). To better illustrate, untrained consumers rated steaks lower for tenderness from British crossbred steers assigned to 1 of 7 implant strategies compared with steaks from a non-implanted control (Roeber et al., 2000). Fortunately, postmortem aging of 7 and 14 d has been demonstrated to effectively mitigate any differences from implanting based on trained sensory analysis (Barham et al., 2003) though, it has been suggested to eliminate tenderness differences a 21 d aging period should be conducted (Igo et al., 2011). In some contrast, Barham et al. (2003) originally detected reductions in tenderness among trained sensory panelists but did not detect a difference among implant strategies after 7 or 14 d postmortem aging on untrained consumer panelists, indicating that moderate (2 implants/reimplantation strategy in the feedyard) implanting does not negatively affect general consumer eating satisfaction. Wheeler (2004) determined untrained consumer panelists have the ability to repeatedly (0.80) conduct sensory analysis effectively for the beef *longissimus* and describe steaks as tender, intermediate, and tough. Among the literature reviewed, fewer studies (Apple et al., 1991; Gerken et al., 1995) utilizing trained panelists concluded that implanting did not influence tenderness ratings, suggesting that implanting had negligible effects on beef tenderness (Barham et al., 2012).

To provide added beneficial effects, supplementing cattle while on feed with monensin and tylosin reduces previously described digestive ailments (Nagaraja and Chegappa, 1998; Stackhouse et al., 2012; Elanco, 2017a and 2017b) and feeding RH prior to harvest improves animal performance, though it is predicted to cause decreased

consumer acceptance (Woerner et al., 2011). Minimal data exists, but Hilton et al. (2009) determined trained panelist palatability ratings for initial and sustained tenderness were not influenced by supplementation of monensin and tylosin. In regard to feeding RH, supplementation level may slightly decrease tenderness. Gruber et al. (2008) determined RH supplementation at 200 mg RH • hd^{-1} • d^{-1} produced steaks that were rated less tender by trained panelists than steaks from non-supplemented steers. In contrast, other trained panelists were unable to detect tenderness differences between steaks from cattle that were fed RH (100 – 200 mg RH • hd^{-1} • d^{-1}) compared wtih an unsupplemented control. However, upon feeding RH at a rate of 300 mg RH • hd^{-1} • d^{-1} steaks were rated slightly tougher (FDA, 2003). Although Arp et al. (2013) determined trained panelists were unable to detect variations in the level of RH supplemented (200 and 300 mg RH • hd^{-1} • d^{-1}) on subsequent tenderness ratings. Untrained consumers panelists have not been able to detect differences in tenderness ratings for RH supplementation versus an non-supplemented control (Garmyn et al. 2014; Harsh et al., 2015). Furthermore, extended postmortem aging (21 – 28 d) has improved both trained and consumer sensory tenderness ratings (Hilton et al., 2009; Leheska et al. 2009; Rodas-Gonzalez et al., 2012). It is understood that supplementation of RH may decrease objective tenderness, but minimal impacts on consumer acceptability are generally observed (Platter et al., 2008).

Juiciness

Aggressively implanted cattle can result in decreased trained sensory panelist ratings for juiciness when compared with a single, delayed implant strategy (Barham et al., 2012). In contrast, trained sensory panelists may not be able to detect differences in juiciness between implanted and non-implanted steaks (Barham et al., 2003; Barham et

al., 2012). Supplementing monensin and tylosin during the final 35 d prior to harvest has been shown to increase trained panelist ratings for steak juiciness (Hilton et al., 2009). Supplementation of RH during the final 28 – 42 d prior to harvest has been shown to have no influence on trained panelists ratings for juiciness (FDA, 2003; Arp et al., 2013). However, Gruber et al., (2008) did report RH supplementation (200 mg RH • hd^{-1} • d^{-1}) reduced trained panel juiciness ratings, and other studies (Hilton et al., 2009; Leheska et al., 2009; Garmyn et al., 2010) determined ZH supplementation also negatively influenced sensory ratings for juiciness. However, untrained consumer panelists (n = 120) did not detected differences in juiciness between steaks from cattle supplemented with RH (308 mg RH • hd^{-1} • d^{-1}) and a non-supplemented control (Garmyn et al., 2014). Still, more research is necessary, utilizing an untrained consumer audience, to determine how production management decisions influence steak juiciness.

Beef Flavor

Aggressively implanting cattle can lower trained sensory panelist evaluations for flavor ratings versus a single delayed implant (Barham et al., 2012) or, versus non-implanted cattle (Apple et al., 1991). Untrained consumer panelists rated USDA Choice steaks aged 21 d from implanted cattle similar to non-implanted cattle for beef flavor (Igo et al., 2011). Moreover, untrained consumer panelists from five metropolitan areas have been unable to distinguish flavor differences among steaks from steers implanted consecutively with two implants in comparison with non-implanted cattle (Barham et al., 2003). Though a relationship exists when consumer panelists like flavor as steaks tend to also be rated better in tenderness and juiciness whereas when consumers dislike flavor, steaks tend to be rated tough and dry (Roeber et al., 2000). Still in the same study, there

were no differences among consumer ratings for beef flavor and intensity for steaks produced from steers administered 1 of 7 implant strategies (combination of estrogenic and androgenic compounds) compared with non-implanted steers (Roeber et al., 2000). In some contrast, crossbred steers assigned to 1 of 10 implant strategies and were implanted 2, 3, 4, or, 5 times from branding to reimplanting in the feedyard, had desirable consumer beef flavor ratings, though eating satisfaction was achieved from a majority (60 – 74%) of consumers (Platter et al., 2003).

Limited literature exists on feeding monensin and tylosin on trained consumer palatability ratings, removal from the diet 30 d prior to harvest or, feeding to harvest did not affect beef flavor when β-AA (ZH) is fed (Hilton et al., 2009). Supplementation of RH at 200 - 400 mg RH • hd^{-1} • d^{-1} prior to harvest did not influence trained panelists ratings for beef flavor (FDA, 2003; Arp et al. 2013). In contrast, steers fed RH at a rate of 200 mg RH • hd^{-1} • d^{-1} produced steaks that were rated slightly lower for beef flavor by trained panelists than steaks from unsupplemented steers (Gruber et al., 2008). Similarly, untrained consumer sensory ratings for beef flavor from RH supplementation (308 mg RH • hd^{-1} • d^{-1}) have been intermediate to a non-supplemented control and ZH (8.3 mg/kg of DM) supplemented steers (Garmyn et al., 2014).

Overall Acceptability

Aggressively implanting cattle has decreased sensory panelist evaluations of overall mouthfeel (Kerth et al., 2003; Barham et al., 2012) and overall eating quality (Platter et al., 2003). As an example, crossbred steers assigned to 1 of 10 lifetime implant strategies that were successively implanted 2 to 5 times from branding to reimplanting in the feedyard and produced steaks that had reduced overall eating quality as evaluated by

consumer panelists (Platter et al., 2003). In contrast, Roeber et al. (2000) found steaks produced from steers subjected to 1 of 7 implant strategies (combination of estrogenic and androgenic compounds) to be rated similarly to the non-implanted control for overall liking (Roeber et al., 2000). Postmortem aging duration and QG has been reported to influence consumer panelist palatability ratings. For example, Select steaks aged 14 d from cattle that were implanted successively in the feedyard with 2 implants were rated lower in overall consumer acceptability versus a control (Igo et al., 2011). Though, in the same study, postmortem aging duration and QG improved consumer overall acceptability ratings. Choice steaks from successively implanted cattle aged 21 d were similar to the control (Igo et al., 2011). Also, the implant dosage can affect outcomes; moderately implanting (two implants in the feedyard) *Bos indicus*- influenced cattle did not result in detriments to overall mouthfeel and acceptability of steaks aged 7 and 14 d as rated by untrained consumer panelists from five metropolitan areas (Barham et al., 2003).

Though limited literature exists about feeding monensin and tylosin on consumer palatability ratings, trained consumers described steaks from cattle fed β-AA (ZH), monensin and tyslosin as acceptable for overall quality (Hilton et al., 2009). However, there is some disparity among trained and untrained consumers' ability to describe palatability (Harsh et al., 2015). As an example, untrained consumer panelists were unable to detect differences in overall liking of steaks from all-natural production (no growth promotants technologies) compared with steaks from steers implanted once (TBA/E_2) in the feedyard, supplemented monensin, tylosin, and a β-AA (ZH; 6.76 mg/kg) for 20 d prior to harvest, and ultimately ranked them higher in liking than steaks from steers implanted once (TBA/E_2) in the feedyard (Harsh et al., 2015). Whereas

trained consumers in the same study rated steaks from all-natural production and steaks from steers implanted once (TBA/E_2) in the feedyard and fed monensin and tylosin, similarly (Harsh et al., 2015). Garmyn et al. (2014) found steers supplemented with RH (308 mg RH • hd^{-1} • d^{-1}) to be similar to a non-supplemented control for overall liking and Platter et al. (2008) suggests supplementing cattle with RH likely results in minimal impacts on consumer acceptability. Further, consumer panelists consuming steaks from the more aggressive β-AA (ZH) could not detect differences in overall palatability (Mehaffey et al., 2009; Hilton et al., 2009). Though, sensory analysis of RH is much more limited than ZH, especially when comparing treatments to an effective control that never received other growth promotants. It is understood that supplementation of RH may increase objective tenderness, but minimal impacts on consumer acceptability are generally observed (Platter et al., 2008).

Evolving Consumer Preferences

The Consumer

In 2018, US red meat consumption is forecasted to be 98.4 kg (USDA, 2009) and is three times greater than the global average (Daniel et al., 2011). While US beef consumption was 25.3 kg in 2016 (NCBA, 2016), demand is predicted to be strong in 2018 (Haley, 2017). Given the importance of meat in American's diet, it is integral to understand perceptions about animal production that influence consumer preferences (Olynk Widmar et al., 2013). It is understood that food consumption patterns have changed since the 1970s from the demand for processed foods to the current desire for "clean labels" (McCluskey, 2015). Different factors have contributed to this shift in preference but one major factor is the increasing age of the US population. Nearly 13% of

the US population is 65 years or older and this proportion is expected to increase to 21% by 2050 (McCluskey, 2015). The future expectancy is to continue to have an older population because of the health-conscious movement that is occurring. In 2015, 69% of adults were classified as overweight and obese (CDC, 2015). This national issue sparked media attention and reinforced concerns about human health politically, environmentally, and socially (Machen, 2010). Therefore, restaurants began posting calorie information and prominence of nutritional labeling arose (McCluskey, 2015). In addition to increased health awareness, another important factor is consumer education. The US population has become more educated as 34% of Millennials have at least a bachelor's degree (Patten and Fry, 2015). From a study conducted by NCBA (2012), 85% of consumers ate at quick service restaurants, and of those, 95% were Millennials. Therefore, Millennials are driving the shift in marketing of many quick service restaurants (Chipotle, Elevation Burger, etc.), which are now providing beef raised without antibiotics (NRDC, 2015).

Credence Attributes

Perhaps greater access to disclosed information through the education system is contributing to consumers' desire to make a difference with their purchases. Beef raised without the routine use of antibiotics is the fastest growing market (NRDC, 2015) in meat sales among beef, pork, chicken, and turkey, which experienced a 25% increase from 2009-2012 (Perrone, 2012) despite a decline in per capita meat consumption (NRDC, 2015). These marketing initiatives have caused USDA-FSIS (2016) to provide guidelines for label approval for Animal Raising Claims including "raised without antibiotics", "raised without hormones", etc. These credence attributes are specific to allowable practices for raising livestock for meat production and can include guidelines for raising,

handling, and housing livestock during the production process (Caswell and Mojduszka, 1996). Overall, there is an increased abundance of food standards, certifications, and labels with claims about socially responsible production, geographical origin, organic, and many other attributes (McCluskey, 2015). These certifications or labels can be related to environmental and social preferences and have initiated marketing for "natural," "organic," "free-range," "certified humane," "environmentally friendly," and "local" as consumers want to know more about where their food comes from (Umberger et al., 2009; McCluskey, 2015).

Natural

The perception of personal benefit and altruistic behavior have been found to drive the demand for "natural" beef (Umberger et al., 2009). However, the term "natural", as regulated by the USDA-FSIS, only indicates the product is minimally processed with no added ingredients and does not have added benefits for consumer food safety (Umberger et al., 2009; Machen, 2010). An online survey evaluating 798 US households determined that food safety and animal welfare were the most important factors (52% and 69%, respectively) influencing ground beef purchases (Olynk et al., 2013). The term "natural" can result in consumer confusion because companies often market multiple credence attributes together (Umberger et al., 2009). To reduce confusion, the term "raised without hormones" is now mandated by USDA-FSIS (2016) instead of the generic natural description. Consumers perceive "no hormones" important or very important in studies conducted by Sparling (2001) and Lusk and Fox (2002) who determined consumers were willing-to-pay (WTP) more (10% - 17%) for beef labeled as "not raised with growth hormones."

Beef's Role in Consumer Preference

Education has been proven as an effective tool to shift priorities in consumer preference (Mennecke et al., 2007). Development of consumer education programs that teach consumers about the value of different characteristics (feed type, breed, USDA QG etc.) will improve consumers' ability to make educated decisions (Mennecke et al., 2007). To illustrate this point, animal science students placed more priority on intrinsic cues (cut, quality, and marbling) and ultimately made more informed decisions than business students. Consequently, education can change attitudes and product priorities (Mennecke et al., 2007).

Consumers should not fear beef from an implanted animal, as the level of hormone in the product is minimal in comparison to the amount naturally produced by a human body. As previously mentioned, Johnson and Beckett (2014) illustrated that if a prepubescent girl ate 453.6 g (1 lb.) of meat daily, from an implanted animal administered 10 times above the manufacturer's recommendation, she would be consuming 0.031μg of testosterone from meat, which is approximately $1/1000^{th}$ of her daily production. Moreover, consumers should not fear subtherapeutic antibiotic use of monensin and tylosin as Thomas et al. (2017) discovered no correlation among presence of antimicrobial resistant genes in the gut microbiota from cattle administered antibiotic feed additives.

In regard to consumer preference, there is a demand for lean beef from health-conscious consumers. Recently in 2014, Laura's Lean Beef became the largest natural beef brand in the US (BEEF Magazine, 2014). Non-branded lean beef (≤ 8.2g of total fat and ≤ 3g of saturated fat) can also be found in the retail case (McNeill et al., 2012). There

are several reasons for these availabilities including use of growth promoting technologies and faster access to genetics (McNeill et al., 2012). The utilization of both additive technologies and genetic predictors have optimized production for beef flavor and leanness (Field, 2007). Nevertheless, if consumer preferences continue to indicate a demand for natural beef production the abundance of lean beef may be reduced but this may result in greater of retention of beef consumers, which is a positive for the beef industry (Machen, 2010). However, it is important not to promote one type of beef product at the expense of another (Machen, 2010).

Beef Labeling Regulations

The Federal Meat Inspection Act (FMIA) requires food manufactures to obtain approval of labels for meat products prior to marketing (USDA-FSIS, 2014). To be approved, labels must adhere to the USDA Food Safety Inspection Service (USDA-FSIS) labeling guidelines for meat, poultry, and egg products (USDA-FSIS, 2017a). In addition to the USDA-FSIS labeling regulations for information that must be on the Principle Display Panel (PDP; product name, handling statement, legend/establishment number, net weight statement) and on the package (ingredients statement, signature line, nutritional facts, and mandatory safe handling instructions) labels may optionally contain a claim and a statement to portray product attributes (FDA, 2013). The statement is used to describe the claim and begins with an asterisk on the meat label (USDA-FSIS, 2016). The USDA-FSIS Labeling and Program Delivery Staff (LPDS) only needs to evaluate four types of labels: 1) labels for religious exempt products, 2) labels for export with deviations from domestic requirements, 3) labels with special statements and claims, and 4) labels for temporary approval (USDA-FSIS, 2017b). Labels submitted for review can

either be sketch approved by the LPDS or generically approved if in immediate compliance of applicable regulations (USDA-FSIS, 2014). Some examples of special statements and claims that need to undergo sketch approval include: third-party animal raising claims, no antibiotics administered, Certified claims, gluten free, all natural, and non-genetically modified. (USDA-FSIS, 2014). Some examples of generically approved statements include: 100% pure, made with real cheese, environmental claims, and USDA Prime, etc. (USDA-FSIS, 2014). Upon label development, the amount of information provided is important to consider because if in excess, it risks panelist overload or may yield boredom and impatience (Sal-aün and Flores, 2001). Consumer cognitive capacity and desire to read and process information must also be considered (Caswell and Mojduszka, 1996). Consumers are unique and may have different types of quality desires that cause labels to not be preferred the same (Brunsø et al., 2005). In retail selection, consumers may make purchases based upon additional factors besides intrinsic quality cues, such as brand and price (Bredahl, 2004). For example, special statements and claims have been permitted for labeling without the use of antibiotics to provide more customer options (Levitt, 2015). Development of beef labels with claims and statements that indicate greater environmental responsibility (i.e. water reduction, reduced CO_2 emissions, etc.) will be appealing to targeted consumers at retail (Tonsor and Shupp, 2009; White and Brady, 2014).

Beef Marketing and Economics

Beef Marketing and Management Options

Currently the USDA-AMS has 91 certified beef programs such as Certified Angus Beef (USDA-AMS, 2017a), which was the first program to be certified. There are

also process verified programs (PVP) that offer producers the ability to qualify their cattle for certain domestic and export markets and increase production value. The USDA-AMS (2017c) provides third-party auditing and has approved companies (IMI Global, Lindsay Ranch, Ranchers Connecting Ranchers, etc.) for auditing livestock feeding claims such as value-added calf (VAC) programs, NHTC, never fed beta-agonist, and grass-fed. These livestock feeding programs (NHTC, never fed beta-agonist, source verified (ASV)) were originally developed to market US beef internationally and meet trade barrier requirements, which have ultimately led to the development of cattle with specific production management characteristics (Zimmerman et al., 2012). The emerging of the NHTC market influenced calf prices and management practices of cow-calf producers (EN, 2012).

Value Added Calf Programs

Within the cow-calf segment, control for animal health and feeding performance has also influenced the beef industry to offer premiums for abiding by calf management programs. These certified calf health programs or VAC programs (VAC24, VAC34, VAC34P, VAC45, VACPC) contain specifications for preconditioning practices (McNeill, 2001; Zimmerman et al., 2012). Though the broad term VAC can include credence attributes such as naturally raised, ASV and other value associations requiring third-party verification (Smith, 2007). In 2010, premiums for VAC34, VAC34P, and VAC45 programs ranged from $2 - $4 cwt and VAC45 calves received $2 - $5 more per cwt because they had been weaned 45 d. Producers that generically describe cattle as weaned, non-implanted, black hided, and with all vaccinations tend to miss these specific profit opportunities (Zimmerman et al., 2012). In addition to these certified calf health

programs, the NHTC market (data from 2010) has provided an economic incentive of $1 - $2.75 per cwt (Zimmerman et al., 2012). In 2006, premiums for natural market steer calves were $0.81 - $1.09 and heifer calves were $0.73 per cwt. Further, the NHTC-market eligible calf premiums were greater ($1.81 - $2.78) per cwt for both steers and heifers in 2010 (Zimmerman et al., 2012). Another method to add value to calves is implanting, consistent groups of implanted calves were not discounted and did not receive lower base calf prices suggesting that gains from implants would increase profitability (Zimmerman et al., 2012). Overall, providing third-party auditing or utilizing calf-implant strategies have provided greater profit advancements by allowing for improved weaning weight (WW), VAC, natural, NHTC or, certified cattle marketing programs to meet the demands of domestic and international consumers (Zimmerman et al., 2012).

Beef Marketing Options

To produce these classifications of cattle, a pricing mechanism must exist to afford production of offspring that matches consumer preferences (Gillespie et al., 2004). Traditional or conventional cash auction methods are useful for live beef animals (weaned calves, stockers, cull bulls, cows, and heifers; Gillespie et al., 2004) that are marketed by BW. Though specialty marketing programs, like Superior Livestock Auction (SLA), the oldest online video auction, provides private-treaty internet listings and started marketing for the Certified Natural Cattle program in 2004 and the NHTC program in 2008 (Zimmerman et al., 2012). Another marketing option is a carcass grid-based system that exists to help producers receive higher prices for cattle that meet the specific grid criteria. Either breed associations or cattlemen firms formed beef carcass alliances

(BCA), which are predominately dominated by British breeds (Certified Angus, Certified Hereford) and some Continental breeds (Gelbvieh Alliance, Limousin Grid). These grids (Angus America, Angus GeneNet, Farmland Supreme, HiPro Producer's Edge, US Premium Beef etc.) were developed to target high quality beef production (Sartwelle et al., 2014). Though the first BCA that existed was for Natural/implant-free (Coleman's Natural Meats, Laura's Lean Beef, Maverick Ranches Beef, and B3R Country Meats) carcasses that in some cases also banned ionophores, antibiotics, and other feed additives (Sartwelle et al., 2014). These specific types of BCA are likely to continue due to consistent higher returns compared with cash markets given that producers can progress the genetic makeup of the cowherd and/or conduct ASV (Sartwelle et al., 2014).

Natural/implant-free BCA present some tradeoffs due to the potential to increase animal morbidity, mortality (because of prohibition of antibiotics and/or antimicrobials) and loss of gain efficiency (because of loss of implants and feed additives) affecting HCW and potential to fulfill specifications (Sartwelle et al., 2014). In an organic example, the loss of performance requires a 39% higher sale price (Fernandez and Woodward, 1999). From a meta-analysis, a naturally raised steer would require more incentive ($0.14/kg BW) to be as valuable as a conventionally raised steer due to the loss of performance (Gadberry, 2008; Wileman et al., 2009). To have a functioning value-based marketing system, producers must be paid to raise what consumers demand (Cross and Savell, 1994). Selling NA or NHTC calves needs an assured incentive. Continuous and projected price reporting for cattle with credence attributes is needed so that producers can determine if retaining ownership is an option and have guidance to make management decisions.

Improvements from Growth Promotant Use in Beef Production

In 2016, the economic impact of the US beef industry was $65.6 billion in farm cash receipts for cattle and calves (NCBA, 2016). The use of growth promotant technology improves efficiency and reduces the cost of production (Machen, 2010). Perhaps use of technology and improved efficiency explains why, in 2016, the average cost of USDA Choice beef sold $0.33 less in retail than in 2015 (NCBA, 2016). Optimizing cattle production efficiently while minimizing inputs such as feed costs (purchased or harvested) that account for nearly two-thirds of total operating costs are important for long-term sustainability and profitability of an operation (USDA-ERS, 2010). Beef consumers benefit from use of growth promotant technologies to keep production costs low, which ultimately means more affordable beef prices and more lean and healthy beef options (Johnson and Beckett, 2014).

Segment Costs of Production

From a meta-analysis of 170 trials and use of the 2005 market prices, the estimated production and feed costs for each segment were: cow-calf, $183 - $247/cow/yr.; stocker, $0.30/d - $0.45/d; and feedyard, $0.04/lb. of feed (Lawrence and Ibarburu, 2007). The estimated labor cost at the stocker segment ranged from $6 - $24/hd and at the feedyard was $27/hd for feeding steers 184 d and heifers 201 d. Veterinary costs at the cow-calf segment ranged from $10 - $25/cow/yr. and cost at the stocker and feedyard was $10/hd (Lawrence and Ibarburu, 2007).

Segment Economic Benefits of Technology Use

At the cow-calf level, use of de-wormer had the greatest impact followed by calf-implants on WW, though most cow-calf operations do not use ionophores or implants

(Lawrence and Ibarburu, 2007). At the stocker level, use of de-wormers and implants were most important followed by ionophores, subtherapeutic antibiotics, and fly control and collectively cost $80.79/hd. If these technologies were removed the represented cost would be $126/hd and if the management changed to a natural program (still using de-wormer) the cost would be $101/hd (Lawrence and Ibarburu, 2007). Further, when feed costs are higher growth promoting technologies are more cost effective. In NE, removal of all mentioned technologies increased fed cattle prices by 20% or, $17/cwt. Overall, use of the five pharmaceutical technologies had a cost savings of over $365 per hd for the lifetime of the animal (Lawrence and Ibarburu, 2007). In a separate meta-analysis specifically evaluating implants, steers that were implanted had a $77 benefit and removing implants and all pharmaceutic technologies would cost $155/hd (Wileman et al., 2009). In a separate lifetime analysis, calves administered an implant during the suckling, grazing, and finishing period had an increased value of $93 per hd (Duckett and Andrae, 2001). Similarly, a stair-step implant program maximized quality and yield value ($85.68) on the rail compared to non-implanted carcasses (Reinhardt, 2007). These studies illustrate the greater premiums obtained from improved efficiency from technology utilization versus non-implanted controls.

In the feedyard, adoption of growth promotant technologies is the highest (95%) and along with implants this segment also takes advantage of another technology, β-AA (Campiche et al., 2004; Lawrence and Ibarburu, 2007). However, the use of β-AA usually has a greater input cost compared with implants. For example, use of ZH increased production costs by $20 per hd, but returned more ($0.06/kg/hd) due to growth improvement and increased ($0.04/kg HCW) the overall economic net return (Stackhouse

et al., 2012). However, cattle producers may obtain greater profit from adoption of management practices for naturally raised or NHTC cattle although premiums may vary dependent upon market conditions (Stackhouse et al., 2012; Zimmerman et al., 2012). Natural cattle can bring a similar net return to commercial cattle if sold at a 8% premium (Stackhouse et al., 2012). If consumer demand continues to increase for these specialized programs, premium variation could be reduced and there could be more consistent added profit. Still, traditional determinants of reduced BW and a greater potential for decreased animal health make use of growth promotant technology including Tylan, critically important.

Retail Costs for Beef

Various conditions such as weather, supply, access, and production volume influence the retail cost for beef. For example, drought conditions from 2008 – 2012 caused high feed prices and resulted in decreased inventory of cattle (USDA-ERS, 2017d). As feed became more affordable, cattle production rebounded slowly (USDA-ERS, 2017d). The increased volume of cattle helped to stabilize beef price volatility at the retail case resulting in a drastic improvement in demand since 2010 (Speer, 2016). Consumer spending for beef in 2015 captured a record high at $340 per person, which is an increase by $80 in five years (Speer, 2016). Although total beef consumption has declined from 2000 – 2016 (29 kg – 25 kg, respectively) this is not a reflection of beef demand (Campiche, 2004; NCBA, 2016; Speer, 2016). Beef has strong pricing power due to the direct result of improved demand (Speer, 2016). In fact, since the 2000s wholesale beef prices have steadily trended upward and between 2016 – 2017 the USDA wholesale price spread has consistently been positive: rib, +1.79%; chuck, +9.33%; loin, +13.33%;

brisket, +0.45%, and round, +15.87% (USDA-ERS, 2017d). These trends from wholesale prices were reflected in the National Retail Report, which show stability and some increases (USDA-AMS, 2017b). These price trends from 2016 – 2017 for specific retail cuts include: ribeye steak +11.61%, flat iron + 10.75%, t-bone steak - 3.83%, brisket-flat + 33.62%, and ground round + 11.41% (USDA-AMS, 2017b). These price spreads convey critical information to the beef supply chain about the distribution of cost along the marketing chain and efficiency of transforming cattle to retail beef (USDA-ERS, 2017d). Demand for beef in 2018 should remain strong given firm packer margins, fed cattle prices, and continued growth in US beef exports (Haley, 2017). Though with the emergence of natural beef, NHTC beef, and beef raised without antibiotics in the retail case, reporting of the associated cost to the consumer is limited.

Consumer Willingness-to-pay

In economics, a wide array of research has been conducted to evaluate the allocation of a food dollar used to purchase commodities sold in proportion to their annual share in the US market. In 2015, each 1$ expenditure on food contributed 15.6 cents to the farm share (USDA-ERS, 2017c). The expenditure spent on food items are associated with private benefits such as nutrients, quality, taste or, physical appearance (White and Brady, 2014). Historically, consumers have demonstrated that beef tenderness is important to palatability (Dikeman, 1987; Savell and Shackelford, 1992) and have been WTP for steak tenderness (Boleman et al., 1997; Miller et al., 2001) and marbling guarantees (Killinger, 2004). Though, consumers are not always WTP a premium for steaks that should be more acceptable (Dransfield et al., 1998). Recent beef research efforts have been devoted to understanding how much consumers are WTP for niche

retail products such as grass-fed, organic, natural, and local meat (Umberger et al., 2002; White and Brady, 2014). Consumers in North America have been WTP a 29.1% premium for niche grass-fed, all natural, and local beef (White and Brady, 2014). Other factors from production management decisions have influenced consumer WTP such as beef raised without antibiotics (Sneeringer et al, 2015). In a national survey, Farm News Media (2016) shared results from a Cargill Animal Nutrition survey that discovered 54% of US consumers were WTP more for beef raised without antibiotics. Other marketing and production factors such as labeling and organic certification have been found to increase WTP (Lyford, 2010). Organic beef labeling has increased beef cost by $6.56/kg and represents a 47% premium (White and Brady, 2014). Consumers that read labels and have positive attitudes towards the term natural are more likely to purchase natural beef (Campiche et al., 2004). Beef labels provide extrinsic and intrinsic quality cues that guide consumer inference about the product quality and allow them to form an expectation about the product, which relates to purchasing behavior, satisfaction, and future purchasing decisions (Brunsø et al., 2005; Grunert, 2005). The newest beef marketing evaluations have been conducted on environmental reduction efforts. In North America consumers were WTP a premium (14.8%) for pure environmental reduction efforts of water usage (White and Brady, 2014). This premium is less than the niche (29.1%) premiums mentioned earlier and when evaluated in-person, WTP decreased by 11.2% indicating that location and beef type influences WTP (White and Brady, 2014). Though from a farm-level economic analysis, the mid-west region has the greatest opportunity to reduce water use (41.4 L/kg) but to do this, consumers need to be WTP 10% greater premiums or $1.10 more per kg (White and Brady, 2014). Improved beef labeling is

needed that can successfully be appealing for the majority of beef consumers and assist with beef production being focused on environmental sustainabity (White and Brady, 2014). Demand for environmentally friendly food products is already increasing in the UK (Gadema and Oglethorpe, 2011) and will most likely increase in the US.

Environmental Sustainability

The beef industry has defined beef sustainability as meeting the growing demand while balancing environmental responsibility (Rotz et al., 2015). Environmental responsibility can be improved by reducing the input needed for animal productivity and achieving the same or more volume of end product (Stackhouse et al., 2012). There are several ways these improvements can occur individually, or in combination of production practices: nutrition, reproduction, genetics, and management (Boadi et al., 2004). Management tools commonly used in the beef industry are the previously mentioned growth promoting technologies for enhance animal efficiency (Stackhouse et al., 2012). Moreover, the use of these technologies mitigate greenhouse gas (GHG) and ammonia (NH_3) emissions from cattle production per unit of end product (Stackhouse et al., 2012). Therefore, growth promoting technologies can be employed to provide a cost-effective method for increased efficiency (Stackhouse et al., 2012) and environmental sustainability. In review of research, a meta-analysis determined implanted steers had greater ADG, DMI, and lower (-$77) per animal cost of production than non-implanted steers (Wileman et al., 2009). However, beef demand presents a challenge as consumers and retailers are desiring more “natural” beef products, which influence producer management decisions regarding the use of growth promoting technologies (Stackhouse et al., 2012). Other management decisions include the addition of by-products such as

distillers grains to replace corn in cattle diets for improved efficiency, though when overfed the reactive N increases (~10%) because of excess protein being excreted as urea and volatilized as ammonia (Rotz et al., 2013). In addition to by-product influences, other aspects that influence efficiency of production are the climate and topography that cattle are raised in. Overall, production of cattle with associated feed crops and the resulting impact on the environment is not well understood (Rotz et al., 2013).

Integrated Farm Systems Model

Measuring sustainability is challenging as the beef supply chain is very complex (Rotz et al., 2015). The Integrated Farm Systems Model (IFSM) is a tool used to asses environmental and economic sustainability of farming operations (Rotz et al., 2013; Rotz et al., 2015). The model provides a process-level simulation of performance, environmental impacts, and economics of farms, ranches, and feedyards (Rotz et al., 2013). Energy, protein, and mineral requirements for cows, calves, replacement animals, stockers, and finishing cattle are determined from the Cornell Net Carbohydrate and Protein System (level 1; Fox et al., 2004; Rotz et al., 2015). Crop growth and development is estimated daily based upon soil water and nitrogen availability, ambient temperature, and solar radiation (Rotz et al., 2013). Allocation of feed and predicted animal response is dependent upon the nutrient content of the feeds available and the nutrient requirements of the cattle. These predictions can be conducted for cows, calves, replacement females, stocker, and finished cattle (Rotz et al., 2005). To determine annual carbon, energy, water, and reactive nitrogen footprints, a life cycle assessment (LCA) can be conducted (Rotz et al., 2013). Collectively these predictions represent the net GHG emissions, fossil energy use, water use, and reactive N loss from production systems from

the cow-calf segment to harvest (Rotz et al., 2015). This model accounts for inputs of resources such as fuel, natural gas, electricity, fertilizer, purchased feed, machinery, seed, and pesticides (Rotz et al., 2013). The total resources are divided by the volume of feed or, BW produced to determine the footprint (Rotz et al., 2013). Recent environmental focuses using this model have predicted: 1) GHG emissions from carbon dioxide, methane, and nitrous oxide tracked from crop, animal, and manure sources; 2) energy use; 3) water use; 3) and reactive nitrogen loss (Rotz et al., 2013).

Carbon Footprint and Greenhouse Gas Emissions

Improvements in beef production from the 1970s to 2007 have resulted in a 6% - 16% decrease in C footprint or net GHG emission (Capper, 2011; Rotz et al., 2013). This is because GHG production per unit of meat is decreased and thus, results in lower C footprint (Boadi et al., 2004). Currently beef cattle production causes a C footprint ranging from 10 – 15 kg CO_2 equivalent (CO_2e)/kg BW (Beauchemin et al., 2010; Stackhouse et al., 2012; Rotz et al., 2013). Environmental conditions and climate widely influence these outcomes due to production system management decisions among simulated operations (Rotz et al., 2015). Specific to the upper Midwest, C footprint has ranged from 14.8 kg - 10.9 kg CO_2e/kg BW according to Pelletier et al. (2010) and Rotz et al. (2013), respectively. Use of growth-promoting technologies has been shown to effectively increase animal performance (ADG (0.1 – 0.2 kg/d), final shrunk BW (42 kg), and G:F (0.01)) and measures of sustainability (Stackhouse et al., 2012). In CA, use of implants and β-AA have decreased C footprint by 4% - 9%, respectively (Stackhouse et al., 2012). This subtle decrease may be due to the fact that 68% - 74% of GHG emissions occur prior to application of growth promotant technology, while calves are still nursing

(Stackhouse et al., 2012). Still, these efficiencies in C footprint reduction are similar to the dairy industry use of recombinant bovine ST that has been determined to reduce C footprint of milk production by 7 – 9% (Capper et al., 2008; Rotz et al., 2010). To provide a more comprehensive tool that encompasses the beef supply chain C footprint, Rotz et al. (2015) conducted a cradle-to-farm gate study that provides a baseline for comparing technology utilization and sustainability of beef production systems with carcass weight (CW) as an end outcome. In this cradle-to-farm gate approach, total GHG emissions ranged from 14 – 26 kg CO_2e/kg CW among regions in KS, OK, and TX (Rotz et al., 2015).

Energy Utilization

In comparison to 1970, beef cattle production has not improved the energy footprint (Rotz et al., 2013). This is because in the 1970s there was little irrigation and less corn production, which limited energy use. Today, more equipment is powered by gasoline engines that require more fuel, and more corn is grown and irrigated. To reduce energy footprint, placing more emphasis on reduction of fuel and feed use is necessary. In the cradle-to-farm gate analysis, energy use was reported as 51 MJ/kg CW (Rotz et al., 2015). Though regional differences can influence fossil fuel use. Among the climates of KS, OK, and TX, production management decisions influenced fossil fuel energy use from 26 – 83 MJ/kg CW (Rotz et al., 2015). In another example, the annual energy footprint of beef produced at the Roman L. Hruska US Meat Animal Research Center (MARC) was 27.0 MJ/kg BW much less than 44.8 MJ/kg BW determined in an upper Midwestern US beef production system (Pelletier et al., 2010). This range in value stems from fertilizer production, fuel and electricity use, and other resources. Though,

comparing values should be cautioned as each system has unique pre-chain inputs (Rotz et al., 2013). Reports investigating the influence of growth promotant technology use on the energy footprint and practical improvements to reduce use are limited (Rotz et al., 2013).

Water Utilization

Globally, agriculture accounts for 92% of freshwater and of that 29% is directly or indirectly used for animal production (Gerbens-Leenes et al., 2013). The water footprint for beef production has increased by 42% since 1970 due to greater irrigation of feed, when precipitation is not included, and feed is purchased (Rotz et al., 2013). Though the current water footprint is 5% less than 1970 when precipitation is included given the greater yield of corn (Rotz et al., 2013). The annual water footprint determined for the MARC production system, excluding precipitation was 2,789 ± 914 L/kg BW and with precipitation the water footprint was greater (21,340 ± 5,600 L/kg BW; Rotz et al., 2013). Regardless, most of the water used was for feed production as cattle drinking water was 1% or less (Rotz et al., 2013). In the cradle-to-farm gate environmental footprint study, the water use with precipitation was 2,470 ± 455 L/kg CW. Most of the water use is associated with producing feeding for the finishing segment (Rotz et al., 2015). Reports investigating the influence of growth promotant technology use on water reduction and practical improvements to reduce use, are limited (Rotz et al., 2013).

Ammonia Emissions and Reactive Nitrogen Loss

In comparison to the 1970s, the current beef production system has decreased reactive nitrogen loss by 3% due to offsetting effects (Rotz et al., 2013) such as improved corn yield and use of growth promoting technologies. To determine the reactive nitrogen

loss or simply the total nitrogen loss, the IFSM tracks nutrient flows to predict the environmental losses, accumulation, depletion or, emissions of ammonia from denitrification and leaching losses of N, erosion of sediment among farm boundaries, and runoff of N and P (Rotz et al., 2015). The first study to encompass total reactive nitrogen loss was simulated for MARC. There the annual reactive nitrogen footprint of beef production was 91.7 ± 18.4 g N/kg BW (Rotz et al, 2013). Most (61%) of the footprint was associated with cattle on pasture during the cow-calf segment of which ammonia emissions contributed to the majority (81%) followed by nitrate leaching (6%) and, nitrous oxide emission (9%; Rotz et al., 2013). The KS, OK, and TX cradle-to-farm gate study determined the reactive N loss was 138 ± 12 g N/kg CW though the variation is due to runoff and leaching of N. On the eastern side of the region, there was more rainfall compared with the western side, which had greater NH_3 volatilization (Rotz et al., 2015). The total NH_3 emission from all production segments was 88 g/kg CW. Emission was slightly greater (44%) from urine and fecal deposition during the cow-calf segment compared with the feedyard (43%) from manure deposition. This contributed to GHG emissions being greater during the cow-calf segment is due to breeding stock producing a calf and increasing the enteric emission from consumption of a high forage diets (Rotz et al., 2015).

It is well understood that use of growth promotant technology has increased the efficiency of beef produced and can influence economic and biological efficiencies in addition to environmental and animal welfare issues (Wileman et al., 2009). In regard to reactive nitrogen loss, use of β-AA (receiving a TBA/E_2 implant at the stocker and feedyard, and ionophore, and tylosin in the feedyard plus ZH 20 d prior to harvest)

reduced NH_3 by 7% in an entire beef production system and in the feedyard by 4 - 9 g/kg CW (Stackhouse et al., 2012). This is the result of increased N efficiency due to the physiologic response of the β-AA (ZH) causing greater muscle mass and protein synthesis with less protein degradation (Mersman, 1998). The reduction in NH_3 is important because protein is being spared leading to less concentration of urine urea nitrogen (UUN) that could be volatized as NH_3 (Stackhouse et al., 2012). As expected, use of β-AA (ZH) reduce NH_3 by 6% versus natural production and interestingly, reduced NH_3 by 14% versus implanted cattle (receiving a TBA/E_2 implant at the stocker and feedyard, and ionophore, and tylosin in the feedyard). Therefore, use of ZH at the feedyard 20 d prior to harvest serves as a NH_3 and GHG mitigation tool (Stackhouse et al., 2012). However, ZH has not been commercially available since 2013.

Future Improvements in Environment Sustainability

Utilizing livestock to support human nutritional needs is documented (White and Hall, 2017) to have some GHG emissions, though use of growth promoting technologies may reduce the GHG and NH_3 emissions.

CONCLUSION

The adoption rate of growth promotant technologies by beef producers is high because of improvements in animal and carcass performance, economic viability, return on investment, improved resource management, and reduced environmental impacts. However, a majority of research that is available on growth promotant technologies has focused on carcass performance, meat quality, and sustainability utilizing zilpaterol hydrochloride, which is not commercially available. This necessitates research utilizing ractopamine hydrochloride to determine if the use of this technology combined with or

without monensin, tysolsin, and growth promoting implants influences animal and carcass performance, production economics, and environmental impacts. Additionally, there is limited information about the carcass performance and meat quality of carcasses from cattle raised as NHTC, or those raised with monensin and tylosin in combination with anabolic steroids and RH supplementation. Given that demand for Natural beef production is increasing, an improved understanding about how the management practices associated with producing NHTC cattle influence meat quality, consumer acceptability, economic profitability, and the environment, is needed.

Additionally, an effective control is needed for adequate comparison among treatments such as cattle "raised without the use of antibiotics" to provide an adequate baseline for comparison. Moreover, the use of different levels of technology needs to be described more effectively to convey the impacts on animal efficiency and environment sustainability. Upon producing these beef products raised with different levels of growth promotant technology, consumer palatability and perception must be considered.

A majority of consumer palatability research was conducted with trained panelists, which is not the beef industry's target consumer. This necessitates the need for analysis of meat quality variables utilizing untrained consumers to determine if production systems influence beef palatability. These procedures should be tested without the consumer knowing what they are eating to serve as a baseline and then, test production information, and production information plus the product to better gauge consumer preference and change in preference. From the literature, no research effort has evaluated consumer palatability and label preferences when animal performance and environmental impacts are disclosed. Recent trends in beef marketing indicate that there

is a demand for beef produced without growth enhancement technologies such as “non-hormone treated cattle” and cattle “raised without antibiotics.” This trend is not unexpected given that the average American beef consumer is several generations removed from production agriculture and may not understand the reason for these technologies to be used and the regulations in place to ensure that all meat is safe and wholesome. Previous research has shown that consumer panelists were unable to detect tenderness or palatability differences for beef produced naturally in comparison with beef produced with growth promotant technology. However, these cattle were not produced from a similar source or fed to the same compositional endpoint, which may influence sensory characteristics. Further, sensory characteristics may not be the primary driver of willingness-to-pay if consumers are concerned about how their food is produced including animal production method and the environmental impact. The beef industry has recognized this concern and has committed to “Grow Consumer Trust in Beef and Beef Production” however, how to best differentially market beef with full use of technology, remains a challenge.

To ease this challenge and provide insight, a consumer focus group is needed to understand consumer desires for meat products and marketing. This topic is timely and important to the national beef industry as beef markets are undergoing rapid change due to the growth in alternative production systems and protein choices. Growth in these sectors is in direct response to consumer demands; however, the industry may have opportunities to differentiate beef products that are produced with technology as well as products raised without.

Therefore, the objectives of this dissertation were to:

1. determine the influence of production systems on cattle and carcass performance, the environmental impacts and natural resource use, and the economic return of different levels of growth promotant technologies;
2. determine the influence of production systems on objective measures of meat quality, steak tenderness and determine untrained consumer palatability preferences, willingness-to-pay, and palatability ratings for beef produced with different levels of growth promotant technology;
3. determine the most effective marketing strategy for beef produced with different levels of growth promotant technology by testing label descriptions derived from scientifically analyzed production outcomes from the animal performance data for efficiency and sustainability.

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CHAPTER II

Cattle and carcass performance, economic return, and environmental life cycle analysis of production systems

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ABSTRACT

The objective of this study was to determine the impact of different production systems on animal and carcass performance, production economics, and environmental measures. Angus × Simmental crossbred steer calves (n =120) were stratified by birth date, birth weight, dam age, and assigned randomly to 1 of 4 treatments: 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC, fed monensin and tylosin); 3) implant (IMPL, administered a series of three implants, and 4) implant plus fed a beta-agonist (IMBA, IMPL treatment plus, fed ractopamine-HCl for the last 30 d prior to harvest). Weaned steers were backgrounded in a drylot and finished in an individual feeding system to collect individual animal performance data. At harvest, standard carcass measures were collected for USDA Yield Grade (YG) and Quality Grade (QG) determination. Total production expenses and branded carcass value were obtained to conduct an economic analysis of each production system. Information from the cow-calf, backgrounding, and finishing phases were obtained to simulate production systems using the Integrated Farm System Model (IFSM) and conduct a farm gate life cycle assessment (LCA) of greenhouse gas (GHG) emissions, energy use, water use, and

reactive N loss. Hot carcass weight (HCW) and final calculated body weight (FCBW) for IMPL and IMBA were similar ($P > 0.05$) and heavier ($P < 0.01$) than NA and NHTC, which were similar ($P > 0.05$). The ADG was greatest ($P < 0.05$) for IMPL, while IMBA was intermediate ($P < 0.05$), and NA and NHTC were the lowest ($P < 0.01$) but did not differ ($P > 0.05$). The DMI for IMPL and IMBA were similar ($P > 0.05$) and greater ($P < 0.01$) than NA, which was intermediate ($P < 0.01$) to NHTC. Gain to feed (G:F) was greatest ($P < 0.01$) for IMPL. No differences ($P > 0.05$) were detected for 12th rib backfat thickness, YG, or proportions of carcasses in each YG and QG. The marbling score for NA and NHTC was similar ($P > 0.05$) and greater ($P < 0.01$) than IMPL and IMBA, which were similar ($P > 0.05$). The actual branded carcass value was similar ($P > 0.01$) for NA and IMPL and greater ($P < 0.05$) than NHTC and IMBA, which were similar ($P > 0.05$). The environmental analysis revealed that IMPL and IMBA reduced GHG (CO_2e per kg HCW) emissions by 6.5 - 7.8%, energy use (MJ per kg HCW) by 3.4 - 5.5%, water use (kg H_2O per kg HCW) by 4.4 - 5.8%, and reactive N loss (g N per kg HCW) by 1.0 - 5.5% in comparison to NA.

INTRODUCTION

By 2050 the world population is anticipated to be more than 9 billion and to feed this population, 80% of agricultural production must come from increased yield (FAO, 2009). Accompanying this demand for increased food production is often conflicting demand for products, such as beef, to be raised without growth promotant technologies and antibiotics (AgMRC, 2012; Mathews and Johnson, 2013; Perrone, 2012). Growth promotant technologies have been known to improve animal productivity resulting in more efficient meat production (Lawrence and Ibarburu, 2007; Nagaraja and Chegappa, 1998; Johnson et al., 2013). However, the average American beef consumer is several generations removed from production agriculture and given this disconnect, consumers often question technologies utilized to improve production efficiency, creating a growing demand for beef with credence attributes (Umberger et al., 2009) such as, "raised without the use of hormones" and "raised without antibiotics" (USDA-FSIS, 2016; USDA-PVP, 2018). Cattle producers are faced with a dichotomy between producing more beef and producing beef without growth promotant technologies, which may have lasting impacts on operational longevity and sustainability. The implications of not utilizing growth promotant technologies including hormone-based implants, ractopamine HCl (RH), monensin, and tylosin on animal performance, economic return, and the environmental impact of cattle fed to a similar compositional endpoint is unclear (Machen, 2010; Stackhouse et al., 2012b). Therefore, the aim of this research was to test the hypothesis that raising cattle with growth promoting technologies would result in improved animal performance, profitability, and reduce environmental impacts compared with naturally

raised cattle. Therefore, the objective of this study was to determine if production systems using different levels of growth promotant technology influence animal and carcass performance, production economics, and the use of natural resources and environmental emissions.

MATERIALS AND METHODS

Animals and Experimental Design

All animal care and experimental protocols were approved by the South Dakota State University (SDSU) Animal Care and Use Committee (approval number 15-091E). One hundred and twenty Angus × Simmental calves born within a 45 d period at the Antelope Range and Livestock Reserach Station near Buffalo, SD, were utilized. A completely randomized designed was used to stratify calves by birth date, birth weight, and dam age to 1 of 4 treatments: 1) no antibiotics (NA; receiving no technology); 2) non-hormone treated cattle (NHTC; fed 300 mg monensin [Rumensin 90, Elanco Animal Health, Greenfield, IN]) and 90 mg tylosin [Tylan 40, Elanco Animal Health] during the finishing phase March 29 to harvest); 3) implant (IMPL; same technologies as NHTC and administered a series of three implants including a low-potency calf implant [36 mg zeranol; Ralgro, Merck Animal Health, Madison, NJ] at an average of 74 ± 12 d of age on June 29, a moderate-potency initial feedyard implant [80 mg trenbolone acetate and 16 mg estradiol; Revalor-IS, Merck Animal Health] at an average of 235 ± 12 d of age on December 8, and a high potency finishing re-implant [200 mg trenbolone acetate and 20 mg estradiol; Revalor-200, Merck Animal Health] at an average of 330 ± 12 d of age on March 11) and 4) all previous technologies plus fed a beta-agonist (IMBA; same technologies as IMPL and fed 200 mg RH •steer^{-1}• d^{-1} [Optaflexx 45; Elanco Animal Health] for the last 30 d prior to harvest. Beef Quality Assurance (BQA) protocols were used throughout the course of the study (BQA, 2010) and implants were administered subcutaneously in the middle third of the ear by a single technician for each

administration day. Implant needles were changed as needed to be effective and disinfected after each use with a sponge soaked in 2% chlorhexidine solution.

Pre-Weaning Calf Management and Backgrounding

Study initiation occurred on June 29, 2015. All steers were branded and individually weighed without shrink in a hydraulic squeeze chute with load cells mounted under the chute (Weigh-Tronix model 1015; Avery Weigh-Tronix, Fairmont, MN). Also, calves allocated to IMPL and IMBA received a pre-weaning implant and were managed as a common group with all other treatments. Calf weights were recorded again on September 16 and pre-weaning vaccinations were administered including a killed vaccine for clostridial diseases (Vision 7 Somnus with SPUR, Merck Animal Health) and a modified live vaccine for prevention of respiratory viruses and *Mannheimia Haemolytica* (Pyramid 5+ Presponse SQ, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO). At weaning on October 26, steers were boosterd with the 5-way vaccine and weighed then shipped approximately 322 km to the SDSU Cottonwood Range and Livestock Field Station near Phillip, SD. Steers were acclimated to high quality grass hay and dried distillers grain as a common group for two weeks. On November 9, steers were dewormed (Dectomax Pour-On Solution, Zoetis, Parsippany, NJ) and initial backgrounding period weights were recorded. On November 10, steers were blocked by initial weight (November 9) sorted into 12 pens (9.1 m of bunk space per head (hd)) according to three weight blocks (light, medium, and heavy) per treatment for a 56 d backgrounding period (until January 5, 2016) on a high roughage ration (grass hay, concentrate pellets, dry corn cobs, glycerin, distillers grains, limestone, and minerals).

Feed was delivered with a mixer wagon (Farm Aid, model 340; Corsica, SD) each morning at 0900 h. On December 8 steers were weighed, and IMPL and IMBA steers were administered a moderate-potency initial feedyard implant. On January 4, steers were weighed, vaccinated for respiratory diseases (Bovi-Shield Gold 5, Zoetis, Parsippany, NJ) and then re-weighed (to account for variations in fill) on January 5 prior to being shipped approximately 430 km to the University of Nebraska-Lincoln West Central Research and Extension Center in North Platte, NE.

Feedlot Management

Upon arrival at the feedyard all steers were maintained within their original pen assignment and received four concentrate-adaptation diets over a period of 65 d (January 6 - March 11) and fed for 7, 7, 40, and 11 d, respectively. On the morning of March 11, steers were dewormed (Ivermax Pour-On, Aspen Veterinary Resources Ltd., Greeley, CO), individual weight was recorded, IMPL and IMBA steers were re-implanted with a high potency finishing implant. After processing on March 11, all steers were placed into the GrowSafe feeding system (GrowSafe Systems Ltd., Airdrie, AB Canada) to collect individual feed intake. Steers were allowed an 18 d adaptation period to the feeders and data collection began on March 29 and continued to harvest. Steers were allocated to be fed in four groups according to treatment protocol (Group 1 = NA, Group 2 = ½ NHTC and ½ IMPL, Group 3 = ½ NHTC and ½ IMPL, and Group 4 = IMBA) and were rotated among four pens to mitigate the influence of pen on animal performance. Weights were recorded on March 28 and 29 after adaption in the GrowSafe feeding system. Each morning (0800 h) and evening (1600 h) a feed truck and delivery unit (Roto-Mix, model

274; Dodge City, KS) provided the final finishing diet (Table 2.1). Steers assigned to NHTC, IMPL, and IMBA were fed the finishing ration including Rumensin 90 and Tylan 40 as a pre-mixed supplement from the beginning of the acclimated finishing period (March 29) to harvest for either 90, 71, or 90 d, respectively. To ensure that NA did not receive Rumensin 90 or Tylan 40 from the other treatments, during the evening feed delivery the delivery unit was flushed clean with ground hay prior to feeding the NA diet and that diet was fed first during the morning feeding. Steers within the NA treatment received the finishing ration for 71 d. Additionally, IMBA steers were supplemented 200 mg RH•steer^{-1}• d^{-1} in their ration for the last 30 d prior to harvest. A separate feed wagon (Roto-mix, 220; Dodge City, KS) was utilized to deliver the feed ration containing RH to the IMBA treatment to prevent any potential carry over to the other treatments. On April 26, steers were weighed (Table 2.2) and ultrasounded by Cattle Performance Enhancement Company (CPEC, Oakley, KS) to predict the terminal harvest date for each treatment to achieve a common compositional endpoint [~1.53 cm 12th rib backfat thickness (FT)]. Two separate harvest dates were predicted as determined by ultrasound. Steers from NA and IMPL were harvested on June 8 and NHTC and IMBA were harvested on June 27. On the day of harvest steers were transported approximately 100 km to Tyson Fresh Meats in Lexington, NE. Cattle were not weighed prior to being shipped to the processing facility to reduce the incidence of bruising and injury; therefore, the FCBW was determined as HCW divided by 0.635.

From March 29 to harvest, animal performance data were collected for analysis of body weight (BW), average daily gain (ADG), dry matter intake (DMI), and gain to feed

(G:F). Throughout the study all cattle had ad libitum access to fresh water. Due to the animal health protocol, 3 NA steers were removed from animal and carcass performance analyses because they required an antibiotic for disease control. However, these 3 hd were included in the economic analyses to report the cost of antibiotic use and the opportunity loss from not achieving the no antibiotic beef program premium. Three steers died during finishing due to reasons unrelated to treatment including: right-sided congestive heart failure (1 steer from NA), chronic pneumonia (1 steer from NHTC), and hardware disease (1 steer from IMBA). A total of 117 steers were harvested (NA = 29, NHTC = 29, IMPL = 30, and IMBA = 29).

Carcass Evaluation and Sample Collection

Carcasses (n = 117) were tracked individually through harvest and HCW was recorded. Following carcass chilling (approximately 24 h), trained SDSU personnel recorded FT, LM area, and KPH used to calculate USDA Yield Grade (YG), and determined marbling score and carcass maturity to calculate USDA Quality Grade (QG) for each carcass according to USDA guidelines. Plant assigned USDA YG and QG were utilized for analysis of the proportion of carcasses within each YG and QG category (Table 2.3). Total carcass value and carcass value per 45.4 kg (hundredweight) for each production system were determined using plant assigned grid base values, premiums, and discounts. Carcasses in the NA, IMPL, and NHTC treatment groups were marketed on the Gene Trac Grid (Tyson Fresh Meats). On June 8, the base carcass price per hundredweight for NA and IMPL was $206.31 and on June 27, NHTC received a base price of $188.24 per hundredweight. The IMBA was marketed on the True Value Grid

(Tyson Fresh Meats) on June 27, and received a base price of $187.74 per hundredweight.

Economic Evaluation

The total production cost of each treatment was determined by accounting for expenses including: total feed cost and yardage during backgrounding and finishing, technology costs as required by treatment, actual or adjusted cost of morbidity, third party auditing fee (NA and NHTC only), and transportation. The total production cost was also calculated with and without the initial cost of the weaned calf (Table 2.4). Table 2.5 includes the plant assigned base carcass value per hundredweight, the branded beef premiums per carcass, and the total YG and QG premiums and discounts per treatment.

The total branded carcass value was determined by calculating

[(total QG and YG premiums/hundredweight – total QG and YG discounts/hundredweight) × (HCW/100) + (total plant premiums per hd – total plant discounts per hd)].

Total premiums and discounts per hd consisted of adjustments for performing above or below the YG and QG threshold set by the grid and also included the per carcass branded beef premiums (Table 2.5). The branded beef premiums provided by Tyson Fresh Meats were applied to NA ($275 per hd) and NHTC ($175 per hd) as if third party auditing was conducted to ensure the integrity of cattle "raised without antibiotics" and "raised without the use of hormones," respectively. The cost of gain (COG) was calculated by:

[(total production cost) / (final calculated body weight (FCBW (HCW/.635)) - shrunk (6%) weaning weight (WW)].

The net return was calculated by:

[(total branded carcass value – total production cost)].

All costs and returns were calculated including and excluding the cost of the calf ($249 per hundredweight), which was determined based on price reports on the day of weaning from the Faith Livestock Commission Company (located 174 km from the Antelope Range and Livestock Research Station; Table 2.6). As stated earlier, a total of 3 NA steers were treated with an antibiotic for respiratory disease and were excluded from the animal performance, carcass performance. Economic evaluation adjustments are described below.

Economic Evaluation Adjusted for National Animal Morbidity

Actual feedyard percent morbidity was 6.89%, 10.34%, 3.33%; and 13.79% for the NA, NHTC, IMPL, and IMBA treatments, respectively. Actual number of steers treated for illness during the finishing segment included 2, 3, 1, and 4 steers for the NA, NHTC, IMPL, and IMBA treatments, respectively. Considering that the study did not have sufficient numbers to adequately evaluate the influence of production systems on measures of animal health, adjustments were made according to the National Animal Health Monitoring System (NAHMS; USDA-APHIS, 2011). The total adjusted percent morbidity was made according to NAHMS and the actual morbidity percentage was not included in this total adjusted percent morbidity. The total adjusted percent morbidity was 25.8% according to feedyard morbidity data from feedyards in the Central region with greater than 8,000 hd (USDA-APHIS, 2011; Table 2.7). This morbidity adjustment was applied to all treatments and expenses were also adjusted according to NAHMS data

(USDA-APHIS, 2011) including treatment for: respiratory disease (17.90%; $23.10 per hd), pneumonia (2.9%; $21.80 per hd), and digestive issues (5.0%; $8.80 per hd). Given that the NA treatment was not provided antibiotics, adjustments were made to account for morbidity and therapeutic treatment according to NAHMS (USDA-APHIS, 2011). These adjustments were made to include the 25.8% morbidity rate and the adjusted treatment cost. In addition, a deduction of $70.95 (i.e. .258 × $275) was applied to each carcass receiving the NA branded beef premium ($275) to account for opportunity loss of cattle that would have to be treated and removed from the branded beef program ("raised without antibiotics"; Table 2.7).

Surveys Among Beef Industry Segments for Environmental Simulation

To predict the environmental impact of each production system, information was gathered from in-person interviews at each industry segment where the cattle were raised using surveys (Major input parameters needed for the Integrated Farm Systems Model; IFSM) developed by Rotz et al. (2016). The survey parameters allowed for characterization of each segment's soil and grazing conditions, animal and feeding information, and manure handling practices. Survey respondents were the University employed managers of each segment operation. By segment, the operations included: cow-calf (South Dakota State University, Antelope Range and Livestock Research Station, Buffalo, SD); backgrounding (South Dakota State University, Cottonwood Range and Livestock Field Station, Phillip, SD); and finishing (University of Nebraska-Lincoln, West Central Research and Extension Center, North Platte, NE). Table 2.8 provides soil information for each segment.

Simulation Modeling Procedure

Each segment was simulated using typical production practices for the Northern Plains region based upon the production information gathered for this study and supplemented with data reported by Asem-Hiablie et al. (2016). The IFSM is a software tool available through Internet download (USDA-ARS, 2016) for producers and researchers to assess the environmental impact of agricultural production systems including beef and dairy operations (Rotz et al., 2015). The IFSM simulates feed production, animal performance, manure production and handling, and over 25 years of weather data to estimate average annual emissions of production systems within the respective location (Stackhouse et al., 2012a). Each segment was assessed for crop production, feed use, animal performance, and return of manure nutrients back to the land (Rotz et al., 2016).

To determine the annual carbon emissions, energy use, water use, and reactive N footprint, a cradle-to-farm gate life cycle assessment (LCA) was conducted for each production system. Nutrients were tracked to predict the losses at each segment and potential accumulation or depletion in the soil (Rotz et al, 2015). These losses included: NH_3 emissions, denitrification, and leaching losses of N; erosion of sediment across farm boundaries; and the runoff of N and P (Rotz et al., 2016). The production system simulation also allowed for prediction of annual emissions from pre-chain resources. Pre-chain sources included emissions occurring during the production of purchased feed and energy. National emission factors were used to calculate pre-chain energy sources (Rotz et al., 2013; Table 2.9). The pre-chain emission factors for purchased feed were obtained

from IFSM simulations of crop farms (Rotz et al., 2015). As described by Rotz et al. (2015), direct and pre-chain emission factors were collectively totaled then divided by each production system's mean feedyard final shrunk body weight (SBW; Table 2.10). This final SBW was divided by the dressing percentage (DP, 63.5%) to determine the environmental footprint on a HCW basis.

Each segment was simulated over 25 yr using actual daily weather data to best estimate animal performance. The weather data used for each segment was obtained from the closest weather station. By segment, the weather station data were: cow-calf (Dickinson, ND), backgrounding (Phillip, SD), and finishing (North Platte, NE). For each of these segments, meteorological information was obtained hourly from the National Climatic Data Center (NOAA, 2014) and processed into daily values (needed for IFSM) utilizing AERMET (USEPA, 2004). Average annual solar radiation, temperature, precipitation, and wind are summarized by segment in Table 2.11.

Equipment, Transportation, and Energy Simulation

Equipment and machinery were simulated per segment. The cow-calf segment included two tractors for a total use of 340 h per yr and one pickup truck used for a total of 150 h per yr. The backgrounding segment consisted of one tractor used 100 h per yr and a mixer wagon used 2,000 h per yr. The finishing segment used one tractor for a total use of 3,700 h per yr, a mixer wagon for 2,000 h per yr, two skid loaders used 550 h per yr and one pickup truck was used for 150 h per yr. Animal transportation between segments was included external to the IFSM simulation based upon actual total distances of 644, 876, and 203 km, respectively, to account for two semi-trucks. Energy use during

transportation assumed an energy consumption of 0.00122 MJ per km · kg which produced a carbon emission of 0.088 g CO_2e per km · kg (Rotz et al., 2015).

Fuel and electricity use simulated for each segment was compared to reported data (Asem-Hiablie et al., 2016) to verify that the LCA was representative of production practices in the Northern Plains region. Simulated fuel use was 33 L per cow, 7.7 L per animal, and 3.7 L per animal for the cow-calf, backgrounding, and feedyard segments, respectively. Electricity use was 65 kWh per cow, 15 kWh per animal, and 42 kWh per animal for the cow-calf, backgrounding, and feedyard segments, respectively. These average values from the simulated production segments were comparable with the data reported for the central plains regions (Asem-Hiablie et al., 2015; Asem-Hiablie et al., 2016).

Production System Animal Simulation

Within the IFSM model, the animal diets at each segment were simulated equally for all treatments. Diets were formulated to meet animal requirements for energy, protein, and mineral using the Cornell Net Carbohydrate and Protein System, level 1(Fox et al., 2004; Rotz et al., 2015). Allocation among feeds was adjusted to approximately match the annual feed use reported for each segment to assure proper representation of feed use. Animal growth performance was set to meet initial and final SBW measured for each segment. When all treatments were applied in the finishing segment, animal performance was determined by the ADG calculated between the initial and final SBW. The model decreases ADG 10% linearly each month until reaching the final SBW (Rotz et al., 2005, 2016). When a growth promoting implant is administered during any segment, the

potential ADG is increased by 10% while the target final SBW is increased 5% (Rotz et al., 2005). Further, a fiber ingestive capacity (FIC) is adjusted monthly for cattle groups receiving growth promoting implants and ionophores (Rotz et al., 2005). The FIC is used to provide a limit of the potential fiber intake and is a function of total body capacity affected by leanness (Tess and Kolstad, 2000; Rotz et al., 2005). The FIC increases 10% during each implant administration whereas use of an innophore decreases FIC by 3 - 6%. Because the IMBA treatment provided no HCW improvement over implanting and supplementing Rumensin and Tylan alone (IMPL; Table 2.2 and 2.3), no further adjustments for RH supplementation were made as performance was proportionate to the initial and final SBW.

All production systems were managed equally within each segment except for any deviations according to treatment described herein including, use of growth promotant technology. The simulated Angus cow-herd and bulls (270 and 14 hd, respectively), and replacement females (58 hd) were grazed on 1,103 ha of rangeland with a stocking rate of 4.1 ha per cow per month. Annually the herd replacement rate was modeled as 20%, mortality was 3%, and the dressing percentage (DP) of cull cows was 55%. To predict the number of calves finished, a 2% twin rate, a 12% mortality rate, and a 2.5% post-weaning mortality rate were assumed during the cow-calf segment. Within the model, the IMPL and IMBA calves were administered an implant and all calves were weaned at 6 months (number of months is the closest accuracy available) of age and transported (322 km) to the backgrounding segment. All manure was returned to pasture and no manure was

exported to other agricultural sectors, which is typical for a Northern Plains cow-calf operation (Asem-Hiablie et al., 2016).

Per treatment, the backgrounding segment simulated 4,000 hd, which is a typical size for the Northern Plains region (Asem-Hiablie et al., 2016). For all treatments, the backgrounding segment lasted 3 months and cattle were fed grain prior to being transported (438 km) to the finishing segment. For both backgrounding and finishing, all of the manure was exported from the feedyard for other agricultural use, which is typical in this Northern Plains region (Asem-Hiablie et al., 2016).

The feedyard was simulated with 5,000 hd, which is similar to feedyards found in the Northern Plains region (Asem-Hiablie et al., 2016). All treatments were on feed for either 5 (NA and IMPL) or 6 months (NHTC and IMBA) as the model simulates monthly information. Thus, 5 and 6 months captured the biological terminal endpoint goal of 1.53 cm FT and best estimated the 19 d difference in harvest date among treatments. All treatments except NA received an ionophore, and IMPL and IMBA were implanted during the cow-calf, backgrounding, and feedyard segments. Unique to this analysis, the simulation used each production system's actual initial and final SBW (Table 2.10) for the feedyard to predict animal response and environmental impacts for each production system.

Life Cycle Assessment

Post simulation of each segment for each treatment, environmental impacts were integrated to form a LCA to account for all environmental impacts from the cow-calf segment to harvest per treatament. Therefore, the environmental impacts were summed

across the three segments and divided by the HCW to obtain the full production system environmental impacts per treatment. The environmental impacts included: net greenhouse gas emission (CO_2e per kg HCW), energy use (MJ per kg HCW), non-precipitation (blue water) water consumption (kg H_2O per kg HCW), and reactive N loss (N per kg HCW). The non-precipitation water use primarily included water to irrigate feed crops and drinking water. The N loss accounted for all forms of reactive N loss including: ammonia emission, nitrate leaching and runoff, nitrous oxide emission, and NOx emitted through denitrification and the combustion of fossil fuels (Rotz et al., 2016).

Statistical Analysis

Treatments were evaluated in PROC MIXED of SAS 9.4 (SAS Inc., Cary, N.C.) in a completely randomized design with steer used as the experimental unit. Fixed effects included animal performance (FCBW, ADG, DMI, and G:F), carcass performance (HCW, FT, LM area, KPH, YG, marbling score, overall maturity, and QG), and economic performance (total branded carcass value, total production cost, COG, and net return). There were no random effects specified. The influence of treatment on the proportion of carcasses assigned to each USDA YG and QG were analyzed using a binary distribution in PROC GLIMMIX of SAS. Treatment was tested as a fixed effect and the intercept was specified as a random effect. All statistical analyses used dam age as a covariate and the denominator degrees of freedom were approximated using the Kenward-Roger option in the model statement. Least squares means and SEM were computed for all variables and separated using least significant differences (PDIFF) when tests for fixed effects were significant at $P \leq 0.05$. The environmental impacts were determined from treatment

production information to fulfill the major input parameters for simulation capacity within the IFSM using calculations according to USDA-ARS (2016).

RESULTS AND DISCUSSION

Animal Performance

Treatment did not influence ($P > 0.05$) pre-weaning, backgrounding, or initial feedyard BWs (Table 2.2). However, treatment influenced ($P = 0.032$) average BW at the initiation of the individual feed intake portion of the study on March 28 and 29. The IMPL and IMBA (477 ± 8.98 kg and 470 ± 8.81 kg, respectively) treatments were similar ($P > 0.05$) and heavier ($P < 0.05$) compared with NA and NHTC (450 ± 9.51 kg and 444 ± 8.81 kg, respectively), which were similar ($P > 0.05$). Twenty-eight d later, on April 26 BW differences remained consistent as treatment influenced ($P = 0.001$) the final BW collected during the feeding period. The IMPL and IMBA (549 ± 9.58 kg and 549 ± 9.40 kg, respectively) were similar ($P > 0.05$) and heavier ($P < 0.05$) in comparison with NA and NHTC (510 ± 10.14 kg and 505 ± 9.40 kg, respectively), which were similar. At harvest (either June 6 or 27), FCBW of steers with increased levels of growth promotant technology (IMPL and IMBA; 610 ± 9.72 kg and 612 ± 9.88 kg, respectively) was heavier ($P < 0.05$) than steers with lower levels of growth promotant technology (NA and NHTC; 540 ± 10.45 kg and 557 ± 9.88 kg, respectively; Table 2.2). The increase in FCBW gained from implant administration is similar to BW increases reported by others (Duckett et al., 1997; Bruns et al., 2005). Bruns et al. (2005) determined a single estradiol-TBA implant administered at either d 1 or d 57 in the feedyard increased BW by 2% from d 57 to 112 compared with a non-implanted control. Growth promoting implants have been shown to improve growth rate by 8 – 30% (Preston, 1999; Johnson and Beckett, 2014) and consecutive re-implantation has been shown to improve growth rate by 5 – 20% (Preston,

1999). In the current study, IMPL improved FCBW by 13% (70 kg) compared with NA, and by 10% (53 kg) compared with NHTC. Use of RH has also been demonstrated to improve BW. In a meta-analysis evaluating 44 studies, final BW improved by approximately 8 kg compared with a non-supplemented control (Lean et al., 2014). Moreover, Scramlin et al. (2010) fed crossbred steers RH (200 mg RH $\bullet hd^{-1} \bullet d^{-1}$ for 33 d) and also reported heavier (8 kg) final BW in comparison with a non-supplemented control. In the current study, FCBW of steers supplemented with RH did not differ ($P > 0.05$) from IMPL but were heavier ($P < 0.05$) compared with NHTC and NA (by 55 and 72 kg, respectively), which were similar ($P > 0.05$). Strydom et al. (2009) fed Bonsmara steers RH (at 30 ppm) for 30 d prior to harvest and also reported no influence of supplementation on final BW when compared with steers implanted (Revalor-S) at the start of the intensive growth period.

Throughout the finishing segment (March 29 to harvest), ADG was greatest ($P < 0.05$) for IMPL (2.11 ± 0.046 kg), while IMBA (1.79 ± 0.47 kg) was intermediate, but greater ($P < 0.05$) than NA and NHTC (1.54 ± 0.049 kg and 1.45 ± 0.047 kg, respectively), which were not different ($P > 0.05$). Johnson et al. (1996) determined the use of a single moderate potency combination implant (Revalor-S; 120 mg TBA and 24 mg E_2) during finishing improved ADG by 16% for the entire finishing duration (143 d) compared with a non-implanted control. In the current analysis, IMPL increased ADG by 41% compared with NA and NHTC, which were similar ($P > 0.05$). Additionally, Goodrich et al. (1984) determined steers and heifers fed Rumensin and utilizing subsequent implants (zeranol, progesterone-estradiol or, testosterone-estradiol) consistently improved ADG and G:F.

Feeding tylosin has also repeatedly been shown to improve ADG compared with cattle not fed tylosin (Brown et al., 1975; Vogel and Laudert, 1994). Therefore, the combined effects of monensin, tylosin, and implants in this study may be additive and explain why IMPL steers had an increased ADG compared with NA and NHTC. In relation to the IMBA treatment, a summary of six studies concluded that supplementing RH increased ADG by 17.4% (Laudert et al., 2005) and in a meta-analysis of 49 studies, ADG of RH supplemented cattle was increased by 0.19 kg $\bullet hd^{-1} \bullet d^{-1}$ (Lean et al., 2014). In the current study, use of RH in addition to successive implantation and supplementation with monensin and tylosin decreased ADG by 15% compared wtih IMPL. Given that IMPL improved ADG by 37% compared with NA, the lack of response of IMBA may be due to the limited number of available β_1 cellular receptors (Mersmann, 1998; Johnson et al., 2014) and no net increase in DMI other than implanting and feeding monensin and tylosin. Although Boler et al. (2012) did report an increase in ADG for cattle supplemented with RH in comparison with an non-supplemented control. Boler et al. (2012) credited that the improved response in this study, compared to others that also ulilized RH and multiple implants, had increased growth potential because steers only received one implant. Perhaps in the current study, successive implantation had maximized the response potential for ADG and G:F, minimzing the influence of RH.

The DMI of IMPL and IMBA (12.88 ± 0.221 kg and 12.58 ± 0.225 kg, respectively) was similar ($P > 0.05$) and greater ($P < 0.05$) than NA (11.54 ± 0.237 kg), which was intermediate and greater ($P < 0.05$) than NHTC (10.81 ± 0.225 kg). Similarly, Boler et al. (2012) compared RH supplemented steers (200 and 300 $mg \bullet steer^{-1} \bullet d^{-1}$) to an implanted

(Component TE-S) control and reported no effect of RH on DMI. Avendaño-Reyes et al. (2006) also implanted and re-implanted steers (with Synovex-C and Synovex Plus) prior to feeding RH (300 mg•steer^{-1}• d^{-1}) and in contrast to the current study, determined RH steers consumed less (8.37 kg vs. 8.51 kg) dry matter compared with the control steers that were re-implanted. When comparing NA and NHTC in the present study, steers in the NHTC treatment had a reduction in DMI of 6%, which is similar to the 6.4% reduction in DMI reported by Goodrich et al. (1984) in a summary of 228 trials. Tylosin has been reported to be less effective at reducing DMI than monensin. Among 40 trials, cattle (6,971) fed tylosin (90 mg•hd^{-1}• d^{-1}) did not reduce DMI compared wtih a control (Vogel and Laudert, 1994). Therefore, the inclusion of monensin is likely the factor influencing the reduction in DMI of NHTC compared with NA (Goodrich et al., 1984; Stock et al., 1995).

The G:F was greatest ($P < 0.05$) for IMPL (0.16 ± 0.003 kg) compared with NA, NHTC, and IMBA (0.13 ± 0.004 kg, 0.13 ± 0.004 kg, and 0.14 ± 0.004 kg, respectively), which were similar ($P > 0.05$; Table 2.3). The use of successive implantation (IMPL) with tylosin and monensin supplementation improved G:F by 0.03 kg or 23% in comparison with NA. Similarly, Johnson et al. (1996) determined implantation with a single combination implant (120 mg trenbolone acetate and 24 mg estradiol) improved G:F by 13% compared with a non-implanted control. In contrast to IMBA, Scramlin et al. (2010) supplemented crossbred steers with RH (200 mg•steer^{-1}• d^{-1} for 33 d) and reported an improvement in G:F by 0.024 kg compared with a non-supplemented control. Moreover, Avendaño-Reyes et al. (2006) determined RH (300 mg•hd^{-1}• d^{-1} for 33 d) improved G:F

by 0.06 kg compared with a re-implanted control. In the current study, RH supplementation did not improve ($P > 0.05$) G:F compared to NA and NHTC and decreased ($P < 0.05$) G:F by 0.02 kg or 12.5% compared with IMPL. Perhaps the suggestion by Boler et al. (2012) that successive implantation maximizes growth potential and reduces the opportunity for improvement in growth efficiency from RH supplementation explains the lack of improvement in ADG, DMI, and G:F for IMBA in comparison with IMPL. Moreover, it is understood that RH targets β_1 cellular receptors that have limited cellular receptor availability as they only represent a small (1- 4%) population of mRNA in bovine tissue (Johnson et al., 2014) and vary anatomically (Mersmann, 1998).

Carcass Performance

Treatment did not influence ($P > 0.05$) FT, YG, or proportions of carcasses in each YG and QG (Table 2.3). The HCW of steers with greater levels of growth promotant technology (IMPL and IMBA, 387.38 ± 6.168 kg and 388.63 ± 6.271 kg, respectively) was heavier ($P < 0.05$) compared with NA and NHTC (343.10 ± 6.636 kg and 353.69 ± 6.272 kg, respectively), which were similar ($P > 0.05$). Other studies have reported that supplementing steers RH caused a 5 - 14 kg increase in HCW compared with implanted controls (Avendaño-Reyes et al., 2006; Scramlin et al., 2010). Quinn et al. (2008) reported no difference in final BW, HCW, YG, or KPH between heifers that were implanted (Revalor-H) and heifers that were implanted and provided RH supplementation (200 mg•hd^{-1}• d^{-1} for 28 d). Moreover, while utilizing crossbred steers, Scramlin et al. (2010) reported

RH supplementation (200 mg•hd^{-1}• d^{-1}) did not influence YG in comparison with a non-supplemented control.

The NA, IMPL, and IMBA (1.78 ± 0.049 %, 1.75 ± 0.046, % and 1.85 ± 0.047 %) treatments did not differ ($P > 0.05$) in percent KPH but were lower ($P < 0.05$) than NHTC (2.19 ± 0.047 %), which had the greatest ($P < 0.05$) percent KPH. The LM area was greatest ($P < 0.05$) for IMPL (92.16 ± 1.393), NHTC and IMBA (83.91 ± 1.417 and 87.55 ± 1.416, respectively) were similar ($P > 0.05$) and IMBA was greater ($P < 0.05$) than NA (81.95 ± 1.499), which was similar ($P > 0.05$) to NHTC. In regard to IMBA and IMPL, other research has also determined no influence of RH supplementation at a rate of 200 mg•hd^{-1}• d^{-1} on LM area in comparison with an implanted control (Quinn et al., 2008; Scramlin et al. 2010). In contrast, Boler et al. (2012) determined supplementing RH at 200 and 300 mg•hd^{-1}• d^{-1} improved LM area in comparison with a single implanted control (120 mg trenbolone acetate and 24 mg estradiol plus 29 mg tylosin tartrate).

To further evaluate carcass performance, individual measures for carcass quality were assessed. Each treatment influenced ($P < 0.001$) advancements in overall maturity in the following order: IMBA (142.94 ± 1.569), NHTC (132.45 ± 1.570), IMPL (127.38 ± 1.544), and NA (122.20 ± 1.661). Scramlin et al. (2010) and Woerner et al. (2011) determined RH supplementation (200 mg•hd^{-1}• d^{-1}) did not influence overall maturity in comparison with steers provided an initial implant and/or were re-implanted with a terminal implant. Limited information exists regarding the influence of monensin and tylosin on carcass maturity. Successive implantation has been reported (Platter et al., 2003) to linearly increase overall maturity. Using a similar successive (Ralgro, Revalor IS, and Revalor 200)

implant, RH (300 mg•hd^{-1}• d^{-1}), monensin (360 mg•hd^{-1}• d^{-1}), and tylosin (90 mg•hd^{-1}• d^{-1}) supplementation protocol, Webb et al. (2017) determined that the average overall maturity score was 144 (A^{44}), which is numerically closest to IMBA (143, A^{43}). In the current study, IMBA and NHTC were harvested (on June 27), 19 d after the IMPL and NA treatment groups were harvested (June 8). Perhaps, the difference in average age (14.6 and 13.9 mo) on harvest date influenced overall maturity. Nevertheless, all treatments produced A maturity carcasses, thus these differences did not affect quality grade determination (Table 2.3).

Treatment influenced ($P = 0.004$) carcass marbling scores. The lower levels of technology (NA and NHTC; 553.93 ± 18.140 and 561.61 ± 17.146, respectively) had similar ($P > 0.05$), but greater ($P < 0.05$) marbling compared with treatments using more growth promotant technology (IMPL and IMBA; 486.49 ± 16.861 and 503.67 ± 17.141, respectively), which were similar ($P > 0.05$; Table 2.3). Boler et al. (2012) also reported that RH supplementation did not influence marbling score compared with implanted steers. Further, Woerner et al. (2011) reported that steers re-implanted during finishing (with and without RH supplementation) produced carcasses with lower marbling scores compared to a control (receiving one implant during finishing). Morevover, in a review of 37 trials examining steers administered an anabolic steroid while on a finishing diet, Duckett et al. (1996) detected a mean reduction (-24%) in marbling. In contrast, some studies have determined that implant administration caused decreased marbling scores in comparison with a non-implanted control (Johnson et al., 1996; Scheffler et al., 2003, Smith et al., 2007). In a review of 77 research trials conducted by Duckett et al. (1997), a

single combination implant improved carcass HCW, LM area, and identified an inverse relationship between larger LM area and a corresponding smaller degree of marbling in comparison with a non-implanted control. This "dilution effect" described by Duckett et al. (1999) occurs from hypertrophy of skeletal muscle and is likely responsible for the lower marbling score of carcasses from the IMPL treatment, which also had the largest LM area. In the current study, the NHTC and NA treatments were similar ($P > 0.05$) in marbling suggesting that monensin and tylosin have no negative influences on marbling score (Table 2.3). Although there are few studies evaluating the use of monensin on carcass quality, Goodrich et al. (1984) conducted regression models from 60 trials and determined monensin decreased marbling score (-0.39%) in comparison with a non-supplemneted control.

Actual Economics of Carcass Performance

Production system influenced ($P < 0.05$) total carcass value. The NA and IMPL treatments ($1,889.38 ± 31.207 and $1,826.36 ± 30.663, respectively) were similar ($P > 0.05$) and greater ($P < 0.05$) in value than NHTC and IMBA ($1,771.10 ± 31.183 and $1,689.54 ± 31.178, respectively), which were similar ($P > 0.05$; Table 2.6). To determine if production systems influenced net return, an analysis of actual input costs for production and fiscal return from the carcasses were evaluated. Optimizing cattle production while minimizing input costs, such as feed that accounts for nearly two-thirds of total operating costs, are important for long-term sustainability and profitability of an operation (USDA-ERS, 2010).

Actual Production Cost

To emulate the purchase of weaned calves for a backgrounding operation, the cost of weaned calves was included and represented on a per hd basis including actual morbidity and treatment expenses (Table 2.6). Treatment tended ($P = 0.09$) to influence the total production cost. The NA treatment ($1,607.00 ± 29.542) had a lower ($P < 0.05$) total production cost compared with IMBA ($1,712.13 ± 29.515), though NHTC and IMPL ($1,673.21 ± 29.519 and $1,645.25 ± 29.027, respectively) were similar ($P > 0.05$) and did not differ from all other treatments. To emulate retained ownership from the cow-calf segment onward, the cost of the weaned calf was excluded. In this analysis, treatment influenced ($P < 0.05$) the total production cost. The NA and IMPL treatment ($438.93 ± 3.561 and $434.52 ± 3.499, respectively) were similar ($P > 0.05$) and had the lowest ($P < 0.05$) total production cost, while NHTC ($495.35 ± 3.558) was intermediate ($P < 0.05$) and IMBA ($508.56 ± 3.558), had the highest ($P < 0.05$) total production cost (Table 2.6).

Including the cost of the calf, NA, NHTC, and IMPL treatments were similar ($P > 0.05$) for total production cost, while IMBA was the greatest ($P < 0.05$; Table 2.6). Excluding the calf cost, NA and IMPL were similar ($P > 0.05$) and had fewer days on feed than NHTC, which was intermediate ($P < 0.05$) and IMBA resulted in the greatest ($P < 0.05$) total production cost. In some agreement, Stackhouse et al. (2012b) estimated that supplementing Holstein cattle ZH increased the feedyard production cost by $20 per animal in comparison with a non-implanted and non-supplemented control. In the present study, lack of growth promotant technology (NA) resulted in reduced ($P < 0.05$) production cost including and excluding the cost of the calf, by $103 and $67, respectively, in comparison with IMBA.

Actual Cost of Gain

When including the cost of the calf at weaning, treatment influenced ($P < 0.0001$) COG. Treatments (NA and NHTC; \$5.58 ± 0.105 and \$5.55 ± 0.105, respectively) with lower levels of technology were similar ($P > 0.05$) and had higher ($P < 0.05$) COG in comparison with treatments (IMPL and IMBA; \$4.74 ± 0.103 and \$4.88 ± 0.105, respectively) using increased levels of growth promotant technology, which were similar ($P > 0.05$). Cattle receiving monensin, tylosin, growth promoting implants, with and without RH (IMBA and IMPL) had reduced COG by \$0.76 per kg in comparison with cattle raised with and without monensin and tylosin (NHTC and NA). When not considering the cost of the calf and emulating retained ownership of cow-calf producers, treatment also influenced ($P < 0.0001$) COG. The IMPL treatment (\$1.25 ± 0.032) had the lowest COG, NA and IMBA (\$1.54 ± 0.033 and \$1.45 ± 0.033, respectively) were similar ($P > 0.05$) and intermediate ($P < 0.05$), while NHTC (\$1.65 ± 0.033) had the highest COG. The reduced days on feed, growth promotant technology cost, and adequate BW gain from weaning (October 26) to harvest (FCBW on June 8) of IMPL reduced COG and resulted in a lower total production cost in comparison with IMBA. The COG was highest for NHTC due to the cost of monensin and tylosin, and a longer duration on feed without significant improvements in BW gain (Table 2.6).

Production management decisions that have a lower total production cost do not always result in a lower COG due to losses in BW performance and duration of time on feed. Treatments using more technology (IMPL) reduced COG more effectively due to improvements in BW gain and reduction in days on feed (19 d). The use of RH (IMBA)

was less consistent (depending upon if calf cost was included or excluded) in reducing COG in comparison with IMPL. Consistent with the current study, when excluding the cost of the calf, Stackhouse et al. (2012b) determined growth promoting implants decreased production cost by $0.25 per kg of HCW in comparison to a control not utilizing growth promotant technology.

Actual Net Return

Including the cost of the weaned calf, each treatment influenced ($P < 0.0001$) net return in the following descending order: NA ($282.38 ± 18.836); IMPL ($181.11 ± 18.508); NHTC ($37.89 ± 18.822) and IMBA (-$22.59 ± 18.819; Table 2.6). When retaining ownership from the cow-calf segment onward and excluding the cost of the weaned calf, treatment influenced ($P < 0.0001$) net return. Treatments NA and IMPL ($1,450.45 ± 31.606 and $1,391.84 ± 31.055, respectively) were similar ($P > 0.05$) and returned greater value ($P < 0.05$) than NHTC and IMBA ($1,215.75 ± 31.581 and $1,180.99 ± 31.576, respectively), which were similar ($P > 0.05$; Table 2.6). No difference ($P > 0.05$) in net return occurred when feeding monsinsin and tylosin, and providing growth promoting implants (IMPL) in comparison to not supplying growth promotant technology (NA). Treatments NA and IMPL either gained a benefit from the branded beef premium ($275; Table 2.5) or the improved FCBW, respectively. Further, NA, IMPL, and NHTC were sold on grids with higher base prices ($206.31, $206.31, $188.24, respectively) in comparison with IMBA ($187.74), which was discounted because of RH supplementation (as assigned by Tyson Fresh Meats).

The decreased FCBW performance of NHTC in comparison with IMPL and IMBA required a longer time on feed (19 d). Additionally, NHTC carcasses received a lower branded beef premium ($175; Table 2.5) for "beef raised without the use hormones" than NA. A meta-analysis evaluating the economic perforamce of naturally raised steers determined that a greater ($0.14 per kg BW) incentive would be needed to return as much value as conventionally raised steers due to the loss in BW performance (Gadberry, 2008; Wileman et al., 2009). In another meta-analysis comparing conventional and nonconventional beef production in the feedyard, implanting steers provided more ($77) value, likely due to improvements in ADG and G:F (Wileman et al., 2009). When producing cattle for specific programs such as "raised without antibiotics" or "raised without the use of hormones", it is important to ensure premiums can be captured to offset losses (40 kg on avg) in FCBW and HCW performance. In the current study, the premium ($275 per animal) for NA or beef "raised without antibiotics" substantially improved net return. Though, without this premium, or with reductions in the premium, implanting alone may provide a greater net return. However, IMBA had the lowest net return (including and excluding the cost of the calf) given the lack of greater improvements in BW gain and HCW (Table 2.7).

Adjusted Economics of Carcass Performance

To determine if treatment within the geographic central region of the US influenced carcass value, adjustments for morbidity and treatment expenses were analyzed according to USDA-APHIS (2011). Similar to the actual analysis, treatment influenced ($P = 0.002$) total carcass value (Table 2.7). The NA and IMPL treatements ($1,818.43 ± 31.207 and

$1,826.36 ± 30.663, respectively) were similar ($P > 0.05$) and higher value than NHTC and IMBA ($1,711.10 ± 31.183 and $1,689.54 ± 31.178, respectively), which were similar ($P > 0.05$). In the actual evaluation of NA, no morbidity was assumed (Table 2.6). The adjustment for morbidity in the central region caused a decline ($70.95) in per hd carcass value due to cattle not qualifying for the branded beef premium (that did not permit antibiotic usage). However, the statistical significance between the actual and adjusted analyses is consistent, suggesting NA and IMPL have the greatest carcass value ($1,840.13 on avg) in comparison to NHTC and IMBA.

Adjusted Total Production Cost

To determine if treatment within the geographical central region of the US influenced total production cost, adjustments for morbidity and treatment expenses were analyzed according to USDA-APHIS (2011; Table 2.7). Analyses of input expenses and fiscal return from the carcasses were calculated (Table 2.4). These evaluations were conducted to emulate the purchase of a weaned calf by a backgrounding operation, therefore the cost of the weaned calf was included in the calculation. Similar to the actual analysis, treatment tended to influence ($P = 0.09$) total production cost. The NA treatment ($1,611.87 ± 28.972) had lower ($P < 0.05$) total production cost compared with IMBA ($1,714.38 ± 28.944), while NHTC and IMPL ($1,678.84 ± 28.949 and $1,652.03 ± 28.972, respectively), were similar to all treatments ($P > 0.05$).

To emulate retained ownership from the cow-calf segment onward, the cost of the weaned calf was also excluded. Each treatment influenced ($P < 0.0001$) total production cost in the descending order: IMBA ($510.81 ± 0); NHTC ($500.98 ± 0.00); NA ($443.80 ±

0.00); and IMPL ($441.29 ± 0.00). Overall, the total production cost for the adjusted analysis ($474.22) was higher ($4.88) per hd in comparison with the actual ($469.34) analysis. When including the cost of the calf, results between the actual and adjusted analyses for total production cost were statistically consistent. In the adjusted analysis, cow-calf operations excluding the cost of the calf, caused NA to have an increased ($2.51) total production cost in comparison with IMPL. As expected, the adjustment for morbidity in NA increased the total production cost more than the actual analysis.

Adjusted Cost of Gain

As expected, in the adjusted analysis when including the cost of the calf at weaning, treatment influenced ($P < 0.0001$) COG. Cattle in the IMPL and IMBA treatments ($4.76 ± 0.098 and $4.89 ± 0.100, respectively) were similar ($P > 0.05$) and more ($P < 0.05$) cost efficient in gain compared with NA and NHTC ($5.59 ± 0.010 and $5.57 ± 0.010, respectively), which were similar ($P > 0.05$). This result for COG including the calf cost is consistent with the actual analysis. Upon excluding the cost of the calf, each treatment influenced ($P < 0.0001$) COG in the descending order: NHTC ($1.67 ± 0.28); NA ($1.55 ± 0.28); IMBA ($1.46 ± 0.028) and IMPL ($1.27 ± 0.028). In comparison to the actual analysis, the adjustment for morbidity and treatment expense caused NA to have a greater ($P < 0.05$, $0.09 per kg) COG in comparison with IMBA. This response is due to the adjustment for morbidity in NA and the loss in FCBW gain in comparison to IMBA.

Adjusted Net Return

Including the cost of the weaned calf in the adjusted analysis, treatment influenced ($P < 0.0001$) net return. The NA and IMPL treatments ($206.56 ± 17.580 and $174.34 ±

17.273, respectively) were similar ($P > 0.05$) and returned more ($P < 0.05$) profit than NHTC ($32.26 ± 17.566), which was intermediate ($P < 0.05$), while IMBA (-$24.84 ± 17.563) was the least ($P < 0.05$) profitable (Table 2.7). In comparison to the actual analysis while including the calf cost, the adjustments for morbidity and treatment expense caused NA and IMPL to be similar ($P > 0.05$) in net return. Whereas in the actual analysis, NA was the most ($282.38) profitable treatment. Including the cost of the calf in the adjusted analysis, the net return is influenced by treatment, which is likely ($P < 0.05$) to cause variations (± $231.40) in revenue. Emulating retained ownership and excluding the cost of the calf in the adjusted analysis caused the net return to be consistent with the actual analysis. Treatment influenced ($P < 0.0001$) net return where NA and IMPL ($1,374.63 ± 31.207 and $1,385.07 ± 30.663, respectively) were similar ($P > 0.05$) and more profitable than NHTC and IMBA ($1,210.10 ± 31.183 and $1,178.74 ± 31.178, respectively), which were similar ($P > 0.05$; Table 2.7). Upon retaining ownership from the cow-calf segment onward in the adjusted analysis, treatment ($P < 0.0001$) influenced variations (± $206.33) in revenue. Although there can be premiums associated with branded beef programs not allowing use of antibiotics, there are tradeoffs due to the potential of increased animal morbidity in addition to a loss of efficiency in BW gain and the risk of not fulfilling program specifications (Sartwelle et al., 2014).

Environmental Impact of Production Systems

Greenhouse Gas Emissions

To encompass the beef supply chain, Rotz et al. (2015) evaluated C footprint emissions on a HCW basis among 28 production systems within KS, OK, and TX. The

greatest GHG emission factor was from urine and fecal deposition during the cow-calf segment (44%) in comparison with the feedyard (43%). In the current study, a LCA estimated the GHG emissions for each treatment in the descending order: NA, 18.1 CO_2e per kg HCW; NHTC, 17.9 CO_2e per kg HCW; IMBA, 17.0 CO_2e per kg HCW; and IMPL, 16.7 CO_2e per kg HCW (Table 2.12). For beef production, the baseline GHG emission for a LCA was estimated to range between 13.8 – 25.8 kg CO_2e per kg HCW among the regions of KS, OK, and, TX (Rotz et al., 2015). The GHG emission estimates within this study comply within Rotz et al. (2015) baseline estimates. Upon evaluating the efficiency of growth promotant technology utilization, NHTC, IMPL, and IMBA were predicted to reduce GHG emissions by 1.2%, 7.8%, and 6.4%, respectively in comparison with NA (Figure 2.1.). An analysis also utilizing the IFSM to simulate the environmental impacts of raising Angus cattle in California was conducted by Stackhouse et al. (2012a). In some similarity, use of an implant in the stocker segment, an ionophore, tylosin, and a re-implantation of estrogen and trenbolone acetate without and with ZH in the feedyard segment, decreased C footprint (by 4% and 9%, respectively) in comparison with a natural production system not utilizing growth promotant technology (Stackhouse et al., 2012a). In the current study, the use of implants in the cow-calf (36 mg zeranol), backgrounding, (80 mg trenbolone acetate and 16 mg estradiol) and feedyard (200 mg trenbolone acetate and 20 mg estradiol, respectively) segments caused a greater reduction (7.8%) in C footprint in comparison to NA. However, supplementation of RH (200 steer•hd^{-1}• d^{-1}) in addition to all growth promotant technologies used in the current study was 2.6% less effective in reducing GHG

emissions than the influence of ZH supplementation in Stackhouse et al. (2012a). In this study, C footprint was decreased by 1.2%, 7.8%, and 6.5% among NHTC, IMPL, and IMBA, respectively. The environmental impact from GHG emission is greater from losses in BW performance and the longer time on feed required to obtain the same compositional endpoint (1.5 cm). This study shows that the greatest improvement in reducing environmental impacts of GHG emissions is from IMPL in comparison to all other treatments. Use of monensin, tylosin, and successive implantation in the cow-calf, backgrounding, and finishing segments reduced GHG emissions most effectively.

Energy Use

An analysis conducted at the US Meat Animal Research Center (MARC) in Clay Center, NE estimated energy use for cattle production in 1970 in comparison with 2011 and determined a slight reduction (0.17 MJ per kg BW or 5%) using current production systems (Rotz et al., 2013). However, energy usage is still relatively similar to 1970 because there is less land available for increased corn production needs, which require fertilizer and greater combustion of fossil fuels from gasoline powered engines and potentially, increased irrigation (dependent upon the climate; Rotz et al., 2013). Rotz et al. (2013) encouraged new technology intervention to improve sustainability of cattle production. In the current study, a LCA estimated the energy used for each treatment in the descending order: NA, 43.3 MJ per kg HCW; NHTC, 43.1 MJ per kg HCW; IMBA, 41.8 MJ per kg HCW; and IMPL 41.0 MJ per kg HCW. These ranges in energy utilization per HCW are within the LCA baseline (26 – 83 MJ per kg HCW) among the regions of KS, OK, and TX (Rotz et al., 2015). The NHTC, IMPL, and IMBA were

predicted to reduce energy use for beef production by 0.1%, 5.5%, and 3.4%, respectively (Figure 2.1.). Although there was a (3.4%) reduction in energy use from IMBA, the IMPL was 2% more efficient in comparison. The predominante factor for production efficiency is producing heavier HCW among the LCA. Although it is recommended to sell cattle fed β-AA by HCW (Maxwell, 2014) research has discovered no improvement in HCW from RH (200 – 308 $mg \bullet hd^{-1} \bullet d^{-1}$) supplementation (Quinn et al., 2008; Garmyn et al. 2014). Rotz et al. (2015) estimated total fossil energy inputs were 52 MJ per kg HCW and of that, 50% occurred during the cow-calf segment, whereas 26% occurred in the feedyard. Use of growth promoting implants during the cow-calf, backgrounding, and feedyard segments with supplementation of monensin and tylosin, (IMPL) provide greater reductions (5.5%) in energy utilization in comparison to no growth promotant technology use (NA).

Water Use

From the MARC analysis comparing beef production in 1970 to 2011, the current water footprint has declined by 5% due to improved corn yield and water use efficiency (Rotz et al., 2013). The annual water footprint determined by MARC excluding precipitation was 2,789 ± 914 L per kg BW and with precipitation the water footprint was greater (21,340 ± 5,600 L per kg BW; Rotz et al., 2013). Non-precipitated water use in beef production includes fresh water for irrigation to produce feed (Rotz et al., 2015) and drinking water for cattle, which is estimated to be less than 1% of total water use (Rotz et al., 2013). In the current study, a LCA estimated the use for each treatment in the descending order: NA, 2,997 L H_2O per kg HCW; NHTC, 2,966 L H_2O per kg HCW;

IMBA, 2,866 L H_2O per kg HCW; and IMPL, 2,824 L H_2O per kg HCW. Non-precipitated water use within the regions of KS, OK, and TX, were estimated by the LCA excluding Holstein cattle, but included cull beef cows, and ranged between 976 – 7,630 L per kg HCW. Within the same study, the mean water footprint was estimated to be 2,180 L per kg HCW and 57% of this use was estimated to be from the feedyard segment (Rotz et al., 2015). On average among all treatments, the current study utilized a greater volume of water (2,913 L per kg HCW) in comparison to Rotz et al. (2015) (2,180 L per kg HCW) most likely due to differences in the feeding duration and feed production. In the current study, steers were fed in the feedyard between 5 - 6 months vs. 4 – 5 months among the largest feedyard operations in Rotz et al. (2015). Additionally, Rotz et al. (2015) estimated larger (10,000 - 180,000 hd) feedyard operations that also had crop land for corn and grain silage production. The current study did not produce feed and relied upon irrigated purchased feedstuffs that required considerable amounts of water to produce (Rotz et al., 2015). However, use of growth promoting technologies among NHTC, IMPL, and IMBA reduced water use per unit of beef produced by 1.0%, 5.8%, and 4.4%, respectively in comparison to NA (Figure 2.1.). Studies evaluating water use have ranged in units reported (i.e. grey, blue, and green water footprint, or boneless beef per kg per animal) and the type of water used (i.e. precipitated versus non-precipitated) within the calculations, making comparisons difficult (Becket and Oltjen, 1993; Gerbens-Leenes et al., 2013; Rotz et al., 2013). Although precipitated water is important for feed production, it varies with region and may or may not be used for the cattle thus, leaving it out of the model is justifiable for improved comparisons (Rotz et al., 2013). More

research investigating the influence of growth promotant technology on HCW performance to improve water use efficiency of pre-chain inputs is needed.

Reactive N Loss

Improving protein sparing is important to reduce the concentration of urine urea nitrogen (UUN) that can be volatilized as ammonia (NH_3). The MARC study determined the reactive N loss for beef production was 91.7 ± 18.4 g N per kg BW and a majority (61%) of the footprint was from cattle grazing pastures during the cow-calf segment. In this analysis, NH_3 contributed the greatest (81%) to the footprint, whereas nitrate (NO_3) leaching and nitrous oxide (NOx) contributed 6% and 9%, respectively (Rotz et al., 2013). Beef production has decreased reactive N loss by 3% in 2011 in comparison to 1970 due to improved grain yield and animal ADG from genetic selection (Rotz et al., 2013). Previous research (Mersman, 1998) has shown use of growth promotant technologies such as β-AA increase N efficiency due to the physiologic responses causing greater muscle mass and protein synthesis. In the current study, the LCA estimated the reactive N loss for each production system in the descending order: NHTC, 137 g N per kg HCW; NA, 136 g N per kg HCW; IMBA, 135 g N per kg HCW; and IMPL, 129 g N per kg HCW. These results are within the range (75 - 222 N per kg) of the LCA analysis conducted among the regions of KS, OK, and TX with a mean reactive N loss of 135 ± 11 g N per kg HCW. In the current study, production systems utilizing growth promoting technologies from NHTC, IMPL, and IMBA reduced reactive N loss by 0.9%, 5.5%, and 1.1%, respectively in comparison to NA (Figure 2.1.). In some similarity, Stackhouse et al. (2012b) determined use of an implant in the stocker segment,

an ionophore, tylosin, and re-implantation of estrogen and trenbolone acetate with supplementation of ZH in the feedyard segment decreased NH_3 emissions by 14 g per kg HCW in comparison with a natural production system not utilizing growth promotant technology (90 versus 104 g per kg HCW, respectively). In the current study a 1 g per kg HCW reduction in reactive N loss was detected for IMBA in comparison to NA. The greatest reduction occurred for IMPL, which reduced reactive N emissions by 7 g per kg HCW in comparison to NA. The 13 g per kg HCW greater reduction of reactive N loss from ZH supplementation experienced by Stackhouse et al. (2012b) in comparison to RH supplementation in the current study is likely due to the availability and affinity of the β_2-beta-andrenergic agonist receptors (AAR) within the skeletal tissue of bovine (Mersmann, 1998). Although RH is a β-AA, it is more effective on the β_1-AAR (Garmyn and Miller, 2014), which are less abundant (1 - 4%) in bovine tissue (Johnson et al., 2014). However, use of anabolic steroids (implants) have been known to cause N retention (Lone, 1997) and improve efficiency because of the effects of the GH increasing acidophils (Nichols et al., 2002) and affecting metabolic anabolism and catabolism causing protein accretion without any apparent effects on protein degradation (Hart and Johnson, 1986). Thus, implanting can be an effective N loss mitigation tool. Evaluation of implant protocols among the industry segments for continued improvement to mitigate reactive N loss and cause greater pre-chain efficiency per HCW should be evaluated especially as ZH is not commercially available (Comerford, 2017). The current study used successive implantation in the calf, backgrounding, and finishing segments while providing monensin and tylosin during finishing and effectively decreased reactive

N loss by 7 and 8 g N per kg HCW in compariston to no growth promotant technology and use of only monensin and tylosin in the finishing segment, respectively.

IMPLICATIONS

Steers receiving monensin, tylosin, and growth promoting implants with and without ractopamine HCl had greater BW, DMI, HCW, reduced COG and GHG emissions (6.5 – 7.8%), energy use (3.4 – 5.5%), water use (4.4 – 5.8%), and reactive N loss (1.1 - 5.5%) in comparison to steers not receiving any growth promotant technology. Carcass marbling scores were greater for steers raised with less technology (no implant or β-AA). The net return was greater for steers branded as receiving no antibiotics and steers receiving monensin and tylosin, and growth promoting implants when excluding the cost of the weaned calf. This conveys that there are production management options for producers to maximize profitability including use of growth promoting implants, though when combined with a low-dose of ractopamine HCl a greater cost of production may be encountered, potentially resulting in the lowest net return. Steers branded as not receiving antibiotics, monensin, tylosin, or growth promoting implants may yield a high net return, but do not appear to be as environmentally sustainable as treatments utilizing growth promotant technolgy. Use of growth promoting implants with monensin and tylosin resulted in heavier, low choice carcasses that had an improved net return and minimized the environmental impact. Therefore, it may not be efficacious for producers to supply a low-dose of ractopamine HCl, or limit the use of growth promoting implants in order to maximize profitability and environmental sustainability under production conditions similar to those described in the study.

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Table 2.1. Composition of finishing diet (% of DM) fed to steers[1]

Item	Composition[2]
Ingredient composition	
Dry-rolled corn	47.76
Wet corn gluten	40.02
Prairie hay	7.21
Liquid supplement[3]	5.02
Nutrient composition	
NE_m, Mcal/kg	2.04
NE_g, Mcal/kg	1.38
CP	13.93

[1] During finishing steers received four concentrate-adaptation diets over a period of 65 d (January 6 - March 11) fed for 7, 7, 40, and 11 d, respectively.

[2] Steers only within the treatment receiving ractopamine HCl (200 $mg \bullet hd^{-1} \bullet d^{-1}$) were supplemented.

[3] Supplement contained 58.25% ground corn, 29.57% limestone, 5.59% iodized salt, 4.65% ammonia chloride, 0.93% trace mineral mix, 0.25% thiamine, and 0.21% Vitamins A, D, and E. Diet was formulated to provide 300 mg monensin (Elanco Animal Health, Greenfield, IN) and 90 mg Tylan (Elanco Animal Health) per steer daily.

Table 2.2. Least squares means for production system influence on body weight (BW)

	Treatment[1]				
Weight, kg[3]	NA	NHTC	IMPL	IMBA	*P*-Value[2]
Pre-Weaning					
Birth Weight[4]	40 ± 0.91	40 ± 0.84	41 ± 0.86	40 ± 0.84	0.959
June 29, 2015	119 ± 6.94	122 ± 6.31	122 ± 6.43	127 ± 6.31	0.862
September 16, 2015	204 ± 6.01	207 ± 5.57	208 ± 5.68	211 ± 5.57	0.868
October 26, 2015	243 ± 6.38	246 ± 5.92	249 ± 6.03	251 ± 5.92	0.766
Backgrounding[5]					
November 9 and 10, 2015	249 ± 6.63	254 ± 6.14	257 ± 6.26	258 ± 6.14	0.789
December 8, 2015	264 ± 6.87	267 ± 6.48	271 ± 6.49	271 ± 6.37	0.860
Feedyard[6]					
January 4 and 5, 2016	281 ± 6.96	280 ± 6.45	292 ± 6.58	286 ± 6.45	0.591
March 11, 2016	411 ± 9.37	404 ± 8.68	425 ± 8.85	430 ± 8.68	0.154
GrowSafe[7]					
March 28 and 29, 2016	450^{a} ± 9.51	444^{a} ± 8.81	477^{b} ± 8.98	470^{b} ± 8.81	0.032
April 26, 2016	510^{a} ± 10.14	505^{a} ± 9.40	549^{b} ± 9.58	549^{b} ± 9.40	0.001
June 6 or 27, 2016[8]	540^{a} ± 10.45	557^{a} ± 9.88	610^{b} ± 9.72	612^{b} ± 9.877	< 0.0001

[a,b] Least squares means within row with different superscripts differ ($P \leq 0.05$).

[1] Calves were stratified by birth date, birth weight, and dam age to 1 of 4 treatments: 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC), fed Rumensin (300 mg •hd^{-1}• d^{-1}) and Tylan (90 mg •hd^{-1}• d^{-1}) during finishing; 3) implant (IMPL), administered a series of three implants including a low-potency calf implant (36

mg zeranol), a moderate-potency initial feedyard implant (80 mg trenbolone acetate and 16 mg estradiol), and a high potency finishing re-implant (200 mg trenbolone acetate and 20 mg estradiol) and fed Rumensin (300 mg $\bullet hd^{-1} \bullet d^{-1}$) and Tylan (90 mg $\bullet hd^{-1} \bullet d^{-1}$) during finishing, and 4) IMPL plus fed a beta-agonist (IMBA), 200 mg ractopamine hydrochloride $\bullet hd^{-1} \bullet d^{-1}$ for the last 30 d prior to harvest.

[2] Probability of a difference among least squares means.

[3] Dam aged used as a covariate.

[4]Average calf birth date was April 17, 2015.

[5] Upon beginning the backgrounding period, initial two-day weights were obtained to account for variations due to fill and averaged to assign calves to pens based upon 3 (light, medium, and heavy) weight blocks within treatment, steers were fed over a period of 56 d on a high roughage ration.

[6] Upon arrival to the feedyard, initial two-day weights were obtained to account for variations due to fill and steers were maintained within their original pen assignment until March 11 when they were acclimated to the GrowSafe system in 4 pens (one treatment per pen) while receiving 4 step-up diets over a period of 65 d.

[7]After a 17 d acclimation period to the GrowSafe system a high concentrate finishing ration was fed over a period of 71 or 90 d dependent upon treatment harvest date, initial two-day weights were obtained to account for variations due to fill and steers were allocated to be fed in 4 groups according to treatment protocol (Group 1 = NA, Group 2 = ½ NHTC and ½ IMPL, Group 3 = ½ NHTC and ½ IMPL, and Group 4 = IMBA) so that steers were rotated approximately every 2 weeks during finishing within 4 GrowSafe pens to inhibit any chance of pen effect.

[8]Steers were harvested at targeted 1.5 cm of 12th rib-fat thickness, steers finished earlier (NA and IMPL) within treatment were harvested June 8, 2016 and the remaining steers (NHTC and IMBA) were harvested June 27, 2016, to minimize bruising prior to harvest, final calculated body weight (FCBW) were conducted based upon hot carcass weight and 63.5% dressing percentage.

Table 2.3. Main effect least square means for effect of production system on feedlot performance and carcass characteristics[1]

	Treatment[1]				*P*-value[2]
Item	NA	NHTC	IMPL	IMBA	
Feedlot Performance					
ADG, kg	$1.54^{a} \pm 0.049$	$1.45^{a} \pm 0.047$	$2.11^{c} \pm 0.046$	$1.79^{b} \pm 0.047$	< 0.0001
DMI, kg	$11.54^{b} \pm 0.237$	$10.81^{a} \pm 0.225$	$12.88^{c} \pm 0.221$	$12.58^{c} \pm 0.225$	< 0.0001
G:F	$0.13^{a} \pm 0.004$	$0.13^{a} \pm 0.004$	$0.16^{b} \pm 0.003$	$0.14^{a} \pm 0.004$	< 0.0001
Carcass Characteristics[3]					
HCW, kg	$343.10^{a} \pm 6.636$	$353.69^{a} \pm 6.272$	$387.38^{b} \pm 6.168$	$388.63^{b} \pm 6.271$	< 0.0001
Adj. 12th rib backfat, cm	1.51 ± 0.082	1.33 ± 0.077	1.49 ± 0.076	1.50 ± 0.768	0.294
LM area, cm^2	$81.95^{a} \pm 1.499$	$83.91^{ab} \pm 1.417$	$92.16^{c} \pm 1.393$	$87.55^{b} \pm 1.416$	< 0.0001
Adj. KPH, %	$1.78^{a} \pm 0.049$	$2.19^{b} \pm 0.047$	$1.75^{a} \pm 0.046$	$1.85^{a} \pm 0.047$	< 0.0001
Yield grade	2.83 ± 0.108	2.66 ± 0.102	2.67 ± 0.101	2.93 ± 0.102	0.194
Carcass Maturity[5]	$122.20^{a} \pm 1.661$	$132.45^{c} \pm 1.570$	$127.38^{b} \pm 1.544$	$142.94^{d} \pm 1.569$	< 0.0001
Marbling score[4]	$553.93^{b} \pm 18.140$	$561.61^{b} \pm 17.146$	$486.49^{a} \pm 16.861$	$503.67^{a} \pm 17.141$	0.004
USDA Yield Grade[6,7]					
Yield grade 2, %	0.27 ± 0.091	0.44 ± 0.096	0.53 ± 0.095	0.27 ± 0.085	0.144
Yield grade 3, %	0.65 ± 0.096	0.52 ± 0.954	0.37 ± 0.090	0.59 ± 0.094	0.205
Yield grade 4, %	0.06 ± 0.047	0.03 ± 0.032	0.06 ± 0.043	0.12 ± 0.064	0.602
USDA Quality Grade[6,8]					
All Choice, %	0.82 ± 0.077	0.83 ± 0.071	0.90 ± 0.055	0.97 ± 0.032	0.352
Low Choice, %	0.15 ± 0.073	0.16 ± 0.070	0.36 ± 0.092	0.30 ± 0.089	0.239
CAB, %	0.65 ± 0.096	0.66 ± 0.090	0.40 ± 0.092	0.62 ± 0.092	0.181
Upper 2/3rds Choice and CAB, %	0.65 ± 0.096	0.66 ± 0.090	0.54 ± 0.094	0.66 ± 0.090	0.740
Prime, %	0.17 ± 0.076	0.17 ± 0.071	0.06 ± 0.044	0.03 ± 0.031	0.252

[a,b,c,d] Least squares means within row with different superscripts differ ($P \leq 0.05$).

[1] Calves were stratified by birth date, birth weight, and dam age to 1 of 4 treatments: 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC), fed Rumensin (300 mg •hd^{-1}• d^{-1}) and Tylan (90 mg •hd^{-1}• d^{-1}) during finishing; 3) implant (IMPL), administered a series of three implants including a low-potency calf implant (36 mg zeranol), a moderate-potency initial feedyard implant (80 mg trenbolone acetate and 16 mg estradiol), and a high potency finishing re-implant (200 mg trenbolone acetate and 20 mg estradiol) and fed Rumensin (300 mg •hd^{-1}• d^{-1}) and Tylan (90 mg •hd^{-1}• d^{-1}) during finishing, and 4) IMPL plus fed the beta-agonist (IMBA), ractopamine hydrochloride (200 mg •hd^{-1}• d^{-1}) for the last 30 d prior to harvest.

[2] Probability of a difference among least squares means.

[3] All measurements were determined by trained SDSU personnel using USDA-AMS grading standards except for proportions of USDA Quality Grade and USDA Yield Grade which were assigned by USDA-AMS grading officials.

[4] Marbling score: 300 = $Slight^0$; 400 = $Small^0$; 500 = $Modest^0$; 600 = $Moderate^0$.

[5] Combined skeletal and lean maturity: 100 = A0; 200 = B0; 300 = C0.

[6] Assigned by USDA grader; only one carcass received a USDA Select Quality Grade, and one carcass received a USDA Yield Grade 1 and there were no carcasses assigned Yield Grade 5.

[7] GLIMMIX analysis failed to converge for USDA Yield Grade 1 (n = 1) or yield grade 5 (n = 0).

[8] GLIMMIX analysis failed to converge for USDA Select Quality Grade (n = 1).

Table 2.4. Expense inputs and information per head within each beef production system

	Treatment[1]			
Expenses, $	NA	NHTC	IMPL	IMBA
Cost of Calf [2]	1,167.00	1,178.00	1,122.00	1,203.00
Backgrounding DOF[3]	71	71	71	71
Backgrounding Feed Bill[4]	44.75	44.75	44.75	44.75
Backgrounding Yardage[5]	24.50	24.50	24.50	24.50
Feedyard DOF[6]	154	173	154	173
Finishing Feed Bill[4]	266.57	310.18	257.93	310.18
Finishing Yardage[5]	53.90	60.90	53.90	60.90
Total Anabolic Steroids[7]	0.00	7.81	7.81	7.81
Monensin and Tylosin[8]	0.00	6.57	7.94	12.58
Ractopamine HCl[9]	0.00	0.00	0.00	6.01
Cost of Morbidity[10]	0.00	5.00	4.24	8.35
Cost of Morbidity, Adjusted[11]	10.60	10.60	10.98	10.60
Third Party Auditing Fee	10.00	10.00	0.00	0.00
All Transportation	33.48	33.48	33.48	33.48

[1] Mean cost per head within treatment: 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC), fed Rumensin (300 mg $\bullet hd^{-1} \bullet d^{-1}$) and Tylan (90 mg $\bullet hd^{-1} \bullet d^{-1}$) during finishing; 3) implant (IMPL), administered a series of three implants including a low-potency calf implant (36 mg zeranol), a moderate-potency initial feedyard implant (80 mg trenbolone acetate and 16 mg estradiol), and a high potency finishing re-implant (200 mg trenbolone acetate and 20 mg estradiol) and fed Rumensin (300 mg $\bullet hd^{-1} \bullet d^{-1}$) and Tylan (90 mg $\bullet hd^{-1} \bullet d^{-1}$) during finishing, and 4) IMPL plus fed the beta-agonist (IMBA) ractopamine hydrochloride (200 mg $\bullet hd^{-1} \bullet d^{-1}$) for the last 30 d prior to harvest. Two separate harvest dates occured to obtain 1.35 cm 12th rib fat thickness including June 7 (NA and IMPL) and June 28 (NHTC and IMBA) among treatments.

[2] Cost of 250 kg calves October 26, 2015 at the Faith Livestock Commission Company.

[3] High roughage ration provided for the same days on feed (DOF).

[4] Cost of the diet during backgrounding was calculated from these prices of individual ingredients: corn ($118 per kg), distillers grain ($75 per 91 kg), hay ($270 per 91 kg), limestone $270 per 91 kg), and minerals ($806 per 91 kg) and the feedyard diet cost was determined from the actual total bill from the feedyard.

[5] Rate based upon $0.35/hd/d.

[6] Days on feed (DOF) started upon arrival and includes acclimation and step-up rations thru finishing to account for all costs of feed delivered.

[7] Includes cost of 36 mg zeranol (Ralgro; $1.36), 80 mg trenbolone acetate and 16 mg estradiol (Revalor IS; $2.66), and 200 mg trenbolone acetate and 20 mg estradiol (Revalor 200; $3.79). Cost for dewormer and vaccination were not included in the analysis.
[8] Per head costs were determined by amount fed divided by number of head per pen and adjusted for days on feed (DOF).
[9] Beta-agonist mixed inclusion cost was $247.60 per 907 kg of total mixed ration fed, per head costs were determined by amount fed divided by number of head per pen and adjusted for days on feed (DOF).
[10] Actual cost of therapeutic antibiotic use for ailments including respiratory disease, pneumonia, and digestive issues.
[11] To account for national morbidity rate and cost of treatment, USDA-APHI (2000) was referenced for feedyards with greater than 8,000 head in the Central region. All treatments received a total 25.8% morbidity rate and when applied, treatment expenses including respiratory disease (17.90%) cost of $23.10 per hd treated, pneumonia (2.9%) cost of $21.80 per hd treated, and digestive issue (5.0%) cost of $8.80 per hd treated were calculated. Given that NA is except from antibiotics, adjustments were made according to USDA-APHIS (2000) for the 25.8% morbidity rate and consequently in addition to treatment cost per head ($53.70), a deduction of $70.95 was applied to each NA branded carcass premium to account for opportunity loss.

Table 2.5. Plant assigned premiums and discounts for each beef production system

	Treatment[1]			
Variable	NA	NHTC	IMPL	IMBA
Base Carcass Value per 45 kg[2]	206.31	188.24	206.31	187.74
Branded Beef Premium, per carcass[3]	275.00	175.00	0.00	0.00
Total Branded Beef Premium, Adjusted				
Total Yield Grade Premiums	0.00	71.50	146.72	0.00
Total Yield Grade Discounts	0.00	123.00	0.00	0.00
Total Quality Grade Premiums	480.53	575.65	863.25	1,414.91
Total Quality Grade Discounts	0.00	0.00	0.00	0.00

[1] Mean cost per head within treatment: 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC), fed Rumensin (300 mg $\bullet hd^{-1} \bullet d^{-1}$) and Tylan (90 mg $\bullet hd^{-1} \bullet d^{-1}$) during finishing; 3) implant (IMPL), administered a series of three implants including a low-potency calf implant (36 mg zeranol), a moderate-potency initial feedyard implant (80 mg trenbolone acetate and 16 mg estradiol), and a high potency finishing re-implant (200 mg trenbolone acetate and 20 mg estradiol) and fed Rumensin (300 mg $\bullet hd^{-1} \bullet d^{-1}$) and Tylan (90 mg $\bullet hd^{-1} \bullet d^{-1}$) during finishing, and 4) IMPL plus fed the beta-agonist (IMBA) ractopamine hydrochloride (200 mg $\bullet hd^{-1} \bullet d^{-1}$) for the last 30 d prior to harvest. Two separate harvest dates occured to obtain 1.35 cm 12th rib fat thickness including June 7 (NA and IMPL) and June 28 (NHTC and IMBA) among treatments.

[2] Dependent upon volatile market price of harvest date.

[3] Rate based upon \$0.35/hd/d.

[4] Includes cost of 36 mg zeranol (Ralgro; \$1.36), 80 mg trenbolone acetate and 16 mg estradiol (Revalor IS; \$2.66), and 200 mg trenbolone acetate and 20 mg estradiol (Revalor 200; \$3.79).

[5] Adjusted for d on feed and amount fed.

[6] To account for morbidity rate among NA, adjustments were made based upon NAHMS (USDA-APHIS, 2000) for 25.8% morbidity and apply a deduction (\$70.95) to each branded carcass premium.

Table 2.6. Profitability of technology use and branded programs including actual morbidity and associated expenses

	Treatment [2]					
Variable, $[1]	NA	NHTC	IMPL	IMBA	SEM[3]	*P*-Value[4]
Total Carcass Value	1,889.38[b]	1,711.10[a]	1,826.36[b]	1,689.54[a]	31.060	< 0.0001
Total Production Cost, Including Calf Cost[5]	1,607.00[a]	1,673.21[ab]	1,645.25[ab]	1,712.13[b]	29.400	0.085
Total Production Cost, Excluding Calf Cost	438.93[a]	495.35[b]	434.52[a]	508.56[c]	3.544	< 0.0001
Cost of Gain, kg Including Calf Cost[5]	5.58[b]	5.55[b]	4.74[a]	4.88[a]	0.104	< 0.0001
Cost of Gain, kg Excluding Calf Cost	1.54[b]	1.65[c]	1.25[a]	1.45[b]	0.033	< 0.0001
Net Return, Including Calf Cost[5]	282.38[d]	37.89[b]	181.11[c]	(22.59)[a]	18.750	< 0.0001
Net Return, Excluding Calf Cost	1,450.45[b]	1,215.75[a]	1,391.84[b]	1,180.99[a]	31.450	< 0.0001

[a,b,c,d] Least squares means within row with different superscripts differ ($P \leq 0.05$) and tendencies were considered when $P > 0.5$ to $P < 0.01$.

[1]Age of the dam was used as a covariate for all variables.

[2] Mean cost per head within treatment: 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC), fed Rumensin (300 mg •hd^{-1}• d^{-1}) and Tylan (90 mg •hd^{-1}• d^{-1}) during finishing; 3) implant (IMPL), administered a series of three implants including a low-potency calf implant (36 mg zeranol), a moderate-potency initial feedyard implant (80 mg trenbolone acetate and 16 mg estradiol), and a high potency finishing re-implant (200 mg trenbolone acetate and 20 mg estradiol) and fed Rumensin (300 mg •hd^{-1}• d^{-1}) and Tylan (90 mg •hd^{-1}• d^{-1}) during finishing, and 4) IMPL plus fed the beta-agonist (IMBA) ractopamine hydrochloride (200 mg •hd^{-1}• d^{-1}) for the last 30 d prior to harvest. Two separate harvest dates occured to obtain 1.35 cm 12th rib fat thickness including June 7 (NA and IMPL) and June 28 (NHTC and IMBA) among treatments.

[3]Standard error of the mean.

[4] Probability of a difference among least squares means.

[5]Cost of 249.5 kg calves October 26, 2015 at the Faith Livestock Commission Company.

Table 2.7. Profitability of technology use and branded programs after National Animal Health Monitoring System (NAHMS; USDA-APHIS, 2011) adjustments for morbidity and associated expenses were applied[1]

	Treatment [3]					
Variable, $ [2]	NA	NHTC	IMPL	IMBA	SEM[4]	*P*-Value[5]
Total Carcass Value	1,818.43[b]	1,711.10[a]	1,826.36[b]	1,689.54[a]	31.060	0.002
Total Production Cost, Including Calf Cost[6]	1,611.87[a]	1,678.84[ab]	1,652.03[ab]	1,714.38[b]	28.833	0.088
Total Production Cost, Excluding Calf Cost	443.80[b]	500.98[c]	441.29[a]	510.81[d]	0.000	< 0.0001
Cost of Gain, kg Including Calf Cost[6]	5.59[b]	5.57[b]	4.76[a]	4.89[a]	0.993	< 0.0001
Cost of Gain, kg Excluding Calf Cost	1.55[c]	1.67[d]	1.27[a]	1.46[b]	0.028	< 0.0001
Net Return, Including Calf Cost[6]	206.56[c]	32.26[b]	174.34[c]	(24.84)[a]	17.500	< 0.0001
Net Return, Excluding Calf Cost	1,374.63[b]	1,210.12[a]	1,385.07[b]	1,178.74[a]	31.060	< 0.0001

[a,b,c,d] Least squares means within row with different superscripts differ ($P \leq 0.05$) and tendencies were considered when $P > 0.5$ to $P < 0.01$.

[1]To account for national morbidity rate and cost of treatment, USDA-APHIS (2000) was referenced for feedyards with greater than 8,000 head in the Central region. All treatments received a total 25.8% morbidity rate and when applied, treatment expenses including respiratory disease (17.90%) cost of $23.10 per hd treated, pneumonia (2.9%) cost of $21.80 per hd treated, and digestive issue (5.0%) cost of $8.80 per hd treated were calculated. Given that NA is except from antibiotics, adjustments were made according to USDA-APHIS (2000) for the 25.8% morbidity rate and consequently in addition to treatment cost per head ($53.70), a deduction of $70.95 was applied to each NA branded carcass premium to account for opportunity loss.

[2]Age of the dam was used as a covariate for all variables.

[3] Mean cost per head within treatment: 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC), fed Rumensin (300 mg •hd^{-1}• d^{-1}) and Tylan (90 mg •hd^{-1}• d^{-1}) during finishing; 3) implant (IMPL), administered a series of three implants including a low-potency calf implant (36 mg zeranol), a moderate-potency initial feedyard implant (80 mg trenbolone acetate and 16 mg estradiol), and a high potency finishing re-implant (200 mg trenbolone acetate and 20 mg estradiol) and fed Rumensin (300 mg •hd^{-1}• d^{-1}) and Tylan (90 mg •hd^{-1}• d^{-1}) during finishing, and 4) IMPL plus fed the beta-agonist (IMBA) ractopamine hydrochloride (200 mg •hd^{-1}• d^{-1}) for the last 30 d prior to harvest. Two separate harvest dates occured to obtain 1.35 cm 12^{th} rib fat thickness including June 7 (NA and IMPL) and June 28 (NHTC and IMBA) among treatments.

[4] Standard error of the mean.

[5] Probability of a difference among least squares means.

[6] Cost of 249.5 kg calves October 26, 2015 at the Faith Livestock Commission Company.

Table 2.8. Soil characteristics used for locations throughout each production segment[1]

		Soil Texture[1], %		
Segment	Soil Type	Clay	Silt	Sand
Cow-Calf	Medium Sandy Loam	15	25	60
Backgrounding	Shallow Clay Loam	34	33	33
Finishing	Medium Sandy Loam	15	25	60

[1] Soil texture based on typical soils found in each area as defined by USDA official soil series description (NRCS, 2015).

Table 2.9. Emission factors used in the life cycle assessment to represent the pre-chain emission occurring during the production of resources used in producing beef cattle within all industry segments and production systems generated from the Integrated Farm Systems Model[1].

Emission Source	Greenhouse Gas Emissions, kg CO_2e[2], kg	Energy Use, MJ	Non-precipitated Water Use, L/kg[3]	N Loss, g N/kg[4]
Purchased Feed[5]				
Corn	0.30	2.92	0.28	4.10
Forage	0.15	2.01	0.30	0.20
Protein Cubes[6]	1.00	4.00	0.18	2.00
Crude Protein	0.34	3.99	0.13	1.84
Non-Degradable Protein	0.41	4.40	0.18	2.60
Minerals	1.52	12.23	0.05	1.00
Energy Sources[7]				
Fuel	0.522/L	4.01/L	-	-
Natural Gas	0.668/m^3	2.46/m^3	-	-
Electricity	0.629/kWh	5.00/kWh	-	-

[1] Derived through simulations among different production systems with the Integrated Farm System Model (IFSM; Rotz et al., 2016).

[2] CO_2e = CO_2 equivalent units.

[3] Non-precipitated water use primarily includes water to irrigate feed crops and drinking water.

[4] Includes all forms of reactive N loss, including ammonia, nitrate leaching and runoff, nitrous oxide and NOx from denitrification and combustion of fossil fuels (Rotz et al. 2016).

[5] Accounts for emissions and resource utilization per kg of DM fed. Utilized the US Meat Animal Research Center pre-chain emissions as a base for all beef production segments and systems (Rotz et al., 2013), incorporated actual diet information from cow-calf, backgrounding, finishing, and simulated each segment according to the Cornell Net Carbohydrate and Protein System, level 1 (Fox et al., 2004).

[6] Accounts for cows supplemented with protein cubes during only the cow-calf segment.

[7] Utilized the US Meat Animal Research Center pre-chain emissions as a base for all beef production segments and systems (Rotz et al., 2013).

Table 2.10. Feedyard initial and final shrunk body weights used per production system

wt, kg	Animals Simulated	Treatments[1]			
Feedyard[2]	5,000	NA	NHTC	IMPL	IMBA
Initial wt[3]		269.96	269.16	280.14	274.84
Final wt[4]		518.65	534.64	585.64	587.46

[1] 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC), fed monensin (300 mg •hd^{-1}• d^{-1}) and tylosin (90 mg •hd^{-1}• d^{-1}) during finishing; 3) implant (IMPL), administered a series of three implants including a low-potency calf implant (36 mg zeranol), a moderate-potency initial feedyard implant (80 mg trenbolone acetate and 16 mg estradiol), and a high potency finishing re-implant (200 mg trenbolone acetate and 20 mg estradiol) and fed Rumensin (300 mg •hd^{-1}• d^{-1}) and Tylan (90 mg •hd^{-1}• d^{-1}) during finishing, and 4) implant plus fed the beta-agonist (IMBA) ractopamine hydrochloride (200 mg •hd^{-1}• d^{-1}) for the last 30 d prior to harvest. Two separate harvest dates (June 7 (NA and IMPL) and June 28 (NHTC and IMBA)) occurred to obtain 1.35 cm of 12^{th} rib fat thickness among treatments.

[2] All weights were shrunk 4% to account for fill.

[3] The initial wt. was obtained from the average weight collected from each treatment between January 4 and 5 prior to arriving to the feedyard on January 5.

[4] To minimize bruising prior to harvest, a final calculated body weight (FCBW) was calculated based upon hot carcass weight and a 63.5% dressing percentage.

Table 2.11. Summary of 25 yr. of weather data (daily solar radiation, daily mean temperature, annual precipitation, and daily wind speed) used to simulate each segment of each production system[1]

	Solar, MJ/m^2		Temperature, °C		Precipitation, mm		Wind, m/s	
Segment	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cow-Calf	12.3	1.83	6.0	1.07	402	97.84	5.62	0.36
Backgrounding	14.8	0.44	8.7	0.98	418.1	121.30	4.89	0.21
Finishing	15.5	0.92	48.9	1.31	20.6	5.04	10.05	0.29

[1] Obtained from the Integrated Surface Database of the National Climatic Data Center, National Oceanic and Atmospheric Administration (NOAA, 2014). These meteorological data sets were processed using AERMET, a meteorological processor (USEPA, 2004).

Table 2.12. Greenhouse gas emissions and natural resource use for beef production systems utilizing different levels of growth promotant technology expressed per unit of final hot carcass weight (HCW)

		Treatment[1]			
Production Component	Unit	NA	NHTC	IMPL	IMBA
Greenhouse Gas Emissions	kg CO_2e[2]/kg HCW	18.1	17.9	16.7	17.0
Energy Use	MJ/kg HCW	43.3	43.1	41.0	41.8
Non-precipitated Water Use[3]	L/kg HCW	2,997	2,966	2,824	2,866
Reactive N Loss[4]	g N/kg HCW	136.0	137.0	129.0	135.0

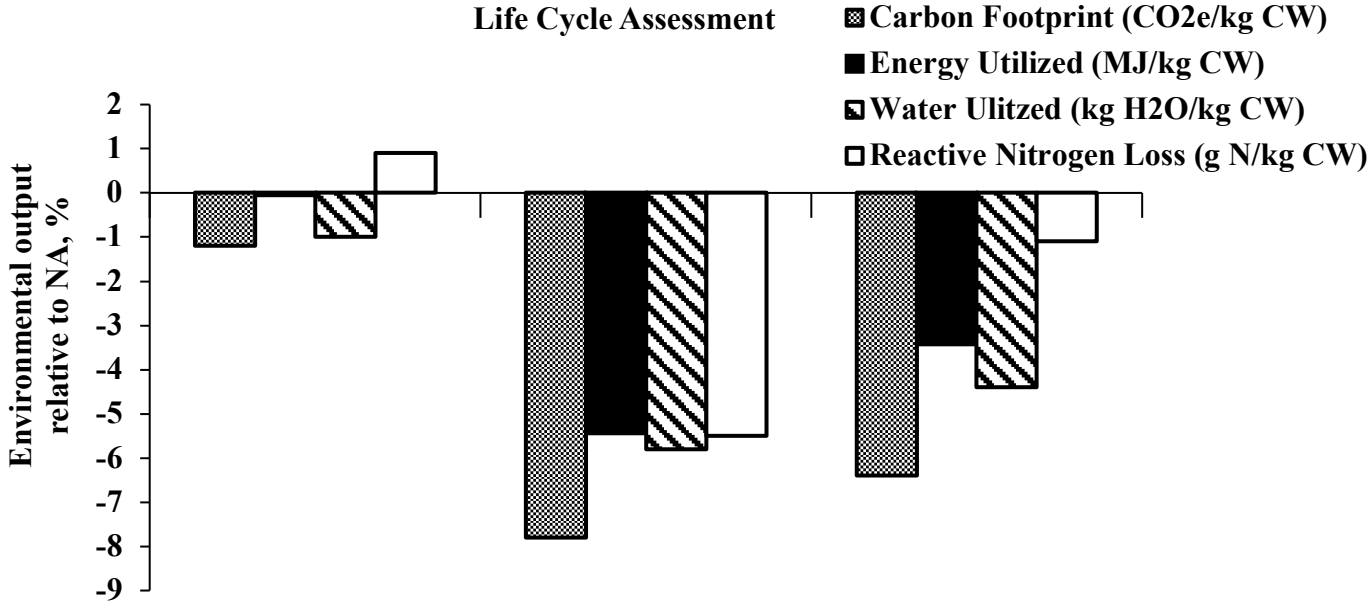
[1] 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC), fed monensin (300 mg $\bullet hd^{-1} \bullet d^{-1}$) and tylosin (90 mg $\bullet hd^{-1} \bullet d^{-1}$) during finishing; 3) implant (IMPL), administered a series of three implants including a low-potency calf implant (36 mg zeranol), a moderate-potency initial feedyard implant (80 mg trenbolone acetate and 16 mg estradiol), and a high potency finishing re-implant (200 mg trenbolone acetate and 20 mg estradiol) and fed Rumensin (300 mg $\bullet hd^{-1} \bullet d^{-1}$) and Tylan (90 mg $\bullet hd^{-1} \bullet d^{-1}$) during finishing, and 4) implant plus fed the beta-agonist (IMBA) ractopamine hydrochloride (200 mg $\bullet hd^{-1} \bullet d^{-1}$) for the last 30 d prior to harvest. Two separate harvest dates (June 7 (NA and IMPL) and June 28 (NHTC and IMBA)) occurred to obtain 1.35 cm of 12^{th} rib fat thickness among treatments.

[2] CO_2e = CO_2 equivalents.

[3] Non-precipitated water use primarily includes water to irrigate feed crops and drinking water.

[4] Includes all forms of reactive N loss, including ammonia, nitrate leaching and runoff, nitrous oxide and NOx from denitrification and combustion of fossil fuels (Rotz et al. 2016).

Figure 2.1. Influence of beef production system on measures of sustainability by USDA Integrated Farm System Model. Environmental outputs of steers provided Rumensin and Tylan (NHTC), steers administer a series of three implants, Rumensin, and Tylan (IMPL), and steers provided a beta-agonist, three implants, monensin, and tylosin (IMBA) were expressed relative to steers receiving no technology (NA), which served as the control[1]



Carbon Footprint, %	-1.19	-7.80	-6.45
Energy Utilized, %	-0.05	-5.45	-3.43
Water Utilized, %	-1.02	-5.75	-4.35
Reactive N Loss, %	0.93	-5.53	-1.07

[1]Environmental outputs were calculated as indicated per kg of hot carcass weight (HCW). Furthermore, CO_2e = CO_2 equivalent units, non-precipitated water use primarily includes water to irrigate feed crops and drinking water, and N loss includes all forms of reactive N loss, including ammonia, nitrate leaching and runoff, nitrous oxide and NOx from denitrification and combustion of fossil fuels (Rotz et al. 2016)

CHAPTER III

Influence of production systems on beef quality attributes

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ABSTRACT

The objective of this study was to compare the influence of different beef production systems on end product quality. Angus × Simmental crossbred steer calves (*n* = 120) were stratified by birth date, birth weight, dam age, and assigned randomly to 1 of 4 treatments: 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC, fed monensin and tylosin); 3) implant (IMPL, administered a series of three implants, and 4) implant plus fed a beta-agonist (IMBA, IMPL treatment plus, fed ractopamine-HCl for the last 30 d prior to harvest). Muscle biopsy samples from the longissimus dorsi (LD) were extracted from a subset (*n* = 16) of steers to determine the influence of pre-harvest management on gene expression of μ-calpain, m-calpain, and calpastatin using real-time rt-PCR. Following carcass chilling (approximately 24 hr), marbling score, skeletal maturity, and objective color (L*, a*, and b*) were evaluated. The right strip loin of each carcass was removed and portioned into 2.54 cm steaks and designated to 7, 14, or, 21 d postmortem aging periods for analysis of cook loss and Warner-Bratzler shear force (WBSF). The anterior face of each sample was used for analysis of ether extractable fat and moisture. Expression of calpastatin was increased ($P < 0.05$) in NHTC and IMBA treatments and there was a tendency for expression of m-calpain to be increased ($P < 0.01$) in NHTC compared to NA. Treatment influenced ($P < 0.01$)

marbling score, NA and NHTC were similar ($P > 0.05$) and had greater ($P < 0.05$) marbling compared to IMPL and IMBA, which were similar ($P > 0.05$). Skeletal maturity was greater ($P < 0.01$) for IMBA compared with all other treatments. Treatment influenced ($P < 0.05$) objective L*, a*, and b* color. The NA and IMPL treatments had increased ($P < 0.01$) L* values, NHTC was intermediate, and IMBA had the lowest ($P < 0.01$) L* values. The NA and IMPL treatments had increased ($P < 0.01$) a* values compared with NHTC and IMBA. The NA and IMPL treatments had increased ($P < 0.01$) b* values, NHTC was intermediate, and IMBA had the lowest ($P < 0.01$) b* values. Cattle in the NA and NHTC treatments produced steaks with an increased ($P < 0.01$) percentage of crude fat compared with the IMPL and IMBA treatments, which were similar ($P > 0.05$). Percent moisture of NA steaks were lower ($P < 0.01$) than all other treatments. No differences ($P > 0.05$) were detected for percent cook loss however, steaks from NA and NHTC treatments were more ($P < 0.05$) tender than IMPL and IMBA, which were similar ($P > 0.05$). Collectively, these results suggest that production systems with limited use of growth promoting technology produce carcasses with improved marbling score, and tenderness. However, the difference in tenderness is not explained by changes in expression of genes involved in the calpain system.

INTRODUCTION

Demand for food production is increasing as the world population continues to grow (AgMRC, 2012). Use of growth promotant technologies such as feed-grade antimicrobials, antibiotics, implants, and beta-andrenergic agonists could be key to meet this demand through improved animal performance (Preston, 1999; Duckett and Andrae, 2001; Jones et al., 2012). Use of ractomamine-HCl (RH) has been shown to improve ADG and feed efficiency of cattle (Avendano-Reyes et al., 2006; Walker et al., 2006), while implants increase protein deposition by enhancing both the rate and efficiency of muscle growth (Dayton and White, 2014). Therefore, these technologies could be key to efficiently provide more protein for the growing world demand. However, reports investigating the influence of these technologies on beef tenderness are mixed (Avendano-Reyes et al., 2006; Quinn et al., 2008; Strydom et al., 2009). Some research indicates that repetitive use of implants during various segments of production may negatively impact meat quality and tenderness (Platter et al., 2003). Tenderness variability a critical issue facing the beef industry (Morgan et al., 1991; Koohmaraie and Geesink, 2006) and it is necessary to fully understand the impact of pre-harvest technologies on this palatability trait.

It is well established that tenderness is regulated by three intrinsic mechanisms: 1) sarcomere length, 2) collagen content and solubility and 3) postmortem proteolysis/aging (Geesink et al., 2006). Given that sarcomere length of the longissimus muscle postmortem is primarily associated with fixed skeletal attachments, it is unlikely that changes in sarcomere length are responsible for variations in tenderness associated with growth promoting technologies and differences in collagen are unlikely in cattle of a

similar age and genetic background. Therefore, the hypothesis that the use of growth promoting technologies would influence gene expression and resultant enzymatic function of the calpain system, which would alter proteolysis was tested. The calpain system is comprised of two calcium dependent proteases (μ– and m-calpain) that degrade structural proteins and their specific inhibitor (calpastatin). The objective of this study was to compare the influence of different levels of growth promoting technology use on expression of genes encoding for the calpain system (μ-calpain, m-calpain, and calpastatin), meat quality, and steak tenderness.

MATERIALS AND METHODS

Animals

All animal care and experimental protocols were approved by the South Dakota State University (SDSU) Animal Care and Use Committee (approval number 15-091E). One hundred and twenty Angus × Simmental crossbred male calves born within a 45 d period at the SDSU Antelope Field Station herd near Buffalo, SD, were utilized for this study. Prior to weaning, calves were stratified by birth date, birth weight, and dam age and assigned randomly to 1 of 4 treatments: 1) no antibiotics (NA; receiving no technology); 2) non-hormone treated cattle (NHTC; fed 300 mg monensin [Rumensin 90, Elanco Animal Health, Greenfield, IN] and 90 mg tylosin [Tylan 40, Elanco Animal Health] during the finishing phase March 29 to harvest); 3) implant (IMPL; same technologies as NHTC and administered a series of three implants including a low-potency calf implant [36 mg zeranol; Ralgro, Merck Animal Health, Madison, NJ] at an average of 74 ± 12 d of age on June 29, a moderate-potency initial feedyard implant [80 mg trenbolone acetate and 16 mg estradiol; Revalor-IS, Merck Animal Health] at an average of 235 ± 12 d of age on December 8, and a high potency finishing re-implant [200 mg trenbolone acetate and 20 mg estradiol; Revalor-200, Merck Animal Health] at an average of 330 ± 12 d of age on March 11) and 4) implant plus fed a beta-agonist (IMBA; same technologies as IMPL and fed 200 mg RH •steer^{-1}• d^{-1} [Optaflexx 45; Elanco Animal Health] for the last 30 d prior to harvest). Beef Quality Assurance (BQA) protocols were used throughout the course of the study (BQA, 2010) and implants were administered subcutaneously in the middle third of the ear by a single technician. Implant needles were changed as needed to be effective and disinfected after each use with a

sponge soaked in 2% chlorhexidine solution. Steer calves were managed from pre-weaning to finishing as described in Chapter II. Composition of the finishing diet is presented in Table 3.1.

Muscle Biopsies

Biopsy samples (approximately 40 mg) were collected from the LD for analysis of gene expression using a subset (n = 16) of steers. Steers with a BW closest to the treatment mean BW on April 26 were designated for the subsample. Biopsies were conducted for NA and IMPL 6 d prior to harvest and NHTC and IMBA 5 d prior to harvest. Steers were restrained and prepared for incision of the right LD between the 12th and 13th rib junction, 3 cm lateral from the midline. A 12.7 cm^2 area was shaved, scrubbed with povidone-iodine solution, and wiped with a 70% alcohol solution prior to the incision. A total of 5 mL of lidocaine was injected subcutaneously in a circle around the incision cite depositing approximately 1 mL per 5 injections. Three minutes was allowed for establishment of the local anesthesia and a 10 mm incision was made using a sterile disposable No. 11 scalpel. A BARD Magnum Reusable Core Biopsy Instrument (C.R. Brad, Inc., Tempe, AZ) with a disposable 12G × 10 cm needle was inserted into the incision cite to collect tissue samples and repeated (5 - 7 times per steer). Tissue samples were immediately snap frozen in liquid N before storage at -80°C. After collection, the injection cite was sprayed with Vetericyn (Vetericyn, Rialto, CA) and steers were closely monitored.

RNA Extraction, cDNA Conversion, and real-time RT-PCR

Snap frozen samples were powdered in liquid N using a mortar and pestle and approximately 60 mg of sample were placed into 1.5 mL tubes containing 700µL of QIAzol

Lysis Reagent. Total RNA was extracted from samples using the miRNeasy Mini Kit (Catalog No. 217004 QIAGEN, Germany). Following the miRNeasy Mini Kit quick-start protocol, RNA was separated from genomic DNA. The concentration and purity of RNA was evaluated spectrophotometrically (Nanodrop 2000, Thermo Scientific, Wilmington, DE) and RNA concentration was diluted to 200 ng/µL. A high-capacity cDNA Reverse Transcription Kit (Part #4368814, Applied Biosystems, Foster City, CA) was used to convert RNA to cDNA using a thermal cycler (MyCycler Thermocycler #170-9703, Bio-Rad Laboratories, Hercules, CA) at the parameters recommended by the manufacturer set at 1 cycle at 25ºC for 10 min, 37°C for 12 min, and 85ºC for 5 min.

The cDNA was diluted to 50% using RNA-free water, rt-PCR was performed to evaluate the expression of genes associated with the calpain system (µ-calpain, m-calpain, and calpastatin) within the LD muscle. The National Center for Biotechnology Information (NCBI; United States Library of Medicine, Bethesda, MD) database was utilized to identify messenger RNA sequences. GeneBank accession numbers were then used to design primers using PrimerQuest software (Integrated DNA Technologies, Coralville, IA). Accession numbers, forward primer sequences, and reverse primer sequences for each housekeeping gene (EEF1A2 and SF3A1) are presented in Table 3.2. The relative quantity of the cDNA of interest was determined using RT^2 Real-Time™ SYBR Green/ROX PCR Master Mix (PA-012-24, SABiosciences, Frederick, MD) with appropriate forward and reverse primers (10 nM), and 1 µL diluted cDNA. Assays were performed using a Mx3005P thermal cycler (Agilent Technologies, Stratagene Product Division, Waldbronn, Germany) with parameters recommended by the manufacturer, which included Segment 1: 95°C for 10 min and Segment 2: 40 cycles of (95ºC, 30 s;

55ºC, 60 s; 72°C, 60 s). Reaction specificity was determined by melting curves for each amplicon after completion of amplification.

Carcass Evaluation and Sample Collection

Steers were tracked individually through harvest at a commercial processing facility in Lexington, NE. Following carcass chilling (approximately 24 h), carcass measurements for marbling score and skeletal maturity were determined and recorded by trained university personnel. After chilling, carcasses were ribbed between the 12th and 13th rib and the exposed LD was allowed to bloom for approximately 30 min prior to objective color (L*, a*, and b*) measurements. A Minolta colorimeter (model CR-310; Minolta Corp., Ramsey, MJ; 50 mm diameter measuring space and D65 illuminant) was used to obtain the measurements recorded from two locations of the left LD (medial and lateral) and averaged for each carcass. Both striploins were collected from each carcass and transported under refrigeration (2.2°C) to the SDSU Meat Laboratory in Brookings, SD. Striploins were trimmed to 0.64 cm of external fat, the connective tissue, *gluteus medius*, and *multifidus dorsi* were removed so that only the LD remained. The most anterior portion of both LD muscles was faced to obtain a square anterior edge and the remaining portion of the LD was fabricated into 2.54-cm steaks. The left anterior face of the LD was aged for 14 d postmortem and utilized to determine crude fat percentage. Consistently, the 3 most anterior steaks from the right striploin were assigned to 7, 14, or 21 d postmortem aging periods and vacuum-sealed for analysis of percent cook loss and Warner-Bratzler shear force (WBSF). Vacuum-sealed samples were aged in the absence of light at 2-3°C and immediately after each specified aging period was attained steaks

were frozen (-20°C) and checked regularly for seal integrity until thawed for evaluation of percent moisture, ether extractable fat, percent cook loss, and tenderness.

Moisture and Ether Extractable Fat Percentage

As described by Webb et al. (2017) steaks were thawed slightly and prepared for powdering using a Waring commercial blender (model 51BL32; Waring Laboratory Division, Lancaster, PA) once powdered, individual samples were stored in bags (Whirlpack; Nasco, Fort Atkinson, WI) and frozen (-20°C). For analysis, duplicated powdered samples (5 g) were weighed into tins, covered with filter papers, and dried in an oven at 101°C for 24 h. Once dried, samples were placed into desiccators for 1 h prior to recording the nonextracted weight for calculation of percent moisture. Samples were extracted according to the AOAC International (Horwitz, 2000; method 960.39) with the exception that the Soxhlet extractor (model 80068-154; Chemglass Life Sciences LLC, Vineland, NJ) was used with petroleum ether instead of a Goldfisch apparatus. Ether extraction was conducted for 60 h followed by evaporating samples at room temperature before placing the tins into the oven for 4 h at 101°C (Bruns et al., 2004). Dried, extracted samples were put into desiccators for 1 h prior to re-weighing. Crude fat was calculated by determining the difference among the pre- and post-extraction sample weight and was expressed as a percent of the pre-extracted sample weight.

Percent Cook Loss and Warner-Bratzler Shear Force

Steaks designated for WBSF determination were thawed for 24 h at 4°C. Prior to cooking, each raw steak was weighed in g then placed on an electric clam shell grill (George Forman 9 Serving Classic Plate Grill, Model GR2144P, Middleton, WI) and the target internal peak temperature was 71°C. During cooking the MicroNeedle probe of a AquaTuff

thermometer (Model 35140, Cooper-Atkins Corporation, Middlefield, CT) was placed into the geometric center of each steak to continuously monitor the temperature, steaks were pulled from the heating element prior to reaching the target temperature and allowed to peak to obtain the final temperature recorded. After cooking, each steak was cooled for 1-2 h at 4°C before removing 6 cores (1.27 cm in diameter) parallel to the muscle fiber orientation (AMSA, 2015). A single, peak shear force measurement was obtained for each core using a Warner-Bratzler machine (G-R Electric Manufacturing Company, Manhattan, KS). The peak shear force was recorded for each core and averaged to obtain a single shear force value per steak.

Statistical Analysis

Fold change differences in gene expression between NA, which served as the control, and NHTC, IMPL or IMBA were analyzed using the Relative Expression Software Tool (REST; 2008, Corbett Research & M. Pfaffl, Technical University Munich) according to the procedures of Pfaffl (2001). Relative expression is dependent upon the expression ratio of a target gene compared with a reference gene and is accepted for most investigations of physiological change in the level of gene expression (Mohrhauser et al., 2015). Target gene expression was standardized by a non-regulated reference-gene. The expression ratio occurs when the investigated transcripts are tested for significance using a Pair Wise Fixed Reallocation Randomization Test (Pfaffl et al., 2002). In this study, EEF1A2 and SF3A1 were used as reference genes for each LD muscle biopsy sample. Means were tested to a predetermined significance level of $P \leq 0.05$ with trends considered ($P > 0.05$ to ≤ 0.10).

For all other analyses, the influence of production system was evaluated using PROC MIXED of SAS (version 9.4, SAS Inc., Cary, N.C.) in a completely randomized design with steer used as the experimental unit. Meat quality data (marbling score, skeletal maturity, objective color, percent moisture and crude fat) was analyzed by production system as the fixed effect and dam age was used as a covariate.

Percent cook loss and WBSF were analyzed using production system as a fixed effect, and dam age and peak cooking temperature were used as covariates. Postmortem aging periods (7, 14, or 21 d) were denoted as a repeated measure and were further evaluated for their interaction with treatment. The variance-covariance structure for response variables was selected using the Schwarz's Bayesian information criteria (BIC) fit statistic.

For all statistical analyses conducted using PROC MIXED, no random effects were specified and denominator degrees of freedom were approximated by the Kenward-Roger option in the model statement. Least square means and SEM were computed for all variables and separated using least significant differences (PDIFF) when tests for fixed effects were significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Treatment did not influence ($P > 0.05$) the expression of μ-calpain ($P > 0.10$) compared with the control (NA). There was no difference in μ- and m-calpain, or calpastatin expression between the IMPL and NA treatments ($P > 0.10$; Table 3.3). Gerken et al. (1995) also determined implanting with either an estogenic, an androgenic, or a combination implant (estrogenic and androgenic) did not influence gene activity of μ- or m-calpain in comparison to a nonimplanted control. However, steers receiving either a single estrogenic or a combination implant had increased calpastatin activity compared to a non-implanted control (Gerken et al., 1995). Differences in calpastatin results of Gerken et al. (1995) and the present study may be related to differences in specific implants administered or the diffence between assays utilized to quantify differences in calpastatin (activity versus gene expression).

Expression of calpastatin was upregulated ($P < 0.05$) and m-calpain expression tended to be upregulated ($P < 0.10$) in samples from the NHTC treatment compared to NA. Limited research exists evaluating the effect of monensin and tylosin on expression of the calpain system in muscle. Hilton et al. (2009) evaluated the withdrawal of monensin and tylosin while feeding zilpaterol hydrochloride (ZH) [Zilmax; Merck Animal Health] during the last 35 d prior to harvest, and determined expression of calpain or calpastatin was not influenced by removal of these products from the diet. However, the current study did not evaluate change in experession when these technologies were removed from the diet, which could explain the inconsistent results.

Expression of calpastatin was upregulated ($P < 0.05$) in the IMBA treatment compared with NA. Others have also reported beta-adrenergic agonist (β-AA)

supplementation up-regulated calpastatin expression and confirmed that calpastatin expression increased with β-AA induced muscle hypertrophy (Killefer and Koohmaraie, 1994). Walker et al. (2010) extracted muscle biopsies from the *biceps femoris* (BF) and *longissimus* muscle (LM) of 16 steers administered an implant (120 mg trenbolone acetate and 24 mg estradiol-17β) and fed 200 mg RH•steer^{-1}• d^{-1} for 29 d. Walker et al. (2010) did not observe any difference in expression of calpastatin when compared to steers only implanted and not fed RH. This result is similar to the current study and illustrates that implanting alone may not cause an increase in calpastatin expression.

Marbling score, skeletal maturity, and color were evaluated to determine the influence of treatment on measures of carcass quality. Marbling has repeatedly been shown to be an important trait for consumer eating satisfaction in cooked beef (Hankins and Ellis, 1939; Cole and Badenhop, 1958; Webb et al., 2014). Carcasses from NA (554 ± 18.140) and NHTC (562 ± 17.146) did not differ ($P > 0.05$) but were greater ($P \leq 0.05$) in marbling than IMPL (486 ± 16.861) and IMBA (504 ± 17.141), which were similar ($P > 0.05$; Table 3.4). The reduced ($P \leq 0.05$) marbling score (-54 on average compared to NA, NHTC and IMBA) in IMPL translated into a reduced ($P \leq 0.05$) USDA QG (Low Choice) in comparison with NA and NHTC. This reduction of marbling score and consequent lower QG caused by IMPL is not unexpected as the use of anabolic steroids has been well documented to decrease marbling score and consequently result in fewer carcasses grading USDA Choice, and an increase in the carcasses stamped a lower USDA QG (Kuhl, 1992; Bartle et al., 1992; Foutz et al., 1997; Preston, 1999; Platter et al., 2003; Bruns et al., 2005; Pritchard, 2008; Johnson, 2015). Duckett et al. (1996) conducted a review of 37 trials examining steers administered an anabolic steroid while on a finishing

diet and reported reductions a marbling score percent (24%) reduction that translated into a lower percentage (14.5%) of carcasses grading USDA Choice in comparison to a non-implanted control. In contrast, some studies show that implants have no negative effect on marbling score or USDA QG (Johnson et al., 1996; Scheffler et al., 2003, Smith et al., 2007). Differences among these studies are likely due to variations in genetics, the potency of the implant(s) utilized, and the number and timing of when implants were administered. The reduction in marbling score of carcasses in the IMBA treatment supplemented with 200 mg RH•steer^{-1}• d^{-1} is also not unexpected as the use of RH has been shown to decrease (10%) marbling score in comparison with an non-supplemented control (Winterholler et al., 2006; Gruber et al., 2007). Boler et al. (2012) also reported equal response in QG to supplementation of either 300 or 200 mg RH•steer^{-1}• d^{-1}.

Marbling combined with physiological maturity (vertebral ossification, size and shape of the ribs, and color and texture of the LM at the 12th rib) allows for the assignment of the voluntary USDA QG (USDA Prime, USDA Choice, USDA Select; USDA, 1997; Acheson et al., 2014). The USDA QG system utilizes physiological maturity to capture animal age-related differences that impact meat tenderness, flavor, and juiciness. Skeletal maturity is used to determine if an animal is less than 30 mo. of age and qualifies for A maturity unless, dentition or age documentation can be provided (USDA-AMS, 2017). The NA treatment produced carcasses that were least mature (117 ± 1.847), NHTC and IMPL were similar ($P > 0.05$) and intermediate (127 ± 1.746 and 126 ± 1.717, respectively), and IMBA (138 ± 1.746) was most advanced in maturity though, all production systems resulted in carcasses with A maturity (A^{17} to A^{38}; Hale et al., 2013). In contrast others have reported no difference in skeletal maturity of cattle supplemented with RH in comparison to

implanted cattle (Scramlin et al., 2010; Woerner et al., 2011). Although harvest date was the same, the IMPL treatment was more skeletally mature in comparison with NA. This was not unexpected as administration of exogenous estrogenic steroids has been reported to increase skeletal maturity due to hyperestrogenism (Acheson et al., 2014) by 10 points on a scale of 100 per degree of maturity (Duckett et al. 1996). A Platter et al. (2003) determined overall maturity increased with successive implant administered. Skeletal maturity has also been known to increase as cattle age and a reduction in steak tenderness can occur (Acheson et al., 2014). In this study, the age of steers at harvest was approximately 13 mo. (419 ± 12 d of age; NA and IMPL) and 14 mo. (438 ± 12 d of age; NHTC and IMBA). Although cattle age was similar, research has shown that QG influences objective measures of beef tenderness (Smith et al., 1985; Gruber et al., 2006, and Garmyn et al., 2011) and that age is only responsible for 6% of the variation in tenderness (Palmer, 1963).

Treatment influenced ($P < 0.0001$) L* values. Carcasses from NA and IMPL (44 ± 0.327 and 44 ± 0.304, respectively) were similar ($P > 0.05$) and lightest in color, NHTC (43 ± 0.309) was intermediate ($P < 0.05$), and IMBA (42 ± 0.309) was darkest ($P < 0.05$) in color (Table 3.4). In contrast, Garmyn et al. (2014) reported L* values were similar between carcasses from steers fed RH and a non-supplemented control. Moreover, Avendaño-Reyes et al. (2006) observed lighter steaks from carcasses of cattle supplemented RH compared to a control. Differences in L* results among studies could be due to variations in breed (e.g. British type, Charolais and Brangus), or in the level and duration of RH supplementation.

Treatment influenced ($P < 0.0001$) a* values. Carcasses from NA and IMPL (26 ± 0.271 and 27 ± 0.252, respectively) were similar ($P > 0.05$) and redder ($P < 0.05$) in color than NHTC and IMBA (25 ± 0.256 and 24 ± 0.256, respectively), which were not different ($P > 0.05$). Garmyn et al. (2014) also reported that a* values were decreased due to RH supplementation of steers in comparison to a non-supplemented control. In contrast, Reiling and Johsnon (2003) conducted a retail display study and determined steaks from implanted cattle had reduced a* values (at d 0) compared to steaks from the non-implanted control. Differences between studies could be related to the study conditions (retail diplay versus in-plant evaluation).

Carcasses from NA and IMPL (12 ± 0.129 and 12 ± 0.120, respectively) were similar ($P > 0.05$) and had increased ($P < 0.05$) b* values, or were yellower in color than NHTC (11 ± 0.122), which was intermediate and greater ($P < 0.05$) than IMBA (10 ± 0.122). At d 0 of retail display, Reling and Johnson (2003) determined that steaks from steers implanted with zeranol and re-implanted with a combination implant (trenbolone acetate and estradiol) had lower b* values compared to a non-implanted control however, steers implanted and re-implanted with the same combination implant were similar to the control, which is consistent with the current study comparison between NA and IMPL. Hilton et al. (2009) evaluated carcass color from cattle that had monensin and tylosin removed during the finishing phase and determined b* values were not influenced. However as mentioned previously, the current study evaluated the supplementation of monensin and tylosin not the removal and due to no other research investigations of the influence of supplementation of monensin and tylosin on carcass color, this study is referenced as the only comparison. If the animal production goal is to improve carcass weight, it appears that the use of growth promoting implants is less

detrimental to steak color without a β-AA. Though in contrast to the results for IMBA, Avendaño-Reyes et al. (2006) found no difference in RH supplementation on a* or b* values in comparison to a non-supplemented control. Moreover, Woerner et al. (2011) determined initial implanting, terminal implanting, and RH supplementation did not influence color (L*, a*, b*) values. However, these studies (Avendaño-Reyes et al., 2006; Woerner et al., 2011) have variations in breed type (Charolais and Brangus), animal age (calf-fed), implant protocol (progesterone and estradiol benzoate) and timing of administration in comparison to the current study.

Treatment influenced ($P < 0.0001$) percent crude fat (Table 3.4). The NA and NHTC (7.38 ± 0.307% and 7.11 ± 0.290%, respectively) treatments were similar ($P > 0.05$) but greater ($P \leq 0.05$) than IMPL and IMBA (5.49 ± 0.285 % and 5.89 ± 0.290 %, respectively), which were not different ($P > 0.05$). Treatment also influenced ($P < 0.0001$) percent moisture. The NHTC, IMPL, and IMBA (70.39 ± 0.219 %, 71.23% ± 0.215 %, and 71.20 ± 0.219 %, respectively) treatments were similar ($P > 0.05$) and greater ($P \leq 0.05$) in moisture than NA (69.67 ± 0.232; Table 3.4). These results suggest that use of successive implantation with monensin and tylosin with and without RH decrease percent crude fat in comparison with a control receiving no growth promoting technologies. Moreover, the decrease in percent crude fat in IMPL and IMBA compared to NA is expected, and inversely so is the increased percent moisture in comparison to NA. Although utilizing nonpregnant cull cows, Cranwell et al. (1996) agreed that use of an implant (200 mg trenbolone acetate) decreased percent crude fat and inversely increased moisture. In contrast, Handcock et al. (2005) evaluated steaks from heifers supplemented RH (10, 20, or 30 ppm) in comparison to a non-supplemented control

and determined there was no influence on percent crude fat or moisture. This referenced study utilized heifers unlike the steers in the current analysis.

To evaluate cooked steak quality, treatments were analyzed to determine percent cook loss and objective steak tenderness. Treatment did not influence ($P = 0.680$) percent cook loss (Table 3.4). There was no interaction ($P = 0.52$) between treatment and aging period, although tenderness of all steaks improved ($P < 0.05$) with aging (2.45 ± 0.048 kg at 7 d vs. 2.21 ± 0.039 kg at 14 d vs. 2.14 ± 0.041 kg at 21 d). Steaks from NA (2.01 ± 0.075 kg) and NHTC (1.94 ± 0.071 kg) were similar ($P > 0.05$) and more tender ($P < 0.05$) than IMPL (2.49 ± 0.070 kg) and IMBA (2.63 ± 0.071 kg), which were similar ($P > 0.05$). However, steaks from all treatments could be certified tender (≤ 4.4 kg) and very tender (≤ 3.9 kg; ASTM, 2011). Several studies have also demonstrated a decrease in tenderness values of steaks from implanted cattle (Morgan et al., 1997; Roeber et al., 2000; Platter et al., 2003). The increase mean WBSF value from implant administration has also been demonstrated to cause less desirable consumer tenderness ratings (Platter et al., 2003). However, others have reported minimal negative influences on steak tenderness from cattle administered successive implants (androgenic, estrogenic, and combinations) (Nichols et al., 2002; Gerken et al., 1995). In contrast, Gerken et al. (1995) compared the effects of meat tenderness from administering Brangus steers with a single implant (either estrogenic, androgenic, or a combination) to a non-implanted control. Depending upon the implant, there were variations in steak tenderness. Brangus steers implanted with a single combination implant produced top sirloin steaks similar in tenderness to the non-implanted control however, none of the single implant strategies decreased strip loin or top round steak tenderness values in comparison to the non-implanted control.

Research has repeatedly demonstrated that RH supplementation negatively influences beef tenderness (Avendaño-Reyes et al, 2006; Gruber et al., 2007; Strydom et al., 2009; Scramlin et al., 2010; Boler et al., 2012; Arp et al., 2013). Moreover, trained sensory panels have detected an increase in connective tissue in steaks from carcasses of steers supplemented RH (400 mg RH•steer^{-1}• d^{-1}) and ultimalty found those steaks to be tougher in comparison with a control (Arp et al., 2013). However, a few studies (Schroeder et al., 2003; Arp et al., 2013) suggest that a low dose of RH (200 mg RH•steer^{-1}• d^{-1}) does not decrease steak shear force values in comparison with a non-supplemented control. Perhaps the non-significant difference in tenderness from supplementation of a low dose of RH in Arp et al. (2013) is due to the control, which was implanted. Moreover, the current study detecting an increase in steak toughness from steers supplemented RH at a low dose, may have been more sensitive to differences in steak tenderness as all cattle were from a similar genetic population.

Most similar to the design of the current research, Woerner et al. (2011) evaluated the combination of providing an initial and terminal implant then, supplemented calf-fed steers and heifers 200 mg RH•hd^{-1}• d^{-1}. Overall, WBSF values were not influenced by the initial or terminal implants however, RH supplementation increased mean WBSF value by 0.23 kg, which tended to cause a loss in predicted consumer acceptance. This increase in toughness may be due to the negative effects of β-AA on postmortem tenderization. It is not suprising that use of β-AA in this study increased expression of calpastatin as it has repeatedly been documented to increase calpastatin activity and potentially cause new collagen cross-links, which may decrease meat tenderness (Goll et al., 1997; Strydom et al., 2009; and Roy et al., 2015). Tenderness variability is among the most critical issues

facing the beef industry today (Guelker et al., 2013), and it is necessary to fully understand the impact of use or absence of pre-harvest technologies on the palatability of beef derived from current and similar genetics that are managed to a comparable compositional endpoint.

IMPLICATIONS

Animal gene expression of calpastatin may be an inconsistent predictor of objective measures for meat tenderness. Cattle "raised without antibiotics" (not supplemented with monensin and tylosin), or "raised without the use of hormones" (only using monensin and tylosin) produced steaks that contained more marbling, crude fat, and were more tender in comparison to steaks produced from carcasses of cattle additionally receiving growth promoting implants with and without ractomamine-HCl. Although there are performance benefits of supplying growth promoting implants and ractopamine-HCl there may be greater detriments to carcass quality and meat tenderness compared to cattle supplemented with or without monensin and tylosin. Research efforts to improve management of growth promotant technology use to prevent reductions in marbling score, crude fat, and steak tenderness are needed to ensure consumer satisfaction while improving carcass weight and production efficency. Although beyond the scope of this study, evaluating muscle fiber type, diameter, and collagen concentration could provide insight into the mechanism responsible for reduced tenderness in steaks produced with growth promoting implants and ractopamine HCl.

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Table 3.1. Composition of finishing diet (% of DM) fed to steers[1]

Item	Composition[2]
Ingredient composition	
Dry-rolled corn	47.76
Wet corn gluten	40.02
Prairie hay	7.21
Liquid supplement[3]	5.02
Nutrient composition	
NE_m, Mcal/kg	2.04
NE_g, Mcal/kg	1.38
CP	13.93

[1] During finishing steers received four concentrate-adaptation diets over a period of 65 d (January 6 - March 11) fed for 7, 7, 40, and 11 d, respectively.
[2] Steers only within the treatment receiving 200 mg•hd^{-1}• d^{-1} of ractopamine HCl were supplemented.
[3] Supplement contained 58.25% ground corn, 29.57% limestone, 5.59% iodized salt, 4.65% ammonia chloride, 0.93% trace mineral mix, 0.25% thiamine, and 0.21% Vitamins A, D, and E. Diet was formulated to provide 300 mg monensin (Elanco Animal Health, Greenfield, IN) and 90 mg Tylan (Elanco Animal Health) per steer daily.

Table 3.2. Primer sequences for housekeeping genes and genes of interest for *Longissimus lumborum* and muscle samples.

Gene		Primer Sequence	Accession Number
EEF1A2[1,2]	forward	5' - GGTACTGGACAAGCTGAAGG - 3'	NM_001037464
	reverse	5' - GCGTCGATGATGGTGATGTA - 3'	
SF3A[1,3]	forward	5’ - GCCCGTGGTGGGTATTATTTA -3’	NM_001081510
	reverse	5’ - TGTTGATCTCGTTCTGTCGTATC - 3’	
Calpastatin	forward	5’ - GCCAAAGGAACACACAGAGCCAAA - 3’	NM_001030318
	reverse	5’ - TTCTCTGATGGTGGCTGCTCACTT -3’	
μ-Calpain	forward	5' - ATTTCCAGCTGTGGCAGTTTGGTG - 3'	NM_174259
	reverse	5' - TCACCTTGGCATAGGCTTTCTCCA - 3'	
m-Calpain	forward	5' - TGACCCAAACTGGGCATCTGTCTA - 3'	NM_001103086
	reverse	5' - AAACAAGCTTGGGTGGTTTCCCTG - 3'	

[1]Housekeeping Gene.
[2]EEF1A2 = Eukaryotic Translation Elongation Factor 1.
[3]SF3A1 = Splicing Factor 3.

Table 3.3. Relative expression of genes in the *Longissimus dorsi* muscle of steers.

	Treatment[1]								
	NHTC			IMPL			IMBA		
Gene	Fold Change[2]	95% CI	*P*-value	Fold Change	95% CI	*P*-value	Fold Change	95% CI	*P*-value
μ-Calpain	0.886	0.177 – 5.110	0.840	1.266	0.568 – 2.823	0.519	1.595	0.789 – 2.574	0.110
m-Calpain	1.601	0.932 – 3.997	**0.081**	1.020	0.718 – 1.447	0.784	1.120	0.365 – 3.520	0.733
Calpastatin	1.560	1.095 – 2.266	**0.010**	1.042	0.853 – 1.187	0.631	1.615	1.318 – 2.029	**0.025**

[1] Treatments: 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC), fed monensin (300 mg •steer^{-1}• d^{-1}) and tylosin (90 mg •steer^{-1}• d^{-1}) during finishing; 3) implant (IMPL), administered a series of three implants including a low-potency calf implant (36 mg zeranol), a moderate-potency initial feedyard implant (80 mg trenbolone acetate and 16 mg estradiol), and a high potency finishing re-implant (200 mg trenbolone acetate and 20 mg estradiol) and fed Rumensin (300 mg •steer^{-1}• d^{-1}) and Tylan (90 mg •steer^{-1}• d^{-1}) during finishing, and 4) implant plus fed the beta-agonist (IMBA) ractopamine hydrochloride (200 mg •steer^{-1}• d^{-1}) for the last 30 d prior to harvest.

[2] Fold change compares steers within production system to steers receiving no technology (NA), fold change greater than 1 denotes increased expression within production system.

Table 3.4. Main effect least square means for effect of production system on carcass characteristics, meat quality, and tenderness.

	Treatment[1]				*P*-value[2]
Variable	NA	NHTC	IMPL	IMBA	
Marbling score[3,4]	553.93[b] ± 18.140	561.61[b] ± 17.146	486.49[a] ± 16.861	503.67[a] ± 17.141	0.0044
Skeletal Maturity[3,5]	116.51[a] ± 1.847	126.91[b] ± 1.746	126.35[b] ± 1.717	137.59[c] ± 1.746	< 0.0001
L*	43.89[c] ± 0.327	42.69[b] ± 0.309	43.84[c] ± 0.304	41.81[a] ± 0.309	< 0.0001
a*	26.36[b] ± 0.271	24.73[a] ± 0.256	26.72[b] ± 0.252	24.09[a] ± 0.256	< 0.0001
b*	11.87[c] ± 0.129	10.57[b] ± 0.122	11.95[c] ± 0.120	10.02[a] ± 0.122	< 0.0001
Ether, %	7.38[b] ± 0.307	7.11[b] ± 0.290	5.494[a] ± 0.285	5.894[a] ± 0.290	< 0.0001
Moisture, %	69.67[a] ± 0.232	70.39[b] ± 0.219	71.23[b] ± 0.215	71.20[b] ± 0.219	< 0.0001
Cook Loss, %	18.92 ± 0.596	19.67 ± 0.564	19.88 ± 0.555	19.39 ± 0.564	0.6762
WBSF, kg	2.01[a] ± 0.075	1.94[a] ± 0.071	2.49[b] ± 0.070	2.63[b] ± 0.071	< 0.0001

[a,b,c] Means lacking a common superscript differ ($P < 0.05$)

[1] Treatments: 1) no antibiotics (NA, receiving no technology); 2) non-hormone treated cattle (NHTC), fed Rumensin (300 mg •steer^{-1}• d^{-1}) and Tylan (90 mg •steer^{-1}• d^{-1}) during finishing; 3) implant (IMPL), administered a series of three implants including a low-potency calf implant (36 mg zeranol), a moderate-potency initial feedyard implant (80 mg trenbolone acetate and 16 mg estradiol), and a high potency finishing re-implant (200 mg trenbolone acetate and 20 mg estradiol) and fed Rumensin (300 mg •steer^{-1}• d^{-1}) and Tylan (90 mg •steer^{-1}• d^{-1}) during finishing, and 4) implant plus fed the beta-agonist (IMBA) ractopamine hydrochloride (200 mg •steer^{-1}• d^{-1}) for the last 30 d prior to harvest.

[2] Probability of a difference among least squares means.

[3] Measurements were determined by trained SDSU personnel according to USDA-AMS grading standards.

[4] Marbling score: 300 = Slight^{0}; 400 = Small^{0}; 500 = Modest^{0}; 600 = Moderate^{0}.

[5] Skeletal maturity: 100 = A0; 200 = B0; 300 = C0.

CHAPTER IV

Identifying consumer preferences and willingness-to-pay for beef raised in different production systems

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ABSTRACT

The objectives of this study were to evaluate meat quality characterisitcs, identify consumer palatability preferences, willingness-to-pay (WTP), and label preferences for beef raised in different production systems. Untrained consumer panelists (*n* = 105) were recruited from the surrounding areas of St Paul, MN to determine their share of preference (SOP) for beef palatability, willingness-to-pay (WTP), and label preferences for beef raised from four treatments: 1) no antibiotics or growth promotants ("raised without antibiotics"; NA); 2) non-hormone treated ("raised without hormones"; NHTC); 3) implant (IMPL); and 4) IMPL plus a beta-adrenergic agonist (IMBA). Carcasses were evaluated for marbling score, striploins were collected, steaks were fabricated (2.54 cm), vacuum packaged, and aged for 14 d before freezing for meat quality and consumer analyses. Steaks for the meat quality analyses were analyzed for percent lipid, moisture, cook loss, and Warner-Bratzler shear force (WBSF). During the consumer analysis, panelists participated in three consecutive panels to determine their SOP and change in SOP between panels including: 1) Undisclosed with Meat (samples provided with no production information); 2) Disclosed without Meat (only production information provided); and 3) Disclosed with Meat (samples provided along with production

information). Meat quality analyses for marbling score and percent lipid were similar ($P > 0.05$) between NA and NHTC and greater ($P < 0.05$) than IMPL and IMBA, which were similar ($P > 0.05$). The WBSF values of NA and NHTC were similar ($P > 0.05$) and more tender ($P < 0.05$) than IMPL and IMBA, which were similar ($P > 0.05$). During the Undisclosed without Meat panel treatment influenced ($P < 0.05$) panelist SOP. The NA was most preferred ($P < 0.05$) and IMBA was least preferred ($P < 0.05$), while NHTC and IMPL were intermediate and similar ($P > 0.05$). In the Disclosed without Meat panel each treatment influenced ($P < 0.05$) panelist SOP. The NA was most preferred ($P < 0.05$), NHTC was intermediate ($P < 0.05$), and IMPL was more preferred ($P < 0.05$) than IMBA. In the Disclosed with Meat Panel, each treatment influenced ($P < 0.05$) panelist SOP. Treatment NHTC was most preferred ($P < 0.05$), NA was intermediate ($P < 0.05$), and IMPL was more preferred ($P < 0.05$) than IMBA. During the Undisclosed with Meat and Disclosed without Meat panel, treatment did not influence ($P > 0.05$) panelist WTP. However, during the Disclosed with Meat panel, each treatment influenced ($P < 0.05$) panelist WTP. Panelist were WTP more ($P < 0.05$) for NHTC, NA was second highest ($P < 0.05$) in value, and IMBA was higher valued ($P < 0.05$) than IMPL. In regard to panelists' preference of labeling descriptions for each treatment, panelists' preferences were not influenced ($P > 0.05$) by label descriptions within treatment. In conclusion, treatments utilizing growth promoting implants, with and without a beta-adrenergic agonist, increased WBSF, which may be detectable by untrained consumer panelists as NA and NHTC captured greater SOP in both Undisclosed and Disclosed with Meat panels. During the Disclosed with Meat panel, NHTC was the most preferred followed by NA, indicating that when information is provided consumers are accepting and WTP

more for beef judiciously provided an antimicrobial and antibiotic to ensure animal health.

INTRODUCTION

Producing more food with fewer resources to feed 9 billion people by 2050 is a global goal (AgMRC, 2012). If cattle with the genetic potential to grow are provided adequate nutrition, growth promotant technologies (Rumensin, Tylan, anabolic implants, and beta-adrenergic agonist (β-AA)) can enhance beef production efficiency and contribute significantly to the goal of producing more food with fewer resources. Use of ractomamine-HCl (RH) has been shown to improve ADG and feed efficiency of cattle (Avendano-Reyes et al., 2006; Walker et al., 2006), while implants increase protein deposition by enhancing both the rate and efficiency of muscle growth (Dayton and White, 2014). These technologies have also been reported to mitigate NH_3 and greenhouse gas emissions (Stackhouse et al., 2012). However, the benefits of these technologies on environmental measures and produciton efficiency may not be well understood by consumers (Troy and Kerry, 2010). In fact, consumers are increasingly demanding beef with credence attributes such as cattle "raised without antibiotics" and "raised without hormones" (Andersen, 1994; VanOverbeke, 2007; USDA-AgMRC, 2017). Given this dichotomy between reducing resource utilization and decreasing the use of technology, it is critical to understand the influence of different growth promoting technologies on measures of meat quality and consumer preferences related to these traits (Mathews and Johnson, 2013). Providing consumer panelists beef with and without production information to identify shares of preference (SOP) and the change in SOP, willingness-to-pay (WTP), and identify label preferences will offer insight to more appropriately differentiate beef marketing. Therefore, the hypotheses are that objective measures of meat quality will differ among treatments and panelists will not be able to

detect these differences in palatability but will prefer treatments using less technology when production information is provided. Therefore, the objectives of this study were to evaluate meat quality characterisitcs, identify consumer palatability preferences, WTP, and label preferences for beef raised in different production systems with differing levels of growth promotant technology.

MATERIALS AND METHODS

Research procedures involving human subjects at the commercial consumer testing center were exempt from the Common Rule (CFR 45 Part 46.101). All protocols were approved by South Dakota State University Human Subjects Committee (IRB-1702018-EXM).

Sample Collection

One hundred and twenty beef strip loins (IMPS #180; AMS, 2014) from the left side of carcasses representing four different treatments were collected for analysis. Prior to carcass fabrication, South Dakota State University (SDSU) personnel used official USDA grade standards to assign USDA marbling scores at a commercial beef processing facility in Lexington, NE. The beef striploins analyzed represented these four treatments: 1) no-antibiotic and no technology utilized (NA; "raised without antibiotics" and serves as the control); 2) non-hormone treated, but fed Rumensin and Tylan during the finishing phase (NHTC; "raised without hormones"); 3) implanted with a series of three implants and fed Rumensin and Tylan during the finishing phase (IMPL); and 4) IMPL treatment plus fed ractopamine-HCI (RH) 200 mg • $steer^{-1}$ • d^{-1} 30 d prior to harvest (IMBA). The IMPL and IMBA treatments were administered a series of three implants including a low-potency calf implant [36 mg zeranol; Ralgro, Merck Animal Health, Madison, NJ] at an average of 74 ± 12 d of age, a moderate-potency initial feedyard implant [80 mg trenbolone acetate and 16 mg estradiol; Revalor-IS, Merck Animal Health] at an average of 235 ± 12 d of age, and a high potency finishing re-implant [200 mg trenbolone acetate and 20 mg estradiol; Revalor-200, Merck Animal Health] at an average of 330 ± 12 d of age.

Product Handling

Striploins were transported under refrigeration (2°C) to the SDSU Meat Laboratory where the exterior fat was trimmed to 0.64 cm and the connective tissue, *gluteus medius*, and *multifidus dorsi* were removed. After trimming the *loingissimus dorsi* steaks were fabricated to 2.54 cm and individually vacuum-sealed and wet-aged in the absence of light at 2-3°C for 14 d. A sub-set (n = 72) of striploins representing the mean marbling score of each treatment were selected for meat quality and taste panel analyses. Marbling scores are provided in Table 4.1. In order to accommodate the experimental design, 16 striploins were included in the subsample for NA, NHTC, and IMBA and 24 striploins were selected from the IMPL treatment. The anterior face of the left striploin was removed and utilized to determine ether extractable fat and additional steaks from the right striploin were designated for Warner-Bratzler shear force (WBSF) analysis following the same procedures as described in Chapter III. The remainder of the left striploin was fabricated into 2.54 cm steaks and the first and second most anterior steaks per striploin were paired to minimize variation of anatomical location for the consumer panel composition, described below. Post fabrication, individual steaks were vacuum-sealed and checked regularly to ensure seal integrity. Immediately after wet-aging for 14 d at 2-3°C, steaks were frozen (-20°C) and remained frozen until thawed.

Panel Composition

Consumer sensory sessions were conducted at a private consumer research and testing facility (Food Perspectives Inc. (FPI), Plymouth MN). Untrained consumer panelists (n = 105) were recruited from the surrounding areas of St Paul, MN. Panelists were recruited so that sex (50% female and 50% male) was nearly proportional among

the analyses. Four sessions consisiting of approximately 26 confirmed beef consumers (consumed beef at least one time per week) per session participated for compensation. Within each session, there were three panels delivered in the following order: 1) Undisclosed with Meat (samples provided with no production information); 2) Disclosed without Meat (only production information provided); and 3) Disclosed with Meat (samples provided along with production information). Within each panel, three flights of treatments were delivered in a randomized set of three samples so that the four treatments could have direct comparison and panelists could select their most and least preferred sample among the three treatments or sample options per flight. Each session lasted approximately 1.5 h. Individual panelists were provided: an electronic survey on an iPad (Apple, Cupertino, CA); an expectorant cup; bottles of purified water and apple juice; and unsalted crackers. To reduce any bias of researcher presence, FPI staff instructed panelists to cleanse their palate between each sample and judge each sample on palatability. Researchers were able to confirm procedures by monitoring each session through visual mirrors and on a television screen.

Sample Preparation

Samples were thawed at 2-3°C for 24 h prior to cooking. All samples were monitored with a MicroNeedle probe AquaTuff thermometer (Model 35140, Cooper-Atkins Corporation, Middlefield, CT) while cooking to monitor acheivemnt of the target peak temperature (71ºC; range = 69.3 – 74.8 ºC). Steaks were cooked on electric clamshell grills (George Forman 9 Serving Classic Plate Grill, Model GR2144P, Middleton, WI). All cooked steaks were allowed to rest for four min to allow juices to redistribute prior to cutting. To maintain an acceptable sample temperature all cutting and portioning was

conduted under heat lamps. Steaks were trimmed of external edges and connective tissue prior to being portioned into samples (1.27 x 1.27 cm). Each consumer was given two samples to represent each treatment for palatability evaluation within each flight. Immediately after portioning, samples were placed on plates and stored in a warming oven set at 50°C until serving.

Consumer Panels

On each plate, three treatments were represented according to a randomly generated number corresponding to the iPad survey instrument (Qualtrics, Provo, UT) to allow for direct comparison among treatments, as previously mentioned. During the Undisclosed and Disclosed with Meat panels, the FPI staff served prepared plates to each panelist. The sensory panel was designed such that panelists were asked to evaluate four treatments during flights 1 to 3. Panelist were asked by FPI staff to wait to evaluate the next sample until their palates were cleansed. After consuming the treatments represented on each plate, panelists were instructed by FPI staff to identify their most and least preferred sample during each flight's randomized treatment comparison. Panelist were able to select their most and least preferred sample by touching the randomly generated number corresponding to their sample selection on an individual iPad. The Undisclosed with Meat panel was conducted to determine panelist palatability preference of treatments, with no other information provided. After making their most and least preferred sample selection, panelists were automatically asked to rate the tenderness, juiciness, beefy flavor, and overall acceptability of their most preferred sample. Attribute description responses were measured on a continuous line scale ranging from 0% to 100%.

Prior to indicating WTP for the most preferred sample, a cheap talk script was presented to panelists to reduce hypothetical bias. Hypothetical bias is the difference between hypothetical behavior and behavior under real economic consequences (Tonsor and Shupp, 2011). A WTP analysis emulating the procedures of Tonsor (2012) required panelists to answer a double-bounded, dichotomous choice question: 'would you be willing-to-pay $10.35 for a 12 oz. boneless Beef Loin Top Loin Steak, also known as a Strip Steak, with the same characteristics as your most preferred sample?' Based on the panelists "No" or "Yes" response, Qualtrics randomly generated a second value for consideration. If the panelist selected "No," the new value ranged between $5.00 to $10.29/12 oz., or approximately 50% less than $10.35/12 oz. If the panelist selected "Yes," the new value ranged between $10.40 to $15.00/12 oz., or approximately 50% more than $10.35/12 oz. Attribute description and WTP was not requested for the least preferred sample to prevent panelist fatigue. After each flight, any remaining samples and waste were discarded.

For the second panel, Disclosed without Meat no beef products were provided but panelists were provided cattle raising information relative to each production system (Table 4.2). Consistently, three of the four treatments were provided within each flight so that direct comparisons between treatments could be made. Three flights were used to assess panelist preference of each treatment by selecting the most and least preferred sample using iPads. This panel was conducted to determine panelists' perception of the treatment's production information. Willingness-to-pay was requested for the panelists most preferred selection.

In the final panel, Disclosed with Meat, panelists were provided with both cattle raising information for each treatment and the corresponding beef samples to assess palatability. The FPI staff encouraged panelists to read each treatment production information first then, consume the sample to make selections of their most and least preferred sample within flight. This panel was conducted to determine both perception and palatability of treatments. As described previously, attribute description and WTP was determined for only the most preferred selection. At the conclusion of each session, all waste was discarded and serving areas were re-set. Qualtrics automatically saved individual consumer survey selections.

Ranking of Labels

Prior to the consumer panel, researchers developed product label claims and corresponding statements to represent each beef production system using animal performance data and environmental output estimates reported in Chapter II, claims and statements were developed according to the Animal Raising Claims for Label Submission Guidelines (USDA-FSIS, 2016). The claims and corresponding statements were reviewed by the United States Department of Agriculture-Food Safety Inspection Service (USDA-FSIS) Labeling and Program Delivery Division (LPDD) to assess acceptability for commerce. Further, USDA (2002) has adopted the terms “no antibiotics added,” “no antibiotics administered,” or “raised without antibiotics” to replace “antibiotic free”, which is considered mislabeled as USDA cannot guarantee this due to limitations of scientific testing procedures. Utilizing LPDD staff to review label claims provided assurance that the novel labels were not mislabeled or false and misleading (U.S. Code, 2012, tit. 21, §§333, 352).

An online pre-survey of ten labels (containing a claim and a corresponding statement) per treatment was conducted using an online survey software instrument (Decipher; Atlanta, GA). The pre-survey captured 500 beef consumer responses balanced across the Northeast, Midwest, Southern, and Western US to rank label descriptions for each treatment from 1 to 10 (1 = best representation through 10 = worst representation). Survey respondents were balanced by sex (50% female and 50% male) and selected from a population that was the primary household shopper or shared shopping responsibility. The survey response time (averaged 15.23 min) was monitored to ensure adequate surveys were collected for preference determination. The top five product label descriptions identified per treatment were re-assessed during the in-person FPI consumer panel. At the conclusion of the three panels, panelists were asked to rank product label descriptions 1 to 5 (1 = best representation through 5 = worst representation) according to preference for each of the four treatments using an individual iPad.

Demographic Questionnaire

At the conclusion of each session, panelists were asked to complete a demographic survey to quantify: a) sex; b) household size; c) marital status; d) age; e) household income; f) education level; g) weekly beef consumption; h) weekly physical activity; and i) eating habits. Panelists were also asked to identify their most trusted source for third-party process verification for products that require auditing such as Organic and Grass Fed beef.

Focus Group

A sub-set (n = 18) of panelists were selected according to beef eater type (light = consumed beef 1 – 2 times per week; medium = consumed beef 3 – 4 times per week; and

heavy = consumed beef atleast 5 times per week) to participate in a 30 min focus group at the end of the third panel. Panelists were screened to ensure they would be wiling to verbally share their opinions for focus group qualification. Six compensated panelists from each beef eater type (light, medium, and heavy) with sex and income balanced as much as possible, participated. There were a total of three focus groups conducted. The focus group took place in a controlled room without distractions. Researchers watched the exchange through a one-way mirror and could listen to the discussion via a speaker system allowing for responses to be recorded. A recording of the sessions was also collected to allow the moderator to analyze and generate a report. A FPI professional moderator was used to ask panelists a series of questions to better understand consumer perceptions and marketing preferences.

Statistical Analysis

Meat quality analyses were statistically conducted as outlined in Chapter III. For the consumer panel analyses, the PROC OPTEX function of SAS 9.4 was used to determine the number of samples served per panel and the randomized sample serve order per flight. Four treatments were randomized into three flights, where each of the four treatments appeared randomly in an unbalanced, randomized complete design so that each treatment was compared to each other treatment at least once. Utilizing this method for selection reduced selection bias in comparison to alternative rating options because there was only one way to make selections (Cohen and Neira, 2003). These data were analyzed using a multinomial logit (MNL) model. The resulting MNL coefficient estimates were used to calculate the SOP, or the percentage of preference for each of the four treatments among the panelists (Wolf and Tonsor, 2013). Although the MNL

coefficient estimates have little to no economic interpretation, the SOP convey the importance, or relative liking, of treatments. The calculated SOP results in a percentage determined by the number of times a treatment was selected as best (*j*) and worst (k) collectively from all panelists (Wolf and Tonsor, 2013). The following SOP equation, $j = e^{\lambda_j} / \sum_{k=1}^{j} e^{\lambda}$, was used to calculate the SOP where λ represents the coefficient estimate generated from the MNL output (Wolf and Tonsor, 2013). Following Wolf and Tonsor (2013), the SOP for each treatment were tested to see if they differed from each other treatment. Following Krinsky and Robb (1991) and Poe (2005), the MNL estimated coefficients and variance terms were simulated by 1,000 using a multivariate normal distribution and a complete combinational test was used to assess pairwise comparisons. Pairwise comparisons allowed researchers to empirically test if statistical differences existed among the SOP for all treatments within each panel. Significance was determined at $P \leq 0.05$.

Consumer demographics were analyzed using a random effect binary logistic regression model that was fitted using the PROC GLIMMIX function of SAS 9.4. Treatment served as the fixed effect and panelists were included as a random intercept. The Tukey adjustment for multiple testing procedures was used to separate the factor levels (sex, household size, etc.) and the Loess Smooth function was used for model diagnostics. Least squares means were compared using the PDIFF option when F-tests were significant when $P \leq 0.05$ and tendencies were considered when $P > 0.05$ to ≤ 0.10.

Panelist ratings for descriptive attributes including: tenderness, juiciness, beefy flavor, and overall acceptability were analyzed using the PROC MIXED function of SAS 9.4. Treatment served as the fixed effect and panelist was the random effect. The

denominator degrees of freedom were approximated by the Kenward-Roger option in the model statement. Least squares means were compared using the PDIFF option when F-tests were significant when $P \leq 0.05$ and tendencies were considered when $P > 0.05$ to ≤ 0.10.

Panelist WTP was analyzed using the PROC LIFEREG procedure by evaluating the double-bounded, dichotomous choice responses for the most preferred treatment per flight. To determine the influence of treatments within each panel, a pooled restricted model within treatment was compared to treatments unrestricted model as described by Tonsor (2012). Pooling within treatment allowed for determination of WTP difference among all treatments. A likelihood ratio test was used to test the null hypothesis to determine if WTP was the same per treatment, similar to Tonsor (2012). If the null was rejected, it implies that at least one of the treatments had a different WTP. Therefore, treatment mean WTP estimates were calculated and six comparisons were made among all possible treatment combinations. Significance was determined when $P \leq 0.05$.

Treatment label descriptions were analyzed using a random effect multinomial logistic regression model with a cumulative logit link for ranking using labels as a factor. Least squares means were compared using the PDIFF option when F-tests were significant when $P \leq 0.05$ and tendencies were considered when $P > 0.05$ to ≤ 0.10.

RESULTS AND DISCUSSION

Meat Quality of Sensory Steaks

For the meat quality analysis, the same sub-set (n = 72) of striploins representing treatment mean marbling scores were analyzed to characterize the consumer sensory steaks. Treatment influenced ($P < 0.05$) percent crude fat and moisture (Table 4.3). Percent lipid was similar ($P > 0.05$) between NA and NHTC, which were 1.5% greater ($P < 0.05$) on average than IMPL and IMBA, which were similar ($P > 0.05$). However, all treatments had a fat percentage above 3%, which is proposed by Savell and Cross (1988) to be the minimal percentage of intramuscular fat necessary for consumer acceptability. As expected, percent moisture was inverse to percent lipid. The NA and NHTC were similar ($P > 0.05$) and had less ($P < 0.05$) percent moisture than IMPL and IMBA, which were similar ($P > 0.05$). In regard to IMPL and IMBA, Garmyn et al. (2014) also found no influence on percent crude fat or moisture when comparing British-type steers fed RH (308 mg • steer^{-1} • d^{-1}) to implanted steers not fed RH.

The percent cook loss was similar ($P > 0.05$) between IMPL and IMBA, though IMBA was not different from NA ($P > 0.05$; Table 4.3). In regard to IMPL and IMBA, Arp et al. (2013) also reported no difference in percent cook loss between treatments fed RH (200 mg • steer^{-1} • d^{-}) and an implanted control not receiving RH. Though Garmyn (2014) reported steers fed RH (308 mg • steer^{-1} • d^{-}) produced steaks that had a greater percent cook loss compared with a control. Perhaps this variation in percent cook loss is due to the differences in the level of RH supplemented.

To determine objective tenderness for each production system, the right strip loin was used to obtain the three most anterior steaks for postmortem aging periods of 7, 14,

or 21 d as outlined in Chapter III. No interaction was detected for WBSF ($P = 0.52$) among treatments and aging period however, tenderness improved ($P < 0.001$) with postmortem aging (2.45 ± 0.05 kg, 2.21 ± 0.04 kg, 2.14 ± 0.04 kg for 3, 14, and 21 d respectively). Overall, steaks from NA and NHTC were more tender ($P < 0.05$) by 0.29 kg than steaks from IMPL and IMBA, which were similar ($P > 0.05$; Table 4.4). In regard to IMPL being tougher than NA and NHTC, other studies have indicated that implants have minimal influences on beef tenderness in comparison to a non-implanted control (Belk and Cross, 1988; Duckett et. al., 1996; Pritchard, 2000). Moreover, Gerken et al. (1995) determined cloned Brangus steers administered a single androgenic and combination implant in comparison with a control were not tougher. Barham et al. (2003) implanted *bos indicus* influenced cattle and confirmed implant treatment did not increase WBSF in comparison with a non-implanted control. Perhaps variations in implant protocol, potency, breed, and postmortem aging duration is reasoning for these differences in comparison to the current study. Though consistent with the current study, Foutz et al. (1997) determined the use of two trenbolone acetate implants caused steers to produce carcasses with tougher steaks than steers only implanted once using trenbolone acetate, or twice with estradiol. Other research also confirms that the use of implants increased steak toughness (Morgan et al., 1997; Roeber et al., 2000; Platter et al., 2003a). Though in a review by Hutcheson (2008) implant treatment effects on WBSF gradually diminish with greater postmortem aging and conclude there are little negative effects from growth promotant implants on beef tenderness. Regardless, all treatment WBSF values were below 3.9 kg of shear force, which is the threshold value for consumer desirability (Shackelford et al., 1991) and the certified very tender claim (ASTM, 2011).

In regard to IMBA, a majority (approximately 60-80%) of cattle on feed in the US are fed RH (Chichester, 2017). The negative influence of RH on carcass tenderness has been described as minimal and manageable with adequate postmortem aging (Scramlin et al., 2010; Boler et al., 2012; Garymn et al., 2014). For example, Arp et al. (2013) fed steers RH at 200 mg • steer^{-1} • d^{-1} and discovered steaks were similar to the non-supplemented control. However, steers fed RH at 300 and 400 mg • steer^{-1} • d^{-1} produced carcasses with steaks that were similar and tougher in WBSF values in comparison to the non-supplemented control (Arp et al., 2013). Multiple research studies have found an increase in shear force due to supplementation of RH in comparison to a non-supplemented control (Avendaño-Reyes et al., 2006; Strydom et al., 2009; Scramlin et al., 2010; Boler et al., 2012; Garmyn et al., 2014). However, some of these studies have also concluded that postmortem aging 14 d or more mitigated differences in tenderness (Scramlin et al., 2010; Garmyn et al., 2014). Garymn et al. (2014) noted an interaction between RH supplementation and aging where, RH responded greater to 21 d aging and consequently resulted in the lowest WBSF values in comparison with a control. In the current study, aging steaks only 14 d did not improve tenderness of IMBA to the same level as steaks from non-RH supplemented steers. Perhaps aging more than 14 d would produce results more similar to Garymn et al. (2014).

Demographics

Demographic information was obtained from 105 recruited panelists (Table 4.4), which have similar demographics to the US population according to the 2011-2015 American Community Survey 5-year estimate (US Census Bureau, 2017). The sensory, perception, and beef production system marketing preferences were evaluated by male

(50.5%) and female (49.5%) panelists, which is similar to the US population (49.2% male and 50.8% female; US Census Bureau, 2017). The US Census Bureau (2017) median annual household income was $53,889, which represents 27.6% of recruited panelists and 71% of all panelist households earned at least $50,000 annually. The median age of people living in the US is 37.6 years therefore, panelists in this study (mean = 50 yr) were older as the "Baby Boomer" generation (over 50 years of age) accounted for the greatest percentage (60%) of the sampled population, "Millennials" (ages 18 to 34) accounted for the second greatest percentage (23%), and "Generation X" (ages 35 to 50) accounted for the lowest percentage (17%) of the sampled population. The FPI recruitment process validated that all panelists consumed beef at least one time per week. The beef consumption group with the greatest percentage of participants (52%) was "Medium" beef-eaters who consumed beef 3 - 4 times per week. The "Light" beef-eaters consumed beef 1 - 2 times per week and comprised the second largest percentage (39%) of panelists. Therefore, 91% of panelists were considered "Medium to Light" beef eaters.

Shares of Preference

Horsley (2015) described palatability-related preferences for beef branding and marketing for Certified Angus Beef (CAB) steaks. The CAB steaks were rated 10% higher for consumer overall liking when identified with the CAB Brand, indicating the potential to differentiate preferences based on label information. In effort to analyze beef consumer preferences and perception of different production systems, individual panelist results were combined and SOP for each treatment were determined (Fig. 4.1). In order to evaluate SOP for beef palatability, panelists were provided samples from each production system without any additional information. During this Undisclosed with Meat panel

treatment influenced ($P < 0.05$) SOP. The NA had the greatest ($P < 0.05$) SOP, NHTC and IMPL were similar ($P > 0.05$) and intermediate ($P < 0.05$) to IMBA, which was least preferred ($P < 0.05$; Table 4.5). The order of preference by percentage was: 1) NA, 27.82%; 2) NHTC, 26.39%; 3) IMPL, 25.91%); and 4) IMBA, 19.88%. Similar to the current findings for IMBA, Gruber et al. (2008) reported that trained sensory panelists rated steaks from steers fed RH (200 mg • steer^{-1} • d^{-1}) lower for tenderness, juiciness, and slightly lower for beef flavor in comparison with a control. In the same study, untrained panelists agreed with trained panelists that there were differences in palatability from RH supplementation (Gruber et al., 2008). Though in the current study, consumers were unable to differentiate between NHTC (26.39%) and IMPL (25.91%) during the Undisclosed with Meat panel ($P > 0.05$). Similarly, Harsh et al. (2015) reported that natural (similar to NA treatment receiving no growth promotants and no Rumensin or Tylan) and conventionally implanted (similar to IMPL treatment receiving 40 mg of estradiol and 200 mg of trenbolone acetate on d 0 and fed 33 and 9 mg/kg of monensin and tylosin daily, respectively) steers produced carcasses with steaks that were similar in tenderness and palatability during trained and untrained consumer panels. However, Harsh et al. (2015) did not detect differences in tenderness or palatability for conventional plus fed zilpaterol hydrochloride (ZH), which is inconsistent with the current study as IMBA was least preferred (19.88%) by panelists during the Undisclosed with Meat panel ($P < 0.05$). Perhaps this inconsistency between ZH supplementation in Harsh et al. (2015) and the current study is due to the type of β-AA supplemented and its potency. However, Arp et al. (2013) used trained sensory panelists and determined

tenderness ratings for steaks from steers fed RH 300 and 400 mg • steer^{-1} • d^{-1} were rated lower in tenderness than steaks from steers not supplemented RH.

At retail, consumers must make meat purchases prior to tasting, based on appearance of the meat and evaluation of the label information (Brunsø et al., 2005; Grunert, 2005). Therefore, to determine if intrinsic cues influence behaviors and perceived satisfaction, treatment production system information was evaluated without sampling any beef. During this Disclosed without Meat panel, the same panelists participated and were asked to provide their preferences for production system information (Table 4.6). Each treatment's production system information influenced ($P < 0.05$) SOP among panelists in the follow order: 1) NA (50.41%); 2) NHTC (32.17%); 3) IMPL (11.88%); and 4) IMBA (5.53%). Consumer perception was responsible for these differences and has been shown to influence behavior (Troy and Kerry, 2010). In contrast, European studies indicate that origin labeling has no influence on consumer quality evaluations or impacts on purchasing preference (Bonnet and Simioni, 2001; Grunert 2005). Although consumers have differences in perception, they still find it challenging to predict eating quality prior to consumption (Brunsø et al., 2005).

To further investigate product palatability combined with product information, the same panelists participated in a Disclosed with Meat panel, which revealed treatment influenced ($P < 0.05$) panelists SOP for both palatability and perception (Table 4.7). Though USDA-FSIS has permitted products labeled as "raised without the use of antibiotics" to be marketed in effort to reduce potential development of antibiotic-resistant bacteria from food products (Levitt, 2015). However, results of this study indicate a greater preference for NHTC (36.68%) compared with NA (34.01%; $P < 0.05$),

which indicates that when panelists are able to taste and evaluate production information they preferred the NHTC treatment. Further, panelists preferred IMPL (19.68%) to IMBA (9.63%; $P < 0.05$). The order of preference differed ($P < 0.05$) among each treatment as follows: 1) NHTC (36.68%); 2) NA (34.01%); 3) IMPL (19.68%); and 4) IMBA (9.63%). In comparison to the Undisclosed without Meat panel, when panelists were provided production system information in addition to product palatability SOP for NA lifted 6.19% and NHTC lifted 10.29%. Whereas, SOP for IMPL decreased 6.23% and IMBA decreased 10.25% (Fig. 4.1).

The CAB study reported by Horsley (2015) determined that the CAB Brand disclosure largely influenced palatability ratings and resulted in a 10% brand lift for overall liking and 13% brand lift for overall flavor liking. However, steaks merchandized as USDA Select resulted in a 10% brand decrease in tenderness ratings. In a separate study conducted by Brunsø et al. (2005), consumers were evaluated 'before purchase' and 'after purchase' for preferences of culled dairy cow beef from different fattening diets. To validate this study, Grunert (2005) evaluated additional fattening diets and determined consumers were subjectively influenced by visual quality perceptions. Moreover, consumers demand credence attributes for enhanced trust (Andersen, 1994). For growth promotant technology continued use, it is paramount to determine options for credence attribute development (Troy and Kerry, 2010). However, major American meat vendors are committing to not use antibiotics in animals that supply meat products (Strom, 2015; Centner, 2016). Though the current results agree with Troy and Kerry (2010) that consumers can recognize benefits and effective communication of risk must be transparent. Perhaps consumer messaging about the federal law inhibiting antibiotic drug

residues at an unsafe level in meat products is needed (U.S. CFR, 2016, tit. 21 § 510.110).

Influence of Consumer Demographics on Shares of Preference

Results from the SOP for each panel and consumer demographic information for those corresponding selections were analyzed to determine if a relationship exists for preference. During the Undisclosed with Meat panel, preference for NA was influenced ($P < 0.05$) by beef eater type. The most preferred selection of NA, was more ($P < 0.05$) by heavy (33%) and light (30%) beef eaters compared with medium (19%) beef eaters (Table 4.8). Also during the Undisclosed with Meat Panel, household size, marital status, age, and beef consumption group tended ($P < 0.10$) to influence panelists least preferred selections (Table 4.9). Barham et al. (2003) also evaluated palatability among consumer demographics but determined additional education post-high school decreased beef attribute ratings for overall quality, flavor, juiciness, and tenderness. Perhaps these consumer panelists were more sensitive and had more developed beef quality desires that allowed them to be more particular in preference. In some similarly to the present study, family income did not influence overall quality, beef flavor, juiciness, or tenderness scores (Barham et al., 2003).

Demographics were also evaluated to determine if there was an influence on preference based on production system information during the Disclsoed without Meat panel. Panelist demographics influenced ($P < 0.05$) the most preferred selection of NA and IMPL. Females (58%) were 14% more ($P < 0.05$) likely than males (44%) to select NA as the most preferred production system (Table 4.10), whereas males (17%) were 12% more ($P < 0.05$) likely to prefer IMPL than females (5%). Verbeke and Ward (2005)

reported similar findings for males who had a lower interest in quality guarantees. Further in the Disclosed without Meat panel, sex tended ($P < 0.10$) to influence panelists least preferred selections of IMPL (Table. 4.11). Females (45%) were 8% more ($P < 0.05$) likely to dislike ($P = 0.07$) IMPL than males (37%).

To determine the influence of palatability and production information, panelist demographics were evaluated following the Disclosed with Meat Panel. Demographics did not influence ($P > 0.05$) the most preferred selections of all production systems (Table 4.12). Though, panelist demographics did influence ($P < 0.05$) the least preferred selections for NHTC and IMPL (Table 4.13). Marital status influenced ($P < 0.05$) preference for NHTC, single (9%) panelists preferred NHTC 4% less than those who were married (5%). Also, heavy beef eaters (22%) preferred NHTC 17% less than medium (5%) beef eaters ($P < 0.05$), though light beef eaters were similar in preference ($P > 0.05$). Perhaps heavy beef consumers were less concerned about hormone use in beef production. Household size also influenced ($P < 0.05$) panelists' least preferred selections of IMPL. Single households (40%) preferred IMPL 12% less ($P < 0.05$) than two-person households (28%), though households with three or more persons were similar ($P > 0.05$). Marital status and beef consumption group tended ($P < 0.10$) to influence panelists least preferred selections for IMPL (Table 4.13). Married persons (35%) were 2% more likely ($P = 0.08$) to dislike IMPL in comparison with single persons (33%). Medium beef eaters (37%) were most likely ($P = 0.09$) to dislike IMPL by 6% in comparison with Light beef eaters (31%), who were intermediate ($P < 0.10$) to Heavy beef eaters (26%) that were least likely ($P < 0.10$) to dislike IMPL.

Consumer Sensory Attributes

Untrained sensory panelist ratings for tenderness, juiciness, flavor, and overall acceptability for the Undisclosed with Meat panel are provided in Table 4.14. Panelist ratings for subjective tenderness reflected the WBSF results with the exception that panelists found IMPL (76.34%) to be rated similar to NA (76.21%) and NHTC (77.52%) for tenderness ($P > 0.05$). Wheeler et al. (2004) determined untrained consumer panelists have the ability to repeatedly (80%) be accurate when evaluating tenderness of the *longissimus* and provide effective differentiation between tender, intermediate, and tough steaks. Similar to the current study, Barham (2003) also determined consumer panelists rated steaks from implanted animals tougher than an unimplanted control. Additionally, in the present study marbling scores were similar between NA and NHTC and previous research efforts have found greater marbling to be associated with improved consumer tenderness, juiciness, flavor, and overall palatability ratings (Smith et al., 1985, Lorenzen et al., 2003, and O'Quinn et al., 2015). Perhaps increased toughness found in this study for IMBA is due to the effects of β-AA on postmortem tenderization described by Goll (1997) and illustrated by Strydom et al. (2009) causing greater calpastatin activity and potentially increased collagen cross-links (Roy et al., 2015) causing a decrease in tenderness (Scramlin et al., 2010; Boler et al., 2012; and Garmyn et al., 2014). Though, Garmyn et al. (2014) determined that steaks supplemented with RH were similar to the control for consumer ratings of tenderness and overall liking. Also, Arp et al. (2013) found trained panelists to be unable to detect variations in the level of RH fed (200 vs. 300 mg • steer^{-1} • d^{-1}) on ratings for tenderness, juiciness, and flavor.

In regard to juiciness, untrained panelists found NHTC (67.89%) to be juicier than IMBA (59.41%; $P < 0.05$). In contrast, Barham (2003) did not find steaks from

unimplanted control cattle to be juicier than steaks from implanted cattle. In the current study, beef flavor was consistent with juiciness, as NHTC (71.46%) was rated higher ($P < 0.05$) for beef flavor than IMBA (63.93%). Perhaps differences in consumer ratings for juiciness were influenced by consumer ratings for beef flavor and tenderness as described by O'Quinn et al. (2015). Though, juiciness and beef flavor were similar ($P > 0.05$) between NA, IMPL, and IMBA. Overall acceptability tended ($P = 0.08$) to be influenced by treatment (Table 4.14). Treatments NA, NHTC, and IMPL were rated similar ($P > 0.10$) and tended to be rated higher ($P = 0.08$) in overall acceptability in comparison with IMBA.

Production system information and palatability influenced overall acceptability during the Disclosed with Meat panel (Table 4.15). Panelists ranked NA (80.74%) greater ($P < 0.05$) in overall acceptability than IMPL (74.32%) though, NHTC (77.77%) and IMBA (74.26%) were similar to all treatments ($P > 0.05$). Beefy flavor tended ($P = 0.08$) to be influenced by treatment where NA tended to be greatest ($P < 0.10$) in beefy flavor in comparison with NHTC, IMPL, and IMBA, which were similar ($P > 0.10$; Table 4.15). However, treatment did not influence panelist ratings for tenderness or juiciness ($P > 0.10$). In regard to the positive palatability contributions of NA for overall acceptability, O'Quinn et al. (2015) determined that as lipid level increased, consumer acceptability of tenderness, juiciness, flavor, and overall acceptability also increased, which indicates that lipid positively influences consumer palatability of beef strip steaks. However, NHTC had the same lipid content and marbling score as NA, therefore the discrepancy between NA and NHTC for reduced beef flavor may be due to individual consumer perceptions centered on health concerns and demographics (Resurreccion, 2004).

Willingness-to-pay

Panelist WTP during the Undisclosed with Meat panel is summarized in Table 4.16 and no differences ($P > 0.05$) were detected as the hypothesis was not rejected from the pooled panelist responses. To further investigate WTP, additional models were estimated for the Disclosed panels, though due to panelists selecting different preferences across panels, results were not compared. The Disclosed without Meat panel (Table 4.17) also had no differences ($P > 0.05$) detected as the hypothesis was not rejected from the pooled panelist responses. However, panelist WTP during the Disclosed with Meat panel (Table 4.18) was valued differently ($P < 0.05$) for each treatment as the hypothesis for the model was rejected.

As determined from the Disclosed with Meat panel, panelists' WTP based upon perception and palatability differed ($P < 0.05$) for each treatment in this order: NHTC, \$11.41; NA, \$11.34; IMBA, \$10.48; and IMPL, \$10.36 per 12 oz serving. The greatest ($P < 0.05$) WTP was for NHTC (\$11.41 per 12 oz. serving), which was valued \$1.05 more per 12 oz. serving than IMPL. In comparison, panelists' value differences between NA and NHTC were more similar (only differed by \$0.07 per 12 oz serving), whereas treatments with more levels of technology (IMPL and IMBA) had larger value differences (differed by \$0.12 per 12 oz. serving) when comparing between the lower and higher levels of growth promotant technology use. On average, panelists' valued limited use of technology (NA and NHTC; \$11.38 per 12 oz serving) \$0.96 more per 12 oz. serving in comparison to treatments (IMPL and IMBA; \$10.42) using increased levels of technology. These results are similar to Feuz et al. (2004) who determined WTP for palatability was influenced more by tenderness than marbling degree. Additionally,

Platter et al. (2005) found consumers to perceive differences in value for meat tenderness because they were likely to refuse purchasing of steaks if WBSF values increased. The IMPL and IMBA treatments had similar WBSF values, but were tougher than NA and NHTC, and consumers were WTP less for these treatments. However, when palatability and perception were evaluated together in the Disclosed with Meat panel, consumers were WTP more for beef provided an antibiotic and antimicrobial to maintain animal health and productivity. In other studies, consumers have been WTP more for meat products without antibiotics (McKendree et al., 2013; Sneeringer et al., 2015). Additionally, Farm News Media (2017) reported results from a Cargill Animal Nutrition survey that 54% of US consumers were willing to purchase beef raised without antibiotics. There may be a need to promote judicious antibiotic use to improve animal health and productivity.

Label Ranking

Beef labels provide extrinsic and intrinsic quality cues that guide consumers presumptions of product quality and allow them to form an expectation about the product, which relates to purchasing behavior, satisfaction, and future purchasing decisions (Brunsø et al., 2005; Grunert, 2005). Though, extrinsic label characteristics (i.e. color of the package) were not evaluated as the panel focused on intrinsic (i.e. production guarantees) characteristics. Further, intrinsic (i.e. guarantees to consumers) label guidance must be relevant to consumers for it to be effective and trustworthy (Brunsø, et al., 2005).

Panelists were asked to rank product label descriptions 1 to 5 (1 = best representation through 5 = worst representation) according to preference for each of the

four treatments. Panelists rankings for label descriptions by treatment are presented in Tables 4.19 to 4.22. While no statistical differences ($P > 0.10$) were detected among treatments, panelists were able to distinguish product label rank per production system. The highest ranked label descriptions for IMPL and IMBA show that panelists were accepting of antibiotics and growth promotants when "optimally used to maintain animal health and improve productivity", or "optimally used to maintain animal health in the event of illness and to increase productivity." Panelists ranked environmental conservation label descriptions lower than hypothesized. However, the focus group alludes to the need for more tangible examples of emission reduction and water use on label descriptions for improved beef marketing. During label development for each treatment, the amount of information provided for each label description was considered. Research has demonstrated that too much information may risk panelist overload and yield boredom and impatience (Sal-aün and Flores, 2001). Further, the cognitive capacity to read and process information and the desire to do so were considered as described by (Caswell, 1998). Perhaps a reason why there was no significance per treatment in label preference was due to the conclusion of Brunsø et al. (2005) indicating that consumers are unique and may have different types of quality desires and not all labels are preferred the same to each panelist. In retail application, consumers may make label selections based upon additional factors besides intrinsic quality cues, such as brand and price (Bredahl, 2004).

Trust in Third-Party Verification

In regard to panelists' trust and value for third-party process verification services of audited meat products (i.e. Organic and Grass Fed etc.), most panelists were likely

(85.7%) to prefer USDA followed by private agencies (2.9%). All other panelists either were not comfortable answering this question (6.7%), or thought these programs did not influence their purchases (4.8%). Similarly, Olynk and Ortega (2012) evaluated consumer WTP for verification preferences of dairy cattle management practices and determined USDA certification had the greatest WTP followed by the dairy industry in comparison with retailer certification. In this study, USDA is clearly the desired verification or certification entity trusted by panelists.

Focus Group

Troy and Kerry (2010) describe the importance of "quality cues" as they relate to the belief and purchase choice of the consumer. To assist in "quality cue" discovery, focus groups were evaluated. The goal of these sub-sampled groups was to determine how the beef industry could enhance the perception of technology using scientific knowledge. Group discussion revealed that parents with pre-pubertal daughters perceived the term "hormones" negatively. Whereas the term, "growth promotants" is perceived by panelists to cause unusually large growth, which is not perceived as "natural" and therefore not desired. To panelists, "growth promotants" are perceived as only a producer benefit.

Use of antibiotics also experienced some panelist resistance due to fears associated with antibiotic resistance. Some panelists were also concerned that an animal treated with an antibiotic may pass along the antibiotic to them through beef consumption. Panelists emphasized that due to human antibiotics becoming less effective, any method of transmission of antibiotics is worrisome. However, some panelists were more positive towards the use of antibiotics as they can relate to the need for antibiotic

treatment in the event of illness. Panelists can relate to the need for antibiotics themselves and can understand why an animal would need an antibiotic. In this instance, the use is acceptable as long as it is occasional. Though some very vocal participants stated, “I don’t want to see the word ‘illness’ and think I am eating an animal that was sick” while others stated; “It’s not like the animal was being raised with antibiotics. It only had it for the short time when it was sick.”

Consumers place more concern about how the animal is raised in humane conditions than environmental influences from beef production. When developing labels, descriptions such as “less feed and water resources used” made panelists think that animals were deprived of water and resources. Also, the term, “efficiency” did not resonate well with panelists. This is because “efficiency” provides panelists with the perception that producers are focusing on raising the animal quickly and with less regard for animal care. Consumers prioritized their own health over environmental resources. Some panelists stated, “I think we are all probably concerned about our own health before, or at least as much as the environment” and “A 4% water reduction is a pretty minimal amount. Maybe if we lived in a drought stricken state this would be important, but we don’t.”

Specifically, by beef consumption group, heavy beef eaters were permissive of the term ‘judicious use of antibiotics’. Panelists were willing to read additional information from web addresses on a label that describes how the animal was raised and why growth promotant technologies were used. Panelists stated that their most preferred way to gather information is from their friends and online resources (i.e. YouTube).

Panelists mentioned that free-range livestock may have tougher meat, though they were accepting of that product if the animal was taken care of in a better environment.

Medium beef eaters indicated more concerns about antibiotic use and the possibility that antibiotic residue may be transferable to them through consumption. Panelists also mentioned that if animals are fed a nutritionally balanced diet they should not need growth promotants to support growth. However, some panelists mentioned that animal genetics have been adapted and the use of growth promotant technology should be used to reduce natural resources needed from the environment. When asked how to better market beef produced with growth promotant technology, panelists replied; "by showing a tangible example of how everyday use of the technology reduces an amount of water that is relatable to a physical example." Lastly, the term "efficiency" should be avoided as it implies a producer benefit with no care for the animal.

Light beef eaters were divided about the use of antibiotics. Some panelists did not want any use of antibiotics nor did they want to consume beef from an animal that had been sick. The words "antibiotics given in the event of illness" did not suit some panelists as they found it "creepy." Whereas, other panelists thought it was polarizing that no antibiotics were given to an animal and sympathized the need for judicious antibiotic use for treatment. Panelists were also divided about the environmental impacts evaluated. Some panelists stated that they would be WTP more for beef that was grass-fed and perceived that to be more environmentally friendly, whereas others stated they would not due to budget constraints.

In summary, beef consumers use cues from their lives and other retail foods to provide awareness of health concerns when purchasing beef. Brunsø et al. (2005) describe

that product attributes are not meaningful themselves, but only to the extent that consumers expectations are for their undesired or desired consequences. Beef marketing should focus on the benefits that the product has for the consumer. A positive focus on consumer benefits should be more desirable than terms that resonate a producer benefit. Human health is prioritized before environmental gains in respect to the use of growth promotant technology.

IMPLICATIONS

Untrained panelists were able to differentiate treatments and prefered the palatability of beef from cattle raised without any technology when no beef production system information was provided. Panelists may be able to differentiate differences in meat tenderness, lipid, and moisture, as beef from cattle raised with full technology (monensin, tylosin, implants, and beta-adrenergic agonist) was consistently the least preferred. However, when provided both the production system information and samples to determine beef palatability, panelists preferred beef from cattle raised without hormones, but with judicious use of antibiotics and antimicrobials to maintain animal health and productivity. Overall, panelists disliked the use of hormones and were willing-to-pay more for beef that ensured animal health and wellbeing, which was a priority over environmental conservation and may provide future opportunities for marketing beef raised with antibiotics and antimicrobials.

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Table 4.1. Treatment abbreviations and determined marbling scores[1].

Trt. #	Beef Production System Treatment	Treatment Abbreviation	Treatment (n = 120) strip loin Marbling Score	Consumer Panel strip loin sub-set (n = 72) Marbling Score
1	No technology utilized	NA	554	551
2	Non-hormone treated	NHTC	562	558
3	Implanted	IMPL	487	493
4	Implanted plus fed a beta-agonist	IMBA	504	501

[1]Marbling score determined by SDSU personnel using USDA-AMS grading standards where 200=Traces[0], 300=Slight[0], 400=Small[0], and 500=Modest[0].

Table 4.2. Production system description provided to panelists[1].

Trt. #	Production System Treatment	Treatment Abbreviation	Description[1]
1	No technology utilized	NA	Beef produced from cattle never receiving antibiotics, added hormones, or other growth promoting products throughout their lifetime.
2	Non-hormone treated	NHTC	Beef produced from cattle that never received added hormones or supplements that adjust fat to lean meat. Antibiotics and antimicrobials were used to maintain animal health and productivity.
3	Implanted	IMPL	Beef produced from cattle that never received supplements to adjust fat to lean meat but received other growth promoting technologies including use of antibiotics, antimicrobials, and added hormones. These technologies were used to maintain animal health and improve productivity.
4	Implanted plus fed a beta-agonist	IMBA	Beef produced from cattle that received growth promoting technologies including antibiotics, antimicrobials, added hormones, and supplements to adjust fat to lean meat. These technologies were used to maintain animal health and improve productivity.

Table 4.3. Least squares means for percent lipid, moisture, cook loss and meat tenderness from steaks of carcasses represented in the consumer sensory analysis.

Treatment[1]	Lipid, (%)	Moisture, (%)	Cook Loss (%)	WBSF, kg[2]
NA	7.34[b]	69.79[a]	18.87[ab]	2.15[a]
NHTC	7.27[b]	70.40[a]	17.61[a]	2.13[a]
IMPL	5.58[a]	71.13[b]	20.31[c]	2.44[b]
IMBA	5.92[a]	71.15[b]	19.29[bc]	2.42[b]
SEM[2]	0.31	0.25	0.53	0.09
P-value	< 0.0001	0.004	0.004	0.011

[a,b] Least squares means in the same column lacking a common superscript differ ($P < 0.05$)

[1] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed Rumensin and Tylan during finishing); 3) IMPL (implanted, administered a series of three implants and fed Rumensin and Tylan during finishing); 4) IMBA (implanted plus fed a beta-agonist, same as treatment three plus, fed ractopamine hydrochloride (200 mg $\bullet$ steer^{-1} $\bullet$ d^{-1}) for the last 30 d prior to harvest.

[2] Warner-Bratzler shear force (WBSF).

Table 4.4. Demographic characteristics of sampled participants (n = 105)

Characteristic	Response	Percentage of participants
Sex	Male	50.5
	Female	49.5
Household Size	1 person	20.0
	2 persons	39.0
	3+ persons	41.0
Marital Status	Single	50.5
	Married	49.5
Age	Millennial	17.1
	Generation X	22.9
	Baby Boomer	60.0
Annual Household Income	Under $25,000	11.4
	$25,000 to $49,999	18.1
	$50,000 to $74,999	27.6
	$75,000 to $100,000	28.6
	$100,000 or more	14.3
Education	Did not graduate high school	1.0
	High school graduate	6.7
	Some college or technical school	37.1
	College graduate	38.1
	Post graduate	17.1
Weekly Beef Consumption[1]	Light	39.0
	Medium	52.4
	Heavy	8.6
Weekly Physical Activity	None	1.9
	< 2.5 hours	24.8
	2.5 – 5 hours	38.1
	Greater than 5 hours	35.2
Eating Habits	No restrictions	28.6
	Some healthy foods	26.7
	Mostly healthy foods	42.9
	Only healthy foods	1.9

Table 4.5. Coefficient estimates and shares of preference from the undisclosed with meat consumer panel relative to beef from cattle receiving different levels of growth promotant technology.

	Econometric Estimates	Shares of Preference (%)
Beef Category[1]	MNL	MNL
NA	0.337*	27.820[4a]
	(0.110)[2]	[1.729]
	[0.000][3]	
NHTC	0.284*	26.387[b]
	(0.110)	[1.676]
	[0.000]	
IMPL	0.266*	25.912[b]
	(0.095)	[1.377]
	[0.000]	
IMBA	0.000	19.881[c]
	(0.000)	[1.395]
	[0.000]	
N individuals	309	
N Choices	1,854	
Log likelihood	-547.79	
Pseudo R^2	0.01	

[a,b,c] Percentages in the same column lacking a common superscript differ *(*$P < 0.05$).

[1] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed Rumensin and Tylan during finishing); 3) IMPL (implanted, administered a series of three implants and fed Rumensin and Tylan during finishing); 4) IMBA (implanted plus fed a beta-agonist, same as treatment three plus, fed ractopamine hydrochloride (200 mg • $steer^{-1}$ • d^{-1}) for the last 30 d prior to harvest.

[2] Numbers in ( ) are standard errors.

[3] Numbers in [ ] are standard deviations.

[4] Mean of simulated shares of preference of 1,000 observations drawn from a multivariate normal distribution parameterized using coefficients and variance-covariance terms.

*Implies that the mean importance of the coefficient estimate is different from IMBA when ($P < 0.05$).

Table 4.6. Coefficient estimates and shares of preference from the disclosed without meat consumer panel relative to production information from cattle receiving different levels of growth promotant technology

	Econometric Estimates	Shares of Preference (%)
Beef Category[1]	MNL	MNL
NA	2.218*	50.419[4a]
	(0.172)[2]	[3.085]
	[0.000][3]	
NHTC	1.767*	32.169[b]
	(0.158)	[2.567]
	[0.000]	
IMPL	0.769*	11.881[c]
	(0.124)	[1.125]
	[0.000]	
IMBA	0.000	5.530[d]
	(0.000)	[0.754]
	[0.000]	
N individuals	315	
N Choices	1,890	
Log likelihood	-402.59	
Pseudo R^2	0.29	

[a,b,c,d] Percentages in the same column lacking a common superscript differ *(*$P < 0.05$).

[1] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed monensin and tylosin during finishing); 3) IMPL (implanted, administered a series of three implants and fed monensin and tylosin during finishing); 4) IMBA (implanted plus fed a beta-agonist, same as treatment three plus, fed ractopamine hydrochloride (200 mg • steer^{-1} • d^{-1}) for the last 30 d prior to harvest.

[2] Numbers in ( ) are standard errors.

[3] Numbers in [ ] are standard deviations.

[4] Mean of simulated shares of preference of 1,000 observations drawn from a multivariate normal distribution parameterized by using the coefficients and variance-covariance terms.

*Implies that the mean importance of the coefficient estimate is different from IMBA when ($P < 0.05$).

Table 4.7. Coefficient estimates and shares of preference from the disclosed with meat consumer panel relative to beef from cattle receiving different levels of growth promotant technology

	Econometric Estimates	Shares of Preference (%)
Beef Category[1]	MNL	MNL
NA	1.265*	34.007[4b]
	(0.132)[2]	[2.171]
	[0.000][3]	
NHTC	1.340*	36.676[a]
	(0.134)	[2.271]
	[0.000]	
IMPL	0.718*	19.684[c]
	(0.111)	[1.275]
	[0.000]	
IMBA	0.000	9.632[d]
	(0.000)	[0.977]
	[0.000]	
N individuals	315	
N Choices	1,890	
Log likelihood	-485.39	
Pseudo R^2	0.14	

[a,b,c,d] Percentages in the same column lacking a common superscript differ *(*$P < 0.05$)

[1] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed Rumensin and Tylan during finishing); 3) IMPL (implanted, administered a series of three implants and fed monensin and tylosin during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg $\bullet$ steer^{-1} $\bullet$ d^{-1}) for the last 30 d prior to harvest.

[2] Numbers in ( ) are standard errors

[3] Numbers in [ ] are standard deviations

[4] Mean of simulated shares of preference of 1,000 observations drawn from a multivariate normal distribution parameterized by using the coefficients and variance-covariance terms

*Implies that the mean importance of the coefficient estimate is different from IMBA when ($P < 0.05$)

Table 4.8. Probability of consumer demographic most preferred product category (mean ± SE) during the undisclosed with meat consumer panel.

Effect	N	NA[1]	NHTC	IMPL	IMBA
Sex		*P* = 0.298	*P* = 0.303	*P* = 0.611	*P* = 0.532
Male	53	0.25 ± 0.03	0.25 ± 0.03	0.33 ± 0.04	0.17 ± 0.03
Female	52	0.24 ± 0.03	0.24 ± 0.03	0.36 ± 0.04	0.16 ± 0.03
Household Size		*P* = 0.753	*P* = 0.155	*P* = 0.337	*P* = 0.931
1 Person	21	0.27 ± 0.06	0.24 ± 0.05	0.29 ± 0.06	0.21 ± 0.05
2 Persons	41	0.27 ± 0.04	0.19 ± 0.04	0.41 ± 0.05	0.13 ± 0.03
3+ Persons	43	0.21 ± 0.04	0.30 ± 0.04	0.32 ± 0.04	0.17 ± 0.03
Marital Status		*P* = 0.782	*P* = 0.149	*P* = 0.495	*P* = 0.668
Single	53	0.26 ± 0.03	0.25 ± 0.03	0.30 ± 0.04	0.20 ± 0.03
Married	52	0.23 ± 0.03	0.25 ± 0.04	0.40 ± 0.04	0.12 ± 0.03
Age[2]		*P* = 0.307	*P* = 0.656	*P* = 0.435	*P* = 0.291
Millennial	18	0.35 ± 0.07	0.26 ± 0.06	0.22 ± 0.06	0.17 ± 0.05
Generation X	24	0.25 ± 0.05	0.23 ± 0.05	0.30 ± 0.06	0.22 ± 0.05
Baby Boomer	63	0.22 ± 0.03	0.25 ± 0.03	0.40 ± 0.04	0.14 ± 0.03
Household Income		*P* = 0.947	*P* = 0.723	*P* = 0.742	*P* = 0.508
< $25,000	12	0.28 ± 0.08	0.19 ± 0.07	0.25 ± 0.07	0.28 ± 0.08
$25,000 - $49,999	19	0.22 ± 0.06	0.17 ± 0.05	0.31 ± 0.06	0.24 ± 0.06
$50,000 - $74,999	29	0.25 ± 0.05	0.27 ± 0.05	0.38 ± 0.05	0.10 ± 0.03
$75,000 - $100,000	30	0.22 ± 0.04	0.27 ± 0.05	0.37 ± 0.05	0.14 ± 0.04
> $100,000	15	0.22 ± 0.06	0.29 ± 0.07	0.36 ± 0.07	0.13 ± 0.05
Education Level		*P* = 0.648	*P* = 0.273	*P* = 0.991	*P* = 0.588
Non-High School Graduate	1	0.67 ± 0.33	0.00 ± 0.00	0.00 ± 0.00	0.33 ± 0.33
High School Graduate	7	0.10 ± 0.07	0.29 ± 0.10	0.33 ± 0.11	0.29 ± 0.10
Some College/Tech School	39	0.26 ± 0.04	0.19 ± 0.04	0.38 ± 0.05	0.17 ± 0.04
College Graduate	40	0.25 ± 0.04	0.27 ± 0.04	0.33 ± 0.04	0.15 ± 0.03
Post Graduate	18	0.24 ± 0.06	0.31 ± 0.06	0.33 ± 0.06	0.11 ± 0.04
Weekly Beef Consumption[3]		***P* = 0.005**	*P* = 0.359	*P* = 0.204	*P* = 0.839
Light	41	0.30 ± 0.04[a]	0.21 ± 0.04	0.31 ± 0.04	0.18 ± 0.03
Medium	55	0.19 ± 0.03[b]	0.28 ± 0.04	0.38 ± 0.04	0.16 ± 0.03
Heavy	9	0.33 ± 0.09[a]	0.22 ± 0.08	0.33 ± 0.09	0.11 ± 0.06
Weekly Physical Activity		*P* = 0.165	*P* = 0.477	*P* = 0.634	*P* = 0.902
None	2	0.50 ± 0.22	0.50 ± 0.22	0.00 ± 0.00	0.00 ± 0.00
< 2.5 hours	26	0.19 ± 0.05	0.28 ± 0.05	0.32 ± 0.05	0.21 ± 0.05
2.5 – 5 hours	40	0.28 ± 0.04	0.23 ± 0.04	0.34 ± 0.04	0.15 ± 0.03
Greater than 5 hours	37	0.23 ± 0.04	0.23 ± 0.04	0.39 ± 0.05	0.15 ± 0.03
Eating Habits		*P* = 0.707	*P* = 0.228	*P* = 0.810	*P* = 0.474
No restrictions	30	0.26 ± 0.05	0.18 ± 0.04	0.33 ± 0.05	0.22 ± 0.04

Some healthy foods	28	0.22 ± 0.05	0.27 ± 0.05	0.37 ± 0.05	0.14 ± 0.04
Mostly healthy foods	45	0.24 ± 0.04	0.28 ± 0.04	0.33 ± 0.04	0.14 ± 0.03
Only healthy foods	2	0.33 ± 0.21	0.00 ± 0.00	0.50 ± 0.22	0.17 ± 0.17

[a,b] Descriptive means in the same column within an effect lacking a common superscript differ ($P < 0.05$) after adjusted for multiplicity using the tukey procedure.

[1] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed Rumensin and Tylan during finishing); 3) IMPL (implanted, administered a series of three implants and fed Rumensin and Tylan during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg • steer^{-1} • d^{-1}) for the last 30 d prior to harvest.

[2] Consumers identified age as either Millennial (18-34), Generation X (35-50), or Baby Boomers (over 50).

[3]Consumption including ground beef, steak, pre-cooked and/or further processed beef either at home or dining out where Light is 1-2 per week, Medium is 3-4, and Heavy is 5 or more.

Table 4.9. Probability of consumer demographic least preferred product category (mean ± SE) during the undisclosed with meat consumer panel.

Effect	N	NA[1]	NHTC	IMPL	IMBA
Sex		*P* = 0.965	*P* = 0.476	*P* = 0.663	*P* = 0.236
Male	53	0.21 ± 0.03	0.21 ± 0.03	0.31 ± 0.04	0.28 ± 0.04
Female	52	0.17 ± 0.03	0.22 ± 0.03	0.31 ± 0.04	0.30 ± 0.04
Household Size		***P* = 0.053**	*P* = 0.102	*P* = 0.650	*P* = 0.579
1 Person	21	0.19 ± 0.05	0.16 ± 0.05	0.35 ± 0.04	0.30 ± 0.06
2 Persons	41	0.14 ± 0.03	0.26 ± 0.04	0.30 ± 0.04	0.30 ± 0.04
3+ Persons	22	0.23 ± 0.04	0.21 ± 0.04	0.29 ± 0.06	0.27 ± 0.04
Marital Status		*P* = 0.717	***P* = 0.071**	*P* = 0.608	*P* = 0.107
Single	52	0.16 ± 0.03	0.24 ± 0.03[x]	0.35 ± 0.04	0.26 ± 0.03
Married	53	0.22 ± 0.03	0.19 ± 0.03[y]	0.27 ± 0.04	0.32 ± 0.04
Age[2]		***P* = 0.086**	*P* = 0.374	*P* = 0.164	*P* = 0.699
Millennial	18	0.07 ± 0.04	0.24 ± 0.06	0.37 ± 0.07	0.31 ± 0.06
Generation X	24	0.17 ± 0.05	0.16 ± 0.04	0.39 ± 0.06	0.28 ± 0.05
Baby Boomer	63	0.23 ± 0.03	0.23 ± 0.03	0.26 ± 0.03	0.28 ± 0.03
Household Income		*P* = 0.166	*P* = 0.580	*P* = 0.626	*P* = 0.811
< $25,000	12	0.06 ± 0.04	0.31 ± 0.08	0.44 ± 0.08	0.19 ± 0.07
$25,000 - $49,999	19	0.19 ± 0.05	0.24 ± 0.06	0.31 ± 0.06	0.26 ± 0.06
$50,000 - $74,999	29	0.19 ± 0.04	0.17 ± 0.04	0.33 ± 0.05	0.31 ± 0.05
$75,000 - $100,000	30	0.19 ± 0.04	0.20 ± 0.04	0.28 ± 0.05	0.33 ± 0.05
> $100,000	15	0.29 ± 0.07	0.24 ± 0.06	0.20 ± 0.06	0.27 ± 0.07
Education Level		*P* = 0.408	*P* = 0.346	*P* = 0.633	*P* = 0.477
Non-High School Graduate	1	0.00 ± 0.00	0.00 ± 0.00	0.67 ± 0.33	0.33 ± 0.33
High School Graduate	7	0.29 ± 0.10	0.29 ± 0.10	0.29 ± 0.10	0.14 ± 0.08
Some College/Tech School	39	0.18 ± 0.04	0.24 ± 0.04	0.33 ± 0.04	0.24 ± 0.04
College Graduate	40	0.17 ± 0.03	0.21 ± 0.04	0.27 ± 0.04	0.36 ± 0.04
Post Graduate	18	0.22 ± 0.06	0.17 ± 0.05	0.33 ± 0.06	0.28 ± 0.06
Weekly Beef Consumption[3]		***P* = 0.095**	*P* = 0.516	*P* = 0.724	*P* = 0.854
Light	41	0.17 ± 0.03	0.21 ± 0.04	0.33 ± 0.04	0.28 ± 0.04
Medium	55	0.21 ± 0.03	0.21 ± 0.03	0.29 ± 0.04	0.29 ± 0.04
Heavy	9	0.11 ± 0.06	0.30 ± 0.09	0.30 ± 0.09	0.30 ± 0.09
Weekly Physical Activity		*P* = 0.453	*P* = 0.960	*P* = 0.195	*P* = 0.423
None	2	0.17 ± 0.17	0.17 ± 0.17	0.00 ± 0.00	0.67 ± 0.21
< 2.5 hours	26	0.20 ± 0.05	0.21 ± 0.05	0.36 ± 0.06	0.23 ± 0.05
2.5 – 5 hours	40	0.17 ± 0.03	0.18 ± 0.03	0.35 ± 0.04	0.31 ± 0.04
Greater than 5 hours	37	0.20 ± 0.04	0.27 ± 0.04	0.24 ± 0.04	0.29 ± 0.04
Eating Habits		*P* = 0.835	*P* = 0.633	*P* = 0.967	*P* = 0.538
No restrictions	30	0.17 ± 0.04	0.26 ± 0.05	0.32 ± 0.05	0.24 ± 0.05
Some healthy foods	28	0.20 ± 0.04	0.16 ± 0.04	0.32 ± 0.05	0.32 ± 0.05
Mostly healthy foods	45	0.19 ± 0.03	0.21 ± 0.04	0.29 ± 0.04	0.31 ± 0.04

Only healthy foods	2	0.33 ± 0.21	0.33 ± 0.21	0.33 ± 0.21	0.00 ± 0.00

[x,y] Descriptive means in the same column within an effect lacking a common superscript tend to differ ($P > 0.05$ to 0.10) after adjusted for multiplicity using the tukey procedure.

[1] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed Rumensin and Tylan during finishing); 3) IMPL (implanted, administered a series of three implants and fed Rumensin and Tylan during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg • steer^{-1} • d^{-1}) for the last 30 d prior to harvest.

[2] Consumers identified age as either Millennial (18-34), Generation X (35-50), or Baby Boomers (over 50).

[3]Consumption including ground beef, steak, pre-cooked and/or further processed beef either at home or dining out where Light is 1-2 per week, Medium is 3-4, and Heavy is 5 or more.

Table 4.10. Probability of consumer demographic most preferred product category (mean ± SE) during the disclosed without meat consumer panel.

Effect	N	NA[1]	NHTC	IMPL	IMBA
Sex		***P* = 0.018**	*P* = 0.644	***P* = 0.002**	*P* = 0.983
Male	53	0.44 ± 0.04[b]	0.34 ± 0.04	0.17 ± 0.03[a]	0.05 ± 0.02
Female	52	0.58 ± 0.04[a]	0.33 ± 0.04	0.05 ± 0.02[b]	0.04 ± 0.02
Household Size		*P* = 0.615	*P* = 0.983	*P* = 0.699	*P* = 0.202
1 Person	21	0.46 ± 0.06	0.32 ± 0.06	0.11 ± 0.04	0.11 ± 0.04
2 Persons	41	0.57 ± 0.05	0.33 ± 0.04	0.08 ± 0.02	0.03 ± 0.01
3+ Persons	43	0.48 ± 0.04	0.35 ± 0.04	0.14 ± 0.03	0.03 ± 0.02
Marital Status		*P* = 0.891	*P* = 0.895	*P* = 0.946	*P* = 0.991
Single	52	0.50 ± 0.04	0.35 ± 0.04	0.09 ± 0.02	0.07 ± 0.03
Married	53	0.51 ± 0.04	0.33 ± 0.04	0.13 ± 0.03	0.03 ± 0.01
Age[2]		*P* = 0.901	*P* = 0.873	*P* = 0.443	*P* = 0.672
Millennial	18	0.52 ± 0.07	0.35 ± 0.07	0.07 ± 0.04	0.06 ± 0.03
Generation X	24	0.51 ± 0.06	0.33 ± 0.06	0.13 ± 0.04	0.03 ± 0.02
Baby Boomer	63	0.51 ± 0.04	0.33 ± 0.03	0.11 ± 0.02	0.05 ± 0.02
Household Income		*P* = 0.881	*P* = 0.831	*P* = 0.700	*P* = 0.351
< $25,000	12	0.48 ± 0.08	0.31 ± 0.08	0.11 ± 0.05	0.08 ± 0.05
$25,000 - $49,999	19	0.45 ± 0.07	0.37 ± 0.07	0.07 ± 0.04	0.07 ± 0.04
$50,000 - $74,999	29	0.53 ± 0.05	0.37 ± 0.05	0.14 ± 0.04	0.04 ± 0.02
$75,000 - $100,000	30	0.60 ± 0.07	0.32 ± 0.05	0.12 ± 0.03	0.02 ± 0.02
> $100,000	15	0.60 ± 0.07	0.29 ± 0.07	0.07 ± 0.04	0.04 ± 0.03
Education Level		*P* = 0.573	*P* = 0.887	*P* = 0.609	*P* = 0.977
Non-High School Graduate	1	0.00 ± 0.00	0.33 ± 0.33	0.33 ± 0.33	0.33 ± 0.33
High School Graduate	7	0.43 ± 0.11	0.29 ± 0.10	0.24 ± 0.10	0.05 ± 0.05
Some College/Tech School	39	0.48 ± 0.05	0.38 ± 0.05	0.11 ± 0.03	0.04 ± 0.02
College Graduate	40	0.59 ± 0.05	0.33 ± 0.04	0.05 ± 0.02	0.03 ± 0.01
Post Graduate	18	0.44 ± 0.07	0.28 ± 0.06	0.19 ± 0.05	0.09 ± 0.04
Weekly Beef Consumption[3]		*P* = 0.364	*P* = 0.676	*P* = 0.732	***P* = 0.062**
Light	41	0.53 ± 0.05	0.30 ± 0.04	0.11 ± 0.03	0.07 ± 0.02[xy]
Medium	55	0.51 ± 0.04	0.36 ± 0.04	0.11 ± 0.03	0.02 ± 0.01[y]
Heavy	9	0.41 ± 0.10	0.37 ± 0.09	0.11 ± 0.06	0.11 ± 0.06[x]
Weekly Physical Activity		*P* = 0.937	*P* = 0.713	*P* = 0.389	*P* = 0.806
None	2	0.67 ± 0.21	0.17 ± 0.17	0.00 ± 0.00	0.17 ± 0.17
< 2.5 hours	26	0.48 ± 0.06	0.35 ± 0.06	0.13 ± 0.04	0.04 ± 0.02
2.5 – 5 hours	40	0.48 ± 0.05	0.33 ± 0.04	0.14 ± 0.03	0.05 ± 0.02
Greater than 5 hours	37	0.55 ± 0.05	0.35 ± 0.05	0.06 ± 0.02	0.04 ± 0.02
Eating Habits		*P* = 0.280	*P* = 0.919	*P* = 0.648	*P* = 0.926
No restrictions	30	0.46 ± 0.05	0.34 ± 0.05	0.15 ± 0.04	0.05 ± 0.02
Some healthy foods	28	0.48 ± 0.06	0.35 ± 0.05	0.12 ± 0.04	0.05 ± 0.02
Mostly healthy foods	45	0.57 ± 0.04	0.32 ± 0.04	0.07 ± 0.02	0.04 ± 0.02

Only healthy foods	2	0.17 ± 0.17	0.50 ± 0.22	0.17 ± 0.17	0.17 ± 0.17

[a,b] Descriptive means in the same column within an effect lacking a common superscript differ ($P < 0.05$) after adjusted for multiplicity using the tukey procedure.

[x,y] Descriptive means in the same column within an effect lacking a common superscript tend to differ ($P > 0.05$ to 0.10) after adjusted for multiplicity using the tukey procedure.

[1] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed Rumensin and Tylan during finishing); 3) IMPL (implanted, administered a series of three implants and fed Rumensin and Tylan during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg • steer^{-1} • d^{-1}) for the last 30 d prior to harvest.

[2] Consumers identified age as either Millennial (18-34), Generation X (35-50), or Baby Boomers (over 50).

[3]Consumption including ground beef, steak, pre-cooked and/or further processed beef either at home or dining out where Light is 1-2 per week, Medium is 3-4, and Heavy is 5 or more.

Table 4.11. Probability of consumer demographic least preferred product category (mean ± SE) during the disclosed without meat consumer panel.

Effect	N	NA[1]	NHTC	IMPL	IMBA
Sex		*P* = 0.195	*P* =.318	***P* = 0.067**	*P* = 0.620
Male	53	0.10 ± 0.02	0.07 ± 0.02	0.37 ± 0.04[y]	0.46 ± 0.04
Female	52	0.04 ± 0.02	0.03 ± 0.01	0.45 ± 0.04[x]	0.48 ± 0.04
Household Size		*P* = 0.632	*P* = 0.494	*P* = 0.387	*P* = 0.576
1 Person	21	0.10 ± 0.04	0.05 ± 0.03	0.40 ± 0.06	0.46 ± 0.06
2 Persons	41	0.04 ± 0.02	0.03 ± 0.01	0.44 ± 0.05	0.49 ± 0.05
3+ Persons	43	0.09 ± 0.03	0.07 ± 0.02	0.38 ± 0.04	0.46 ± 0.04
Marital Status		*P* = 0.526	*P* = 0.511	*P* = 0.208	*P* = 0.237
Single	52	0.07 ± 0.02	0.06 ± 0.02	0.39 ± 0.04	0.50 ± 0.04
Married	53	0.07 ± 0.02	0.05 ± 0.02	0.43 ± 0.04	0.45 ± 0.04
Age[2]		*P* = 0.675	*P* = 0.480	*P* = 0.562	*P* = 0.963
Millennial	18	0.02 ± 0.02	0.04 ± 0.03	0.46 ± 0.07	0.48 ± 0.07
Generation X	24	0.09 ± 0.03	0.03 ± 0.02	0.41 ± 0.06	0.48 ± 0.06
Baby Boomer	63	0.08 ± 0.02	0.06 ± 0.02	0.39 ± 0.04	0.47 ± 0.04
Household Income		*P* = 0.416	*P* = 0.736	*P* = 0.335	*P* = 0.439
< $25,000	12	0.03 ± 0.03	0.06 ± 0.04	0.44 ± 0.08	0.47 ± 0.08
$25,000 - $49,999	19	0.11 ± 0.04	0.06 ± 0.03	0.35 ± 0.07	0.48 ± 0.07
$50,000 - $74,999	29	0.06 ± 0.03	0.05 ± 0.02	0.35 ± 0.05	0.55 ± 0.05
$75,000 - $100,000	30	0.09 ± 0.03	0.03 ± 0.02	0.47 ± 0.05	0.41 ± 0.05
> $100,000	15	0.04 ± 0.03	0.07 ± 0.04	0.44 ± 0.07	0.44 ± 0.07
Education Level		*P* = 0.227	*P* = 0.476	*P* = 0.484	*P* = 0.822
Non-High School Graduate	1	0.00 ± 0.00	0.33 ± 0.33	0.67 ± 0.33	0.00 ± 0.00
High School Graduate	7	0.10 ± 0.07	0.19 ± 0.09	0.29 ± 0.10	0.43 ± 0.11
Some College/Tech School	39	0.06 ± 0.02	0.00 ± 0.00	0.42 ± 0.05	0.51 ± 0.05
College Graduate	40	0.03 ± 0.02	0.04 ± 0.02	0.47 ± 0.05	0.46 ± 0.05
Post Graduate	18	0.17 ± 0.05	0.09 ± 0.04	0.28 ± 0.06	0.46 ± 0.07
Weekly Beef Consumption[3]		*P* = 0.977	*P* = 0.594	*P* = 0.820	*P* = 0.907
Light	41	0.05 ± 0.02	0.07 ± 0.02	0.42 ± 0.04	0.46 ± 0.05
Medium	55	0.09 ± 0.02	0.03 ± 0.01	0.40 ± 0.04	0.48 ± 0.04
Heavy	9	0.04 ± 0.04	0.07 ± 0.05	0.37 ± 0.09	0.52 ± 0.10
Weekly Physical Activity		*P* = 0.269	*P* = 0.764	*P* = 0.456	*P* = 0.734
None	2	0.00 ± 0.00	0.00 ± 0.00	0.50 ± 0.22	0.50 ± 0.22
< 2.5 hours	26	0.09 ± 0.03	0.04 ± 0.02	0.36 ± 0.06	0.51 ± 0.06
2.5 – 5 hours	40	0.09 ± 0.03	0.06 ± 0.02	0.46 ± 0.05	0.45 ± 0.05
Greater than 5 hours	37	0.04 ± 0.02	0.05 ± 0.02	0.38 ± 0.04	0.47 ± 0.05
Eating Habits		*P* = 0.240	*P* = 0.658	*P* = 0.898	*P* = 0.950
No restrictions	30	0.13 ± 0.04	0.03 ± 0.02	0.37 ± 0.05	0.47 ± 0.05
Some healthy foods	28	0.06 ± 0.03	0.05 ± 0.02	0.40 ± 0.05	0.49 ± 0.06

Mostly healthy foods	45	0.04 ± 0.02	0.06 ± 0.02	0.44 ± 0.04	0.46 ± 0.04
Only healthy foods	2	0.17 ± 0.17	0.00 ± 0.00	0.33 ± 0.21	0.50 ± 0.22

[x,y] Descriptive means in the same column within an effect lacking a common superscript tend to differ ($P > 0.05$ to 0.10) after adjusted for multiplicity using the tukey procedure.

[1] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed Rumensin and Tylan during finishing); 3) IMPL (implanted, administered a series of three implants and fed monensin and tylosin during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg • steer^{-1} • d^{-1}) for the last 30 d prior to harvest.

[2] Consumers identified age as either Millennial (18-34), Generation X (35-50), or Baby Boomers (over 50).

[3]Consumption including ground beef, steak, pre-cooked and/or further processed beef either at home or dining out where Light is 1-2 per week, Medium is 3-4, and Heavy is 5 or more.

Table 4.12. Probability of consumer demographic most preferred product category (mean ± SE) during the disclosed with meat consumer panel.

Effect	N	NA[1]	NHTC	IMPL	IMBA
Sex		*P* = 0.399	*P* = 0.895	*P* = 0.529	*P* = 0.805
Male	53	0.33 ± 0.04	0.34 ± 0.04	0.24 ± 0.03	0.08 ± 0.02
Female	52	0.39 ± 0.04	0.32 ± 0.04	0.24 ± 0.03	0.05 ± 0.02
Household Size		*P* = 0.836	*P* = 0.752	*P* = 0.476	*P* = 0.116
1 Person	21	0.40 ± 0.06	0.29 ± 0.06	0.21 ± 0.05	0.11 ± 0.04
2 Persons	41	0.34 ± 0.04	0.35 ± 0.04	0.25 ± 0.04	0.06 ± 0.02
3+ Persons	43	0.37 ± 0.04	0.33 ± 0.04	0.25 ± 0.04	0.05 ± 0.03
Marital Status		*P* = 0.847	*P* = 0.411	*P* = 0.332	*P* = 0.583
Single	52	0.39 ± 0.04	0.31 ± 0.04	0.24 ± 0.03	0.06 ± 0.02
Married	53	0.33 ± 0.04	0.35 ± 0.04	0.25 ± 0.04	0.07 ± 0.02
Age[2]		*P* = 0.933	*P* = 0.579	*P* = 0.806	*P* = 0.453
Millennial	18	0.37 ± 0.07	0.33 ± 0.06	0.28 ± 0.06	0.02 ± 0.02
Generation X	24	0.36 ± 0.06	0.30 ± 0.06	0.26 ± 0.05	0.07 ± 0.03
Baby Boomer	63	0.36 ± 0.04	0.34 ± 0.03	0.23 ± 0.03	0.08 ± 0.02
Household Income		*P* = 0.635	*P* = 0.636	*P* = 0.399	*P* = 0.263
< $25,000	12	0.42 ± 0.08	0.42 ± 0.08	0.17 ± 0.06	0.00 ± 0.00
$25,000 - $49,999	19	0.44 ± 0.07	0.26 ± 0.06	0.24 ± 0.06	0.06 ± 0.03
$50,000 - $74,999	29	0.36 ± 0.05	0.31 ± 0.05	0.27 ± 0.05	0.06 ± 0.03
$75,000 - $100,000	30	0.36 ± 0.05	0.37 ± 0.05	0.21 ± 0.04	0.07 ± 0.03
> $100,000	15	0.24 ± 0.06	0.31 ± 0.07	0.31 ± 0.07	0.13 ± 0.05
Education Level		*P* = 0.185	*P* = 0.578	*P* = 0.651	*P* = 0.138
Non-High School Graduate	1	0.33 ± 0.33	0.67 ± 0.33	0.00 ± 0.00	0.00 ± 0.00
High School Graduate	7	0.38 ± 0.11	0.24 ± 0.10	0.29 ± 0.10	0.10 ± 0.07
Some College/Tech School	39	0.38 ± 0.05	0.33 ± 0.04	0.25 ± 0.04	0.04 ± 0.02
College Graduate	40	0.41 ± 0.05	0.33 ± 0.04	0.21 ± 0.04	0.05 ± 0.02
Post Graduate	18	0.22 ± 0.06	0.33 ± 0.06	0.30 ± 0.06	0.15 ± 0.05
Weekly Beef Consumption[3]		*P* = 0.825	*P* = 0.264	*P* = 0.141	*P* = 0.228
Light	41	0.32 ± 0.04	0.35 ± 0.04	0.28 ± 0.04	0.06 ± 0.02
Medium	55	0.39 ± 0.04	0.34 ± 0.04	0.21 ± 0.03	0.06 ± 0.02
Heavy	9	0.41 ± 0.10	0.19 ± 0.08	0.26 ± 0.09	0.15 ± 0.07
Weekly Physical Activity		*P* = 0.661	*P* = 0.468	*P* = 0.753	*P* = 0.586
None	2	0.33 ± 0.21	0.17 ± 0.17	0.33 ± 0.21	0.17 ± 0.17
< 2.5 hours	26	0.33 ± 0.05	0.37 ± 0.06	0.25 ± 0.05	0.04 ± 0.02
2.5 – 5 hours	40	0.35 ± 0.04	0.35 ± 0.04	0.24 ± 0.04	0.06 ± 0.02
Greater than 5 hours	37	0.40 ± 0.05	0.29 ± 0.04	0.23 ± 0.04	0.08 ± 0.03
Eating Habits		*P* = 0.317	*P* = 0.834	*P* = 0.460	*P* = 0.275
No restrictions	30	0.39 ± 0.05	0.31 ± 0.05	0.26 ± 0.05	0.03 ± 0.02
Some healthy foods	28	0.27 ± 0.05	0.37 ± 0.05	0.26 ± 0.05	0.10 ± 0.03
Mostly healthy foods	45	0.40 ± 0.04	0.32 ± 0.04	0.21 ± 0.04	0.07 ± 0.02

Only healthy foods	2	0.33 ± 0.21	0.33 ± 0.21	0.33 ± 0.21	0.00 ± 0.00

[1] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed monensin and tylosin during finishing); 3) IMPL (implanted, administered a series of three implants and fed monensin and tylosin during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg • $steer^{-1}$ • d^{-1}) for the last 30 d prior to harvest.

[2] Consumers identified age as either Millennial (18-34), Generation X (35-50), or Baby Boomers (over 50).

[3]Consumption including ground beef, steak, pre-cooked and/or further processed beef either at home or dining out where Light is 1-2 per week, Medium is 3-4, and Heavy is 5 or more.

Table 4.13. Probability of consumer demographic least preferred product category (mean ± SE) during the disclosed with meat consumer panel.

Effect	N	NA[1]	NHTC	IMPL	IMBA
Sex		*P* = 0.496	*P* = 0.663	*P* = 0.107	*P* = 0.527
Male	53	0.17 ± 0.03	0.08 ± 0.02	0.31 ± 0.04	0.44 ± 0.04
Female	52	0.12 ± 0.03	0.07 ± 0.02	0.36 ± 0.04	0.46 ± 0.04
Household Size		*P* = 0.066	*P* = 0.261	***P* = 0.040**	*P* = 0.256
1 Person	21	0.16 ± 0.05	0.06 ± 0.03	0.40 ± 0.06[a]	0.38 ± 0.06
2 Persons	41	0.19 ± 0.04	0.06 ± 0.02	0.28 ± 0.04[b]	0.47 ± 0.05
3+ Persons	22	0.10 ± 0.03	0.09 ± 0.03	0.36 ± 0.06[ab]	0.46 ± 0.04
Marital Status		*P* = 0.528	***P* = 0.010**	***P* = 0.075**	*P* = 0.426
Single	36	0.13 ± 0.03	0.09 ± 0.02[a]	0.33 ± 0.04[y]	0.45 ± 0.05
Married	52	0.17 ± 0.03	0.05 ± 0.02[b]	0.35 ± 0.04[x]	0.44 ± 0.04
Age[2]		*P* = 0.470	*P* = 0.583	*P* = 0.129	*P* = 0.769
Millennial	18	0.11 ± 0.04	0.11 ± 0.04	0.26 ± 0.06	0.52 ± 0.07
Generation X	24	0.19 ± 0.05	0.04 ± 0.02	0.35 ± 0.06	0.42 ± 0.06
Baby Boomer	63	0.14 ± 0.03	0.07 ± 0.02	0.35 ± 0.04	0.44 ± 0.04
Annual Household Income		*P* = 0.607	*P* = 0.431	*P* = 0.225	*P* = 0.862
< $25,000	12	0.06 ± 0.04	0.03 ± 0.03	0.44 ± 0.08	0.47 ± 0.08
$25,000 - $49,999	6	0.13 ± 0.05	0.11 ± 0.04	0.33 ± 0.06	0.43 ± 0.07
$50,000 - $74,999	29	0.12 ± 0.04	0.10 ± 0.03	0.32 ± 0.05	0.46 ± 0.05
$75,000 - $100,000	30	0.17 ± 0.04	0.06 ± 0.02	0.31 ± 0.05	0.47 ± 0.05
> $100,000	15	0.24 ± 0.06	0.04 ± 0.03	0.33 ± 0.07	0.38 ± 0.07
Education Level		*P* = 0.289	*P* = 0.132	*P* = 0.869	*P* = 0.822
Non-High School Graduate	1	0.00 ± 0.00	0.00 ± 0.00	0.33 ± 0.33	0.67 ± 0.33
High School Graduate	7	0.10 ± 0.07	0.24 ± 0.10	0.33 ± 0.11	0.33 ± 0.11
Some College/Tech School	39	0.13 ± 0.03	0.05 ± 0.02	0.32 ± 0.04	0.50 ± 0.05
College Graduate	40	0.13 ± 0.03	0.06 ± 0.02	0.36 ± 0.04	0.45 ± 0.05
Post Graduate	18	0.24 ± 0.06	0.07 ± 0.04	0.31 ± 0.06	0.37 ± 0.07
Weekly Beef Consumption[3]		*P* = 0.575	***P* = 0.016**	***P* = 0.086**	*P* = 0.366
Light	41	0.15 ± 0.03	0.07 ± 0.02[ab]	0.31 ± 0.04	0.47 ± 0.05
Medium	55	0.16 ± 0.03	0.05 ± 0.02[b]	0.37 ± 0.04	0.42 ± 0.04
Heavy	9	0.04 ± 0.04	0.22 ± 0.08[a]	0.26 ± 0.09	0.48 ± 0.10
Weekly Physical Activity		*P* = 0.637	*P* = 0.380	*P* = 0.782	*P* = 0.672
None	2	0.17 ± 0.17	0.00 ± 0.00	0.50 ± 0.22	0.33 ± 0.21
< 2.5 hours	26	0.13 ± 0.04	0.07 ± 0.03	0.32 ± 0.05	0.48 ± 0.06
2.5 – 5 hours	40	0.17 ± 0.03	0.05 ± 0.02	0.35 ± 0.04	0.43 ± 0.05
Greater than 5 hours	37	0.13 ± 0.03	0.10 ± 0.03	0.32 ± 0.05	0.44 ± 0.05
Eating Habits		*P* = 0.652	*P* = 0.480	*P* = 0.888	*P* = 0.401
No restrictions	30	0.18 ± 0.04	0.09 ± 0.03	0.34 ± 0.05	0.38 ± 0.05
Some healthy foods	28	0.16 ± 0.04	0.06 ± 0.03	0.35 ± 0.05	0.43 ± 0.06
Mostly healthy foods	45	0.12 ± 0.03	0.07 ± 0.02	0.33 ± 0.04	0.49 ± 0.04

Only healthy foods	2	0.00 ± 0.00	0.00 ± 0.00	0.33 ± 0.21	0.67 ± 0.21

[a,b] Descriptive means in the same column within an effect lacking a common superscript differ ($P < 0.05$) after adjusted for multiplicity using the tukey procedure.

[x,y] Descriptive means in the same column within an effect lacking a common superscript tend to differ ($P > 0.05$ to 0.10) after adjusted for multiplicity using the tukey procedure.

[1] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed monensin and tylosin during finishing); 3) IMPL (implanted, administered a series of three implants and fed monensin and tylosin during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg • steer^{-1} • d^{-1}) for the last 30 d prior to harvest.

[2] Consumers identified age as either Millennial (18-34), Generation X (35-50), or Baby Boomers (over 50).

[3]Consumption including ground beef, steak, pre-cooked and/or further processed beef either at home or dining out where Light is 1-2 per week, Medium is 3-4, and Heavy is 5 or more.

Table 4.14. Effect of levels of growth promotant technology on undisclosed with meat consumer sensory analysis of attributes among the most preferred samples of the *longissimus* muscle derived from carcasses of a subsample of steers.

	Treatment					
Trait[1]	NA[2]	NHTC	IMPL	IMBA	SEM	*P* - Value
Tenderness	76.21[b]	77.52[b]	76.34[b]	69.03[a]	2.02	0.009
Juiciness	63.30[ab]	67.89[b]	63.52[ab]	59.41[a]	2.38	0.036
Beefy Flavor	66.86[ab]	71.46[b]	68.23[ab]	63.93[a]	2.25	0.042
Overall Acceptability	76.23[b]	76.50[b]	75.02[b]	70.06[a]	2.33	0.076

[a,b] Values that do not share a common superscript in the same row differ ($P < 0.05$ to $P < .10$).

[1] Sensory panel scale (0-100%, continuous line scale): tenderness (0% = extremely tough, 100% = extremely tender); juiciness (0% = extremely dry, 100% = extremely juicy); flavor (0 % = no presence, 100% = very strong presence; overall acceptability (0% = not acceptable, 100% = very acceptable).

[2] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed monensin and tylosin during finishing); 3) IMPL (implanted, administered a series of three implants and fed monensin and tylosin during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg $\bullet$ steer^{-1} $\bullet$ d^{-1}) for the last 30 d prior to harvest.

Table 4.15. Effect of levels of growth promotant technology on subsequent disclosed with meat consumer sensory analysis of attributes among the most preferred samples of the *longissimus* muscle derived from carcasses of a subsample of steers.

	Treatment					
Trait[1]	NA[2]	NHTC	IMPL	IMBA	SEM	*P* - Value
Tenderness	79.11	77.37	74.49	74.85	2.31	0.175
Juiciness	73.66	72.46	69.60	69.52	2.45	0.264
Beefy Flavor	75.23[b]	74.04[a]	71.18[a]	69.03[a]	2.29	0.079
Overall Acceptability	80.74[a]	77.77[ab]	74.32[b]	74.26[ab]	2.44	0.015

[a,b] Values that do not share a common superscript in the same row differ ($P < 0.05$ to $P < .10$).

[1] Sensory panel scale (0-100%, continuous line scale): tenderness (0% = extremely tough, 100% = extremely tender); juiciness (0% = extremely dry, 100% = extremely juicy); flavor (0 % = no presence, 100% = very strong presence; overall acceptability (0% = not acceptable, 100% = very acceptable).

[2] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed Rumensin and Tylan during finishing); 3) IMPL (implanted, administered a series of three implants and fed monensin and tylosin during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg • steer^{-1} • d^{-1}) for the last 30 d prior to harvest.

Table 4.16. Undisclosed with meat consumer panel hypotheses tests pooling across treatments

Models and Hypothesis Tests	n[1]	LL[1]	WTP[1]	*P*-value
All consumers	309	-361.44	10.53	-
All consumers, NA[2]	76	-93.77	10.59	-
All consumers, NHTC[2]	76	-89.39	10.69	-
All consumers, IMPL[2]	107	-116.34	10.18	-
All consumers, IMBA[2]	50	-58.84	11.11	-
Ho: Pooling across four treatments is okay				>.05

[1] Here n, LL, and WTP denotes the number of respondents in each subsample, log-likelihood value of interval-censored models, and point estimates of willingness to pay (US$ per 12 oz. strip steak at a base price of $10.35), respectively. Models summarized are pooled across treatments and specified to include intercept and scale parameters only, and were estimated with PROC LIFEREG in SAS. Presented *P*-values report results of log-likelihood ratio tests of whether respondents from different subsamples of the examined population can be pooled.

[2] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed Rumensin and Tylan during finishing); 3) IMPL (implanted, administered a series of three implants and fed Rumensin and Tylan during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg $\bullet$ steer^{-1} $\bullet$ d^{-1}) for the last 30 d prior to harvest.

Table 4.17. Disclosed without meat consumer panel hypotheses tests of pooling across treatments

Models and Hypothesis Tests	n[1]	LL[1]	WTP[1]	*P*-value
All consumers	315	-378.70	11.36	-
All consumers, NA[2]	159	-194.06	11.41	-
All consumers, NHTC[2]	105	-126.15	11.02	-
All consumers, IMPL[2]	37	-40.43	11.64	-
All consumers, IMBA[2]	14	-16.09	12.85	-
Ho: Pooling across four treatments is okay				>.05

[1] Denotes the number of respondents in each subsample, log-likelihood value of interval-censored models, and point estimates of willingness to pay (US$ per 12 oz. strip steak at a base price of $10.35), respectively. Models summarized are pooled across treatments and specified to include intercept and scale parameters only, and were estimated with PROC LIFEREG in SAS. Presented *P*-values report results of log-likelihood ratio tests of whether respondents from different subsamples of the examined population can be pooled.

[2] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed Rumensin and Tylan during finishing); 3) IMPL (implanted, administered a series of three implants and fed Rumensin and Tylan during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg $\bullet$ steer^{-1} $\bullet$ d^{-1}) for the last 30 d prior to harvest.

Table 4.18. Disclosed with meat consumer panel hypotheses tests of pooling across treatments

Models and Hypothesis Tests	n[1]	LL[1]	WTP[1]	*P*-value
All consumers	315	-391.39	11.07	-
All consumers, NA[2]	115	-144.36	11.34	-
All consumers, NHTC[2]	105	-131.15	11.41	-
All consumers, IMPL[2]	74	-84.69	10.36	-
All consumers, IMBA[2]	21	-22.31	10.48	-
Ho: Pooling across four treatments is okay				<.001
Ho: Pooling across NA and NHTC is okay				<.001
Ho: Pooling across NA and IMPL is okay				<.001
Ho: Pooling across NA and IMBA is okay				<.001
Ho: Pooling across NHTC and IMPL is okay				<.001
Ho: Pooling across NHTC and IMBA is okay				<.001
Ho: Pooling across IMPL and IMBA is okay				<.001

[1] Denotes the number of respondents in each subsample, log-likelihood value of interval-censored models, and point estimates of willingness to pay (US$ per 12 oz. strip steak at a base price of $10.35), respectively. Models summarized are pooled across treatments and specified to include intercept and scale parameters only, and were estimated with PROC LIFEREG in SAS. Presented *P*-values report results of log-likelihood ratio tests of whether respondents from different subsamples of the examined population can be pooled.

[2] Four beef production systems: 1) NA (no technology utilized, control); 2) NHTC (non-hormone treated, fed Rumensin and Tylan during finishing); 3) IMPL (implanted, administered a series of three implants and fed Rumensin and Tylan during finishing); 4) IMBA (implanted plus fed the beta-agonist ractopamine hydrochloride (200 mg $\bullet$ steer^{-1} $\bullet$ d^{-1}) for the last 30 d prior to harvest.

Table 4.19. Consumer mean rank of novel label claims and statements within NA production system[1]

Rank[2,3]	Label Claim	Corresponding Statement	Mean ± SE[4]
1	Raised Without Antibiotics and Added Growth Promotants	Never Administered Antibiotics, Added Hormones, or Other Growth Promotants	2.12 ± 0.125
2	Conscientiously Raised	Never Administered Antibiotics, Added Hormones, or Other Growth Promotants	2.66 ± 0.125
3	No Antibiotics Ever	Never Administered Antibiotics	3.00 ± 0.125
4	Protectively Raised	Never Administered Antibiotics, Added Hormones, or Other Growth Promotants	3.32 ± 0.125
5	Cautiously Raised	Never Administered Antibiotics, Added Hormones, or Other Growth Promotants	3.92 ± 0.125

[1] Treatment NA is the control group receiving no technology.
[2] Described to consumers as beef produced from cattle never receiving antibiotics, added hormones, or other growth promoting products throughout their lifetime.
[3] Label rank within treatment did not differ $P = 0.149$.
[4] Descriptive means and calculated SE.

Table 4.20. Consumer mean rank of novel label claims and statements within NHTC production system[1]

Rank[2,3]	Label Claim	Corresponding Statement	Mean ± SE[4]
1	Responsibly Raised	Never Administered Hormones or Other Growth Promotants, Antibiotics Provided in The Case of Illness to Maintain Optimal Animal Health and Productivity	2.15 ± 0.127
2	Raised Without Added Growth Promotants	Never Administered Hormones or Other Growth Promotants	2.81 ± 0.127
3	Raised Without Added Hormones	Never Administered Hormones	3.85 ± 0.127
4	Raised With Care	Antibiotics Used to Prevent Illness	3.33 ± 0.127
5	Raised With Judicious Use of Antibiotics	Antibiotics Optimally Used In the Case of Illness to Maintain Animal Health and Productivity	3.86 ± 0.127

[1] Treatment NHTC is non-hormone treated but fed Rumensin and Tylan during finishing.
[2] Described to consumers as beef produced from cattle that never received added hormones or supplements that adjust fat to lean meat. Antibiotics and antimicrobials were used to maintain animal health and productivity.
[3] Label rank within treatment did not differ $P = 0.159$.
[4] Descriptive means and calculated SE.

Table 4.21. Consumer mean rank of novel label claims and statements within IMPL production system[1]

Rank[2,3]	Label Claim	Corresponding Statement	Mean ± SE[4]
1	Thoughtfully Raised	Antibiotics and Growth Promotants Optimally Used to Maintain Animal Health and Improve Productivity	2.35 ± 0.130
2	Environmentally Friendly	Raised with Growth Promoting Technologies to Reduce Carbon Footprint by 8% and Water Utilization by 4%	2.62 ± 0.130
3	Efficiently Raised	Raised Efficiently to Reduce Carbon Footprint, Water Use, Energy Utilization, and Nitrogen Emissions	3.86 ± 0.130
4	Efficiently Raised	Reduced Feed and Water Use for Animal Production	3.51 ± 0.130
5	Renewably Raised	Raised with Growth Promoting Technologies to Reduce Water Utilization by 4%	3.66 ± 0.130

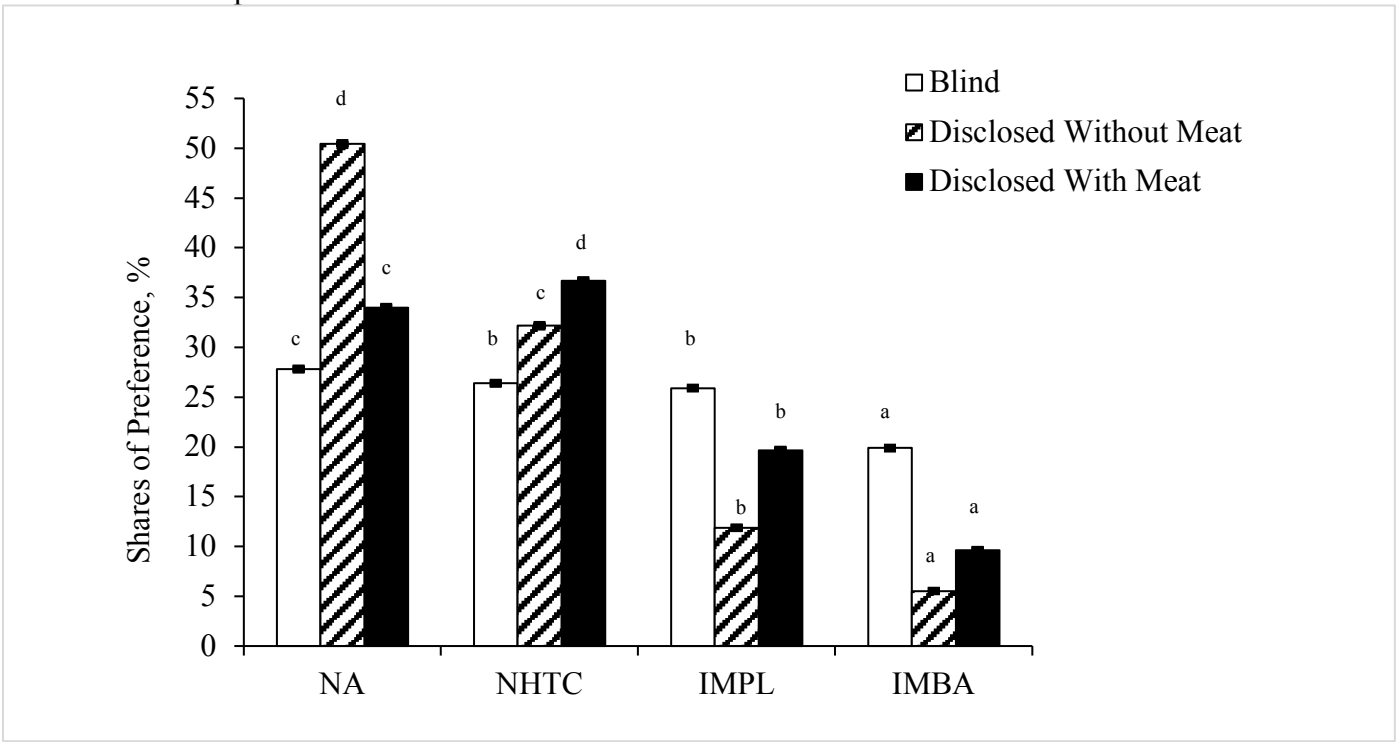
[1] Treatment IMPL is administered a series of three implants and fed Rumensin and Tylan during finishing.
[2] Described to consumers as beef produced from cattle that never received supplements to adjust fat to lean meat but received other growth promoting technologies including use of antibiotics.
[3] Label rank within treatment did not differ $P = 0.178$.
[4] Descriptive means and calculated SE.

Table 4.22. Consumer mean rank of novel label claims and statements within IMBA production system[1]

Rank[2,3]	Label Claim	Corresponding Statement	Mean ± SE[4]
1	Responsibly Raised	Antibiotics and Growth Promotants Optimally Used to Maintain Animal Health in the Event of Illness and to Increase Productivity	2.11 ± 0.127
2	Environmentally Conscious	Raised Efficiently to Reduce Carbon Footprint, Energy Utilization, and Nitrogen Emissions	2.65 ± 0.127
3	Efficiently Raised	Antibiotics and Growth Promotants Optimally Used to Maintain Animal Health and Improve Productivity	3.04 ± 0.127
4	Raised with Environmental Stewardship	Raised with Growth Promoting Technologies to Conserve Environmental Resources	3.50 ± 0.127
5	Wisely Raised	Raised with Growth Promoting Technologies to Conserve Environmental Resources	3.70 ± 0.127

[1] Treatment IMPL is administered a series of three implants and fed Rumensin and Tylan during finishing.
[2] Described to consumers as beef produced from cattle that never received supplements to adjust fat to lean meat but received other growth promoting technologies including use of antibiotics.
[3] Label rank within treatment did not differ $P = 0.156$.
[4] Descriptive means and calculated SE.

Figure 4.1. Comparison of consumer preferences for beef from different production systems among three consecutive panels[1]



[1]Influence of pre- and post- production information on consumer preferences for beef palatability. Treatments include a control group where steers were provided no technology (NA); steers provided monensin and tylosin (NHTC), a series of three implants, Rumensin and Tylan (IMPL), or a beta-agonist, three implants, Rumensin and Tylan (IMBA). Bars within panel signify simulated shares of preference from 1,000 observations drawn from multivariate normal distribution parameterized using the coefficients and variance-covariance terms estimated by a random parameter logit model in SAS MDC. Standard error is indicated by error bars and percentages without a common letter within panel differ ($P \leq 0.05$).