A COMPARISON OF BEHAVIORAL CHARACTERISTICS, CARCASS BY-PRODUCT YIELDS AND CARCASS GRADING PERFORMANCE OF IMPLANTED AND NON-IMPLANTED CROSSBRED STEERS ACROSS VARIOUS MARKETING ENDPOINTS IN A 378-D FEEDING DURATION.

by

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ABSTRACT

Experiment 1 consisted of the evaluation of behavioral characteristics of growing steers in response to implant, feeding duration, diurnal rhythm and dietary roughage via monitoring of activity and rumination time. Charolais × Angus steers (n = 80) were randomized to harvest (0, 42, 84, 126, 168, 210, 252, 294, 336 or 378 DOF) and implant treatment (**REV:** Revalor-XS; on d-0 and d-190 or **CON:** no implant). Activity and rumination were objectively monitored via accelerometers attached to the left ear. Steers consumed 3 rations throughout the study: starter (38.5% roughage), intermediate (23% roughage), and finishing (8.5% roughage). Data was logged in 2-h increments from 77 steers across 361 d and analyzed using mixed models for repeated measures of activity and rumination. Rumination and activity varied ($P < 0.01$) within 24-h, exhibiting bimodal patterns; rumination peaked at 0600 and 1400 h and troughed at 1000 and 1800 h. Activity peaked at 0800 and 1800 h and troughed at 0400, 1200-1400, and 2200 h. Steers administered REV ruminated less (364 vs 380 min/d; $P = 0.04$) than CON, however, 24-h activity was similar ($P = 0.29$) between treatments. Treatment × roughage interactions ($P < 0.01$) occurred for rumination and activity. Rumination tended to differ ($P = 0.06$) between CON consuming 38.5% and 23% roughage, however, CON steers ruminated ($P < 0.01$) more than REV when consuming 8.5% roughage. Implanted and non-implanted steers ruminated less ($P < 0.01$) as roughage inclusion decreased from

38.5% and 23% to 8.5% (457 and 439 vs 317 min/d) in the finishing ration. Activity was highest for steers consuming 38.5% roughage and was similar ($P > 0.05$) among treatments, however, activity decreased ($P < 0.01$) upon transition to 23 and 8.5% roughage. Activity peaks and troughs can be attributed to processing days and weather events. Implanted steers consuming 8.5% roughage were more active (342 vs. 337 and 333 min/d; $P < 0.01$) than steers of both treatments consuming 23% roughage. In conclusion, rumination and activity are responsive to hour of day, dietary roughage and growth-promoting implants.

Experiment 2 was conducted to investigate the development of non-carcass components of implanted or non-implanted Charolais × Angus steers across various marketing endpoints. Growth promoting implants containing trenbolone acetate **(TBA)** and estradiol-17β **(E_2)** are administered to improve rate of gain and feed efficiency of beef cattle. Non-carcass components are by-products of the beef industry that are of metabolic, economic and societal importance. A serial-harvest was conducted to investigate growth of non-carcass components of implanted or non-implanted Charolais × Angus steers. Steers ($n = 80$) were paired and applied to a 2 x 10 factorial treatment structure in a balanced incomplete block design. Steers were randomly appointed to harvest date (0, 42, 84, 126, 168, 210, 252, 294, 336 or 378 days on feed; **DOF**) and implant treatment; **REV** received a Revalor-XS (200mg TBA/40mg E_2) on d0 and d190, whereas **CON** received no implant. Pair was block, steer was experimental unit and data were analyzed using mixed models. Four REV/CON pairs were harvested upon each feeding endpoint. Non-carcass components were removed and weighed; gastrointestinal tracts (**GIT**) were disassembled, weighed, cleaned, and re-weighed. Empty body weight

(EBW), and hot carcass weight **(HCW)** were 6% greater ($P < 0.01$) in REV steers vs. CON. No treatment effects ($P \geq 0.12$) were observed for fill or dressed carcass yield **(DY)**, however, EBW, HCW and DY increased ($P \leq 0.01$) and percentage fill decreased as an effect of DOF. Absolute fill weight did not change across DOF ($P \geq 0.82$). Implanted steers had greater ($P \leq 0.05$) absolute mass of blood, head, hide, oxtail, liver, spleen, bladder, heart, reticulum, omasum, stomach, small intestine, intestines, GIT, total splanchnic tissue and total offal. Implanted steers also had smaller ($P \leq 0.05$) absolute mass of thymus glands and kidney-pelvic-heart fat **(KPH)** than non-implanted steers. Absolute mass of the spinal cord, small intestine and intestines varied across DOF but did not exhibit linear or quadratic growth, whereas all other tissue weights increased ($P \leq 0.05$) or tended to increase ($P \leq 0.06$) with DOF. The brain, limbs, thymus, abomasum, KPH and total internal fat (**TIF**) of REV steers weighed proportionately less ($P \leq 0.03$) and the reticulum weighed proportionately more ($P = 0.03$) than those of CON steers. Proportionate weight of the bladder, gallbladder and spleen was similar for all DOF, whereas all other variables differed ($P \leq 0.04$) across DOF. Observed results suggest that TBA + E_2 implants increase body and carcass weights and alter many non-carcass components, while reducing excess internal fat accumulation.

Improved efficiency associated with TBA + E_2 implants has been attributed to a shift in nutrient deposition away from fat deposits often trimmed from the final product, toward the development of lean muscle. Though a decrease in waste fat will improve carcass cutability, a concurrent reduction in intramuscular fat and carcass quality is often observed in implanted animals marketed prior to achieving target composition. A third experiment was designed to evaluate the development of traits contributing to carcass

yield and quality in response to implant and days on feed **(DOF)** in a 2 × 10 factorial study. Charolais × Angus steers (n = 80) were paired for similarity using genetic markers and projected endpoint composition. Pairs were randomized to 1 of 10 harvest dates corresponding to 0, 42, 84, 126, 168, 210, 252, 294, 336 or 378 DOF. Individuals within pair were then randomly assigned to 1 of 2 implant treatments, in which **REV** steers received a Revalor-XS (200mg trenbolone acetate/40mg estradiol; 4 uncoated and 6 coated pellets) implant on d 0 and d 190, while **CON** steers represented a non-hormone treated **(NHTC)** marketing strategy and received no implant throughout the feeding period. Upon each feeding endpoint, 8 steers (4-REV/CON pairs) were harvested and the shrunk body weight **(SBW),** weight of kidney, pelvic and heart fat **(KPH)**, and hot carcass weight **(HCW)** were obtained. Carcasses were chilled for 48 h and graded according to USDA quality and yield grade standards. All variables were analyzed using mixed models with implant treatment and DOF as fixed effects and pair as random. While no TRT × DOF interactions ($P > 0.05$) were observed in yield grade variables, a TRT × DOF interaction occurred ($P < 0.01$) for skeletal and overall maturity. Implanted steers had a heavier SBW (7%; $P < 0.01$) and HCW (6%; $P < 0.01$), and larger (6%; $P < 0.01$) LM area than non-implanted counterparts. While REV carcasses had 17% less ($P < 0.01$) KPH than CON carcasses, no treatment effects ($P = 0.26$) were observed in marbling, suggesting sustained marbling quality throughout the 378-d feeding period. Marbling and 12th rib fat depth increased linearly ($P < 0.01$) across DOF; SBW, HCW, dressed yield, LM area, KPH, USDA yield grade, and lean maturity increased whereas LM area:HCW decreased quadratically ($P < 0.06$) with additional DOF. These data support a shift in nutrient deposition from waste-fat accumulation to lean tissue

development in response to slow-release TBA + E_2 implants compared to NHTC. Additionally, implanted steers exhibited advanced skeletal maturity, however no concurrent compromise in marbling was observed throughout the 378-d feeding period.

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CHAPTER I

INTRODUCTION

Growth promoting implants are administered to the vast majority of cattle in feedlots, adding invaluable efficiency to numerous facets of beef production (Griffin, 1997; Biswas et al., 2013). Anabolic implants, including those containing trenbolone acetate (**TBA**) and estradiol-17β (**E2**), are implemented in conventional cattle feeding practices to improve growth efficiency and gain in cattle (Reuter et al., 2016), improving yield of red meat products by approximately 10% (Johnson et al., 1996; Guiroy et al., 2002). Improved efficiency associated with TBA + E_2 implants has been attributed to a shift in nutrient deposition away from fat deposits often trimmed from the final product, toward the development of lean muscle (Owens, 1995; Johnson et al., 1996; Guiroy et al., 2002). Growth promoting implants have been reported to improve environmental and economic efficiency for producers and consumers in various aspects of beef production (Griffin, 1997; Biswas et al., 2013).

Evaluating and monitoring behavioral characteristics exhibited by live cattle in the feedlot can be used in the assessment of an animal's physical and physiological state of health and production. Understanding behavioral characteristics has become an important tool for producers in making various managerial and production decisions, while serving contemporary importance in improved animal husbandry (Urton et al,

2005). Rumination and animal movement, or activity, are measures that are evaluated in various modern production and research practices across various sectors of the beef industry. Electronic accelerometers have been used in the objective measurement and quantification of steps, activity, posture, rest, and respiration as a means of detecting reproductive (Peter and Bosu, 1986; Roelofs et al., 2005), feeding (Walker et al., 1985), pain (Currah et al., 2009), stress (Haley et al., 2005) and health events in cattle (Pillen et al., 2016; Richeson et al., 2018). While implants have a great impact on the industry, little published literature discusses the effects of growth promoting implants on animal movement and behavioral characteristics such as rumination and activity throughout various stages in the growth and development of the animal.

Upon harvest and in the eyes of many producers and consumers, lean meat is the primary product of the beef industry. A carcass generally comprises 60-65% of the weight of the live animal. Further, lean product foods comprise approximately only 34-36% of the weight of the live animal, which is similar to the 35-40% of live weight that is removed upon harvest as non-carcass components (Marti et al., 2011; Campbell, 2016). Many non-carcass components are primarily responsible for determining the metabolic efficiency and productivity of an animal, suggesting great importance to producers and cattle feeders (Hutcheson et al., 1997). Post-harvest, non-traditional beef products are used for their biological, pharmaceutical, nutritional and energetic value, reinforcing beef production as a restorative industry (Ockerman and Basu, 2004a). However, there is limited research on the effect of growth promoting implants on the development of non-carcass components in commercial feedlot cattle.

Carcass performance attributes are factors that are of great importance to the producer, the packer, and the consumer. Economically, the quality and yield grade of a beef carcass determine not only the price paid to producers, but also the price paid by consumers. Additionally, yield and quality characteristics greatly contribute to purchase decisions and consumer experience of a final meat product. While cattle implanted with growth promoting implants are associated with reduced waste fat, and thus, improved carcass cutability and red meat yield, implanted cattle are also recognized to display increased maturity and a concurrent decrease in intramuscular fat and carcass quality when marketed prior to achieving optimum target composition (Morgan, 1991; Montgomery et al., 2001).

Understanding relationships between animal behavior, tissue development of both carcass and non-carcass components and growth promoting implants throughout the feeding period will allow the industry to adjust technological implementation and management practices appropriately to optimize production, improve efficiency and maximize welfare. Therefore, the objective of this research was to address the data deficit on behavioral characteristics, development of non-carcass tissue components, and carcass performance via quality and yield attributes, at intermittent stages of growth of contemporarily-crossbred cattle in response to conventional methods incorporating growth promoting implants in comparison to unconventional non-hormone treated cattle (NHTC) across a 378-d feeding and growth period.

CHAPTER II

REVIEW OF LITERATURE

2.1 Growth Physiology of Beef Cattle

Cellular proliferation, together with longitudinal and radial expansion, are mechanisms that result in the growth of organisms and tissue. Growth is often viewed as a simple change in overall live weight and structure, however, growth is dependent on the development of lean muscle, skeletal and adipose tissue. Hyperplasia and hypertrophy are important in the growth of individuals and tissue mass. Cellular differentiation and proliferation occur through the process of hyperplasia, or increase in cell numbers, which is heightened in prepartum development, whereas hypertrophy is a primary source of growth in organisms postpartum and in later stages of growth (Owens et al., 1994; Owens et al., 1995). While in-utero, a fetus will develop and continue to form new muscle fibers, however, after birth, the formation of new muscle fibers ceases and existing muscle fibers grow only in diameter and length. However, both hyperplasia and hypertrophy occur in body components and ultimately determine the shape and structure of individual organs, physiological components and individuals as a whole, throughout growth and development (Simpfendorfer, 1973; Trenkle and Marple, 1983).

Trenkle and Marple (1983) reported the continuous growth of muscular, visceral and skeletal tissue following parturition until the animal reaches approximately 50-60% of its mature weight, at which point, visceral growth begins to slow and the epiphyseal plate of long bones begins to fuse, slowing skeletal growth. Young animals undergo rapid growth and numerous changes occur in the skeletal system as stacking of chondrocytes cause long bones and many smaller bones to fuse together. Muscle cells are multinucleated and satellite cells, housed in muscle tissue, are able to synthesize DNA, divide, and form molecules necessary for the fusion of muscle cells. Fat tissue has demonstrated exponential development, generally increasing drastically upon reaching approximately 50% of mature BW (Simpfendorfer, 1973; Trenkle and Marple, 1983). Growth in adipose tissue generally occurs through enlargement of fat lobules and adipocyte proliferation (Trenkle and Marple, 1983; May, 2014). Owens et al. (1995) reported that muscle development in cattle slows once empty body fat approaches approximately 36% of the animal's empty body weight, however fat will continue to accrue and will increase at an increasing rate and responds primarily to excess energy in the animal's diet, rather than empty body weight. Because lean tissue has high water holding capacity and fat has very little, lean tissue has greater mass per unit volume and thus, is a more efficient means of gain than adipose tissue. As reported by Kerth (2013), bone, muscle and fat have specific gravities of approximately 1.5, 1.06 and 0.92, respectively.

Owens et al. (1995) reported optimal growth of carcass components of cattle during the finishing phase at the feedlot, due to a lesser proportion of live weight comprised of non-carcass components. Simply stated, dressed yield of an animal, or the

proportion of the live weight that the carcass makes up, increases as the animal achieves higher degrees of finish. Hutcheson et al. (1997) reported that beef by-products are a large consumer of fed energy in live animals (70-75%). Owens et al. (1995) also suggested that growth in pursuit of mature mass may vary across different genetics, sex, and environment and in response to an animal's plane of nutrition.

The development of muscular and adipose components are directly associated with nutritional status, activity level, metabolic rate and endocrine status as the animal approaches mature body weight (BW). Quantity of diet consumed, nutrient consumption, and energy density are key determinants in tissue growth, and balance of anabolic and catabolic reactions within the body. The diet is the singular source of energy providing the necessary ATP for physiological maintenance and function, amino acids for protein formation, and vitamins and minerals to be used as cofactors, all contributing to proper physiological function and tissue synthesis (Trenkle and Marple, 1983; May, 2014). The endocrine system also greatly influences the growth of an animal. Somatotropin, or growth hormone (GH) is released from the anterior pituitary, stimulating anabolism of muscle and bone tissue, and increasing lipolysis. Other hormones including prolactin, gonadotropins, and thyrotropins contribute to growth and development of individuals, as well (Simpfendorfer, 1973).

2.1.1. Effect of sex

The sex of an animal, as genetically predetermined, also contributes to the regulation and the development of gonadal organs and thus, production of various hormones and biochemical compounds. Hormone classification and quantification

released differently by sex greatly determines rate and extent of growth of the animal (Trenkle and Marple, 1983).

As historically determined and widely accepted, physiology associated with testes of intact males allows the production and release of higher concentrations of androgenic and estrogenic hormones. Intact males are generally recognized for greater lean:fat ratios, and greater yield of lean muscle when compared to castrated males (steers), heifers and cows. Bull calves are born at a heavier birthweight and with more muscle fibers than heifer calves and the difference in live weight between the sexes continues to increase with time (Simpfendorfer, 1973; Trenkle and Marple, 1983). Furthermore, sex has been reported to influence fiber quantity and size, for males are born with a greater fiber count and cross-sectional diameter than females (Tumova and Teimouri, 2009). Hormonal interactions among all physiological systems present complex interactions that contribute to the growth of an animal.

High concentrations of estrogenic hormones often associated with female systems have been observed to contribute to the earlier obtainment of mature body weight, skeletal maturity and fat deposition than comparable bulls and steers (May, 2014). Researchers have also demonstrated earlier onset and deposition of fat in steers, when compared to bulls, likely due to the reduction and eliminated source of androgenic hormones (Berg and Butterfield, 1968; Lee et al., 1990).

2.1.2. Methods of evaluating growth and composition

Growth and development of animals is most routinely evaluated via visual appraisal and simple measurement of live BW and carcass weight across a unit of time. Growth of the live animal may also be evaluated through measurement of skeletal

components (Trenkle and Marple, 1983). Garrison (2005) developed a system in which skeletal measurements are recorded and used in the prediction of daily gain and target final body weight, in an effort to sort animals into groups that will obtain a target compositional endpoint at a similar time.

Methods for predicting growth and composition have also been developed using animal and carcass conformation, chemical appraisal, and rib-section dissection. Ultrasound technology has also been implemented in the industry since the 1950s in the assessment of growth, composition and physiological status of cattle and livestock species. Technological progression has allowed for further growth analysis and composition prediction using bioelectrical impedance, total body electrical conductivity (TOBEC), and video image analysis (May, 2014). Each method mentioned may be used in the indirect or basal measurement of growth or in the prediction of composition of growth of various physiological components using algorithmic approaches. Indirect methods of measurement are often implemented in production and research settings, due to financial, time and labor-associated restraints.

Direct measurements of growth provide increased precision and accuracy of growth and compositional data due to the elimination of prediction and the application of direct measurement, however, direct measurements are difficult to obtain and require extensive time and labor. Methods of directly measuring growth and composition allow for more exact measurement of body components and organs, and furthermore, physiological components such as muscle, fat and bone (Simpfendorfer, 1973; Trenkle and Marple, 1983). An example of the direct measurement of body composition and growth is implementing a comparative slaughter approach as demonstrated by Lofgreen

and Garrett (1968), in which animals similar in age, genetics and environment are harvested across various time points. Components may be separated and measured accordingly to the researcher's degree of interest.

2.1.3. Growth Promoting Implants

An "implant" as applied in the beef industry, is a product that contains substances that elicit a specific physiological response in cattle, generally used to promote growth. Growth promoting implants, first developed in the late 1950s, are one of the most common growth technologies implemented in the beef industry today, with over 92% of fed cattle receiving at least one implant prior to harvest in 2011 (USDA-NAHMS, 2013). Growth promoting implants contain hormones or analogs of naturally occurring hormones that stimulate anabolic reactions and signal body systems to improve growth efficiency. While implants were initially and primarily employed in stocker and feeding operations, continued development and progression in implant technology have broadened implant markets. Implants are currently implemented in each sector of the beef industry and are administered throughout the life of an animal, including suckling calves and grass-fed cattle. Reuter et al. (2016), reported that many cattle receive up to 3 or more implants throughout their lifetime.

Implants are small rod-shaped pellets that are placed subcutaneously in the center of the backside of the ear using a product-specified applicator or administrator and needle. In accordance with FDA regulations and product labels, implants must only be placed subcutaneously in the middle 1/3 of the ear and between the two pronounced cartilage embedments on the back of the ear. Proper implementation practices include: restraining the animal to restrict motion, cleaning and sanitizing the ear and all supplies,

having trained personnel to ensure proper, efficient placement and insertion of the implant. Proper implantation practices will maximize efficacy, reduce the risk of ear abscesses, and reduce risk of local infection, while ensuring safety of the animal and the administrator (Griffin et al., 1997; Reuter et al., 2016).

2.1.3.1. History

Exogenous hormone administration via implantation was first implemented in the poultry industry when Lorenz (1943) administered a stilbestrol pellet subcutaneously and observed a 43 g increase in weight and greater fat content in implanted cockerels than non-implanted counterparts. Diethylstilbestrol also reduced the size of testes and delayed fertility in young cockerels (Eaton et al., 1955). Implants were then applied to the industry to improve gain and muscle yield in cockerels. The first implant was then evaluated and studied for use in the beef industry in 1947 (Dinussion et al., 1950), and the first commercial implant was FDA approved in 1956 and produced by Chas. Pfizer, Inc. (Terre Haute, IN) and made available to producers in 1957 (Montgomery et al., 2001; Raun and Preston, 2002; Reuter et al., 2016). While the first implant contained a compound called diethylstilbestrol (Montgomery et al., 2001; Raun and Preston, 2002), compounds incorporated in implants evolved toward other estrogenic agents, and further to androgenic compounds in the 1980s. Implants were incorporated in the beef industry to improve rate of gain and feed to gain ratio of all cattle, in a similar manner to intact males, whilst avoiding negative behavior associated with intact males (Montgomery et al., 2001).

Multiple estrogenic compounds, beginning with diethylsilbesterol and progressing to zeranol, estradiol 17-β, and estradiol benzoate, have been used and

included in growth promoting implants, in an effort to mimic naturally occurring estrogenic compounds produced by the body. Androgenic compounds include testosterone and the androgenic analog trenbolone acetate (TBA). Progesterone has also been used in the formulation of growth promoting implants, however, it elicits a minimal response in relation to the primary estrogenic and androgenic compounds in an implant and is not common in modern implants. Trenbolone acetate was first approved as an ingredient in growth promoting implants in 1987 and in 1992 combination implants became a common practice, containing both androgenic and estrogenic compounds (Johnson et al., 1996). The combination of androgenic and estrogenic compounds in a single implant created an additive and synergistic effect, further enhancing protein deposition within the body and decreasing protein degradation that can be observed in response to single-hormone implants (Hayden et al., 1992).

Today, many implants produced by various companies contain similar or identical ingredients and implement similar technologies, however, products differ in formulation, hormone concentration, and substance-release timing. While some implants will release and elicit a return or payout within 60 d post-implant, many will pay out in 90-200 d and others will elicit a return up to 400 d post-implant. Implants used for various ages and sizes of cattle also vary in dosage. Implants intended for use in suckling calves will have a much lower dosage of the active ingredient than stocker or feedlot cattle. Because of systemic effects, implants have not been approved for the use in breeding or lactating cattle. By the year 2000, over 34 different implants containing various formulations were FDA approved and available for use by producers (Montgomery et al., 2001).

2.1.3.2. Mechanism of action

Compounds used in the formulation of implant products have different approaches to elicit the associated growth-promoting response. Estrogenic compounds often included in growth promoting implants are incorporated to interact with the hypophyseal-pituitary system, stimulating release of somatotropin, or growth hormone (GH) released from the secretory granules of the anterior pituitary into circulation (Burton et al., 1994; Griffin et al., 1997). Somatotropins are then transported to the liver to stimulate production and release of somatomedins, such as insulin-like growth factor-I and II (IGF-I and IGF-II). Increased levels of IGF-I are reported to stimulate physiological responses in peripheral tissues including muscle development, bone growth and fat accretion (Johnson et al., 1998, Smith et al., 2018).

Somatotropic stimulation and increased levels of circulating somatomedins have been recognized to increase processes such as bone development, protein accretion, gluconeogenesis, and lipolysis (Burton et al., 1994). While estrogenic compounds stimulate muscle development through increased production of somatotropin and IGF-I (Griffin, 1997), anabolic implants have also demonstrated activation of satellite muscle cells, contributing to hypertrophy of myofibrillar components (Johnson et al., 1998a; Montgomery et al., 2001) via stimulation of increased release of IGF-I from the muscle tissue and the associated binding proteins (Johnson et al., 1998b).

Similarly to estrogenic hormones, androgenic compounds such as testosterone and TBA stimulate increased production of IGF-I, however, rather than stimulating anabolic processes through increased secretion of GH, androgenic compounds interact with the adrenal axis to limit the degree of tissue catabolism and atrophy within the animal

(Griffin, 1997). Reduced protein catabolism has been attributed to reduced secretion and serum concentrations of glucocorticoids (i.e. cortisol) in the blood, in response to heightened levels of testosterone, zeranol, dihydrotestosterone and TBA (Isaacson et al., 1993). Because of the endocrine response elicited from implants and the growth patterns of lean tissue, implants are reported to have the greatest effect on animals that are closest to reaching mature weight and that would otherwise gain muscle at a decreasing rate and deposit fat at an increasing rate (Simpfendorfer, 1973; Griffin, 1997).

To improve the duration of efficacy and the efficiency of implants, many companies have developed proprietary release mechanisms to alter and control hormone delivery to the bloodstream. For example, Revalor-XS (Merck Animal Health, Madison, NJ) is a product containing 40 mg estradiol-17β and 200 mg TBA within 10 small, compressed pellets. Of the 10 pellets, 4 pellets are uncoated to allow for immediate release of hormones into the bloodstream and to initiate implant effects, whereas the remaining 6 pellets are coated with an X70-polymer coating that will slowly release the remainder of the hormones beginning at approximately 70-80 d post-administration, extending the life and delivery of the implant. The delayed release mechanism of Revalor-XS was added to elicit the response of reimplantation, while eliminating the processing required for reimplanting. Currently no implants available on the market have a withdrawal period.

2.1.3.3. Effects

Growth promoting implants have been deemed a top return on investment technology in the beef industry, because implants generally return approximately $15 for every $1 spent in investment (Griffin, 1997; Montgomery et al., 2001). Poland and

Hoppe (1999) reported a return on investment exceeding $20 in feedlot cattle, reaching an upward limit of $43 per $1 spent on the implant in feedlot steers. Most implants available today are approved and labeled for improved growth efficiency through increased rate of gain and gain per unit of feed consumed (gain:feed) in cattle. Implants are recognized to improve average daily gain by up to 21%, while improving feed:gain ratios by up to 11% (Reuter et al., 2016).

Carcasses of implanted animals have also been reported to yield higher quantities of red meat, with reduced fat accretion. Guiroy et al. (2002) observed a 9.5 - 10.4% increase in the weight of the lean carcass of implanted steers and Johnson et al. (1996) observed a 10% increase in carcass protein in implanted animals compared to unimplanted counterparts. Increased efficiency of implanted animals allows for reduced quantities of feed and resources being utilized to produce a higher yield of a high-quality protein product (Johnson et al., 1998). Cattle implanted with anabolic implants have also been observed to reach a similar endpoint composition, while obtaining a greater body weight (BW) and hot carcass weight (HCW) (Hutcheson et al., 1997).

Although implanted animals generally exhibit improved efficiency, aggressive implant administration is recognized to encourage buller behavior in steers and estrus-induced behavior in females, likely due to hormonal influence on animal behavior (Griffin, 1997; Reuter et al., 2016). Implants have also been negatively characterized by causing advanced lean and skeletal maturity in response to heightened estrogenic hormone levels (Dinussion et al., 1950; Belk, 1992). Additionally, carcasses of implanted animals have also been reported to display a reduced degree of marbling – thus affecting carcass quality (Morgan, 1991; Montgomery et al., 2001) and potentially limiting

premiums for packers and producers. Preston et al. (1990) and Guiroy et al. (2002) evaluated the effects of implants on BW and HCW and concluded that implanted cattle may obtain the same degree of marbling when harvested 39.5 kg (steers) and 16.8 kg (heifers) heavier than non-implanted cattle. Owens (1995) also reported implanted carcasses to have increased protein:fat ratios when compared to non-implanted cattle, supporting the proposed mechanism in shifting away from fat deposits and toward protein accretion.

2.2. Rumination and Activity in Beef Cattle

Rumination is defined as the process of regurgitating ingesta in an effort to further reduce particle size, increase lubrication, buffer rumen pH, and improve digestion. Rumination allows consumed feed to be re-exposed to the mechanical breakdown of mastication and mixed with saliva before being re-swallowed (Burfeind et al., 2011; Goldhawk et al., 2013). Rumination is stimulated primarily by gastrointestinal fill, particle size and intake (Welch, 1982). Rumination and activity are often measured in dairy cattle as a measure in evaluating feed and productive efficiency, health and reproductive state. Rumination has been reported to change in response to health (Boreras, 2008; Hamilton et al., 2019), activity, weather, competition, grouping and stocking practices, and feeding practices (Ruckebusch and Bueno, 1978; Grant and Albright, 1995; Goldhawk et al., 2013). The ability to evaluate rumination as a proxy of animal health, and the potential for using rumination measures in early detection of morbidity has been extremely attractive to the beef industry in the cow-calf, stocker, and feedlot sectors (Wolfger et al., 2015).

2.2.1. Methods of measurement

Cattle rumination and activity have been measured using various methods to quantify rumination time and events. Various methods previously and currently implemented to quantify rumination include: direct observation and measurement, acoustic analysis and evaluation, and use of accelerometers and pedometers. Evaluation of rumination via direct observation is labor and time intensive and may be influenced by observer experience and bias, and therefore, may result in unrepeatable and inconsistent measurements. Additionally, rumination may be misidentified or not witnessed altogether by personnel (Rushen et al., 2012; Goldhawk et al., 2013). For this reason, automatic monitoring systems have been sought by producers and researchers for measurement of rumination in cattle. As technology has evolved, more systems have been introduced and are becoming more readily available, affordable, and feasible to implement in commercial operations.

Automated technologies implemented for the measurement of rumination include acoustic measurement, motion activation technology, noseband pressure sensors, automated imaging, and ear tag accelerometers (Braun et al., 2013). Rumination measurement via collars such as the Hi-Tag monitor system (SCR engineers Ltd., Netanya, Isreal), utilize a microphone to identify the sound and acoustics associated with rumination to estimate rumination time in 2-h increments. Burfeind et al. (2011) reported reduced accuracy in measurement of rumination in heifers, likely attributed to differences in the acoustics, neck density and thickness, or diet of young vs. mature dairy cattle. Goldhawk et al. (2013) reported only moderate correlation (r = 0.41) between direct observation and collar acoustic measurement of rumination in beef cattle, attributed to

physiological and dietary variation between beef cattle and dairy cattle, for which the system was designed. Use of support vector machines with bolus motion detection allows for the detection of ruminal motion and contraction, as well as the recovery of rumination period with approximately 86% accuracy (Hamilton et al., 2019).

Halters containing muzzle pressure sensors measure rumination and have been reported to have the highest accuracy of all automated systems, likely due to direct contact with the point of contraction and motion of rumination. Acoustic sensor collars and ear tags containing accelerometers follow pressure sensor halters in accuracy and reliability (Hamilton et al., 2019).

Ear tags with attached accelerometers are currently becoming more common in rumination detection because of the simplicity and non-invasive nature of an ear tag compared to a halter or collar. Many ear tag monitoring systems available today contain 3-dimensional accelerometers that are programmed to record specific motions as a particular activity, such as rumination, and use radio-frequency identification (RFID) which transmit to a receiver, allowing for real-time observations and evaluation (Wolfger et al., 2015). A 3-D accelerometer allows the program to distinguish between the repeatable, monotonous rhythm of rumination and the inconsistent and variable movement associated with chewing, due to different pressures required for each bite (Johansson, 2011). However, because of minimal direct contact and a large variety of motions contributing to readings, tags face a larger amount of variability in readings of rumination and activity, with moderate accuracy compared to method of measurement such as pressure sensors (Wolfger et al., 2015).

Cattle activity, similarly to rumination, has been measured via various methods including: direct observation, GPS, accelerometers, and imaging systems. Because activity is generally described as walking, feeding or heightened movement above standing, and because activity includes actions that can be characterized and visually assessed, direct observation is used as the basis to compare and assess various automated technologies. While GPS and accelerometer systems worn by the animal are easily transferable across locations and animals, imaging systems have been reported to be less accurate and more stationary (Rushen et al., 2012). A challenge faced by many automated technologies is identifying the exact motion of rumination and various other activities, while eliminating white-noise movements and other similar motions (Hamilton et al., 2019).

2.2.2. Effect of breed, age and size

Rumination is largely affected by factors such as diet, particle size, fill, forage intake, etc. however, researchers have also observed differences in rumination among various ages, as well as managerial practices and stage of development.

A study conducted by Swanson and Harris (1958) evaluated change in activity and rumination of Jersey and Holstein calves throughout a 24-h day, in 2-wk. increments. While rumen functionality greatly influences nutritional requirements and efficiency, calves often have delayed rumen development postpartum, until feed is incorporated into the diet. Further, rumination is not essential when the diet is entirely comprised of milk. Most calves (n = 18/26) began ruminating in the first 2-wk. period postpartum with the earliest rumination occurring at 5 days of age. Seven more calves began ruminating in the second 2-wk. period, and the remaining calves began ruminating in the third 2-wk.

period, in which all calves had established regular and extensive rumination. In the same study, rumination events per day increased from 3.1 in the first 2-wk period, to 15.3 in the final 2-wk period. Calves also increased in the amount of time spent ruminating in each rumination event from 15.2 min initially, to 24.6 min in the final period. Minutes spent ruminating increased most dramatically in the first 5 weeks of age. Additionally, as rumination increased with time, minutes spent eating and drinking increased simultaneously, and lying time decreased – suggesting increased activity (Swanson and Harris, 1958).

In 1970, Welch et al. (1970) compared rumination time across Holstein, Guernsey, Ayrshires and Jersey cattle (n = 32) in a 24-h period. While Ayrshires, Holsteins and Jerseys ruminated for 381, 414, and 435 min, Guernsey cattle ruminated only for 316 min in a 24-h period and ruminated less than Jerseys ($P < 0.01$) and Holsteins ($P < 0.05$) even after corrected for metabolic body weight and forage intake. LeShure et al. (2016) also observed differences in rumination between Alpine and Spanish breeds of goats, suggesting a breed effect on rumination.

Both rumination and activity were observed to be greater in cattle grown according to organic standards when compared to cattle grown in a conventional system, likely due to increased forage consumption and more activity required to obtain similar intake. Cattle in each marketing strategy were most active in July, and least active in December, likely in response to weather and energy reserves (Pereira et al., 2016).

2.3. Beef Harvest By-products

Cattle are bred, raised and harvested primarily in pursuit of edible tissues. However, on average, dressed yield of most finished bovine animals is approximately 60-

65% of the live BW, suggesting that approximately 35-40% of the live weight will be removed from the carcass at harvest and may be used for other purposes and products that are often overlooked by producers and consumers (Marti et al., 2011; Campbell, 2016). Ockerman and Basu (2004a) reported approximately 12% of a single beef animal will be usable by-products. While many visceral organs and non-carcass components have edible, cosmetic, practical or pharmaceutical value, others are rendered, or recycled to produce high protein and fat products for feed, fertilizer and biodiesel production, and a few are condemned and appropriately disposed of as risk materials. Feasibly, as Ockerman and Hansen (2000) explain, in addition to the 35-40% of by-products from harvest, the weight of bones and excess carcass fat should be added, for boxed beef is primarily sold boneless and trimmed of excess fat, which then become by-products as well. Any lean tissue trimmed from the carcass, however, is often used in the production of ground beef or low-price point products. Each by-product often has many uses that vary greatly based on factors such as geographic location and religious preference. Most components may be biologically edible if handled and prepared correctly, however many non-carcass components have valuable roles in society, all around the world.

Though non-carcass components can be subdivided into 2 primary categories: edible vs. inedible, the industry is highly interactive and products are versatile depending on demand and price for various purposes of each product (Ockerman and Basu, 2004a). By-products are also discussed as offal or variety meats. While offal is defined as any product from an animal not included as a component of the carcass, variety meats are edible by-products that are sanitarily processed, chilled and sold as a wholesome product that will also be inspected by United States Department of Agriculture (USDA) Food

Safety Inspection Service (FSIS) inspectors (Ockerman and Hansen, 2000). Variety meats are often recognized to differ in physical, chemical and functional properties. Marti et al. (2011) discussed the critical role of by-products in export markets, as well. For these reasons, non-carcass components, or beef by-products, are of great metabolic, economic, industrial and biological importance in each sector of the beef industry, and are expanding into numerous other industries, as well.

Clemen (1927) timelessly explained that "practical commercial processes", "potential markets", appropriate product volume and storage, and personnel training are essential in efficiently and effectively using and marketing a beef by-product. The utilization of beef by-products has many roles including further generation of unrealized revenue for packers and processors, providing consumers and clientele of various disciplines and cultures with a product of unrealized nutritional value, and improving the efficiency of meat production through recycling nutrients and minimizing of waste products.

2.3.1. History & Prevalence

The complete utilization of beef by-products is not a new practice and is, in fact, an artifact of ancient and early civilization. Archeological evidence confirms by-product use prior to recorded history. Initially, hides were commonly used for clothing and shelter, whilst intestines and bladders were used for storage of water and fat and most remaining organs were consumed as food or used in spiritual practice. Bones were carved and used as weapons and tools and manure was dried and used as fertilizer and fuel for cooking and heat. The production of soap-like cleaning substances were upon the first recorded uses of animal by-products dating back to the first century (AD), followed by

the use of animal fat encasing a fiber wick to form candles and lamps. In the foundational years of mass-harvest of cattle and buffalo, animals were harvested primarily for hides and fat, oftentimes wasting large quantities of meat. (Ockerman and Hansen, 2000; NRA, 2003).

As the US was colonized, and upon establishment of the first slaughterhouse in 1662 in Springfield, Massachusetts, beef became a staple product. The 1800's brought about railroads, allowing westward expansion, and the Chicago Stockyards, which quickly became the headquarters for livestock and meat animal markets. The establishment and growth of the meatpacking industry brought about great demand for a disposal system and in the late 1800s, H. W. Heath started the first rendering business, beginning the "invisible industry." In the mid-1900s, the consumption of animal by-products in the US began to decline, resulting in a decrease in price. In conjunction with the domestic reduction in demand, export markets recognized the reduced price and export sales subsequently began to increase (May, 2014). Beef and animal production continues to grow, as has the rendering and by-product markets, which have been a large contributor to developments in animal feeds, fertilizer, pharmaceutical, textile and household products. Today, while pounds of production continue to grow, technology and incorporation of synthetic substances and materials has decreased the demand and thus, market and prices for numerous by-products (Marti, 2011).

In 1997, FDA prohibited the feeding of mammalian protein products back to ruminants, allowing the feeding of ruminant meat and bone meal, a primary product of the rendering process, only to pigs, poultry, pets and to be used as fertilizer. The first bovine animal in the United States with bovine spongiform encephalopathy (BSE) was

identified on December 23, 2003, which affected the entire by-product industry greatly. Many export allies of the US discontinued trade of high-risk by-products, such as the small intestine, banned by Mexico and South Korea, and all beef and variety meats, banned by China. Government regulations established January 12, 2004 called for age identification within slaughter plants and removal of all specified risk materials (SRM's) from animals over 30 months of age in effort to eliminate BSE prions from entering food consumption. Specified risk materials removed and disposed include the tonsils, distal ileum, skull, brain, trigeminal and dorsal root ganglia, eyes, spinal cord, and the vertebral column (USDA-FSIS; 2019). Out of an abundance of caution, many processors remove SRM's from all animals, for each of the SRM's are found in animals of all ages, however, risk of the materials elevate as the animals age above 30 mo. (USDA, 2017a). Specified risk materials removed from bovine carcasses are rendered inedible and will not enter the human or ruminant food supply. Exports of beef by-products have steadily recovered since 2003 and in 2017, the beef and beef variety meat exports totaled as a 7.27 billion dollar industry. In 2010, approximately 74% of all beef offal products were exported. The leading export markets for U.S. beef products are Japan, South Korea, Mexico, Hong Kong, Canada and Taiwan (USMEF).

Today, as beef processors price boxed beef products, the selling price of the carcass is typically equal to the price paid by the packer for the live animal. For this reason, packers utilize beef by-product sales to generate profit for the plant. By-product sales were estimated to comprise 7-12% of processor income in 1984, and anywhere from 15-32.5% of processor income in 1988 (Ockerman and Hansen, 2000). Today, however, many by-product prices have decreased due to a large shift toward synthetic materials in

numerous industries such as household, automobile and textiles (Ockerman and Hansen, 2000).

Marti et al. (2011) reported relatively stable production of beef by-products from 1997 to 2010, growing approximately from 18.5 billion pounds to about 19 billion pounds in 2010. The increase in beef by-products has been attributed to an increase in beef production as a whole. However, in conjunction with increased beef and beef by-product production, a reduction in live weight contributions to by-products, together with an increase in live weight contributions to retail meat products has occurred in response to genetic selection and management practices. An increase in drop-credit value per unit of weight increased approximately 34.8% since 2010. Similarly, across the same time points, the beef cutout value increased 36.4%, suggesting increased revenue received by the beef processor since 2001, however, the value contribution of steer by-products in proportion to total value has remained steady at approximately 10.1% of the value from 2000 to 2010. Effects have been attributed to technological advances and increased efficiency at the production and processing level, therefore, reducing price (Marti et al., 2011).

2.3.2. Beef by-products for human consumption

Edible by-products of the beef industry include a large array of products comprised of skeletal muscle such as oxtail, smooth muscle or offal such as intestines or variety meats such as liver, kidneys and heart. While many beef-byproducts are commonly sought out as delicacies for some cultures and regions, others seek the nutritive value, flavor or low-price point associated with many beef co-products. Edible by-products upon removal at harvest are sorted, chilled and processed appropriately.

Although products considered and sold as edible products fit for human consumption vary by processor and based on market prices of a product for various functions, common products sold for human consumption include: liver, heart, tongue, stomach, thymus, oxtail, edible tallow, bone and tendons, blood, lips, esophagus, head and cheek meat.

2.3.2.1. Liver

The liver, a highly active metabolic organ, averages approximately 5 kg in mass (Ockerman and Basu, 2004a) and is often associated with a rich, irony flavor and a deep purple or brown color (Marti et al., 2011). A liver is removed from the body cavity and separated from the gallbladder and bile ducts. The liver is inspected by USDA personnel for wholesomeness. Any abnormal liver is condemned as inedible and will be diverted into pet foods or rendered. Liver is often exported as whole liver or sold as sliced liver or as an ingredient in further processed products such as braunschweiger and liver paté. Liver is a nutrient rich product, containing rich amounts of heme-iron, B12, Vitamin A and other fat soluble vitamins (Ockerman and Basu, 2004a).

2.3.2.2. Heart

A beef heart weighs approximately 1.4 kg at harvest. The heart is cardiac muscle that is removed from the thoracic cavity as a component of the "pluck," along with the trachea and lungs. The heart is removed from the remainder of the pluck and remaining excess fat and tissue is trimmed. Hearts are generally inspected by USDA FSIS inspectors for evaluation of the thickness of heart valves, chambers and walls (Ockerman and Basu, 2004a). Heart is often sold as a cubed product and is a key ingredient in traditional hot link sausages (May, 2014).

2.3.2.3. Tongue

A tongue of a market beef animal weighs 1.7 kg on average, however weight depends on degree of trim; the full tongue generally includes salivary glands and the epiglottis, whereas a trimmed tongue will consist only of the tongue with salivary glands and all other components removed. Tongues are generally removed post-head removal, washed, chilled and sold with the exterior skin on. Tongues are comprised of dense muscle and are prepared using numerous methods such as pickling, canning and boiling (Ockerman and Basu, 2004a). In the US, tongue is a high-priced exported good, sold as a delicacy in many Asian and Mexican cultures. Beef tongues are sorted by color before they are sold and exported to various markets; for example, Japan desires only white-skin beef tongues (Marti et al., 2011).

2.3.2.4. Stomach

Tripe is a product of the ruminant stomach system, primarily the rumen or reticulum, which is removed upon evisceration of the animal. The stomach compartments are emptied, thoroughly cleaned, scalded, and soaked in water. Further processing to remove the internal layer of the lining is often performed prior to cutting, brining, etc. for marketing of tripe. Beef tripe is often used in Mexican and European style dishes such as menudo. The strong flavor of tripe has been paired well with tomato flavors (Ockerman and Basu, 2004a).

2.3.2.5. Thymus

The thymus gland, often marketed as "sweetbreads" are located in the thorax region of the animal, placed alongside the trachea and ventral to the cervical vertebrae. The thymus is a light tan-colored, lobular gland that weighs approximately 0.05-0.1 kg.

The thymus plays a key role in the immune system in housing immune cells. While the organ is of importance to an immature animal, the thymus has been observed to regress as the animal ages. The thymus is generally trimmed from the housing membrane, washed and chilled prior to distribution (Ockerman and Basu, 2004).

2.3.2.6. Oxtail

Oxtail is the tail of a beef animal consisting of the coccygeal vertebrae, weighing approximately 0.8-1.1 kg, making up approximately 0.25% of the live BW (Ockerman and Basu, 2004a). Prior to removing the hide at harvest, the tail switch is removed. The remaining tail is generally removed at the second to third coccygeal vertebrae following hide removal to minimize contamination. Oxtail is a common ingredient in many soups and slow-cooked dishes and is commonly consumed in the United States (Ockerman and Basu, 2004a).

2.3.2.7. Edible Tallow

Edible tallow is derived from beef fat that is removed from a carcass that has been inspected by the USDA in a food grade facility and is handled in a food-safe manner. Edible tallow is generally processed to provide a safe edible fat product for human consumption. In order to be marketed and distributed as edible tallow, processing procedures and quality standards must adhere to USDA-certified edible beef tallow specifications. Under USDA inspection and specifications for edible tallow, the product must: 1) have a minimum titer of 41, 2) have a fat analysis committee value of 3 or less, 3) contain less than 0.75% free fatty acids and 4) a maximum of 40-45 iodine value, 5) an initial peroxide value of 1.0meq/kg maximum, 6) contain <5 ppm soap, 7) contain 0.1% or less moisture and volitiles, 8) have a Wiley melting point of 42-45°C, 9) have a fat

analysis committee color index of 10 yellow and 1 red, 10) have a smoke point of 224°C and 11) a flash point minimum of 315°C (NRA, 2003). In 2005, the National Renderer's Association reported production of edible tallow to exceed 790,000 metric tons, with approximately 17.5% of total production exported. Edible tallow is often also used in the production of lotions, creams, lubricants and plastic polymers (Pearl, 2004)

2.3.2.8. Bone & Tendons

Beef bones and tendons are often used in the formation of beef broth and stock by commercially cooking bones in hot water, straining and cooling prior to distribution (Ockerman and Basu, 2004a). When saved, beef tendons have been exported to Asia for production of low-cost products, for example, beef-tendon meatballs.

2.3.2.9. Blood

Upon harvest and following stunning, a beef animal is exsanguinated via jugular venous severance to harvest and eliminate blood from the body as the first by-product obtained. Blood is a versatile product and has many functions across numerous industries. Blood may be harvested and processed as an edible product, sold as an ingredient, cooked to produce blood meal – a high protein product commonly used as feed and fertilizer, or harvested as a pharmaceutical ingredient and resource. In most processing plants, harvested blood is mixed with salt or citric acid to preserve and prevent coagulation. Cattle generally yield approximately 10-12 L, or 2.4-6% of the bodyweight of the live animal (Terry et al., 1990, Ockerman and Basu, 2004a; Pearl, 2004). Blood is composed of approximately 80.9% water, 17.3% protein, 0.23% fat, 0.07% carbohydrates and 0.62% mineral (May, 2014).

Blood is generally included in human foods, animal diets or fertilizers as a highly digestible ingredient high in protein and iron. Blood is often flash-dried to produce a blood meal product to be used as animal feed or fertilizer. Blood meal is also commonly fed to nursery pigs raised in confinement, to meet iron requirements in confined environments with limited exposure to iron (Pearl, 2004).

2.3.2.10. Lips

Beef lips are removed at harvest and generally comprise approximately 0.1% of the live animal. Lips are considered a low quality by-product and are primarily sold as a variety meat that will go into processed products such as sausage and other value added products (Ockerman and Hansen,2000; Meeker, 2006).

2.3.2.11. Esophagus

The esophagus, also called the weasand, extends from the epiglottis to the rumen and serves as a passage to deliver consumed feed to the reticulorumen. The esophagus is comprised of an involuntary smooth muscle layer for regulation of food movement and an internal layer of elastin. The weasand meat, or smooth muscle is often separated from the elastin lining and included as an ingredient is sausages and value added products.

2.3.2.12. Head & Cheek Meat

Head and cheek meat are removed and treated similarly to the carcass following removal – being hung, washed and chilled prior to distribution. Cheek meat, or the masseter muscles, are removed from the skull after the head is removed from the carcass. Cheek meat is often cooked in a Mexican style dish such as barbacoa. Head meat, or pate meat, is the remaining meat trimmings from the skull. Pate meat often subjected as lean trim that will be used for ground beef or sausage (Alao et al., 2017)

2.3.3. Beef by-products for animal consumption

Pet food and pet treat companies are also primary clientele of the by-product industry, due to the ability to use inedible product. In 1997, Murray et al. (1997) reported that approximately 25-40% of premium dog foods were comprised of animal by-products. Common ingredients used in the production of pet foods and treats include: lungs, trachea, spleen, kidney, hooves, penis, ears, and bones, as explained above.

2.3.3.1. Lungs & Trachea

The lungs and trachea of beef animals are difficult tissues to process due to texture and composition. Lungs from a typical market animal weigh approximately 4 kg. The trachea is separated from the esophagus following head removal, to assist with evisceration. The pluck is removed from the thoracic cavity once the gastrointestinal tract, liver and spleen are removed from the carcass. The heart is removed from the pluck and prepared for sale as previously described, whereas lungs and trachea will generally be incorporated in pet foods and treats, or will be rendered (May, 2014)

2.3.3.2. Spleen

The spleen, often referred to as the "melt," is considered edible, however, is not commonly consumed and is most often used in the pet industry. The spleen comprises approximately 0.1-0.27% of the liveweight of a finished beef animal and generally weighs 0.9-1.4 kg. The spleen is removed from the left side of the body cavity and is trimmed of a connective tissue membrane prior to sale (Ockerman and Basu, 2004a).

2.3.3.3. Kidney

While kidneys are available as an edible product for humans, as well, consumption is rare and kidneys are more commonly used as an ingredient in pet foods

and treats. Cattle have two lobed-kidneys surrounded by fat, referred to as the kidney knob, and weigh approximately 0.4-0.6 kg each at market weight. Kidneys are removed from the carcass, trimmed, soaked, dried and chilled (Ockerman and Basu, 2004a).

2.3.3.4. Penis

The beef penis, or pizzle, is classified as a fibroelastic penis and contains a high amount of elastin connective tissue. Due to the density of the tissue, the pizzle is generally considered inedible, although some cultures will slow cook to gelatinize the collagen. The penis exposed to the exterior of the carcass is removed upon siding at harvest, however, the remaining pizzle, found internally, must be removed after splitting the carcass.

2.3.3.5. Ears

Ears are removed from the carcass against the skull and at the base of the ears. A sample of tissue from each carcass, oftentimes from the ear, is generally temporarily saved by processors in case an abnormality of a carcass is discovered that requires testing. Ears are often discarded and because of this, has been chosen as the site of administration for growth-promoting implants in beef cattle.

2.3.4. Beef by-products for pharmaceutical use

Many beef products have key roles in pharmaceutical and laboratory products and functions. While by-products contribute to research and medicine in providing ingredients, biological substances and pharmaceuticals products, beef by-products are also important in the development of products and medicinal methods. Blood, along with numerous glands are harvested from beef carcasses for the collection of hormones and enzymes (Marti et al., 2011). Organs, glands and components typically saved at harvest

for pharmaceutical and research purposes include the pancreas, thyroid and parathyroid, pituitary, blood, ovaries and thymus. Occasionally, producers unknowingly ship pregnant females for harvest. Unborn fetuses found by the processor, or "slunks" are retained and drained of blood, which is used for pharmaceutical and research purposes. Hides of older slunks are used for scrolls, drums and other fine leather goods. Valuable pharmaceutical products derived from beef products include hormones, enzymes, cells, serums, coagulation agents, antitoxins and antigens that can be used in the development of vaccines. Some components of beef carcasses and organs can be used in xenotransplantation, or human transplants. Some beef products such as bone and lean are also used for the extraction of vitamins and minerals for supplement industries, such as Ca, and P (Marti et al., 2011).

2.3.4.1. Pancreas

While the pancreas is of great importance in the digestive capability of a live animal, the pancreas is also important post-harvest, in the harvest of biologic compounds used in medicine etc. The pancreas is responsible for producing and secreting insulin – an important biochemical hormone in energy metabolism, regulating cellular uptake of glucose. Exogenous sources of insulin are required by diabetic patients in order to regulate glucose metabolism. A bovine pancreas weighs approximately 0.2 kg, or 0.04% of the live weight. Insulin comprises approximately 0.01% of the weight of the pancreas. According to Fisher and Scott (1934), a bovine pancreas from a 2 year old animal yields approximately 4.83 IU/g of pancreas, equating to approximately 965 IU per pancreas. A diabetic patient requiring 80 IU of insulin per day would require insulin from approximately 30 bovine pancreases for an annual supply.

The pancreas is removed from the gastrointestinal tract, trimmed of excess fat, and immediately frozen. Insulin is extracted upon further processing through chemical extraction of chopped pancreas. The extract is then clarified, purified and precipitated to isolate only the insulin protein (Tie Khouw et al., 1989). In addition to insulin, enzymes released from the pancreas include lipase, trypsin and amylase (Dutson and Pearson, 1992).

2.3.4.2. Thyroid & Parathyroid

The thyroid and parathyroid are removed from the thorax region, on each side of the trachea and near the larynx, for harvest and extraction of thyroxin hormones such as T3 and T4 and to produce thryroid extract (Dutson and Pearson, 1992).

The parathyroid, removed from the thorax region, as well, is important in regulating vitamin D and Ca mobilization within the body. Parathyroid hormone is the primary substance extracted from the parathyroid (Dutson and Pearson, 1992).

2.3.4.3. Pituitary gland

The pituitary gland is located at the base of the brain and is responsible for the release of numerous hormones that regulate various body systems. The pituitary gland is carefully removed from the brain cavity, trimmed and immediately frozen at approximately -20 to -30°C until further processing and extraction. Pituitary glands saved from beef animals at harvest are used for the extraction of somatotropin, thyrotropin (thyroid stimulating hormone, TSH), adrenal corticotropin hormone (ACTH), oxytocin and vasopressin (antidiuretic hormone, ADH) for various therapeutic and pharmaceutical purposes. Although many hormones are still harvested from the pituitary gland of cattle,

many synthetic substances have been developed and are currently being implemented in place of natural hormones.

2.3.4.4. Adrenal gland

The adrenal glands, weighing approximately 2-30 g each, are located adjacent to the kidney. The adrenal glands are removed and saved for the extraction of catecholamines and glucocorticoids such as cortisol (Dutson and Pearson, 1992).

2.3.4.5. Blood

Blood harvested and processed for pharmaceutical purposes is generally stabilized with an anticoagulant, and centrifuged to separate blood components – red blood cells, leukocytes, platelets and plasma. Blood is also used in the extraction of various clotting factors and blood proteins including fibrinogen, immunoglobulins, albumin, thrombin and heparin. While some proteins are used in product formation and developments such as adhesives and emulsifiers, others are used in medicinal, veterinary and laboratory practices (May, 2014).

2.3.4.6. Bile & Gallstones

Products from the gallbladder including bile and gallstones also have various pharmaceutical roles and uses. Biliary treatment has been implemented as a common treatment in traditional Chinese medicine for over 2500 years. Bile acids derived from animal sources, particularly, from bovine species, have been used and prescribed to treat various liver, ductic, dermal, gynecological and cardiac disease. Efficacy of bile acids have been supported as a pharmaceutical agent to regulate receptors and signaling pathways within the gastrointestinal tract and liver. Bile acts as a fat-emulsifying agent because of the detergent-like structure and characteristics. Bile is also used as a

pigmented agent because of the bilirubin and bile pigments of the substance. Gallstones are routinely used as a therapeutic drug, tranquilizer, sedative and aphrodisiac (Wang and Carey, 2014).

2.3.4.7. Ovaries & Testes

Accessory sex glands such as the ovaries and the testes are often harvested and saved from intact cattle for extraction of biochemical compounds and hormones. Testosterone is harvested from beef testes and ovaries are saved for the extraction of progesterone and estrogen, and occasionally, oocytes (Alao et al., 2017). Additionally, prostaglandins may be obtained from the seminal vesicles of a male reproductive system.

2.3.4.8. Slunks

While late-term slunks, or unborn fetuses harvested at slaughter, are often harvested for hides to be used for valuable and quality leather goods such as drums and scrolls, slunks are primarily harvested to obtain bovine fetal serum and blood proteins such as bovine serum albumin (BSA). Fetal bovine serum is an important substance in research in cell culturing. Fetal blood is collected by drawing blood from the heart using a vacuum and a closed system. Blood is immediately processed and frozen upon collection. Bovine amniotic fluid is also saved for biological and research purposes, as a source of stem cells and medium for culturing tissue samples (Neva et al., 1959; Dutson and Pearson, 1992; Marti et al., 2011; Gao et al., 2014).

2.3.5 Inedible beef by-products

Historically, any by-products that were not consumed were used to make clothes, shelter, weapons, etc. As the beef and meat processing businesses progressed and expanded, many inedible products were eliminated in rivers and ditches before realization

of potential value of the products. Inedible products were then applied to fields and vegetation as fertilizer. Use of inedible by-products continued to evolve with the development of products such as soap, candles and biodiesel. Today, nearly all products are used as important components of livestock and animal feed, textile, household, and biodiesel industries. In 2004, reported production of inedible animal proteins was approximately 23.4-24.3 billion kg (Pearl, 2004).

Products are considered inedible for 3 primary reasons: material composition, cleanliness, or risk concern, however, edibility is a function of many other factors including acceptance, economics and demographics. While hides are generally considered inedible due to the dense composition of the hide, carcass trimmings and inedible tallow are considered inedible due to contamination and removal prior to FSIS inspection, the brain and spinal cord are removed and rendered inedible due to the increased risk of bovine spongiform encephalopathy (BSE) upon consumption (Pearl, 2004)

2.3.5.1. Hide

Buffalo and cattle hides were traditionally used in the production of clothing and shelter such as tents and teepees. Currently hides are used in the production of all leather goods, including but not limited to purses, shoes, clothing, automobile seats and interior, etc. Hides and skin are also used in cosmetic and prosthetic products (Ockerman and Basu, 2004b). Hide marketability is directly dependent on leather usage. Leather has been largely replaced in many industries with synthetic materials, causing a reduction in the marketability and price of hides in the United States. While the US holds a small market

for leather, most hides are exported to Asia, Mexico and the European Union (Marti et al., 2011).

As reported in 2011, the value of the hide comprised approximately 75% of total by-product revenue and makes up approximately 4-12% of the weight of cattle at harvest (Ockerman and Basu, 2004b). Hides function as the most exterior protective lining for the body and are comprised primarily of collagen, however, compositions have been reported to be responsive to cattle genetics or breed, age, sex and finish.

Hides are removed at processing facilities utilizing manual separation with knives and mechanical down-pullers. Raw hides are then washed to remove mud and fecal contamination, trimmed to remove excess fat and flesh, graded and sorted based on quality (1, 2 or 3), and sex prediction based on the weight of the hide. (Ockerman and Basu, 2004b; Marti et al., 2011). Processors often preserve hides by drying, salt curing or dehairing and adding preservative chromium compounds. Air-drying is generally done in areas with low-humidity. Salt will generally preserve a hide for weeks, the production of blue chrome hides extends shelf life by several months. Following preservation, hides are often folded and stacked for storage and distribution to further processors.

2.3.5.2. Limbs

Hooves are removed from the carcass prior to removing the hide and are removed just above the dewclaws. The remainder of the metacarpals are removed from the carcass prior to chilling. Many hooves are saved, cleaned and smoked for production of pet treats, however, excess hooves above market demand are rendered to produce meat and bone meal.

2.3.5.3. Horns

Many cattle are genetically or physically dehorned to reduce injury, reduce bruising, and improve carcass yields, however cattle do still occasionally have horns upon harvest. The National Beef Quality Audit (Harris et al., 2016) reports a reduction in the number of cattle with horns harvested compared to previous data and reported prevalence ranging from 31% in dairy bulls, to 17.3%, 12.1% and 9.7% in beef bulls, dairy cows and beef cows, respectively. Oftentimes, horns removed at harvest are rendered, contributing to production of meat and bone meal. However, horns are also sold for the production of keratin based products such as buttons.

2.3.5.4. Specified Risk Materials

Specified risk materials, including the brain, spinal cord, dorsal root ganglia and distal ileum must be removed upon harvest and must not enter the human or animal food supply due to potential risk of consumption of an active BSE prion. A typical bovine brain will weigh 454-482 g on average at market weight. The spinal cord begins at the base of the brain and is housed within and extends the length of the vertebrae. The spinal cord is removed at harvest, after the carcass has been split and is typically removed via vacuum or SRM-specific knives and tools (Ockerman and Basu, 2004a; Pearl, 2004).

2.3.5.5. Carcass Trimmings & Rendered Products

Upon slaughter, carcasses are trimmed to remove all abnormal tissue (i.e. bruised) and contamination prior to USDA inspection and obtaining a final hot carcass weight. Cooking time, temperature and pressure applied to inedible carcass trimmings and other inedible by-products in the rendering process result in the elimination of moisture and the

separation of protein from fat components resulting in a dry product high in protein and minerals, referred to as meat and bone meal, and inedible tallow.

2.3.5.5.1. Protein Products

Meat and bone meal is a high protein, heat-treated product formed in the rendering process of condemned and contaminated materials from the slaughter process (NRA, 2003). The European Union regulates the production of meat and bone by monitoring the temperature (133°C), pressure (300 kPa) and cook time (20 minutes), as well as final product particle size to ensure a safe product. As defined, meat and bone meal must contain 4% phosphorus, approximately 2.2 times more calcium than phosphorus and generally exceeds 50% protein. Animal derived protein products such as meat and bone meal are also recognized for having high levels of essential amino acids such as threonine, methionine and lysine. The equivalent product that may have been formed with a smaller proportion of bone and thus, less phosphorus and protein, is considered meat meal (Pearl, 2004).

2.3.5.5.2. Fat Products

While edible tallow must be removed following USDA inspection under appropriate food safety regulations, inedible tallow is the fat component of all rendered and inedible raw materials. Tallow is evaluated on trading standards based on color, titers, fatty acid composition, contamination and saponification and marketed to clients appropriately. Inedible tallow is commonly included in many livestock rations, or used in the making of soap, fuel and other products. Tallow is an energy dense substance that has been an important component of many animal diets, containing approximately 37 kJ of energy per gram of fat and providing oleic, stearic and palmitic acids. In 2005, over 2.2

million metric tons of inedible tallow were produced and 29% of total production was exported. Tallow is most commonly incorporated in the diets of pigs and finishing cattle to improve the energy supply of the diet. In addition to the inclusion of inedible tallow in animal diets, the energy dense substance may also provide essential fatty acids, improve palatability, texture and nutrient utilization of an animal's diet (NRA, 2003).

Due to the energy-dense nature of fats and tallows, tallows are also used as a fuel source. Upon burning, fats release large amounts of energy that may be used to fuel systems such as heat units. Fats such as inedible tallow may also be used in the synthesis of biodiesel as well (NRA, 2003). The U.S. Energy Information Administration (2018) reported beef and pork fat to comprise 3-6% of the feedstock used in the production of biodiesel from 2014-2017.

2.4. USDA Beef Carcass Grading

Grading carcass beef provides a means to standardize and classify based on characteristics to improve marketing and pricing – important factors to producers, packers and consumers. The first grading system was formed to disperse the responsibility of price determination among standards, to produce a fair and consistent system to determine pricing for all entities. The USDA grading system was developed and has undergone many changes targeted to provide lucid information to allow consumers to understand more about the products they purchase.

Dr. Herbert Mumford first formed a series of bulletins for beef cattle in 1902 as an effort to classify carcasses in a manner that would convey quality characteristics associated with each classification to consumers. Quality grading evolved in the 1900s and was combined with an additional system to estimate carcass yield to form a dual

grading system. Today, while carcasses are mandatorily graded according to both quality and yield grade standards, grades are assigned independently, because yield and quality grades are no longer linked together.

In today's industry, separation by grade also provides packers and producers with the ability to identify consumer demand, and allow the opportunity to adjust management practices as necessary, while ensuring proper payment to producers and a representative cost to consumers (NRC, 1988).

While yield grade is a measure of carcass cutability, or the amount of salable red meat from a carcass, quality grade classifies carcasses based on factors affecting palatability such as marbling and maturity, which greatly influences the value of the carcass. The USDA grading standards require a carcass to be ribbed cleanly between the 12^{th} and 13^{th} rib for measurement of 12^{th} rib fat depth, LM area and to estimate marbling on the 12th rib interface (Meadows, 2019).

2.4.1. USDA quality grade

While carcass and red meat yield is a primary factor to the producer, meat quality is a primary factor to the consumer, as the quality of a meat product is associated with the consumer's experience, acceptance, and purchases of a product. Quality grades are used today to categorize beef carcasses based on factors affecting product appeal and consumer experience. For these reasons, quality demands should drive the production goals of the producer. The eight USDA Quality Grades in use today from highest to lowest quality are: Prime, Choice, Select, Standard, Commercial, Utility, Cutter and Canner (Meadows, 2019).

The youngest quality grades, Prime, Choice, Select, and Standard are limited to A and B-maturity carcasses and young animals (<30 months of age), whereas older animals may grade Commercial, Utility, Cutter and Canner. Often included in industry terminology is "no-roll", which will often not enter retail markets and will generally be sold as low-priced products or used in production of ground beef or value-added processed meats. In general, carcass quality is primarily determined by marbling and maturity – low maturity and high marbling will result in a high quality grade, while increased maturity and decreased marbling will result in a lower quality grade (Miller, 2004).

Consumer demand for quality incentivizes producers to produce such products. Consumer preference and product quality is associated with product palatability, which is an attribute of 3 sensory components: tenderness, flavor and juiciness (Miller, 2004). Variability in consumer preference and product purpose, however, provides demand for a range of quality from high, to satisfy consumer demand for rich flavor and palatability, to what is considered in the United States to be moderate or low quality to provide a lean product for health-conscious consumers, or an affordable product for thrifty consumers. Although a higher USDA Quality Grade is often associated with improved palatability, Smith et al. (1987) report extreme variability in palatability of each quality grade, with occurrences of trained sensory panelists rating some Standard steaks as comparable to Prime. Quality is dependent on numerous factors including marbling, skeletal ossification, and lean color/maturity, in response to an animal's breed/genetics, age/development, production methods, health, pre/postmortem handling, etc. (Miller, 2004).

2.4.1.1. History

Throughout the 1800's, prices for live cattle and beef were determined by the packer and had no basis for consistency, often leaving producers and consumers frustrated with the prices received and paid for the product. Dr. Herbert Mumford, from the University of Illinois, first formed a series of bulletins for beef cattle in 1902 to classify carcasses in a manner that would convey quality characteristics associated with each classification to consumers, while providing a means to standardize market prices for cattle and beef. Mumford developed 7 classifications based on various levels of intramuscular fat, carcass maturity and carcass conformation and were: from best to worst, Prime, Choice, Good, Medium, Common, Cutter and Lower Cutter (Harris et al., 1996).

In 1914, the government funded USDA to develop a third-party market news service, beginning in 1917, to provide reliable daily market reports to beef producers, packers and consumers and required a standardized classification system. While the first official grades and terminology established and used by the USDA were developed in 1916 using a great portion of the work by Mumford and Hall, many adjustments and modifications were made to the system before publication in 1923 as "Market Classes and Grades of Dressed Beef" in USDA Bulletin No.1246. In 1924, the USDA passed the United States Agricultural Products Inspection and Grading Act, permitting federal grading of livestock and carcass. Due to adverse responses to the system by producers, packers and consumers, the government held a series of hearings to acquire the opinions and suggestions of the public and the industry to improve the beef grading system. The standards were adjusted and adopted as a voluntary service by USDA in 1926 as the

Official United States Standards for Grades of Carcass Beef (USDA, 2017). Upon World War II, the US government began mandatory beef grading in response to federal price control programs. Mandatory grading of beef carcasses improved price stability and consistency, greatly increasing consumer satisfaction (Harris et al., 1996).

The USDA quality grading standards continued to evolve and progress over the years. While name changes occurred in 1939, switching the Medium to Commercial, Common to Utility and Lower Cutter to Canner, each quality standard was upgraded to the superior grade and the Commercial class was subdivided, with the top-end renamed Standard. In 1987, Good was re-branded as Select to improve consumer perception, resulting in the 8 quality grade classifications used today – Prime, Choice, Select, Standard, Commercial, Utility, Cutter and Canner (Harris et al., 1996).

2.4.1.2. Marbling

Marbling is the intramuscular formation and deposition of adipose tissue between muscle bundles. Quantity of marbling is of notable economic importance and is the single factor currently used in determining quality grade in carcasses less than 30 months of age, and a key component, along with physiological maturity, in determining quality grade of carcasses over 30 months of age. Marbling plays a key role in each component of palatability: flavor, tenderness and juiciness. Palatability has been reported to increase in response to increasing fat content, with the largest preference from 3 to 7.3% fat in a meat product (Savell and Cross, 1988).

Intramuscular fat has been reported to affect tenderness through various mechanisms and theories including the replacement of tougher tissue with a softer, less dense tissue, providing lubrication upon release of lipids in response to mastication,

protection of proteins from severe denaturation during cooking processes, and by decreasing quantity of tough perimysial tissue with increased marbling. Each theory has been proposed as a mechanism by which marbling improves tenderness, however, the mechanisms may interact and act synergistically to reduce toughness and improve tenderness (Miller, 2004).

2.4.1.3. Maturity

Allen et al. (1974) defined physiological maturity as "the relative stage of development of body processes, functions or composition." Physiological maturity is assessed through evaluation of vertebral ossification and lean color, and influences the palatability of the product and overall consumer experience. Miller (2004) reported that as animal maturity increases, toughness increases, due to increased linkages in heat-resistant, insoluble collagen, whereas carcasses of lower maturity are reported to have more soluble collagen cross-linkages.

Additionally, a study that compared tenderness traits across various age groups of cattle reported a decrease in tenderness with increasing age. Although no difference was observed ($P < 0.05$) in total collagen across age groups, the amount of soluble collagen decreased as the animal aged (Reagan et al., 1976). Physiological maturity was assessed via skeletal ossification, lean color and texture, and was a determining factor of quality grade in all carcasses in the early 1900's. Today, however, maturity is first determined through evaluation of dentition; carcasses that are deemed greater than 30 months of age via dentition are further evaluated for maturity using lean and skeletal maturity determinants (USDA, 2017b).

2.4.1.3.1. Lean Maturity

Because color is a primary component of the visual appearance and the first experience a consumer has with any given meat product, lean color and pigment is an important factor that influences consumer purchases. Lean maturity refers to the pigment lightness or darkness and is primarily an outcome of the quantity of myoglobin in the myofibrillar component of the meat as well as other pigments in smaller quantities. Myoglobin is a water soluble, heme-bound globular protein used to store oxygen in muscle (Cornforth and Jayasingh, 2004). Discoloration may occur upon oxidation and affects the salability of the product, and while discoloration is often a result of time and temperature during retail handling, variation in color may be a result of ante-mortem handling or malpractice at stunning. For example, an animal that is stressed prior to harvest may result in a dark cutter – a quality defect characterized by a dark color, high water holding capacity and a high pH due to limited production of lactic acid and glycogen metabolism (Pearson, 1959). Lean maturity is subjectively evaluated by USDA graders for carcasses greater than 30 months of age. The assessment of lean maturity is highly subjective with no established visual standards. For this reason, color-altering phenomenons such as dark cutting beef or physiological maturation may confound the lean maturity score determined by the grader.

2.4.1.3.2. Skeletal Maturity

Grading standards (USDA, 2017b) declared subjective evaluation of skeletal ossification and color to be a determining factor, together with lean color and texture, of physiological maturity of all carcasses. Similarly to lean maturity scoring, skeletal maturity is highly subjective with no visual standards established for training or

comparison. Skeletal ossification is currently used in determining the maturity of carcasses from animals 30 months of age or older. Upon implementation of skeletal evaluation for determination of maturity, degree of ossification, together with bone and cartilage color were used for the evaluation. As grading standards evolved, the evaluation of bone size and shape was also evaluated in each carcass to determine maturity (Lawrence, 2001). The vertebrae of the animal is the primary area of evaluation of skeletal maturity – for, ossification occurs beginning at the sacral vertebrae, progressing toward the cervical vertebrae as the animal ages.

As declared by USDA, an A maturity carcass should not exceed 30 months of age. A study by Lawrence et al. (2001) suggested that 40% of cattle with eight permanent incisors (>45 mo of age) skeletally qualified as A-maturity carcasses, suggesting room for extensive error in identifying a representative maturity class of a carcass. O'Connor et al. (2007) observed similar results, in that as an animal aged, according to USDA ossification evaluation standards, the probability of a carcass grading B or C maturity increased only minimally. Additionally, the skeletal system may overestimate maturity of some heifers and female cattle due to the heightened presence of estrogen in a female system, encouraging premature skeletal ossification, thus leading to a disadvantage on the grade stand and further limiting marketability. Conversely, skeletal maturity may be underestimated in castrated males, due to complete absence of estrogen producing organs.

2.4.1.3.3. Dentition

Teeth have historically been used in the evaluation and estimation of age of numerous species. Brown et al. (1960) established an association between dental

development and chronological age using dental radiographs of common beef and dairy cattle (n = 869) across different ages. This study concluded that there were no differences observed in developmental dentition between bulls and cows. Brown et al. (1960) also reported emergence of the first permanent incisor into the oral cavity at 23 ± 1 mo of age, the eruption of the second permanent incisor at 30 ± 1 mo of age and the eruption of the third permanent incisor at 36 ± 1 mo of age. Graham and Price (1982) identified the potential of implementing a dentition system as a more accurate means to estimate carcass maturity than skeletal evaluation. While Shorthose and Harris (1990) and Schönfeldt & Strydom (2011) demonstrated reduced tenderness with increased number of teeth, Wythes and Shorthose (1991) and Lawrence et al. (2001) did not observe differences in tenderness among various dental ages.

In response to the first case of BSE in the United States on December 23, 2003, the USDA began implementing evaluation of dentition to identify animals greater than 30 months of age, which are considered to be higher-risk animals for BSE. In this evaluation, animals with 0, 1 or 2 permanent incisors are considered <30 mo of age, whereas the eruption or presence of 3 or more permanent incisors indicates an animal >30 mo of age. On December 5, 2017, the USDA made the most recent change to the U.S. beef grading standards, in which dentition or age documentation is now used to determine age and maturity of beef carcasses. Cattle determined <30 mo of age are classified as A-maturity carcasses, whereas carcasses >30 mo of age will undergo skeletal and lean evaluation for the determination of carcass maturity (USDA, 2017a).

2.4.2. USDA yield grade

The USDA yield grade is used to estimate carcass cutability, or amount of saleable red meat and is determined through evaluation of 12th rib back fat depth, longissimus muscle (LM) area, kidney-pelvic-heart fat, and hot carcass weight. Cutability was re-termed as yield grade in 1973 and is estimated using the USDA yield grading standards. Carcass yield grade, by definition, estimates the amount of boneless, closely trimmed retail cuts from the round, loin, rib and chuck (BCTRLRC).

2.4.2.1. History and development

In 1956, a study by Pierce, Strong, Van Zandt and Murphey reported large variation in the cutability, or red meat yield of carcasses within the same quality grade (Murphey et al., 1960). The need to further classify carcasses based on yield, together with a demand for objective classification of carcass cutability was first evaluated and estimated by Murphey et al. (1960) and adopted by the US government in 1965. As the new carcass yield grade was first implemented, yield and quality were linked to form a dual-grade system until 1989, when the grading systems were uncoupled and assigned independently to each carcass (Harris et al., 1996).

In the development of the first cutability equation, 162 carcasses of various cutability within each quality grade were measured to obtain the length of the carcass, hind limb, length and width and area of the longissimus muscle between the 12th and 13th rib, circumference of the round, body depth, and three measures of fat depth over the longissimus muscle. Carcass sides were fabricated and trimmed to retail standards and weights of each cut were obtained. The study resulted in the development of 10 yield groups with 3% yield range. In this study, Murphey et al. (1960) observed a correlation

between fat thickness and yield of retail cuts – leading to the conclusion that fat measurements can be used to estimate boneless and bone-in yield.

The dual grading system proposed by Murphey et al. (1960) utilized the quality grades in place, in conjunction with the equation below, in which, the percentage of boneless retail cuts from round, loin, rib and chuck was estimated using measurements of the fat thickness over the ribeye, kidney-pelvic-heart-fat percentage of the hot carcass weight, ribeye area, and hot carcass weight (Murphey et al., 1960).

% Boneless retail cuts from round, loin, rib, and chuck = 51.34 – 5.78 (single fat thickness over ribeye, in) – 0.462 (percent kidney fat) +0.740 (area of ribeye,in^2) – 0.0093 (hot carcass weight, lbs).

Using Murphey's equation, the highest cutability carcasses, yielding approximately 53.1%, were in yield group 1 or 2, whereas the lowest cutability animals, yielding approximately 34.7%, were in yield group 10. While this equation improved the grading standards, the sample size was small and unrepresentative of the general cattle population, because some of cattle used to formulate this equation were mature cows. Furthermore, since the development of the equation in 1960, selection, management and feeding practices have changed genotype, phenotype and carcass composition. Each of these suggest a demand for further research, development and improvement in the yield grading system.

The USDA yield grade used in the industry today has been adapted from the cutability equation described above and is an index from 1-5, rather than 1-10, as Murphey et al. suggested (1960) and is as follows (USDA, 2017a):

USDA Yield Grade = 2.5 + 2.5 (adjusted fat thickness, in) + 0.02 (percent kidney, pelvic, heart fat) + 0.0038 (hot carcass weight, lb) – 0.32 (ribeye area, in^2)

As in the cutability equation, a low yield grade of 1-2 indicates a high yielding carcass, whereas a yield grade of 4-5 indicates a carcass of low cutability. A yield grade 1 carcass will display a thin layer of fat on the surface of the rib, loin, round and chuck. Yield grade 1 carcasses may also be a heavily muscled animal or a poor fat-depositing animal and are also associated with minimal fat deposits. A yield grade 2 carcass is generally almost entirely covered by a layer of fat surrounding primals, and will have slight fat deposits, whereas a yield grade 3 carcass will display relatively larger deposits of fat and will only expose lean around the neck and on the round. A yield grade 4 carcass will have a thick layer of fat surrounding the carcass, especially around the loin, ribs, round and hips with excessive fat deposits in the flank, cod and body cavity. A yield grade 5 carcass will display the highest degree of fat deposition in complete cover, and fat deposits. Generally, as yield grade increases, ribeye area has been observed to decrease (USDA, AMS, 2017a).

2.4.2.2. Yield grade in cattle marketing

While all cattle were marketed on the average price of live cattle or dressed basis prior to the 1990s, today, USDA carcass grading traits play a key role in the market price producers receive for cattle/carcasses they sell because of the prevalence of a value-based, grid marketing system implemented in today's beef industry. Marketing cattle via "the grid" system offers incentive to produce a quality carcass of high cutability by paying producers premiums for high quality and cutability, while discounting producer prices received for carcasses of lower quality and cutability. The grid value received by

producers is a factor of 1) hot carcass weight, 2) base price, 3) quality grade, 4) yield grade/cutability, and discounts for non-conforming carcasses. Under a typical value-based grid, carcasses receive premiums or discounts for quality above or below Choice, yield grade below or above 3 and discounts for carcasses below 600 or above 900-1050 lbs. (Johnson and Ward, 2005).

In the interest of the consumer, the National Research Council and the Committee on Technological Options to Improve Nutritional Attributes of Animal Products have suggested that excess carcass subcutaneous fat be trimmed prior to obtaining final hot carcass weight, therefore, encouraging producers to produce a leaner product to maximize profit (NRC, 1988a) In a report of dressing percentages and essential carcass yield by quality grade, Ockerman and Hansen (2000) explained a decrease in dressed yield as carcass quality decreases. Likely occurring in response to degree of finish, carcasses that graded Prime had an average dressed yield of 64%, whereas Choice, Select and Standard carcasses yielded 62, 60 and 57% and Commercial, Utility, Cutter and Canner carcasses yielded 57, 53, 49, and 45% of the live weight.

2.5. Literature Cited

Alao, B. O., A. B. Falowo, A. Chulayo, and V. Muchenje. 2017. The potential of animal by-products in food systems: production, prospects and challenges. Sustain. 9:1089. DOI: 10.3390.

Allen, C. E., E. H. Thompson, and P. V. J. Hegarty. 1974. Physiological maturity of muscle and adipose cells in meat animals. Proc. Recip. Meat Conf. 27: 8-27.

Bae, D. H., J. G. Welch and B. E. Gilman. 1982. Mastication and rumination in relation to body size of cattle. J. Dairy Sci. 66:2137-2141.

Baumont, R., Doreau, M., Ingrand, S. & Veissier, I. 2006. Feeding and mastication behaviour in ruminants. In: Feeding in domestic vertebrates: from structure to behaviour (ed: Bels, V.), 84-107. Cabi International. Wallingford, UK.

Belk, K. E. 1992. Low quality grades-effects of implants on maturity, marbling and incidence of dark-cutting beef. National Beef Quality Audit, Final Report, p 173. National Cattlemen's Assoc., Englewood, CO.

Berg, R. T., and R. M. Butterfield. 1968. Growth patterns of bovine muscle, fat and bone. J. Anim. Sci. 27:611-619.

Bertelsen, B. USDA Quality grades and yield grades. U.S. Premium Beef. http://www.uspb.com/DocumentItem.aspx?ID=21. Accessed on: 17 Mar 2020.

Borderas, T. F., J. Rushen, and A. M. de Passillé. 2008. Behavioral effects of endotoxin-induced fever in dairy calves. J. Anim. Sci. 86:2920–2927. doi: 10.2527/jas.2008-0926.

Braun, U., L. Trösch, F. Nydegger and M. Hässig. 2013. Evaluation of eating and rumination behaviour in cows using a noseband pressure sensor. BMC Vet Res. 9:164. doi: 10.1186/1746-6148-9-164.

Brown. W. A. B., P. V. Christofferson, M. Massler and M. B. Weiss. 1960. Postnatal tooth development in cattle. Am. J. Vet. Res. 21:7-34.

Burton, J. L., B. W. McBride, E. Block, D. R. Glimm, and J. J. Kennelly. 1994. A review of bovine growth hormone. Can. J. Anim. Sci. 74:167-201.

Campbell, J. A. 2016. Understanding Beef Carcass Yields and Losses During Processing. Penn State Extension. Available from: https://extension.psu.edu/understanding-beef-carcass-yields-and-losses-during-processing. Accessed on: 19 Mar 2020.

Clemen, R. A. 1927. By-products in the packing industry. University of Chicago Press, Chicago, IL.

Carcass Beef Grades and Standards. Agricultural Marketing Service. Available from: https://www.ams.usda.gov/grades-standards/carcass-beef-grades-and-standards. Accessed on: 16 Apr 2020.

Cornforth, D. P. and P. Jayasingh. 2004. Chemical and physical characteristics of meat – Colour and pigment. In: C. Devine and M. Dikeman, editors, Encyclopedia of meat sciences. Elsevier Academic Press, London, England. p. 249-256.

Dikeman, M. and C. E. Devine. 2004. Sensory and meat quality, optimization of. In: C. Devine and M. Dikeman, editors, Encyclopedia of meat sciences. Elsevier Academic Press, London, England. p. 1228-1233.

Dinussion, W. E., F. N. Andrews, and W. M. Beeson. 1950. The effects of stilbestrol, testosterone, thyroid alterations, and spaying on growth and fattening of beef heifers. J. Anim. Sci. 9:321–330.

Dutson, T. R., and A. M. Pearson. 1992. Advances in meat research. Inedible meat by-products. Springer, Netherlands.

Eaton, R. D., J. R. Carson and G. Beall. 1955. The effect of diethylstilbestrol implantation in the inmature cockerel on reproductive performance at maturity. J. Poult. Sci. 34:861-867.

EIA. 2018. Biodiesels produced from certain feedstocks have distinct properties from petroleum diesel. U.S. Energy Information Administration. Accessed from: https://www.eia.gov/todayinenergy/detail.php?id=36052. Accessed on: 23 June 2020.

Fisher, A. M. and D. A. Scott. 1934. The insulin content of the pancreas in cattle of various ages. J. Biol. Chem. 106:305-310.

Gao, Yuhua, Z. Zhu, Y. Zhao, J. Hua, Y. Ma, and W. Guan. 2014. Multilineage potential research of bovine amniotic fluid mesenchymal stem cells. Int. J. Mol. Sci. 15: 3698-3710.

Garrison, M. (2005). Cattle Classification and Sorting System. Performance Cattle Company, LLC. Accessed from: http://www.performancecattle.com/html/ccss_research_study.html Accessed on: 20 Mar 2020.

Graham, W. C. and M. A. Price. 1982. Dentition as a measure of physiological age in cows of different breed types. Can. J. Anim. Sci. 62:745-750.

Goldhawk, C., K. Schwartzkopf-Genswein, and K. A. Beauchemin. 2013. Technical note: Validaiton of rumination collars for beef cattle. J. Anim. Sci. 91:2858-2862. doi: 102527/jas2012-5908.

Grant, R. J. and J. L. Albright. 1995. Feeding behavior and management factors during the transition period in dairy cattle. J. Anim. Sci. 73:2791-2803.

Griffin, D. D., and T. L. Mader. 1997. G97-1324 Beef cattle implant update. Historical Materials from University of Nebraska-Lincoln Extention. Available from: https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1309&context=extension hist. Accessed on: 10 Mar 2020.

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

Hale, D. S., K. Goodson, and J. W. Savel. 2013. USDA Beef Quality and Yield Grades. Texas A&M AgriLife Extension Service. https://meat.tamu.edu/beefgrading/. Accessed on: 18 MAR 2020.

Hamilton, A. W. C. Davison, C. Tachtatzis, I. Andonovic, C. Michie, H. J. Ferguson, L. Somerville and N. N. Jonsson. 2019. Identification of the rumination in cattle using support vector machines with motion-sensitive bolus sensors. Sensors. 19:1165. doi: 10.3390/s19051165.

Harris, J. J., H. R. Cross and J. W. Savell. 1996. History of Meat Grading in the United States. https://meat.tamu.edu/meat-grading-history/. Accessed on: 16 Mar 2020.

Harris, M.K., L. C. Eastwood, C. A. Boykin, A. N. Arnold, K. B. Gehring, D. S. Hale, C. R. Kerth, D. B. Griffin, J. W. Savell, K. E. Belk, D. R. Woerner, J. D. Hasty, R. J. Delmore Jr., J. N. Martin, T. E. Lawrence, T. J. McEvers, D. L. VanOverbeke, G. G. Mafi, M. M. Pfeiffer, T. B. Schmidt, R. J. Maddock, D. D. Johnson, C. C. Carr, J. M. Scheffler, T. D. Pringle and A. M. Stelzleni. 2017. National Beef Quality Audit – 2016: Transportation, mobility, live cattle, and carcass assessments of targeted producer-related characteristics that affect value of market cows and bulls, their carcasses, and associated by-products. J. Anim. Sci. 2017.1:570-584. doi: 10.2527/tas2017.0063.

Hayden J. M., W. G. Bergen, R. A. Merkel. 1992. Skeletal muscle protein metabolism and serum growth hormone, insulin and cortisol concentrations in growing steers implanted with estradiol-17β, trenbolone acetate or estradiol-17β plus trenbolone acetate. J. Anim. Sci. 70:2109-2119.

Hutcheson, J. P., D. E. Johnson, C. L Gerken, J. B. Morgan and J. D. Tatum. 1997. Anabolic implant effects on visceral organ mass, chemical body composition and estimated energetic efficiency in cloned beef steers. J. Anim. Sci. 75:2620-2626.

Isaacson, W. K., S. J. Jones, and R. J. Krueger. 1993. Testosterone, dihydrotestosterone, trenbolone acetate, and zeranol alter the synthesis of cortisol in bovine adrenocortical cells. J. Anim. Sci. 71:1771–1777.

Johansson, M. S. 2011. Chewing behavior of growing cattle. Thesis. Institutionen for husdjurens miljo och halsa, Skara.

Johnson, B. J., P. T. Anderson, J. C. Meiske, and W. R. Dayton. 1996. Effect of a combined trenbolone acetate and estradiol implant on feedlot performance, carcass characteristics, and carcass composition of feedlot steers. J. Anim Sci. 74:363–371.

Johnson, B. J., N. Halstead, M. E. White, M. R. Hathaway, A. DiCostanzo, and W. R. Dayton. 1998a. Activation state of muscle satellite cells isolated from steers implanted with a combined trenbolone acetate and estradiol implant. J. Anim. Sci. 76:2779–2786.

Johnson, B. J., M. E. White, M. R. Hathaway, C. J. Christians, and W. R. Dayton. 1998b. Effect of a combined trenbolone acetate and estradiol implant on steady-state IGF-I mRNA concentrations in the liver of wethers and the longissimus muscle of steers. J. Anim. Sci. 76:491–497.

Johnson, H. C. and C. E. Ward. 2005. Market signals transmitted by grid pricing. J. Agr. Resour. Econ. 30:561-579.

Kerth, C. R. 2013. Animal Growth and Empty Body Composition. The Science of Meat Quality. Available from: https://www.google.com/books/edition/The_Science_of_Meat_Quality/SZbSe2q_GbsC?hl=en&gbpv=1&pg=PT7&printsec=frontcover. Accessed on 15 May 2020.

Lawrence, T. E., J. D. Whatley, T. H. Montgomery and L. J. Perino. 2001. A comparison of the USDA ossification-based maturity system to a system based on dentition. J. Anim. Sci. 79:1683-1690.

Lee, C. Y., D. M. Hendricks, G. C. Skelley, and L. W. Grimes. 1990. Growth and hormonal response of intact and castrate male cattle to trenbolone acetate and estradiol. J. Anim. Sci. 58:2682-2689.

LeShure, S. N., T. A. Gipson, A. L. Goetsch, R. Puchala, T. Sahlu. 2016. Effects of forage quality and breed on rumination time in goats. J. Anim Sci. 94:820. doi. 10.2527/jam2016-1682.

Lofgreen, G. P. and W. N. Garrett. 1968. A system for expressing net energy requirements and feed values for growing and finishing beef cattle. J. Anim. Sci. 27:793-806.

Lorenz, F. W. 1943. Fattening cockerels by stilbestrol administration. J. Poult. Sci. 22:190-191.

Marti, D. L, R. J. Johnson, K. H. Mathews, Jr. 2011. Where's the (not) meat? United States Department of Agriculture. Economic Research Service. Available from: https://www.ers.usda.gov/webdocs/publications/37427/8801_ldpm20901.pdf?v=41056. 19 Mar 2020.

May, N. D. 2014. The effect of zilpaterol hydrochloride on non-carcass and carcass yields and grading performance for serially-harvested calf-fed Holstein steers. Thesis, West Texas A&M University, Canyon, TX.

Meadows, L. 2019. What's your beef – Prime, Choice or Select? Washington D.C. (USA): USDA.gov; Available from: https://www.usda.gov/media/blog/2013/01/28/whats-your-beef-prime-choice-or-select?page=1. Accessed on: 27 Feb 2020.

Meeker, D. L. 2006. Essential rendering: all about the animal by-products industry. Kirby Lithographic Company, Inc., Alexandria, VA.

Miller, R. K. 2004. Chemical and physical characteristics of meat - Palatability. In: C. Devine and M. Dikeman, editors, Encyclopedia of meat sciences. Elsevier Academic Press, London, England. p. 256-265.

Montgomery, T. H., P. F. Dew, and M. S. Brown. 2001. Optimizing carcass value and the use of anabolic implants in beef cattle. J. Anim. Sci. 79:E296-E306.

Morgan, J. B. 1991. Tenderness problems and potential solutions. National Beef Quality Audit, Final Report, pp 180. National Cattlemen's Assoc., Englewood, CO.

Murphey, C. E., D. K Hallet, W. E. Tyler and J. C. Pierce. 1960. Estimating yields of retail cuts from beef carcasses. J. Anim. Sci. 19:1240.

Murray, S.M., A.R. Patil, G.C. Fahey, Jr, N.R. Merchen, and D.M. Hughes. 1997. Raw and rendered animal by-products as ingredients in dog diets. J. Anim. Sci. 75:2497-2505.

National Research Council. 1988a. Executive Summary. In: C. Carlson, editor, Designing Foods: Animal Product options in the marketplace. National Academy Press, Washington, DC. p. 1-8.

Neva, F. A., P. Wirth and D. E. Wegemer. 1959. Composition of bovine amniotic and allantoic fluids used as cell culture medium. J. Cell Comp. Physiol. 53:153-161.

NRA. 2003. Pocket information manual - A buyer's guide to rendered products. North American Renderer's Association. Available from: https://nara.org/wp-

content/uploads/2019/10/pocket_information_manual2.pdf. Accessed on: 19 Mar 2020.

NRA. North American rendering: the source of essential, high-quality products. 2nd ed. National Renderers Association, Inc., Alexandria, VA.

Ockerman, H.W., and C.L. Hansen. 2000. Animal Byproduct Processing and Utilization. Technomic, Lancaster, PA.

Ockerman, H. W. and L. Basu, 2004a. Byproducts - Edible, for human consumption. In: C. Devine and M. Dikeman, editors, Encyclopedia of meat sciences. Elsevier Academic Press, London, England. p. 104-112.

Ockerman, H. W. and L. Basu, 2004b. Byproducts – Hides and skins. In: C. Devine and M. Dikeman, editors, Encyclopedia of meat sciences. Elsevier Academic Press, London, England. p. 125-138.

O'Connor, M. E., J. R. Ransom, and M. Feil. 2007. USDA physiological maturity validation study: Validating the relationship between chronological age and physiological maturity in the U.S. fed-beef population. Available from: http://www.maff.go.jp/j/syouan/douei/beef_taiou/pdf/080131b. pdf. Accessed on: 19 March 2020.

Owens, F. N., P. Dubeski, C. F. Hanson. 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci. 71:3138–3150, doi: 10.2527/1993.71113138x

Owens, F. N., D. R. Gill, D. S. Secrist, and S. W. Coleman. Review of some aspects of growth and development of feedlot cattle. J. Anim. Sci. 73: 3152-3172.

Pearl, G. G. 2004. Byproducts - Inedible. In: C. Devine and M. Dikeman, editors, Encyclopedia of meat sciences. Elsevier Academic Press, London, England. p. 112-125.

Pearson, A. M. 1959. Factors indicative of quality in beef and their measurements. In: Beef for tomorrow: proceedings of a Conference. Washington, D.C.

Pereira, G. M., B. J. Heins, and M. I. Endres. 2016. Activity and rumination in an organic vs. a conventional grazing herd. J. Anim. Sci. 94:618. doi: 10.2527/jam2016-1282.

Poland, C. and K. Hoppe. 1999. Implant use in backgrounding calves. North Dakota State University. AS-1178. Available from: https://www.ag.ndsu.edu/dickinsonrec/annual-reports-1/1999-annual-report/implant-use-in-backgrounding-calves.pdf. Accessed on: 22 June 2020.

Raun, A. P. and R. L. Preston. 2002. History of diethylstilbestrol use in cattle. J. Anim. Sci. p.1-7. http://www.asas.org/Bios/Raunhist.pdf.

Reagan, J. O., Z. L Carpenter and G. C. Smith. 1976. Age-related traits affecting the tenderness of the bovine longissimus muscle. J. Anim. Sci. 43:1198-1205.

Reuter, R. G. Mourer, D. Lalman and C. Richards. 2016. Implants and their use in beef cattle production. Oklahoma State University. Available from: https://shareok.org/bitstream/handle/11244/49965/oksd_ansi_3290_2016-02.pdf?sequence=1. Accessed on: 15 Mar 2020.

Ruckebusch, Y. and L. Bueno. 1978. An analysis of ingestive behavior and activity of cattle under field conditions. Appl. Anim. 4:301-313.

Rushen, J., N. Chapinal, A.M. de Passille. 2012. Automated monitoring of behavioural-based animal welfare indicators. Anim. Welf. 21:339-350. doi: 10.7120/09627286.

Savell, J. W. and H. R. Cross. 1988. The role of fat in the palatability of beef, pork and lamb. In: C. Carlson, editor, Designing Foods: Animal Product options in the marketplace. National Academy Press, Washington, DC. p. 1-8.

Schanbacher, B. D. 1984. Manipulation of endogenous and exogenous hormones for red meat production. J. Anim. Sci. 59: 1621-1630.

Schönfeldt HC, Strydom PE. 2011. Effect of age and cut on cooking loss, juiciness and flavour of South African beef. Meat Sci. 87:180–190.

Shorthose, W. R. and P. V. Harris. 1990. Effect of animal age on the tenderness of selected beef muscles. J. Food Sci. 55:1-8.

Simpfendorfer, S. 1973. Relationship of body type and size, sex and energy intake to the body composition of cattle. Thesis. Cornell University. Ithaca, NY.

Smith, G. C., J. W. Savell, and H. R. Cross, Z. L Carpenter, C. E. Murphey, G. W. Davis, H. C. Abraham, F. C. Parrish, JR and B. W. Berry. 1987. Relationship of USDA quality grades to palatability of cooked beef. J. Food Qual. 10:269-286.

Smith, Z. K, A. J. Thompson, J. P. Hutcheson, W. T. Nichols, and B. J. Johnson. 2018. l implants containing trenbolone acetate and estradiol-17β on live performance, carcass

traits and sera metabolites in finishing steers. J. Anim. Sci. 96:1704-1723. doi: 10.1093/jas/sky095.

Swanson, E. W., and J. D. Harris, Jr. 1958. Development of rumination in the young calf. J. Dairy Sci. 41:1768-1776. doi: 10.3168/jds.s0022-0302(58)91161-5.

Tatum, J. D. 2011. Animal age, physiological maturity, and associated effects on beef tenderness. National Cattlemen's Beef Association. Available from: https://www.beefresearch.org/CMDocs/BeefResearch/PE_White_%20Papers/Animal_Age.pdf. Accessed on: 19 March 2020.

Terry, C. A., R. H. Knapp, J. W. Edwards, W. L. Miles, J. W. Savell and H. R. Cross. 1990. Yields of by-products from different cattle types. J. Anim. Sci. 68:4200-4205.

Tie Khouw, B., L. J. Rubin, and B. Berry. 1989. Meat animal by-products of pharmaceutical and food interest. Proc. Rec. Meats Conf. 23-30.

Trenkle, A. and D. N. Marple. 1983. Growth and development of meat animals. J. Anim. Sci. 57:273-283.

Tumova, E., A. Teimouri. 2009. Chicken muscle characteristics and meat quality: A review. Sci. Agric Bohmem. 40:253-258.

USDA-FSIS. 2019. Specified Risk Material (SRM) Control. Inspection Methods. 30-1 – 30-8. United States Department of Agriculture – Food Safety Inspection service. Available from: https://www.fsis.usda.gov/wps/wcm/connect/4716e62b-74be-49c2-aa53-20123d2ff398/IM_SRM_control.pdf?MOD=AJPERES. Accessed on: 05 Aug 2020.

USDA-NAHMS. 2013. Trends in Health and Management Practices on U.S. Feedlots, 1994-2011. National Animal Health Monitoring System, United States Department of Agriculture.

USDA. 2017a. USDA Announces Changes to the U.S. Beef Grade Standards. 2017. USDA Announces Changes to the U.S. Beef Grade Standards Agricultural Marketing Service. Available from: https://www.ams.usda.gov/content/usda-announces-changes-us-beef-grade-standards. Accessed on: 19 Feb 2020.

USDA. 2017b. United States Standards for Grades of Carcass Beef. Federal Register. Available from: https://www.federalregister.gov/documents/2017/06/19/2017-12647/united-states-standards-for-grades-of-carcass-beef. Accessed on: 17 Mar 2020.

USMEF. Total U.S. Beef Exports 2009-2018. United States Meat Export Federation. Available from: https://www.usmef.org/downloads/Beef-2009-to-2018.pdf. Accessed on: 17 Mar 2020.

Wang, D. Q., and M. C. Carey. 2014. Therapeutic uses of animal biles in traditional Chinese medicine: An ethnopharmacological, biophysical, chemical and medicinal review. World J. Gastroenterol. 20:9952-9975. doi: 10.3748/wjg.v20.i29.9952.

Welch, J. G., A. M. Smith, and K. S. Gibson. 1970. Rumination time in four breeds of dairy cattle. J. Dairy. Sci. 53:89-91.

Welch, J. G. 1982. Rumination, particle size and passage from the rumen. J. Anim. Sci. 54:885.

Wolfger, B. E. Timsit, E. A. Pajor, N. Cook, H. W. Barkema, K. Orsel. 2015. Technical note: Accuracy of an ear tag-attached accelerometer to monitor rumination and feeding behavior in feedlot cattle. J. Anim. Sci. 93:3164-3168. doi: 10.2527/jas.2014-8802.

Wythes, J. R. and W. R. Shorthose. 1991. Chronological age and dentition effects on carcass and meat quality of cattle in northern Australia. Aust. J. Exp. Agric. 31:145-152.

CHAPTER III

ACTIVITY AND RUMINATION OF IMPLANTED CHAROLAIS × ANGUS STEERS VS. NON-HORMONE TREATED COUNTERPARTS CONSUMING VARIOUS LEVELS OF ROUGHAGE THROUGHOUT A 361-D FEEDING DURATION

3.1. Abstract

A serial-harvest study was conducted to evaluate rumination and activity of growing steers in response to implant and dietary roughage. Charolais × Angus steers (*n* = 80) were randomized to harvest (0, 42, 84, 126, 168, 210, 252, 294, 336 or 378 DOF) and implant treatment (**REV:** Revalor-XS on d-0 and d-190 or **CON:** no implant). Activity and rumination were objectively monitored via accelerometers attached to the left ear. Steers consumed 3 rations throughout the study: starter (38.5% roughage), intermediate (23% roughage), and finishing (8.5% roughage). Data was logged in 2-h increments from 77 steers across 361 d and analyzed using mixed models. Rumination and activity varied ($P < 0.01$) within 24-h, exhibiting bimodal patterns; rumination peaked at 0600 and 1400 h and troughed at 1000 and 1800 h. Activity peaked at 0800 and 1800 h and troughed at 0400, 1200-1400, and 2200 h. Steers administered REV ruminated less (364 vs 380 min/d; $P = 0.04$) than CON, however, 24-h activity was similar ($P = 0.29$) between treatments. Treatment × roughage interactions ($P < 0.01$) occurred for rumination and activity. Rumination tended to differ ($P = 0.06$) between CON consuming 38.5% and 23% roughage, however, CON steers ruminated ($P < 0.01$)

more than REV when consuming 8.5% roughage. Implanted and non-implanted steers ruminated less ($P < 0.01$) as roughage inclusion decreased from 38.5% and 23% to 8.5% (457 and 439 vs 317 min/d) in the finishing ration. Activity was highest for steers consuming 38.5% roughage and was similar ($P > 0.05$) among treatments, however, activity decreased ($P < 0.01$) upon transition to 23 and 8.5% roughage. Activity peaks and troughs can be attributed to processing days and weather events. Implanted steers consuming 8.5% roughage were more active (342 vs. 337 and 333 min/d; $P < 0.01$) than CON and REV steers consuming 23% roughage. In conclusion, rumination and activity are responsive to hour of day, dietary roughage and growth-promoting implants.

3.2. Introduction

Behavioral and locomotive characteristics have become an important tool for cattle producers in assessing an animal's physical and physiological state of health and production and making various managerial decisions, while serving contemporary importance in improved animal husbandry (Urton et al., 2005). Rumination and animal activity are commonly evaluated in production and research practices across various livestock sectors.

Accelerometer devices allow for objective quantification of movement and have been implemented in the industry since the 1960's. Technological progression in accelerometer devices has allowed for improved accuracy, while also permitting distinction and quantification of various movements such as activity and rumination (Johansson, 2011; Reed, 2015). Electronic accelerometers have been used to objectively estimate and quantify steps, activity, posture, rest, and respiration as a means of detecting reproductive (Peter and Bosu, 1986; Roelofs et al., 2005), feeding (Walker et al., 1985),

pain (Currah et al., 2009), stress (Haley et al., 2005) and health events in cattle (Pillen et al., 2016; Richeson et al., 2018).

Growth promoting implants, an additional technology administered to over 90% of feedlot cattle, add invaluable efficiency to numerous facets of beef production (Biswas et al., 2013; Reuter et al., 2016). Implants have greatly impacted the industry, however, minimal published literature has evaluated the effects of growth promoting implants on animal movement and behavioral characteristics across various stages of development. Understanding relationships between behavior, growth promoting implants and animal development will allow the industry to adjust technological implementation and management practices appropriately, to improve production and maximize welfare. The objective of this experiment was to objectively quantify rumination and activity as the animal grows and transitions through various feedlot diets in response to anabolic implant.

3.3. Materials & Methods

All procedures were approved and executed in accordance with the West Texas A&M University Institutional Animal Care and Use Committee. (Protocol No. 01-08-18).

3.3.1. Animals, Pairing and Treatments

In brief, Charolais × Angus steers (n = 120; 250 ± 107 kg;) were transported approximately 1947 km from Simplot Land and Livestock in Grand View, ID to a private research feedlot (AgriResearch, LLC) in Canyon, TX for feeding throughout the study. Steers were paired for genetic similarity and projected endpoint composition. Pairs were randomized to 1 of 4 pens. Pairing, processing, evaluation of feeding behavior and skeletal measurements are described in a companion paper (Kirpatrick, 2020).

Rumination and activity were evaluated in response to implant, feeding duration (**DOF**), dietary roughage inclusion and circadian hour. Individual steers within pair were randomly assigned to 1 of 2 implant treatments: **REV** steers received a Revalor-XS (200mg trenbolone acetate/40mg estradiol; Merck Animal Health, Madison, NJ) implant on d 0 and d 190, whereas **CON** steers represented a non-hormone treated (NHTC) marketing strategy and received no implant throughout the feeding period.

All steers were transitioned throughout the feeding period from a receiving diet containing 38.5% roughage (d 0 to d 13), to an intermediate diet containing 23% roughage; (d 22 to d 55) and to a final finishing diet containing 8.5% roughage (d 71 to d 377). Two transition periods occurred. Roughage concentrations of the receiving and finishing diet are representative of receiving and finishing diets implemented in the industry as reported by a survey of consulting feedlot nutritionists (Samuelson et al., 2016a).

The 40 REV/CON pairs (80 steers) of smallest variation in pairing criteria (n = 80 steers; 271 kg ± 99 kg) were randomly assigned to one of 10 harvest dates corresponding to 0, 42, 84, 126, 168, 210, 252, 294, 336 or 378 DOF. All remaining animals were retained as replacement pairs in the case of chronic animals treated more than once or upon death or injury.

3.3.2. Measurement of rumination and activity

Each steer received an Allflex eSense Flex accelerometer tag (SCR Engineers Ltd, Netanya, Israel) in the middle one-third of the left ear on d -7 of the study. The accelerometer tag remained in place throughout the entirety of the study as a means for identification and continuous measurement of rumination and activity time (min) in 2-h

increments. Rumination and activity time data was transmitted from the tag to a receiver and logged into the Allflex Heattime Pro (SCR Engineers Ltd, Netanya, Israel) software program and data was downloaded for analysis upon completion of the study. All steers were allowed *ad libitum* access to feed and water throughout the study. Steers were processed every 42 d as described by Kirkpatrick (2020). Rumination and activity data is reported for a total of 77 animals across a 361-d period; data usage began on d 0 at 0000 h and ended on d 361 at 2400.

3.3.3. Statistical Analysis

The study was designed as a balanced incomplete block design with a 2 × 10 factorial treatment arrangement. Steer was experimental unit (n = 80), pair was block (n = 40) and data were analyzed in response to the effects of implant treatment and DOF using the GLIMMIX procedure of SAS (SAS Inc., Carey, NC) with Kenwood-Roger degrees of freedom approximation and compound symmetry covariance structures. Activity and rumination data were repeated measures data for each experimental unit and were also evaluated and analyzed for the fixed effect of dietary roughage level and 2-h interval within a 24-period. Rumination and activity time (min/2h) for 2-h intervals were used for analysis of circadian rhythms (2-h-increments), whereas data summarized into daily rumination and activity time (min/d) were used for the analysis in response to day and dietary roughage inclusion. Implant treatment, h, DOF, and roughage inclusion were fixed effects, pair was included as a random effect. Least squares means were used for the calculation of mean estimates and differences were adjusted using the Bonferroni option.

3.4. Results and Discussion

3.4.1. Circadian Pattern

Though no treatment × 2-h interactions ($P = 0.83$) occurred and no treatment differences (CON 28.6 vs. REV 28.3 min/2-h; $P = 0.29$) were observed in animal activity per 2-h increment, steers exhibited ($P < 0.01$) bimodal activity throughout a 24-h period (**Fig.3.1.**). Steers were most active at 0800 (37.2 min/2h) and from 1600 to 1800 h (36.8 and 39.2 min/2h), and were least active from 2200 h to 0400 h the subsequent day (20.9, 22.2, 21.8 and 19.3 min/2h at 2200, 2400, 0200 and 0400 h), at which point, activity began to increase to approximately 25.9 min/2-h at 0600 and to the first peak at 0800. Steers spent approximately 19% of the total 2-h increment being active compared to 16% in the least active interval (0400). Steers were likely to have increased activity beginning at 0600 h in response to light and anticipation of feeding, inverse to rumination (Gordon and McAllister, 1970; Beauchemin et al., 1990). Veissier et al. (2017) also reported cattle to be most active in evenings from approximately 16-17 h of the day compared to the 1600-1800 h window observed in the present study. Mari et al. (2018) also observed bimodal movement patterns in Holstein steers fed in confinement and peaks in movement occurred from 0900 to 0930 and 1700 to 1900 h. The diurnal activity pattern exhibited in the current study are similar to the activity and behavior of grazing cattle as reported by Werner et al. (2019), who observed bimodal patterns peaking in the mornings and evenings, while troughing in the afternoon and during hours of darkness.

No treatment × 2-h interaction ($P = 1.00$) was observed for animal rumination, however, REV steers ruminated less (30.3 vs. 31.7 min/2h; $P = 0.04$) than CON steers per 2-h interval, resulting in a 16 min reduction (364 vs. 380 min/d) in rumination for

implanted steers. A main effect of h was also observed for rumination ($P < 0.01$); rumination among both treatments also exhibited bimodal patterns, peaking at 0600 (44.2 min/2h) and 01400 h (31.8 min/2h) and troughing at 1000 and 1800h (**Fig. 3.2.**). Rumination time decreased (44.2 to 31.5 min/2h; $P < 0.01$) from 0600 to 0800, likely in response to feeding, which occurred between 0700 and 0800 h and inverse to activity, which peaked at 0800 h. Feeding and activity have repeatedly displayed inverse relationships with rumination and reported troughs in rumination upon feeding (Beauchemin et al., 1990; Beauchemin, 2018). Steers ruminated the least at 1000 (25.5 min/2h), 1800 (19.9 min/2h) and 2000 h (23.9 min/2h). Gordon and McAllister (1970) observed the highest degree of rumination in periods of darkness, and increased feeding and a subsequent decrease in rumination upon light application and suggested a photonic effect on rumination, rather than feeding.

3.4.2. Dietary Roughage

Activity was influenced by both implant and dietary roughage level in a treatment × roughage interaction ($P < 0.01$; **Fig. 3.3.**) Both REV and CON steers were most active (CON 267 and REV 360 min/d; $P < 0.01$) when consuming the highest level of roughage (38.5%), however, this level of roughage was included in the diet upon receiving and early in the feeding period. Activity for both treatments temporarily troughed upon consumption of the intermediate diet (23% roughage), particularly REV steers (333 min/d). While CON steers maintained similar ($P = 1.00$) daily activity upon transition from the intermediate (23% roughage) to the finishing (8.5% roughage) diet, REV steers were active 9 minutes longer ($P < 0.01$) per d when consuming 8.5% roughage. The intermediate diet was fed from 16 October 2018 through 03 December 2018, transition

period to cooler temperatures ranging from an average temperature of 2.8 to 12.8°C, which may have negatively influenced animal activity.

A treatment × roughage interaction ($P < 0.01$; **Fig. 3.4.**) was observed for rumination. Rumination was highest upon consumption of the receiving (38.5% roughage) diet, during which no observed treatment differences ($P = 1.00$) occurred. Welch (1982) and Beauchemin (2018) discussed the stimulatory effect of gastrointestinal fill and neutral detergent fiber associated with roughage inclusion on rumination, supporting the heightened rumination at the highest concentration of roughage in the diet. Decreased rumination in conjunction with reduced roughage is also consistent with the findings of Tomczak et al. (2019).

Though rumination was similar ($P = 1.00$) for cattle of both treatments at 38.5% roughage and REV cattle consuming 23% roughage, CON cattle consuming 23% roughage tended to ruminate less ($P = 0.06$). A reduction ($P < 0.01$) in rumination occurred for both implanted and non-implanted cattle upon transitioning to 8.5% roughage in the finishing diet. Further, REV cattle ruminated 9% ($P < 0.01$) less than CON when consuming 8.5% dietary roughage. Hayden et al. (1992) reported quadratic suppression of serum cortisol concentrations when crossbred steers were implanted with TBA or a combination of TBA and estradiol 17-β. Samuelson et al. (2016b) reported altered rumen fermentation and reduced degradation of organic matter and the neutral detergent fiber portion of feeds when cortisol was applied to an in-vitro system. The reduced rumination by implanted steers in the present study may be associated with a microbial response to the altered cortisol concentrations of implanted steers, however, further research is needed to explore this speculation.

3.4.3. Feeding Duration

No treatment × DOF interactions ($P = 1.00$) were observed for activity or rumination and no main effects of implant treatment were observed for activity ($P = 0.12$). Daily animal activity (**Fig. 3.5.**) was highest initially at the beginning of the study and gradually decreased by approximately 0.03 minutes per day as the feeding duration progressed. The gradual decrease in activity as the feeding duration progressed was consistent with Reed (2015) in the evaluation of steps per day in response to zilpaterol hydrochloride. Transportation and receiving stress may have contributed to heightened activity early in the study. Kroll et al. (2014) demonstrated increased activity and number of steps taken in cattle stressed from tail docking, representing young, stressed cattle similar to cattle in the present study.

Observed peaks and troughs in daily activity are attributed to processing days and weather events including wind, precipitation, heat and cold weather. Ruckebusch and Bueno (1978) also reported reductions in cattle activity in response to heightened wind conditions, which was observed on d 266 and d 359 of the present study, while the remaining weather events in the present study occurred earlier in the feeding period and resulted in heightened activity on d 80, 116 and 170. The highest peak observed throughout the study occurred on d 170, when wind exceeded 53 mph. Average daily activity for all steers was also below average during late winter and spring months, from February to early June, which may have been due partially to heightened spring wind that occurs in the Texas Panhandle. Total minutes of daily activity also troughed on processing days following processing on d 168 throughout the remainder of the study (d 190, 210, 252, 294 and 336). These processing days occurred from April through August,

at which point steers had surpassed traditional market weight, weighting approximately 680 kg on average (Kirkpatrick, 2020).

Rumination responded to both implant treatment and DOF. Implanted steers ruminated less (331 vs. 354 min/d; P <0.01; **Fig. 3.6.**) than non-implanted counterparts. The treatment difference observed reflects the decrease in rumination in implanted steers during the finishing period (302 vs. 332 min/d), for no treatment differences occurred during periods of consuming the receiving (457 min/d) and intermediate ration (439 min/d). Dietary roughage concentration of the present study is also representative of DOF because of the periodic feeding approach. Beauchemin (2018) explained that reductions in rumination time are often observed in response to reduced particle size, as well as the reduction in roughage inclusion, also supporting the decrease in rumination observed in the present study in response to decreased dietary roughage.

3.5. Conclusion

Data from this study suggest that implanted and non-hormone treated cattle exhibit behavioral circadian rhythms that are offset with rumination and activity displaying antagonistic relationships within 24 h. Rumination and activity were highest upon receiving and consuming the highest level of dietary roughage. Administration of growth promoting implants reduced animal rumination in response to hour, dietary roughage and across days on feed, likely in response to feeding behavior and altered microbial activity.

3.6. Literature Cited

Beauchemin, K. A. 2018. Invited review: Current perspectives on eating and rumination activity in dairy cows. J. Dairy Sci. 101:4762-4784. doi: 10.3168/jds.2017-13706.

Beauchemin, K. A., R. G. Kachanoski, G. B. Schaalje and J. G. Buchanan-Smith. 1990. Characterizing rumination patterns of dairy cows using spectral analysis. J. Anim. Sci. 68:3163-3170. doi: 10.2527/1990.68103163x.

Biswas, S., C. A. Shapiro, W. L. Kranz, T. L. Mader, D. P. Shelton, D. D. Snow, S. L. Bartelt-Hunt, D. D. Tarkalson, S. J. van Donk, T. C. Zhang and S. Ensley. 2013. Current knowledge on the environmental fate, potential impact and management of growth-promoting steroids used in the US beef cattle industry. J. Soil Water Conserv. 68:325-336. doi:10.2489/jswc.68.4.325.

Braun, U., L. Trösch, F. Nydegger and M. Hässig. 2013. Evaluation of eating and rumination behaviour in cows using a noseband pressure sensor. BMC Vet Res. 9:164. doi: 10.1186/1746-6148-9-164.

Currah J.M., S.H. Hendrick, and J.M. Stookey. 2009. The behavioral assessment and alleviation of pain associated with castration in beef calves treated with flunixin meglumine and caudal lidocaine epidural anesthesia with epinephrine. Can. Vet. J. 50:375-382.

Gordo, J. G. and I. K. McAllister. 1970. The circadian rhythm of rumination. J. Agri. Sci. 74:291-297. doi: 10.1017/S0021859600022905P.

Haley, D.B., D.W. Bailey, and J.M. Stookey. 2005. The effects of weaning beef calves in two stage on their behavior and growth rate. J. Anim. Sci. 83:2205-2214. doi: 10.2527/2005.8392205x.

Hayden, J. M., W. G. Bergen, and R. A. Merkel. 1992. Skeletal muscle protein metabolism and serum growth hormone, insulin and cortisol concentrations in growing steers implanted with estradiol-17β, trenbolone acetate, or estradiol-17β plus trenbolone acetate. J. Anim. Sci. 70:2109-2119.

Johansson, M. S. 2011. Chewing behavior of growing cattle. Thesis. Institutionen for husdjurens miljo och halsa, Skara.

Kirkpatrick, T.J. 2020. The effect of growth-promoting implants and days on feed on live performance and behavioral characteristics, biometric measurements, empty body composition, and energy retention of serially harvested beef steers. Thesis. West Texas A&M University. Canyon, TX.

Kroll, L. K., D. L. Grooms, J. M. Siegford, J. P. Schweihofer, C. L. Daigle, K. Metz and M. Ladoni. 2014. Effects of tail docking on behavior of confined feedlot cattle. 92:4701-4710. doi: 10.2527/jas.2014-7583.

Mari, B., J. Reed, T. McEvers, N. May, L. Walter, J. Hodgen, J. Hutcheson, and T. Lawrence. 2018. Diurnal movement and consumption patterns of calf-fed Holstein steers fed in confinement. 96:17. doi. 10.1093/jas/sky404.038.

Peter, A.T. and W.T.K. Bosu. 1986. Postpartum ovarian activity in dairy cows: Correlation between behavioral estrus, pedometer measurements and ovulations. Therio. 26:111-115. doi: 10.1016/0093-691X(86)90117-2.

Pillen, J. L., P. J. Pinedo, S. E. Ives, T. L. Covey, H. K. Naikare, and J. T. Richeson. 2016. Alteration of activity variables relative to clinical diagnosis of bovine respiratory disease in newly received feedlot cattle. Bov. Pract. 50:1-8. doi: 10.1093/tas/txy004.

Reed, J. A. 2015. Biometric growth and behavior of calf-fed Holstein steers fed in confinement. Thesis, West Texas A&M University, Canyon, TX.

Reuter, R. G. Mourer, D. Lalman and C. Richards. 2016. Implants and their use in beef cattle production. Oklahoma State University. Available from: https://shareok.org/bitstream/handle/11244/49965/oksd_ansi_3290_2016-02.pdf?sequence=1. Accessed on: 15 Mar 2020.

Richeson, J. T., T. E. Lawrence and B. J. White. 2018. Using advanced technologies to quantify beef cattle behavior. Transl. Anim. Sci. 2:223-229. doi: 10.1093/tas/txy004.

Roelofs, J.B., F.J.C.M. van Eerdenburg, N.M. Soede, and B. Kemp. 2005. Pedometer readings for estrous detection and as a predictor for time of ovulation in dairy cattle. Therio. 64:1690-1703. doi: 10.1016/j.theriogenology.2005.04.004

Ruckebusch, Y. and L. Bueno. 1978. An analysis of ingestive behavior and activity of cattle under field conditions. Appl. Anim. 4:301-313. doi: 10.1016/0304-3762(78)90002-0.

Samuelson, K. L., M. E. Hubbert, M. L. Galyean and C. A. Löest. 2016a. Nutritional recommendations of feedlot consulting nutritionists: The 2015 New Mexico State

and Texas Tech University survey. J. Anim. Sci. 94:2648-2663. doi: 10.2527/jas.2016-0282.

Samuelson, K. L., A. L. Salazar, L. L. Rath, J. B. Alford, E. R. Oosthuysen, S. L. Ivey, D. M. Hallford and C. A. Loest. 2016b. Salivary cortisol concentrations affect rumen microbial fermentation and nutrient digestibility in vitro. J. Anim. Sci. 94:813-814. doi: 10.2527.

Tomczak, D. J., C. L. Lockard, J. S. Jennings, and J. T. Richeson. 2019. Performance, rumination, and rumen pH responses to different dietary energy density and feed management strategies in auction-derived feedlot cattle. J. Anim. Sci. 97:4682-4690. doi: 10.1093/jas/skz323.

Urton, G., M. A. G. von Keyserlingk, and D. M. Weary. 2005. Feeding behavior identifies dairy cows at risk for metritis. J. Dairy Sci. 88:2843-2849. doi: 10.3168/jds.S0022-0302(05)72965-9.

Veissier, I., M. M. Mialon and K. H. Sloth. 2017. Short communication: Early modification of the circadian organization of cow activity in relation to disease or estrus. J. Dairy Sci. 100:3969-3974.

Walker, J.W., R.K. Heitschmidt, and S.L. Downhower. 1985. Evaluation of pedometers for measuring distance traveled by cattle on two grazing systems. J. Range. Manage. 38:90-93.

Werner, J., C. Umstatter, L. Leso, E. Kennedy, A. Geoghegan, L. Shalloo, M. Schick and B. O'Brien. 2019. Evaluation and application potential of an accelerometer-based

collar device for measuring grazing behavior of dairy cows. Anim. 13:1-10. doi: 10.1017/S1751731118003658.

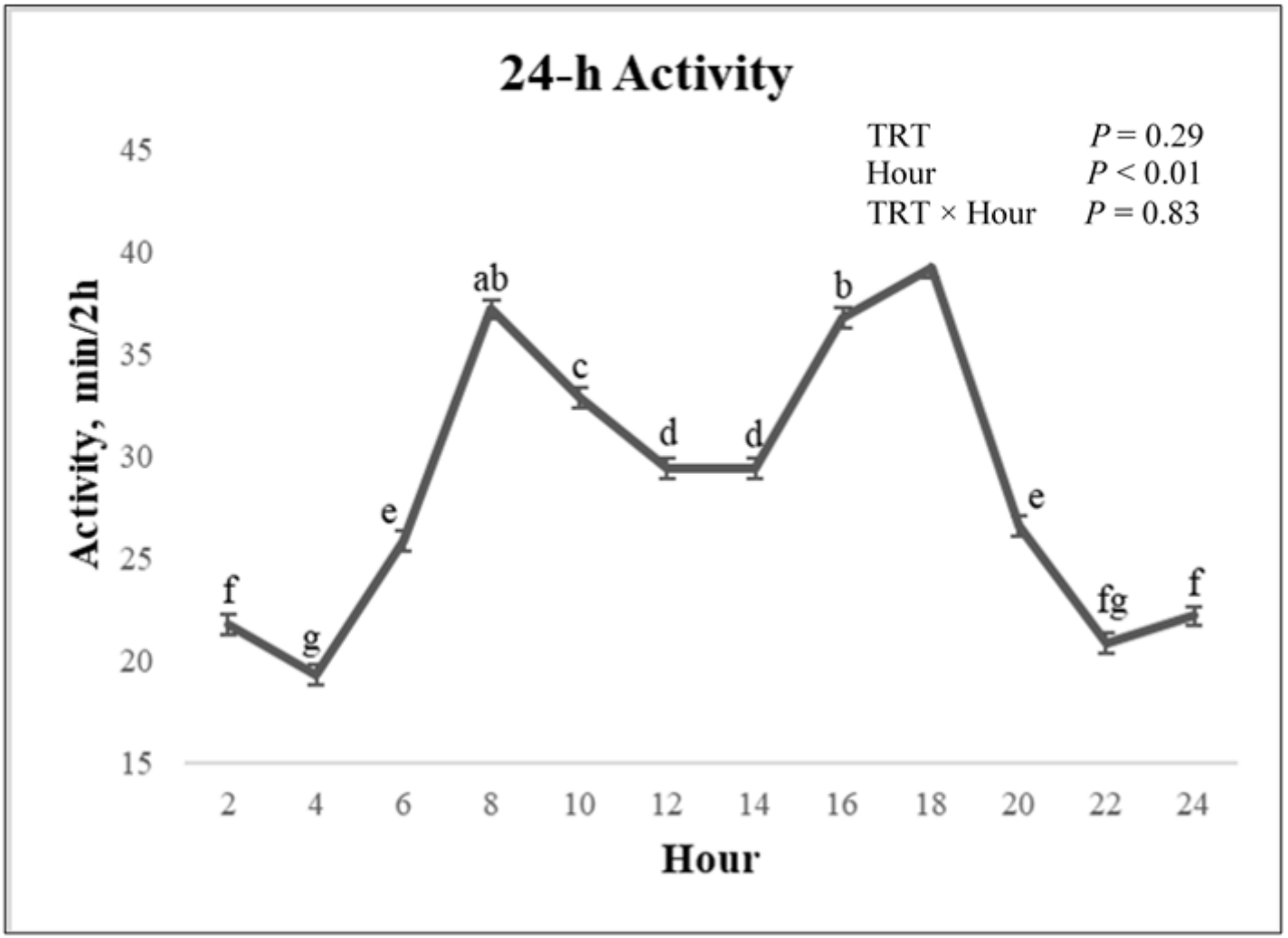

Figure 3.1. Main effects of hour within day on activity of non-hormone treated (CON) cattle and cattle implanted with Revalor-XS (REV), across a 378-d feeding duration.

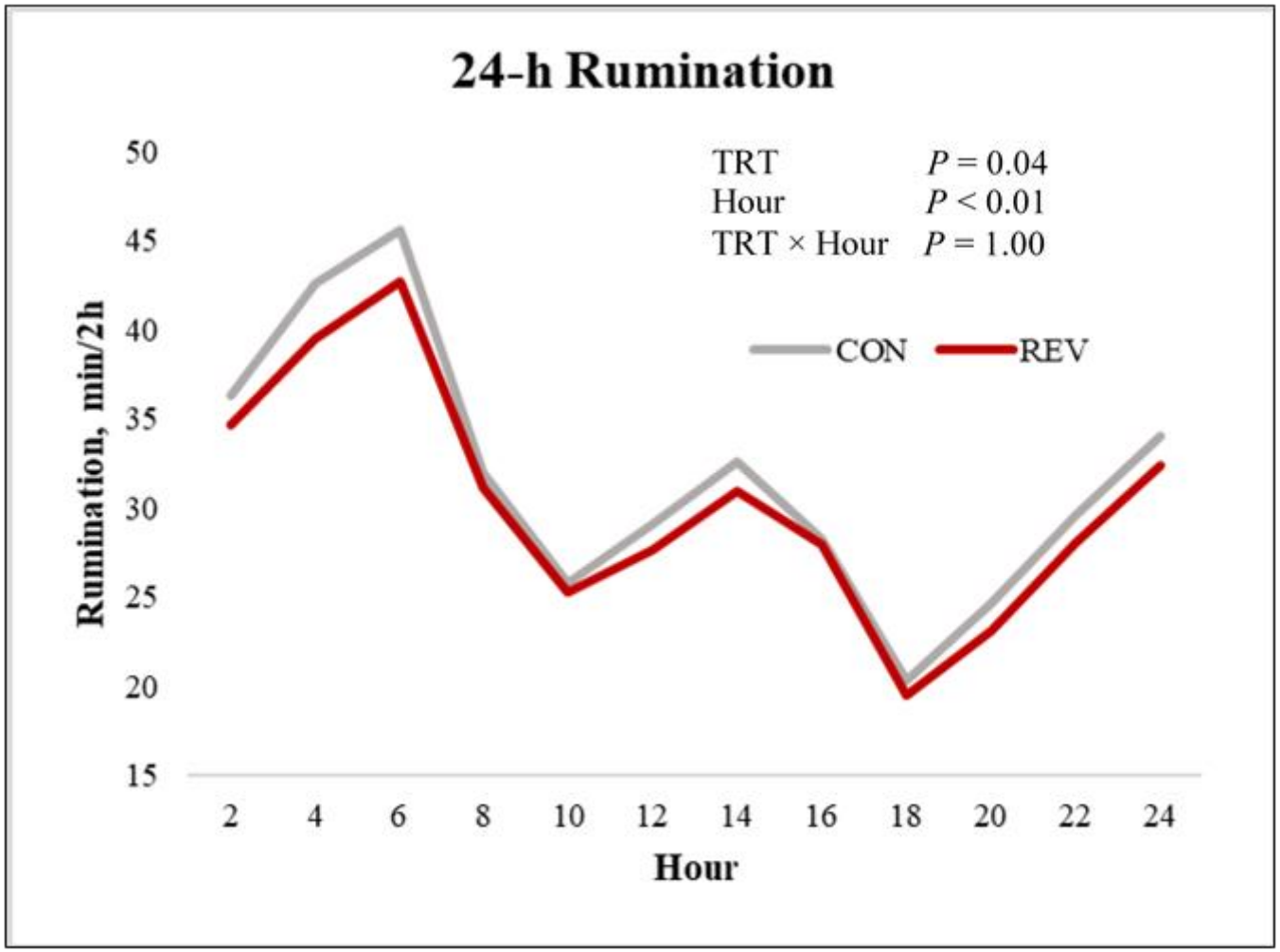

Figure 3.2. Main effects of hour within day on rumination of non-hormone treated (CON) cattle and cattle implanted with Revalor-XS (REV), across a 378-d feeding duration.

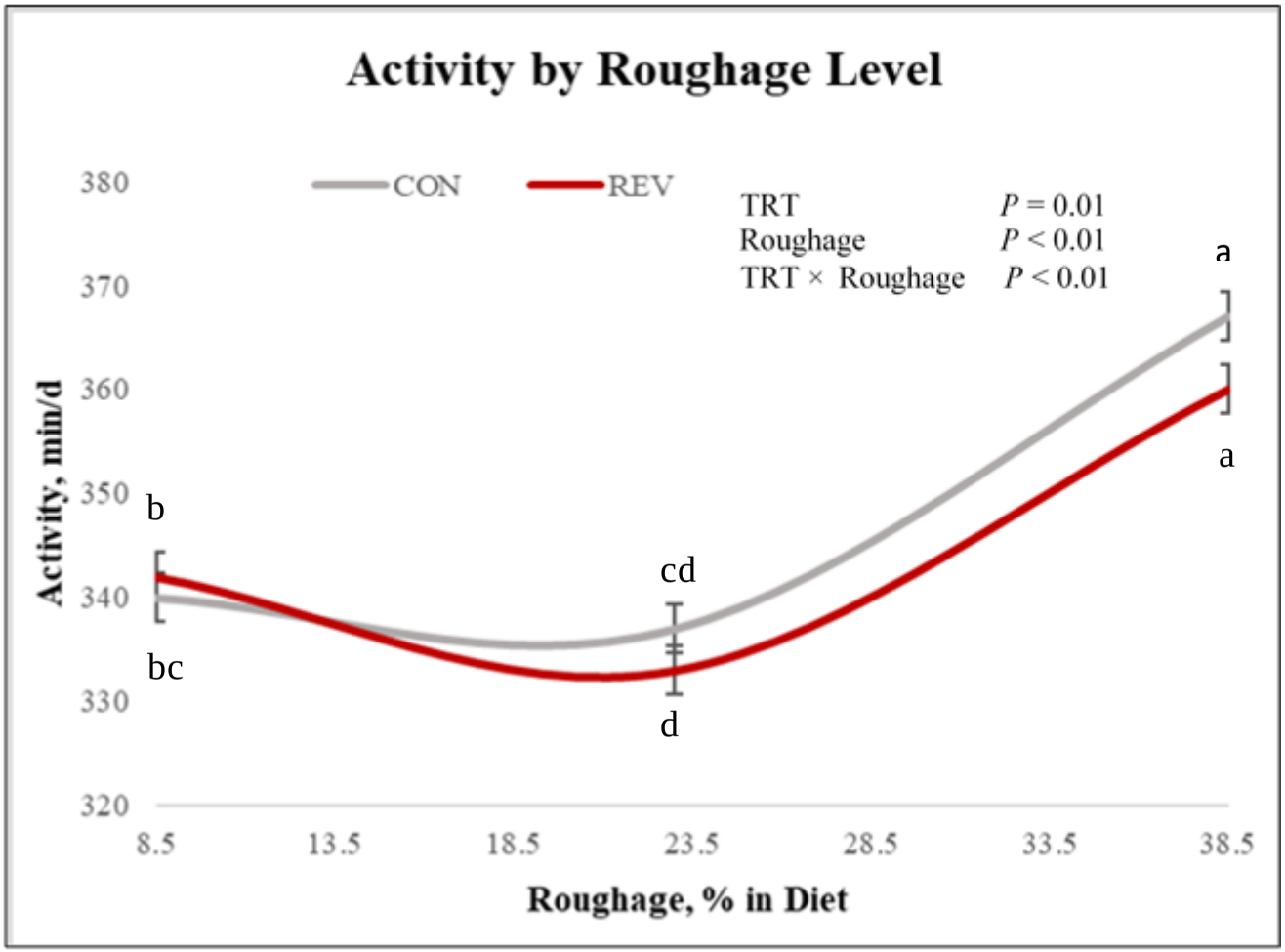

Figure 3.3. Dietary roughage inclusion × implant treatment interaction for activity of non-hormone treated (CON) cattle and cattle implanted with Revalor-XS (REV) across a 378-d feeding duration.

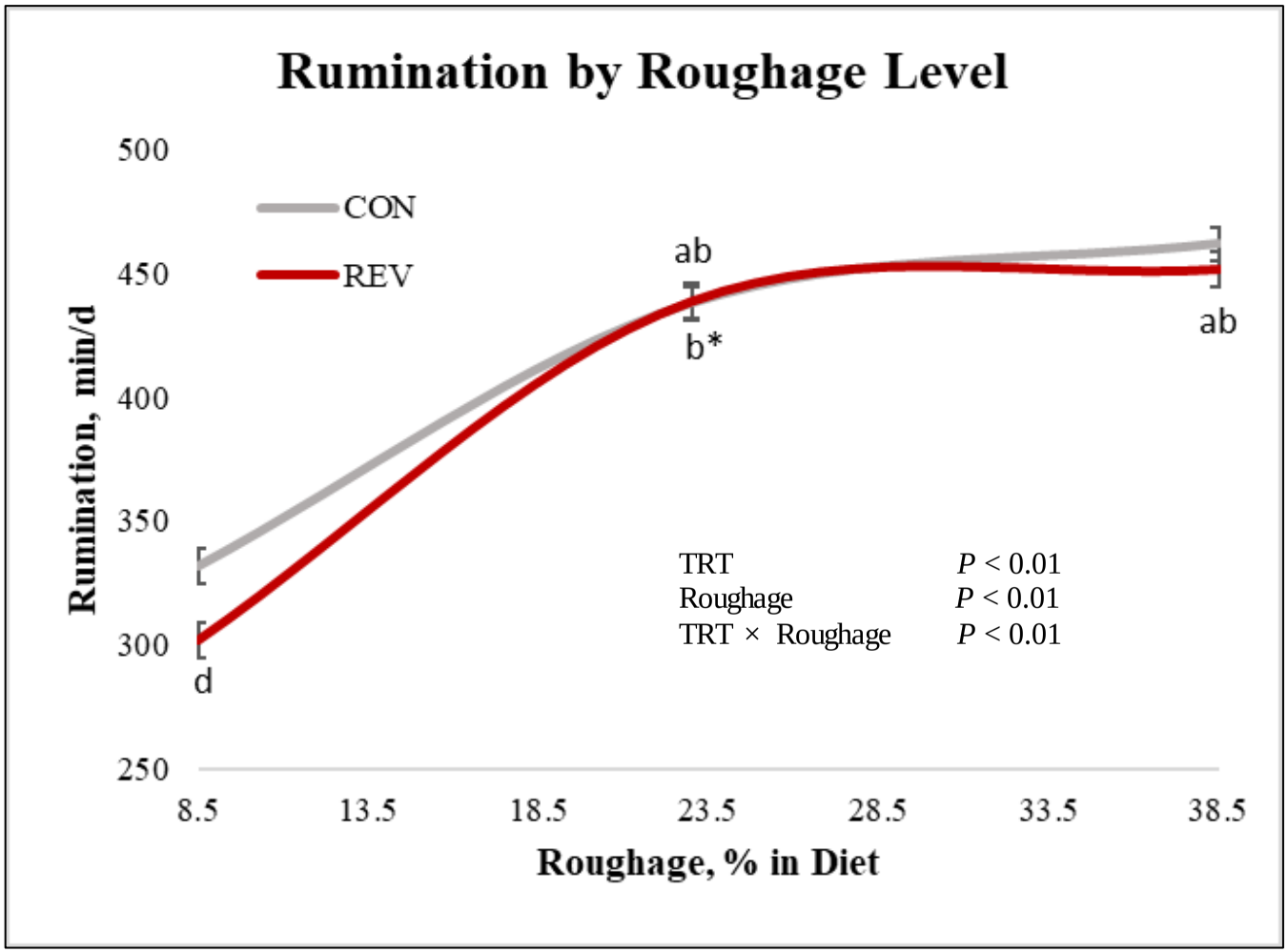

Figure 3.4. Dietary roughage inclusion × implant treatment interaction for rumination of non-hormone treated (CON) cattle and cattle implanted with Revalor-XS (REV) across a 378-d feeding duration.

* Tendency (0.05 < P < 0.10).

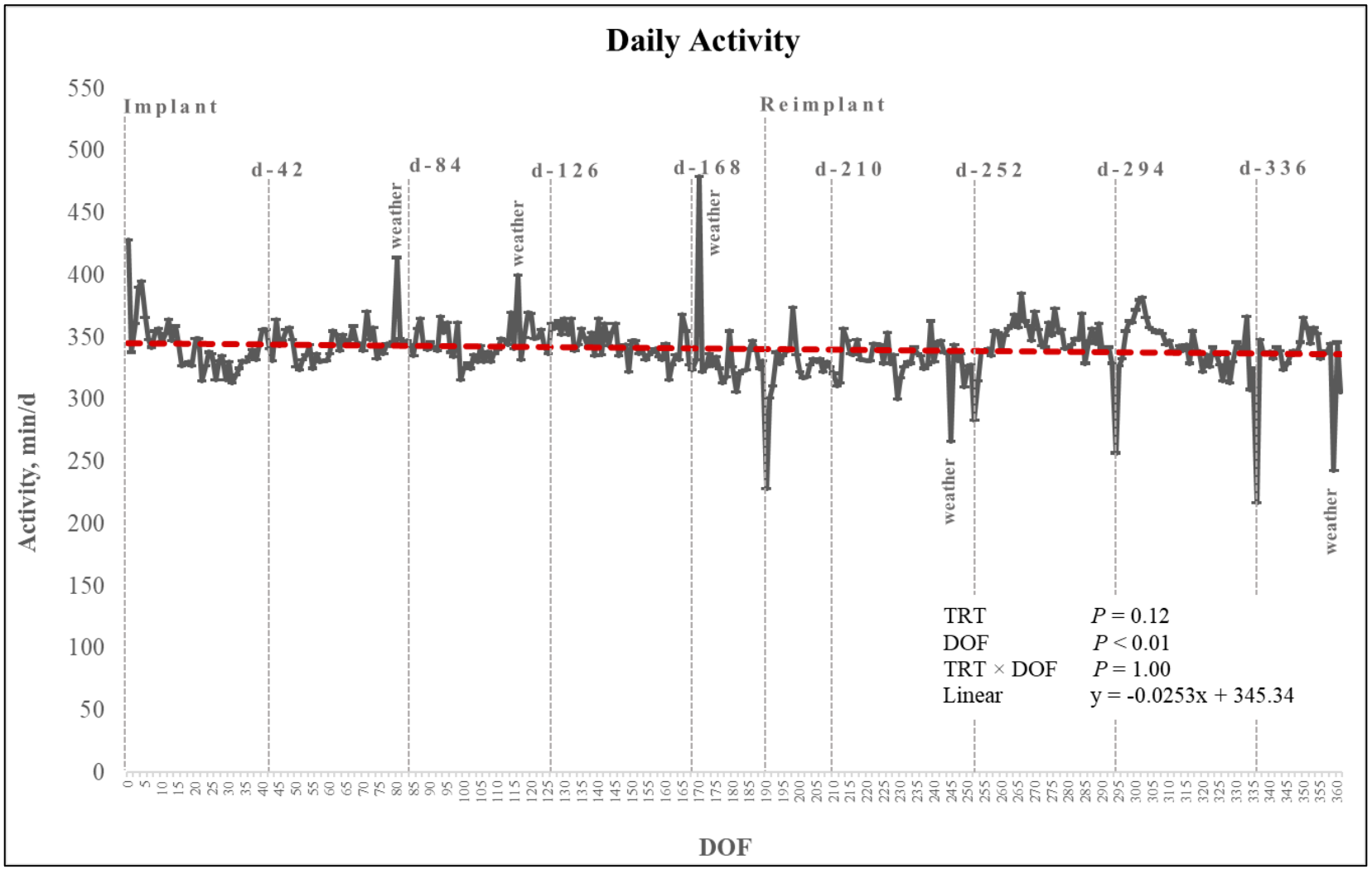

Figure 3.5. Main effects of DOF on daily activity of non-hormone treated (CON) cattle and cattle implanted with Revalor-XS (REV) in a 378-d feeding duration. Linear regression equation represents change across DOF (x).

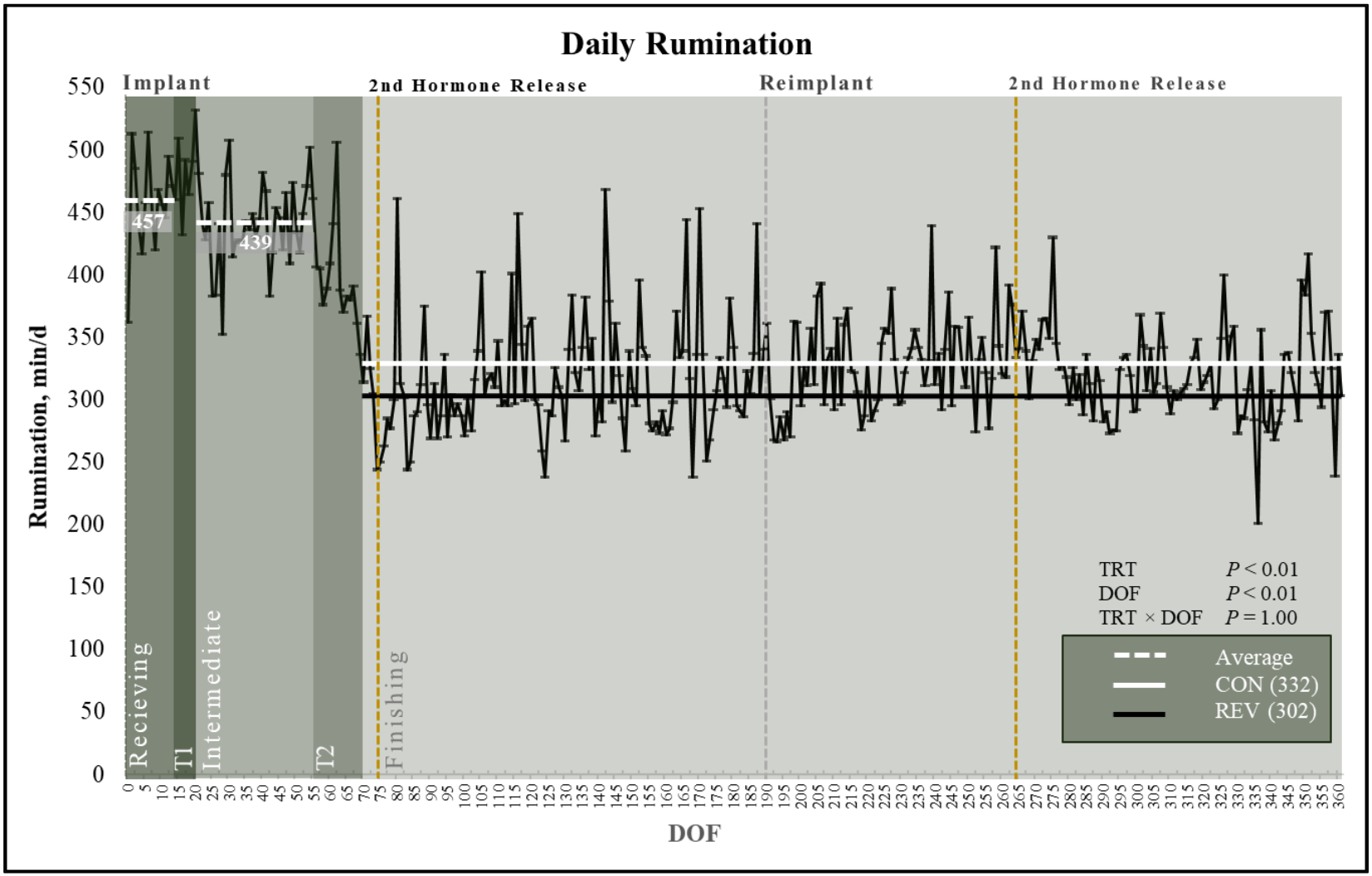

Figure 3.6. Main effects of DOF on daily rumination of non-hormone treated (CON) cattle and cattle implanted with Revalor-XS (REV) in a 378-d feeding duration.

CHAPTER IV

NON-CARCASS COMPONENTS AND BYPRODUCT YIELDS OF TBA + E_2 IMPLANTED STEERS VS. NON-HORMONE TREATED STEERS ACROSS SERIAL HARVEST ENDPOINTS

4.1. Abstract

Growth promoting implants containing trenbolone acetate **(TBA)** and estradiol-17β **(E_2)** are administered to improve rate of gain and feed efficiency of beef cattle. Non-carcass components are by-products of the beef industry that are of metabolic, economic and societal importance. A serial-harvest was conducted to investigate growth of non-carcass components of implanted or non-implanted Charolais × Angus steers. Steers (n = 80) were paired and allocated to a 2 x 10 factorial treatment structure in a balanced incomplete block design. Steers were randomly appointed to harvest date (0, 42, 84, 126, 168, 210, 252, 294, 336 or 378 days on feed; **DOF**) and implant treatment; **REV** received a Revalor-XS (200mg TBA/40mg E_2) on d0 and d190, whereas **CON** received no implant. Pair was block, steer was experimental unit and data were analyzed using mixed models. Four REV/CON pairs were harvested upon each feeding endpoint. Non-carcass components were removed and weighed; gastrointestinal tracts (**GIT**) were disassembled, weighed, cleaned, and re-weighed. Empty body weight **(EBW)**, and hot carcass weight **(HCW)** were 6% greater ($P < 0.01$) in REV steers vs. CON. No treatment effects ($P \geq 0.12$) were observed for fill or dressed carcass yield **(DY)**, however, EBW, HCW and DY

increased ($P \leq 0.01$) and percentage fill decreased as an effect of DOF. Absolute fill weight did not change across DOF ($P \geq 0.82$). Implanted steers had greater ($P \leq 0.05$) absolute mass of blood, head, hide, oxtail, liver, spleen, bladder, heart, reticulum, omasum, stomach, small intestine, intestines, GIT, total splanchnic tissue and total offal. Implanted steers also had smaller ($P \leq 0.05$) absolute mass of thymus glands and kidney-pelvic-heart fat **(KPH)** than non-implanted steers. Absolute mass of the spinal cord, small intestine and intestines varied across DOF but did not exhibit linear or quadratic growth, whereas all other tissue weights increased ($P \leq 0.05$) or tended to increase ($P \leq 0.06$) with DOF. The brain, limbs, thymus, abomasum, KPH and total internal fat (**TIF**) of REV steers weighed proportionately less ($P \leq 0.03$) and the reticulum weighed proportionately more ($P = 0.03$) than those of CON steers. Proportionate weight of the bladder, gallbladder and spleen was similar for all DOF, whereas all other variables differed ($P \leq 0.04$) across DOF. Observed results suggest that TBA + E_2 implants increased body and carcass weights and altered many non-carcass components, while reducing excess internal fat accumulation.

4.2. Introduction

Non-carcass components are of great importance to each sector of the beef supply chain including producers, processors and consumers. Many of these components are organs that determine an animal's productivity and metabolic efficiency (Hutcheson et al., 1997), comprise approximately 12-15% of total processor revenue (McEvers et al., 2011) and have biological, pharmaceutical and nutritional properties, supporting many global industries and populations (Ockerman and Basu, 2004a).

Growth promoting implants are a common and beneficial technology used in conventional cattle feeding operations to improve growth efficiency and weight gain (Griffin, 1997; Biswas et al., 2013; Reuter et al., 2016), and have been reported to improve environmental and economic efficiency for producers and consumers in various aspects. (Capper et al., 2012; Biswas et al., 2013). However, limited research has evaluated the effect of growth promoting implants on the development of non-carcass components in commercial feedlot cattle.

The objective of this research was to investigate the impact of a growth promoting implant on the development of non-carcass components of modern crossbred feedlot steers across a 378-d growing period in comparison to non-hormone treated counterparts.

4.3. Materials & Methods

All experimental procedures associated with this study were executed humanely, following guidelines that had been approved by the West Texas A & M University Institutional Animal Care and Use Committee (Protocol No. 01-08-18).

4.3.1. Animals & Treatments

As described by Kirkpatrick (2020), Charolais × Angus (n = 120) steers were received at the AgriResearch Feedlot (Canyon, TX) weighing approximately 266 ± 122 kg. Steers were paired by age, frame score, genetic similarity and target composition and the 40 pairs of closest pairing intervals were randomly allocated to 1 of 10 harvests corresponding to 0, 42, 84, 126, 168, 210, 252, 294, 336 or 378 DOF. Individuals within pair were randomly assigned to implant treatment; REV steers received a Revalor-XS (200mg trenbolone acetate/40mg estradiol; Merck Animal Health, Madison, NJ) implant

on d 0 and d 190, and CON steers received no implant throughout the feeding period, representing a non-hormone treated marketing strategy (NHTC).

4.3.2. Harvest Procedures

Upon each feeding endpoint (42-d increments), all steers were weighed to obtain live weight (**BW**) and processed as described by Kirkpatrick et al. (2020) and the 4 REV/CON pairs (n = 8 steers) allocated to the appropriate harvest were transported 12.07 km to the Caviness Meat Science and Innovation Center (Canyon, TX; USDA Establishment no. 7124) for harvest the subsequent day. Steers were allowed *ad libitum* access to water, however, received no feed following departure from the feedlot.

A USDA-FSIS inspector performed antemortem inspection on each steer prior to harvest and steers were stunned via captive bolt (Model No. 35-321, Blitz Kerner, Portsmouth, RI) according to standard harvest procedures and immediately shackled to obtain stun weight (Model EDXtreme, Dillon Force Measurement, Dallas, TX). The animal was then exsanguinated via severance of the jugovascular veins and carotid arteries and blood was allowed to drain for 3 minutes, at which point a blood-drained weight was obtained using the same scale. Metatarsals were removed at the tarsus joint whereas the hooves and dewclaw of the front legs were removed dorsal to the proximal sesamoids and the metacarpals were removed at the radial-carpal joint. Metatarsals, metacarpals, hooves and dewclaws were weighed (Model UFM-B60, UWE, New Taipeicity, TW) and summed together as **limbs**. Weight of the ears (removed at the base of the ears), tail switch and oxlips were obtained upon removal and added to the weight of the hide. The hide was manually (straight knives) and mechanically (pneumatic

dehider, Model No. JC-111A, Jarvis, Middletown, CT) removed using a down-puller design (Model No. 1064, LeFiell, Reno, NV) and weighed.

The penis was removed against the ventral abdominal wall and weighed. The head was removed between the occipital condyles and the atlas joint, weighed and inspected by a USDA-FSIS inspector before removing the tongue, epiglottis and salivary glands. The weight of the full tongue, including the tongue, salivary glands and epiglottis was obtained and was then trimmed to remove the hyoid bone, salivary glands and the epiglottis to obtain the weight of a retail-trimmed tongue. The skull was split longitudinally down the bridge of the nasal bone, through the middle of the frontal bone and poll using a band saw (Model No. 3334, BIRO MFG. CO., Marblehead, OH), exposing the brain. The brain was removed from the cranium and the pituitary gland was carefully extracted from the sphenoid bone, and weighed separately using a gram scale (Model No. TL-410, American Scientific Products, Columbus, OH).

The oxtail was removed between the 2nd and 3rd coccygeal vertebrae and weighed for each carcass. Each carcass was eviscerated and the gastrointestinal tract, spleen, liver and gallbladder, pancreas, kidneys, heart, lungs and trachea were removed from the body cavity and were chilled for approximately 24 h prior to disassembly and obtainment of individual component weights. The carcass was split down the middle of the vertebrae for removal and weighing of the spinal cord and pizzle. The weight of the pizzle, or the portion of the penis that is housed internally, was added to the weight of the penis. The thymus gland was removed and weighed following evisceration and carcass splitting by separating the glandular tissue from the thorax region. Kidney-pelvic-heart fat was removed from the kidney, pelvic and heart region within the body cavity and weighed.

All carcass trim removed due to contamination or bruising was collected and weighed. Dressed carcasses were weighed (Rice Lake Weighing Systems, Rice Lake, WI) prior to chilling.

Following the 24-h chill, visceral masses were disassembled and components were weighed individually. All internal fat including omental and mesenteric fat was trimmed from visceral organs and weighed. The pluck was separated into lungs/trachea and heart. The trachea was removed posterior to the epiglottis, whereas the heart was removed from the pluck by severing the pericardium, aorta, and superior vena cava. The liver and the gallbladder were separated via severance of the cystic duct and weighed individually. The pancreas was separated from the duodenum via the sphincter of Oddi, whereas the intestines were separated from the stomach mass at the pyloric sphincter. The esophagus was removed at the gastroesophageal sphincter and the weight of the full stomach was weighed and the reticulum, rumen, omasum and abomasum were emptied, cleaned with water until clear runoff was obtained, and weighed individually. The small intestine was separated from the large intestine at the ileocecal valve. Weights of the full large and small intestines were obtained prior to emptying, cleaning and individual weighing. The bladder was removed at the ureter and was weighed before and after emptying.

4.3.3. Calculations and Empty Body Weight Determination

The empty body weight (**EBW**) of each steer was calculated as the summation of blood, oxlips, limbs, hide, pizzle, oxtail, spinal cord, gallbladder, liver, spleen, thymus, lungs and trachea, heart, kidneys, pancreas, bladder, empty gastrointestinal tract, carcass trim, internal fat, and hot carcass weight. Weights of each non-carcass component

obtained throughout the harvest of each steer were collected and reported on an absolute weight basis and converted to an empty body weight (g/kg of empty body weight) basis, as a corrected-weight measure to allow for proportionate comparison. Corrected weights were obtained by dividing the absolute weight of each variable (g) by the EBW (kg) of each animal. Both absolute weights and empty body weights were used in the calculation of many comprehensive variables. The final **KPH** weight reported is the weight of the fat removed from the kidney, pelvic and heart regions plus the weight of the kidneys, which was added to the weight of the carcass after trim removal for the calculation of hot carcass weight (**HCW**). The weight of the gastrointestinal contents was calculated by subtracting the weight of the empty gastrointestinal tract from the full gastrointestinal tract and was reported as an absolute weight (**Fill**) and as a percentage of the live body weight (**LBW**) reported by Kirkpatrick (2020). Shrunk body weight (**SBW**), also reported and calculated by Kirkpatrick (2020) was used in the calculation of percentage dressed yield (**DY**), or the percentage of the SBW that remains as the dressed carcass after harvest procedures, obtained by dividing the HCW of each animal by the SBW.

Blood weight was calculated by subtracting the blood drained weight from the stun weight. Weight of the gastrointestinal tract (**GIT**) was calculated as the summation of the empty esophagus, stomach, intestines, and bladder. Gastrointestinal fat (**GIT Fat**) was comprised of mesenteric fat and omental fat and total internal fat (**TIF**) was the summation of KPH fat and GIT fat. Total offal (**OFF**) was the addition of the oxtail, kidney, thymus, heart, lungs/trachea, GIT, pancreas, liver, spleen, gallbladder, lips, head, pizzle, hide and limbs. Total splanchnic tissue (**TST**) was calculated as the sum of highly metabolic components including the GIT, liver, spleen and pancreas.

4.3.4. Statistical Analysis

The study was a balanced incomplete block design and utilized a 2 × 10 treatment structure with individual steer as the experimental unit. The GLIMMIX procedure of SAS was used in the analysis of each variable. The model included the main effects of implant treatment and DOF, and the interaction of treatment × DOF and utilized d-0 BW as a covariate to account for variation in steer weight at the beginning of the study. Pair was included as a random effect. Least squares means were used to calculate estimates and differences ($\alpha = 0.05$) in all variables in response to main effects and interactions. Orthogonal contrasts (linear and quadratic) were evaluated for variables in response to DOF as a main effect. Results were deemed significant if $P \leq 0.05$ and tendencies were determined at $P \geq 0.05$ and $P \leq 0.10$. Non-carcass component variables were analyzed and reported on an absolute weight basis and an empty body weight basis for proportionate comparison.

Linear, quadratic, power or exponential regression equations were generated to estimate daily growth of each component that exhibited linear or quadratic relationships across DOF ($P \leq 0.05$) and did not demonstrate treatment × DOF interactions. Proportionate weights (g/kg ebw) were used and analyzed using the REG procedure of SAS (SAS 9.3, SAS Institute, Cary, NC) with DOF and each variable of interest in the model; DOF was the x variable whereas non-component variables represented y. Separate equations were developed for the growth of components of REV and CON that exhibited effects of implant treatment ($P \leq 0.05$).

4.4. Results and Discussion

4.4.1. Body weights, dressed yield and fill

No implant treatment × DOF interactions ($P \geq 0.48$) were observed for BW measurements, HCW, measures of fill or DY (**Table 4.1.**). Main effects of implant treatment were observed for EBW (543 vs. 512 kg) and HCW (379 vs. 356 kg); each were approximately 6% greater ($P < 0.01$) in REV steers than CON, indicating a consistent increase in tissue components. The degree of increase in body and carcass weight is also consistent to the 6% increase in SBW of the same cattle as reported by Kirkpatrick (2020). The greater HCW observed in the present study is comparable to Barham et al., (2012), who reported an 8% increase in HCW and an approximate 10% increase in live weight and represent similar findings by Duckett et al. (1996), Roeber et al. (2000), and Smith et al. (2018). No implant treatment effects ($P \geq 0.14$) were observed for the absolute weight of fill (28.4 vs. 26.4 kg), fill as a percentage of LBW (5.18 vs. 5.23%) or DY (65.7 vs. 65.1%). Similarly to the present study, Duckett et al. (1996), Samber et al. (1996) and Kniffen et al. (1999) also reported consistent DY for implanted and non-implanted cattle.

Empty BW, HCW and DY increased ($P < 0.01$) and percentage fill decreased quadratically ($P < 0.01$) as the feeding duration progressed (**Table 4.1.**). The quadratic effect observed for EBW and HCW follows the sigmoidal growth curve – exhibiting increased growth at a regressing rate over time (Simpendorfer et al., 1974). May et al. (2016) reported linear growth in EBW of Holstein steers from 254 to 534 DOF, however, HCW increased quadratically, similarly to the present study. The absolute weight of gastrointestinal contents, or fill, did not vary across DOF ($P = 0.82$), similarly to

observed results by May et al. (2016). The percentage fill observed in the present study ranged from 10.1% on d 1 and decreased quadratically as cattle quadratically gained weight, to 3.32% on d 378. Percentage fill calculated for cattle harvested on d 168 was approximately 4.81% of the LBW, while cattle exhibited similar percentage of fill for the remainder of the study. Percentage fill from d 210 to d 336 appears to support the 4% pencil shrink commonly implemented in the trade of commercial cattle in the US, however, the LBW used in this in the calculation of percentage fill was collected 24 h prior to harvest, allowing for a higher degree of shrink than standard commercial practice.

4.4.2. Absolute measurements of non-carcass components

An implant × DOF interaction was observed ($P < 0.05$) for the absolute weight of the oxtail, kidneys, pancreas, bladder, reticulum, and carcass trim and tended to occur ($P < 0.10$) for the absolute weight of the lungs, esophagus, and omasum. After visually assessing the relationships of the observed interactions, variation in each of the interactions was speculated to be attributed to small sample size and experimental error.

Implanted animals had greater ($P \leq 0.05$; **Table 4.2.**) absolute mass of omasum (+14%; 2.43 vs. 2.14 kg), spleen (+12%; 1.09 vs. 0.97 kg), blood (+10%; 17.8 vs. 16.1 kg), hide (+9%; 45.9 vs. 42.2 kg), heart (+8%; 2.36 vs. 2.18 kg), liver (+7%; 7.05 vs. 6.57 kg), stomach (+7%; 14.9 vs. 13.9 kg), small intestine (+7%; 4.47 vs. 4.18 kg), GIT (+7%; 22.4 vs. 21.0 kg), intestines (+6%; 7.02 vs. 6.63 kg), TST (+6%; 31.0 vs. 28.9 kg), OFF (+6%; 112 vs. 105 kg), head (+5%; 15.9 vs.15.2 kg), in response to greater body mass of REV steers. Previous researchers have established the importance of many visceral and splanchnic components in animal efficiency and productivity and developmental

response to plane of nutrition (Reynolds et al., 1991; Lobley, 2003; Walter et al., 2018). In the present study, TST increased to the same degree as the body and carcass weights, suggesting proportional growth of splanchnic tissues in response to implant.

Implanted steers tended to have a heavier ($P \leq 0.08$) tongue (1.00 vs. 0.96 kg) and pizzle (0.47 vs. 0.39 kg) than CON steers. Implanted steers also had 10% smaller (0.63 vs. 0.70 kg; $P = 0.05$) thymus glands and 14% less (11.3 vs. 13.1 kg; $P = 0.01$) KPH than non-implanted counterparts on an absolute weight basis. Occasionally during harvest, the thymus was partially or entirely removed upon evisceration rather than after carcass splitting, due to attachment to the pluck, potentially contributing to error in the weights of the thymus. Pillmore et al. (2019) observed a 17 and 51% increase in the absolute weight of the heart and the penis with a concurrent 19% reduction in internal fat and a 30% reduction of cod fat in aggressively implanted Jersey steers. This data supports the observed increase of the absolute mass of the heart and pizzle and reduction of fat mass of implanted steers in the present study. The absolute weights of the liver, spleen, kidneys, pancreas, lungs and trachea, heart and esophagus in the present study are comparable to those reported for implanted crossbred steers consuming ad libitum feed and with similar empty body weights (Walter et al., 2018); each of these variables have little trim and present minimal opportunity for variation upon removal. Other variables such as the blood, tongue, thymus and stomach exhibited larger variation from those reported by Walter et al. (2018) and present larger opportunity for variation upon removal.

Though variation occurred in the absolute mass of the spinal cord, small intestines and intestines, no linear or quadratic growth patterns were detected with increasing DOF.

Positive linear relationships were observed ($P \leq 0.01$; **Table 4.2.**) in the absolute weight of blood, brain, pituitary gland, lips, pizzle, pancreas, spleen, lungs and trachea, esophagus, rumen, omasum, stomach, GIT, KPH and TST in response to DOF. The head, tongue, hide, limbs, gallbladder, liver, thymus, heart, abomasum, large intestine, GIT fat, TIF and OFF exhibited ($P \leq 0.05$) quadratic increases in absolute mass. Weight of the head, tongue, hide, limbs, liver, heart, intestines and OFF exhibited quadratic growth patterns in the current study, however, were reported to grow in a linear fashion in Holstein steers (May et al. 2016). Quadratic relationships observed for these variables followed the growth patterns observed for EBW and HCW and the quadratic growth pattern of muscle described by Simpfendorfer (1974).

4.4.3. Non-carcass components expressed on an empty body weight basis

Interactions (treatment × DOF; $P = 0.01$) occurred for kidneys and carcass trim on an EBW basis, however, these outcomes were primarily a result of experimental error and a highly bruised carcass in the REV treatment group, along with other confounding factors such as contamination, causing variation in the degree of trimming performed on carcasses of each treatment group (**Table 4.3.**).

The KPH (17%; 19.5 vs. 23.5 g/kg), thymus (15%; 1.23 vs. 1.44 g/kg), TIF (9%; 72.8 vs. 80.0 g/kg), limbs (7%; 19.0 vs. 20.5 g/kg), abomasum (7%; 2.80 vs. 3.01 g/kg), brain (6%; 0.80 vs. 0.85 g/kg EBW), and kidneys (4%; 2.11 vs. 2.19 g/kg) of REV steers weighed less ($P \leq 0.05$) on an EBW basis and the lungs and trachea tended (6.18 vs. 6.59 g/kg; $P = 0.06$) to weigh less than those of CON steers. Conversely, the reticulum increased (2.03 vs. 1.90 g/kg; $P = 0.03$) approximately 7% on an EBW basis and the

pizzle tended ($P = 0.09$) to weigh more (0.86 vs. 0.75 g/kg) in REV than CON, likely due to steroidal response on reproductive organs, also observed by Pillmore et al (2019).

The observed reduction in proportionate mass of limbs in REV steers may have been a result of altered bone metabolism, and may be associated with the advanced skeletal maturity of the carcass reported by Pillmore et al. (2019) and Pillmore (2020) and additionally reported by others (Reiling and Johnson, 2003). Pillmore (2019) also reported a decrease in the proportionate weight of the metatarsals and a 42% reduction in skull thickness of aggressively implanted jersey steers on an EBW basis compared to control counterparts indicating alteration of skeletal components. Though estrogens can be applied to advance the fusion of the epiphyseal plate, Kniffen (1999) reported metacarpals of implanted animals to increase in length and overall maturity in steers, though heifers were not affected. Altered bone metabolism and formation in response to exogenous hormone via growth promoting implant is a result of estrogenic influence on chondrocyte and osteoblast activity.

Implant treatment did not alter ($P \geq 0.11$) proportional weights of the hot carcass, blood, head, pituitary, tongue, lips, hide, oxtail, spinal cord, gallbladder, liver, spleen, heart, pancreas, bladder, esophagus, rumen, omasum, stomach, intestines, GIT, GIT fat, TST or OFF. Consistent weights among REV and CON treatments for these variables suggests proportional gain of each component in relation to the empty body mass of the animal, regardless of implant administration.

Hutcheson et al. (1997) reported cattle to have a smaller percentage of the EBW comprised of GIT and total organ mass and a larger percentage of liver, spleen and hide when implanted with combination (Revalor-S) implants as compared to non-implanted

counterparts. The increase in the liver and spleen percentage of the EBW reported by Hutcheson et al. (1997) supports an increase in some splanchnic tissue. Aggressively implanting Jersey steers (Pillmore et al., 2019) also resulted in greater mass of the liver in proportion to the empty body, weighing 1.4 g more per kg of empty body, however, this result was observed in dairy-type cattle that had received a total of 1200 mg of TBA and 120 mg E_2 throughout the study compared to the 200 or 400 mg TBA and 40 or 80 mg E_2 administered in the present study. Though no differences were observed in the proportionate weight of the liver in the present study, differences in liver weight and proportions reported in previous literature are a plausible effect of implant, likely because of somatoropic stimulation of IGF receptors and IGF secretion from the liver in response to hormonal implants.

Weight of spleen on an EBW basis did not vary ($P = 0.16$; **Table 4.3.**) across DOF, though the corrected weight of the oxtail varied ($P \leq 0.01$) but did not exhibit ($P \geq 0.28$) linear or quadratic effects across DOF. Consistency in the proportionate weight of the spleen was not expected, however is a direct factor of individual animal variation, whereas variation in the proportionate weight of the oxtail may have been subject to human error upon removal at harvest.

Proportionate weight of the heart decreased linearly, approximately 0.0015 g•kg•d (**Table 4.4.**). Proportionate HCW contribution to EBW of all cattle increased ($P < 0.01$) quadratically along with the pizzle and GIT fat ($P \leq 0.01$) with increasing DOF. Controversially, the contribution of most non-carcass components, including the blood, head, pituitary gland, tongue, lips, hide, spinal cord, liver, lungs and trachea, pancreas, esophagus, rumen, omasum, stomach, small intestine, large intestine, intestines, GIT,

TST and OFF represented a smaller proportion of the EBW with increasing DOF. These results suggest a shift of nutrient contribution away from visceral and non-carcass components, toward carcass components as the feeding duration progress.

Separate regression equations were generated (**Table 4.5.**) for implant treatment groups for the brain, limbs, thymus, reticulum, abomasum, KPH and TIF variables due to treatment differences ($P \leq 0.05$). The brain, limbs, reticulum and abomasum of both REV and CON decreased quadratically as a proportion of the EBW, whereas the thymus and measures of fat including KPH and TIF, increased quadratically as a proportion of the empty body, over time. Furthermore, non-implanted steers accrued KPH fat in an exponential fashion ($12.25e^{0.003x}$; $r^2 = 0.76$), whereas REV steers accrued KPH fat quadratically ($y = -0.00013x^2 + 0.084x + 10.44$; $r^2 = 0.55$), giving rise to the 17% reduction in mean KPH weight observed in REV compared to CON. The exponential accretion observed in the KPH of CON cattle is consistent with the biological accretion pattern of fat established by Simpfendorfer (1974). Implant however, shifted the accretion pattern to a slower, quadratic accretion. Quadratic effects are speculated to be the predominant effect for the non-carcass components across DOF likely due to plateaued development of non-carcass components in relation to increasing total body mass as the animal matures.

4.5. Conclusions

The observed results from this study suggest that TBA + E_2 implants elicit consistent increases in the EBW and HCW in Charolais × Angus steers, encouraging similar increases in the absolute weight of non-carcass components. Though absolute weights of numerous components of metabolic and industrial importance were greater in

implanted animals, many exhibited comparable growth in proportion to the empty body of NHTC steers. However, as steers were fed for greater lengths of time, NHTC steers deposited fat more readily in internal depots than implanted cattle, comprising a greater proportion of the EBW. Ultimately, implanted steers produced greater masses of carcass and non-carcass products than NHTC steers, however, a reduced proportion of the product of implanted steers was comprised of internal fat.

4.6. Literature Cited

Biswas, S., C. A. Shapiro, W. L. Kranz, T. L. Mader, D. P. Shelton, D. D. Snow, S. L. Bartelt-Hunt, D. D. Tarkalson, S. J. van Donk, T. C. Zhang and S. Ensley. 2013. Current knowledge on the environmental fate, potential impact and management of growth-promoting steroids used in the US beef cattle industry. J. Soil Water Conserv. 68:325-336. doi:10.2489/jswc.68.4.325.

Capper, J. L. and D. J. Hayes. 2012. The environmental and economic impact of removing growth-enhancing technologies from U.S. beef production. J. Anim. Sci. 90:3527-3537.

Campbell, J. A. 2016. Understanding Beef Carcass Yields and Losses During Processing. Penn State Extension. Available from: https://extension.psu.edu/understanding-beef-carcass-yields-and-losses-during-processing. Accessed on: 19 Mar 2020.

Cooper K. B. 2020. Observations of tenderness, yield, and carcass composition in serially slaughtered steer carcasses implanted with Revalor-XS. Thesis. West Texas A&M University. Canyon, TX.

Duckett, S. K., D. G. Wagner, F. N. Owens, H. G. Dolezal, D. R. Gill. 1996. Effects of estrogenic and androgenic implants on performance, carcass traits and meat tenderness in feedlot steers: A review. Prof. Anim. Sci. 22:205-214. doi: 10.15232/S1080-7446(15)32526-2.

Griffin, D. D., and T. L. Mader. 1997. G97-1324 Beef cattle implant update. Historical Materials from University of Nebraska-Lincoln Extention. Available from:

https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1309&context=extension hist. Accessed on: 10 Mar 2020.

Hutcheson, J. P., D. E. Johnson, C. L Gerken, J. B. Morgan and J. D. Tatum. 1997. Anabolic implant effects on visceral organ mass, chemical body composition and estimated energetic efficiency in cloned beef steers. J. Anim. Sci. 75:2620-2626. doi: 10.2527/1997.75102620x.

Johnson, B. J., P. T. Anderson, J. C. Meiske, and W. R. Dayton. 1996. Effect of a combined trenbolone acetate and estradiol implant on feedlot performance, carcass characteristics, and carcass composition of feedlot steers. J. Anim. Sci. 74:363–371. doi: 10.2527/1996.742363x.

Kirkpatrick, T.J. 2020. The effect of growth-promoting implants and days on feed on live performance and behavioral characteristics, biometric measurements, empty body composition, and energy retention of serially harvested beef steers. Thesis. West Texas A&M University. Canyon, TX.

Kniffen, D. M., W. R. Wagner, P. E. Lewis. 1999. Effects of long-term estrogen implants in beef heifers. J. Anim. Sci. 77:2886-2892. doi: /10.2527/1999.77112886x

Lobley, G. E. 2003. Protein turnover – what does it mean for animal production? Can. J. Anim. Sci. 83:327-340. doi:10.4141/A03-019.

May, N. D., T. J. McEvers, L. J. Walter, J. A. Reed. J. P. Hutcheson and T. E. Lawrence. 2016. Byproduct yields of serially harvested calf-fed Holstein steers fed zilpaterol hydrochloride. J. Anim. Sci. 94:4006-4015. doi: 10.2527/jas.2016-0486.

McEvers, T. J., N. D. May, J. A. Reed, L. J. Walter, J. P. Hutcheson and T. E. Lawrence. 2018. The effect of zilpaterol hydrochloride on beef producer and processor revenue of calf-fed Holstein steers. J. Trans. Anim. Sci. 2:290-297. doi: 10.1093/tas/txy062.

Ockerman, H. W. and L. Basu, 2004a. Byproducts - Edible, for human consumption. In: C. Devine and M. Dikeman, editors, Encyclopedia of meat sciences. Elsevier Academic Press, London, England. p. 104-112.

Pillmore, S. L. 2020. A comparison of behavioral characteristics, carcass by-product yields and carcass grading performance of crossbred steers implanted with Revalor-XS to non-hormone treated counterparts across various marketing endpoints in a 378-d serial harvest. Thesis. West Texas A&M University. Canyon, TX.

Pillmore, S. L., T. J. Kirkpatrick, K. Wesley, K. Cooper, T. Tennant and T. Lawrence. 2019. An aggressive implant strategy altered non-carcass components in long-fed Jersey steers. J. Anim. Sci. 97:94. doi: 10.1093/jas/skz258.194.

Reynolds, C. K., H. F. Tyrrell, and P. J. Reynolds. 1991. Effects of diet forage-to-concentrate ratio and intake on energymetabolism in growing beef heifers: whole body energyand nitrogen balance and visceral heat production J. Nutr. 121:994-1003. doi: 10.1093/jn/121.7.994.

Reiling, B. A. and D. D. Johnson. 2003. Effects of implant regimens (trenbalone acetate-estradiol administered alone or in combination with zeranol) and vitamin D_3 on fresh beef color and quality. J. Anim. Sci. 18:135-142. doi: 10.2527/2003.811135x.

Reuter, R. G. Mourer, D. Lalman and C. Richards. 2016. Implants and their use in beef cattle production. Oklahoma State University. Available from:

https://shareok.org/bitstream/handle/11244/49965/oksd_ansi_3290_2016-02.pdf?sequence=1. Accessed on: 15 Mar 2020.

Roeber, D. L., R. C. Cannell, K. E. Belk, J. D. Tatum, and G. C. Smith. 2000. Implant strategies during feeding: Impact on carcass grades and consumer acceptability. J. Anim. Sci. 78:1867–1874. doi: 10.2527/2000.7871867x.

Samber, J. A., J. D. Tatum, M. I. Wray, W. T. Nichols, J. B. Morgan and G. C. Smith. 1996. Implant program effects on performance and carcass quality of steer calves finished for 212 days. J. Anim. Sci. 74: 1470-1476. doi: 10.2527/1996.7471470x.

Sestari, B. B., I. Y. Mizubuti, E. L. A. Ribiero, M. A. A. F. Barbosa, E. S. Pereira, A. P. Pinto, G. E. Cunha, R. C. Gomes, F. L. Massaro, Jr., C. P. Rosolem. 2012. Carcass characterics, non-carcass components and meat quality of Nellore cattle in a feedlot and fed with different corn hybrids. Semina: Ciências Agrárias. 33:3389-3400. doi: 10.5433/1679-0359.2012v33Supl2p3389. doi: 10.5433/1679-0359.2012v33Supl2p3389.

Smith, Z. K., A. J. Thompson, J. P. Hutcheson, W. T. Nichols, and B. J. Johnson. 2018. Evaluation of coated steroidal implants containing trenbolone acetate and estradiol-17β on live performance, carcass traits, and sera metabolites in finishing steers. J. Anim. Sci. 96:1704-1723. doi: 10.1093/jas/sky095.

Walter, L. J., A. N. Schmitz, W. T. Nichols, J. P. Hutcheson and T. E. Lawrence. 2018. Live growth performance, carcass grading characteristics, and harvest yields of beef steers supplemented zilpaterol hydrochloride and offered ad libitum or maintenance energy intake. J. Anim. Sci. 96:1688-1703. doi:10.1093/jas/sky105.

Wesley, K. R. Administration of growth-promoting implants and days on feed effects allometric growth coefficients, fabrication yields, and economic return of serially harvested beef steers. 2020. Thesis. West Texas A&M University. Canyon, TX.

Table 4.1. Body and carcass weights, fill, and dressed yield of non-hormone treated (CON) cattle or cattle implanted with Revalor-XS (REV) in a 378-d serial harvest study.

	Implant Treatment[1]			DOF[1]											*P*-value		
Item	CON	REV	SEM	0	42	84	126	168	210	252	294	336	378	SEM	TRT × DOF	TRT	DOF
Steers	40	40	-	8	8	8	8	8	8	8	8	8	8	-	-	-	
Days of age	406	409	-	213	254	300	339	393	434	476	521	550	597	-	-	-	
Empty BW, kg[2]	512	543	5.94	245^{h}	328^{g}	416^{f}	462^{e}	531^{d}	617^{c}	597^{c}	658^{b}	673^{b}	746^{a}	13.45	0.79	<0.01	<0.01
HCW, kg	356	379	4.82	159^{g}	211^{f}	291^{e}	320^{e}	371^{d}	429^{c}	419^{c}	469^{b}	477^{b}	531^{a}	10.91	0.72	<0.01	<0.01
Dressed yield, %[3]	65.0	65.7	0.73	59.0^{b}	58.0^{b}	70.4^{a}	65.4^{a}	66.0^{a}	67.1^{a}	66.8^{a}	66.5^{a}	68.6^{a}	66.2^{a}	1.90	0.24	0.43	<0.01
Fill, kg[4]	26.4	28.4	0.96	28.4	27.3	24.2	28.1	28.2	26.3	25.4	29.3	29.3	27.4	2.42	0.64	0.12	0.82
Fill, %	5.19	5.27	0.17	10.1^{a}	7.22^{b}	5.54^{bc}	5.39^{c}	4.81^{d}	4.00^{e}	3.79^{e}	4.08^{de}	3.98^{e}	3.32^{e}	0.41	0.87	0.71	<0.01

[1] Steers received no implant **(CON)** or a Revalor-XS **(REV;** Merck Animal Health, Summit, NJ**)** on d0 and d190 of the study; Feeding duration (**DOF**).

[2] Sum of hot carcass weight (**HCW**), internal fat, oxtail, carcass trim, viscera, empty gastrointestinal tract, spinal cord, lips, head, penis, hide and limbs.

[3] Percentage of shrunk body weight (Kirkpatrick, 2020) that is comprised of the dressed hot carcass.

[4] Difference between full gastrointestinal tract and empty gastrointestinal tract (kg).

[a,b,c,d,e,f,g,h] DOF values with different superscripts differ ($P < 0.05$) across DOF.

Table 4.2. Absolute weights (kg) of non-carcass components of non-hormone treated or implanted (Revalor-XS) cattle in 378-d serial harvest study.

	Implant Treatment[1]			DOF[1]											*P*-value		
Item	CON	REV	SEM	0	42	84	126	168	210	252	294	336	378	SEM	TRT × DOF	TRT	DOF
Steers	40	40	-	8	8	8	8	8	8	8	8	8	8	-	-	-	-
Blood	16.1	17.8	0.58	10.5^{d}	14.4^{c}	14.2^{c}	14.5^{c}	15.9^{bc}	19.3^{ab}	19.1^{ab}	19.7^{a}	20.2^{a}	22.1^{a}	1.32	0.90	0.05	<0.01
Head	15.2	15.9	0.20	9.09^{f}	11.8^{e}	13.0^{e}	15.0^{d}	15.7^{cd}	16.7^{c}	16.5^{c}	18.2^{b}	19.3^{ab}	20.1^{a}	0.46	0.73	0.01	<0.01
Brain	0.39	0.39	0.01	0.36^{d}	0.35^{d}	0.36^{d}	0.39^{bcd}	0.39^{bcd}	0.42^{ab}	0.38^{cd}	0.41^{abc}	0.42^{abc}	0.44^{a}	0.01	0.81	0.69	<0.01
Pituitary, g	1.96	2.05	0.08	1.38^{gf}	1.19^{g}	1.55^{efg}	2.07^{bcd}	1.98^{cde}	2.37^{bc}	1.73^{def}	2.49^{ab}	2.43^{abc}	2.87^{a}	0.20	0.55	0.42	<0.01
Lips	0.37	0.40	0.01	0.19^{d}	0.27^{c}	0.31^{c}	0.25^{cd}	0.30^{c}	0.45^{b}	0.41^{b}	0.48^{b}	0.68^{a}	0.48^{b}	0.03	0.88	0.13	<0.01
Tongue	0.96	1.00	0.02	0.59^{f}	0.68^{f}	0.78^{e}	0.92^{d}	1.00^{cd}	1.10^{b}	1.09^{bc}	1.16^{ab}	1.25^{a}	1.23^{a}	0.03	0.60	0.07	<0.01
Hide	42.2	45.9	0.81	25.0^{h}	35.0^{fg}	34.5^{g}	40.6^{ef}	43.8^{de}	52.8^{b}	46.8^{cd}	51.4^{bc}	51.4^{bc}	58.7^{a}	1.98	0.49	<0.01	<0.01
Limbs[2]	9.97	9.75	0.15	6.43^{e}	8.14^{d}	8.70^{d}	9.88^{c}	10.0^{c}	10.8^{bc}	10.0^{c}	10.6^{bc}	11.3^{b}	12.7^{a}	0.37	0.69	0.28	<0.01
Oxtail	1.22	1.32	0.03	0.68	0.81	0.76	1.19	1.31	1.61	1.56	1.45	1.67	1.64	0.07	0.04	0.01	<0.01
Pizzle	0.39	0.47	0.03	0.10^{d}	0.27^{cd}	0.40^{bc}	0.49^{b}	0.44^{bc}	0.42^{bc}	0.58^{ab}	0.46^{b}	0.43^{bc}	0.73^{a}	0.07	0.42	0.08	<0.01
Spinal Cord	0.22	0.23	0.01	0.27^{a}	0.18^{e}	0.19^{de}	0.23^{abcd}	0.22^{bcde}	0.25^{abc}	0.20^{de}	0.20^{cde}	0.27^{ab}	0.21^{cde}	0.02	0.31	0.33	<0.01
Gallbladder	0.14	0.13	0.01	0.06^{e}	0.08^{de}	0.12^{cd}	0.15^{abc}	0.13^{bc}	0.18^{ab}	0.16^{abc}	0.15^{abc}	0.16^{abc}	0.18^{a}	0.02	0.28	0.59	<0.01
Liver	6.57	7.05	0.10	4.08^{e}	5.63^{d}	6.01^{d}	6.24^{d}	7.02^{c}	7.91^{b}	7.28^{bc}	7.48^{bc}	7.73^{b}	8.71^{a}	0.24	0.98	<0.01	<0.01
Spleen	0.97	1.09	0.03	0.50^{f}	0.63^{ef}	0.81^{de}	0.95^{cd}	1.00^{bcd}	1.04^{bc}	1.11^{bc}	1.48^{a}	1.20^{b}	1.57^{a}	0.08	0.65	0.02	<0.01
Thymus	0.70	0.63	0.25	0.24^{f}	0.54^{e}	0.72^{bcd}	1.02^{a}	0.86^{b}	0.81^{bc}	0.57^{de}	0.65^{de}	0.67^{cde}	0.56^{e}	0.06	0.13	0.05	<0.01
Kidneys	1.06	1.09	0.02	0.69	0.88	0.92	1.07	1.14	1.27	1.11	1.13	1.18	1.36	0.04	0.05	0.09	<0.01
Pancreas	0.44	0.43	0.02	0.23	0.32	0.37	0.42	0.44	0.42	0.38	0.49	0.54	0.73	0.05	0.02	0.62	<0.01
Bladder	0.13	0.16	0.01	0.09	0.08	0.12	0.12	0.15	0.15	0.15	0.16	0.24	0.21	0.02	0.04	0.01	<0.01
Lungs/Trachea	3.16	3.17	0.08	2.29^{e}	2.54^{de}	2.88^{cd}	2.87^{cd}	2.93^{cd}	4.06^{a}	3.22^{bc}	3.36^{bc}	3.55^{ab}	3.97^{a}	0.20	0.09	0.97	<0.01
Heart	2.18	2.36	0.05	1.33^{e}	1.20^{e}	1.97^{d}	2.02^{d}	2.21^{cd}	2.79^{ab}	2.42^{bc}	2.87^{a}	2.80^{ab}	3.10^{a}	0.14	0.36	0.01	<0.01
Esophagus	0.30	0.32	0.01	0.23^{e}	0.27^{cde}	0.26^{ed}	0.25^{ed}	0.31^{bcd}	0.33^{bc}	0.33^{bc}	0.37^{b}	0.36^{b}	0.43^{a}	0.02	0.10	0.10	<0.01
Rumen	9.43	10.1	0.27	5.52^{f}	7.13^{ef}	7.77^{e}	7.62^{e}	9.55^{d}	11.5^{bc}	10.3^{cd}	11.9^{abc}	13.4^{a}	12.8^{ab}	0.62	0.38	0.11	<0.01
Reticulum	0.90	1.03	0.02	0.76	0.82	0.94	0.81	0.88	1.15	0.99	0.93	1.15	1.26	0.06	0.05	<0.01	<0.01
Omasum	2.14	2.43	0.07	1.43^{e}	1.99^{d}	1.93^{de}	2.08^{d}	2.29^{cd}	2.95^{a}	2.31^{bcd}	2.29^{cd}	2.71^{abc}	2.87^{ab}	0.19	0.10	0.01	<0.01
Abomasum	1.44	1.42	0.04	1.07^{d}	1.12^{cd}	1.34^{bc}	1.26^{bcd}	1.42^{ab}	1.62^{a}	1.60^{a}	1.60^{a}	1.66^{a}	1.62^{a}	0.09	0.98	0.76	<0.01
Stomach[3]	13.9	14.9	0.31	8.77^{f}	11.1^{e}	12.0^{e}	11.8^{e}	14.2^{d}	17.2^{abc}	15.2^{cd}	16.7^{bc}	18.9^{a}	18.6^{ab}	0.70	0.23	0.02	<0.01
Small intestine	4.18	4.47	0.09	3.84^{cd}	4.96^{a}	4.38^{abc}	4.46^{abc}	4.94^{a}	4.72^{ab}	3.66^{d}	3.52^{d}	4.03^{bcd}	4.75^{a}	0.24	0.63	0.01	<0.01
Large intestine	2.45	2.55	0.09	2.43^{ab}	2.81^{a}	2.10^{b}	2.03^{b}	2.30^{ab}	2.50^{ab}	2.43^{ab}	2.72^{a}	2.76^{a}	2.89^{a}	0.20	0.90	0.43	0.06
Intestines[4]	6.63	7.02	0.14	6.27^{bc}	7.77^{a}	6.48^{bc}	6.49^{bc}	7.25^{ab}	7.22^{ab}	6.08^{c}	6.25^{bc}	6.78^{abc}	7.64^{a}	0.37	0.67	0.03	0.02
GIT[5]	21.0	22.4	0.36	15.3^{e}	19.2^{d}	18.8^{d}	18.6^{d}	21.9^{c}	24.9^{ab}	21.7^{c}	23.5^{bc}	26.3^{a}	26.8^{a}	0.82	0.34	<0.01	<0.01
Carcass trim	2.68	3.31	0.39	1.11	3.47	0.40	2.08	3.18	3.65	2.69	2.61	4.23	6.54	0.90	0.02	0.27	<0.01
KPH[6]	13.1	11.3	0.55	2.74^{g}	4.39^{fg}	7.18^{ef}	9.64^{de}	12.4^{cd}	14.7^{c}	14.0^{c}	16.1^{bc}	19.3^{ab}	21.80^{a}	1.37	0.21	0.01	<0.01
GIT fat[7]	31.9	31.8	1.08	8.45^{e}	13.2^{e}	21.4^{d}	25.2^{d}	32.6^{c}	39.7^{b}	43.2^{ab}	43.4^{ab}	44.3^{ab}	46.7^{a}	2.44	0.99	0.94	<0.01
TIF[8]	43.9	42.0	1.33	10.5^{f}	16.7^{f}	27.6^{e}	33.8^{e}	43.9^{d}	53.1^{c}	56.1^{bc}	58.3^{bc}	62.5^{ab}	67.1^{a}	3.02	1.00	0.31	<0.01
TST[9]	28.9	31.0	0.41	20.2	25.8^{d}	26.0^{d}	26.2^{d}	30.3^{c}	34.3^{b}	30.5^{c}	32.9^{bc}	35.7^{ab}	37.8^{a}	1.01	0.39	<0.01	<0.01
Total offal[10]	105	112	1.25	66.3^{f}	87.3^{e}	90.3^{e}	101^{d}	109^{cd}	126^{b}	114^{c}	124^{b}	129^{b}	141^{a}	3.01	0.49	<0.01	<0.01

[1] Steers received no implant **(CON)** or a Revalor-XS **(REV;** Merck Animal Health, Summit, NJ**)** on d0 and d190 of the study; Feeding Duration **(DOF)**

[2] Sum of the metatarsals and metacarpals

[3] Sum of the rumen, reticulum, omasum and abomasum

[4] Sum of the small intestine and the large intestine

[5] Gastrointestinal tract; Sum of the intestines, stomach, esophagus and bladder

[6] Sum of the kidneys and fat from the kidney, pelvic and heart region

[7] Gastrointestinal fat; comprised of omental and mesenteric fat

[8] Total internal fat; Sum of KPH, omental and mesenteric fat

[9] Total Sphlanchnic Tissue; sum of the GIT, liver, spleen and pancreas

[10] Sum of the oxtail, kidney, thymus, heart, lungs and trachea, GIT, pancreas, spleen, liver, gallbladder, lips, head, pizzle, hide and limbs

[a,b,c,d,e,f,g,h] DOF values with different superscripts differ ($P < 0.05$).

Table 4.3. Weights of non-carcass components of non-hormone treated or implanted (Revalor-XS) cattle in 378-d serial harvest study expressed as a proportion of the empty body (g/kg).

	Implant Treatment[1]			DOF[1]											*P*-value		
Item	CON	REV	SEM	0	42	84	126	168	210	252	294	336	378	SEM	TRT × DOF	TRT	DOF
Steers	40	40	-	8	8	8	8	8	8	8	8	8	8	-	-	-	-
HCW[2]	690	691	2.77	647^{c}	641^{c}	697^{ab}	693^{b}	699^{ab}	695^{ab}	702^{ab}	713^{a}	708^{ab}	710^{ab}	6.26	0.63	0.67	<0.01
Blood	32.6	34.7	1.19	43.7^{a}	44.2^{a}	33.9^{b}	31.1^{b}	30.0^{b}	31.3^{b}	32.3^{b}	29.9^{b}	29.9^{b}	29.9^{b}	2.86	0.38	0.20	<0.01
Head	30.8	30.4	0.33	37.5^{a}	36.1^{a}	31.3^{bc}	32.5^{b}	29.7^{cd}	27.2^{e}	27.7^{de}	27.8^{ed}	28.6^{ed}	27.1^{e}	0.76	0.92	0.40	<0.01
Brain	0.85	0.80	0.01	1.52^{a}	1.09^{b}	0.88^{c}	0.84^{c}	0.73^{d}	0.69^{de}	0.62^{e}	0.63^{e}	0.62^{e}	0.61^{e}	0.03	0.95	0.02	<0.01
Pituitary, mg/kg	4.05	3.89	0.14	5.81^{a}	3.69^{bc}	3.80^{b}	4.47^{b}	3.81^{b}	3.84^{b}	2.88^{c}	3.80^{b}	3.64^{bc}	3.93^{b}	0.37	0.53	0.41	<0.01
Tongue	1.93	1.90	0.03	2.42^{a}	2.08^{b}	1.88^{cd}	1.99^{bc}	1.90^{cd}	1.79^{de}	1.83^{cde}	1.76^{de}	1.86^{cd}	1.66^{e}	0.06	0.75	0.41	<0.01
Lips	0.73	0.73	0.03	0.78^{bc}	0.85^{ab}	0.76^{bc}	0.53^{d}	0.56^{d}	0.73^{bc}	0.69^{bcd}	0.74^{bc}	1.00^{a}	0.66^{cd}	0.06	0.98	0.80	<0.01
Hide	85.1	87.0	1.42	103^{a}	107^{a}	83.4^{cb}	87.7^{b}	82.3^{bc}	85.7^{bc}	78.5^{bc}	78.3^{bc}	76.2^{c}	78.8^{bc}	3.61	0.83	0.28	<0.01
Limbs[3]	20.5	19.0	0.31	26.7^{a}	25.0^{a}	21.1^{b}	21.4^{b}	19.0^{c}	17.8^{cd}	16.8^{d}	16.2^{d}	16.7^{d}	17.2^{cd}	0.71	0.84	<0.01	<0.01
Oxtail	2.40	2.43	0.06	2.74^{a}	2.44^{ab}	1.85^{c}	2.61^{a}	2.40^{ab}	2.59^{a}	2.64^{a}	2.21^{b}	2.49^{ab}	2.20^{bc}	0.14	0.34	0.69	<0.01
Pizzle	0.75	0.86	0.04	0.40^{e}	0.83^{abcd}	0.98^{ab}	1.05^{a}	0.82^{abcd}	0.69^{cd}	0.97^{abc}	0.70^{bcd}	0.63^{de}	0.97^{ab}	0.10	0.50	0.09	<0.01
Spinal cord	0.49	0.47	0.02	1.16^{a}	0.55^{b}	0.46^{bc}	0.50^{bc}	0.42^{bcd}	0.41^{cd}	0.32^{d}	0.30^{d}	0.39^{cd}	0.30^{d}	0.05	0.44	0.41	<0.01
Gallbladder	0.27	0.25	0.01	0.22	0.23	0.28	0.31	0.24	0.29	0.26	0.23	0.23	0.25	0.03	0.41	0.16	0.60
Liver	13.5	13.6	0.20	17.0^{a}	17.2^{a}	14.5^{b}	13.5^{bc}	13.3^{bcd}	12.9^{cde}	12.2^{def}	11.4^{f}	11.5^{f}	11.8^{ef}	0.45	0.96	0.64	<0.01
Spleen	1.91	2.00	0.06	2.06	1.92	1.96	2.06	1.87	1.68	1.87	2.24	1.78	2.10	0.12	0.73	0.24	0.16
Thymus	1.44	1.23	0.05	0.98^{d}	1.68^{b}	1.74^{b}	2.25^{a}	1.63^{b}	1.32^{c}	0.97^{d}	0.99^{d}	0.99^{d}	0.78^{d}	0.11	0.21	<0.01	<0.01
Lungs/Trachea	6.59	6.18	0.15	9.58^{a}	7.76^{b}	6.95^{bc}	6.20^{cde}	5.60^{def}	6.61^{cd}	5.36^{ef}	5.13^{f}	5.28^{ef}	5.38^{ef}	0.36	0.11	0.06	<0.01
Heart	4.34	4.39	0.09	5.42^{a}	3.74^{d}	4.73^{b}	4.34^{bcd}	4.14^{bcd}	4.52^{bc}	4.03^{cd}	4.35^{bc}	4.17^{bcd}	4.18^{bcd}	0.22	0.90	0.69	<0.01
Kidneys	2.19	2.11	0.03	2.87	2.69	2.22	2.32	2.17	2.07	1.86	1.71	1.75	1.840	0.08	0.04	0.05	<0.01
Pancreas	0.87	0.80	0.03	0.94^{ab}	0.98^{ab}	0.88^{abc}	0.90^{abc}	0.82^{abcd}	0.68^{cd}	0.63^{d}	0.74^{bcd}	0.79^{abcd}	0.98^{a}	0.09	0.39	0.11	0.05
Bladder	0.26	0.30	0.02	0.36	0.24	0.28	0.27	0.29	0.25	0.25	0.24	0.36	0.27	0.04	0.33	0.12	0.17
Esophagus	0.63	0.64	0.02	0.97^{a}	0.83^{a}	0.62^{b}	0.54^{b}	0.60^{b}	0.54^{b}	0.55^{b}	0.56^{b}	0.54^{b}	0.59^{b}	0.06	0.13	0.67	<0.01
Rumen	18.9	18.8	0.51	22.5^{a}	21.8^{ab}	18.7^{bcd}	16.4^{d}	18.0^{cd}	18.7^{bcd}	17.2^{cd}	18.1^{cd}	20.0^{abc}	17.3^{cd}	1.21	0.48	0.88	0.02
Reticulum	1.90	2.03	0.04	3.16^{a}	2.49^{b}	2.26^{b}	1.74^{c}	1.67^{cd}	1.86^{c}	1.64^{cd}	1.41^{d}	1.72^{c}	1.70^{c}	0.10	0.25	0.03	<0.01
Omasum	4.47	4.67	0.13	5.99^{a}	6.13^{a}	4.67^{bc}	4.49^{bc}	4.38^{bc}	4.77^{b}	3.84^{cd}	3.48^{d}	4.05^{bcd}	3.93^{bcd}	0.31	0.53	0.26	<0.01
Abomasum	3.01	2.80	0.07	4.45^{a}	3.52^{b}	3.23^{b}	2.74^{c}	2.70^{c}	2.66^{cd}	2.67^{cd}	2.46^{cd}	2.44^{cd}	2.21^{d}	0.17	0.95	0.03	<0.01
Stomach[4]	28.3	28.3	0.59	36.1^{a}	33.9^{a}	28.9^{b}	25.4^{b}	26.8^{b}	28.0^{b}	25.4^{b}	25.4^{b}	28.2^{b}	25.1^{b}	1.47	0.35	0.99	<0.01
Small intestine	9.33	9.25	0.20	16.1^{a}	15.3^{a}	10.7^{b}	9.68^{b}	9.42^{b}	7.74^{c}	6.07^{d}	5.41^{d}	5.97^{d}	6.58^{cd}	0.46	0.86	0.78	<0.01
Large intestine	5.38	5.29	0.22	10.4^{a}	8.69^{b}	5.11^{c}	4.40^{c}	4.40^{c}	4.10^{c}	4.05^{c}	4.18^{c}	4.06^{c}	3.96^{c}	0.55	0.58	0.73	<0.01
Intestines[5]	14.7	14.5	0.29	26.5^{a}	24.0^{b}	15.8^{c}	14.1^{c}	13.8^{cd}	11.8^{de}	10.1^{ef}	9.58^{f}	10.0^{ef}	10.5^{ef}	0.70	0.50	0.65	<0.01
GIT[6]	43.9	43.8	0.71	64.0^{a}	58.9^{b}	45.5^{c}	40.3^{de}	41.5^{cd}	40.6^{de}	36.3^{e}	35.8^{e}	39.2^{de}	36.5^{e}	1.69	0.47	0.90	<0.01
Carcass trim	5.47	5.70	0.65	4.28	10.4	0.93	4.40	5.93	5.97	4.51	3.96	6.46	8.94	1.47	0.02	0.81	<0.01
KPH[7]	23.5	19.5	0.79	10.7^{f}	13.2^{ef}	17.3^{de}	21.1^{cd}	23.2^{bc}	23.7^{abc}	23.7^{abc}	24.6^{abc}	28.7^{ab}	28.9^{a}	1.94	0.20	<0.01	<0.01
GIT fat[8]	58.7	55.4	1.66	32.6^{e}	39.8^{e}	51.5^{d}	55.0^{cd}	61.6^{bcd}	64.3^{abc}	72.5^{a}	66.3^{ab}	65.3^{abc}	61.5^{bcd}	3.74	0.90	0.17	<0.01
TIF[9]	80.0	72.8	2.02	40.4^{d}	50.3^{d}	66.6^{c}	73.8^{bc}	82.6^{ab}	85.9^{ab}	94.4^{a}	89.2^{a}	92.3^{a}	88.5^{a}	4.71	0.88	0.02	<0.01
TST[10]	60.2	60.2	0.79	84^{a}	79.0^{a}	62.8^{b}	56.8^{cd}	57.4^{bc}	55.8^{cde}	51.0^{ef}	50.2^{f}	53.3^{cdef}	51.4^{def}	1.94	0.51	0.98	<0.01
Total offal[11]	215	215	2.16	274^{a}	267^{a}	218^{b}	218^{b}	206^{b}	205^{bc}	191^{d}	188^{d}	191^{cd}	191^{d}	4.95	0.99	0.84	<0.01

[1] Steers received no implant **(CON)** or a Revalor-XS **(REV;** Merck Animal Health, Summit, NJ**)** on d0 and d190 of the study; Feeding duration (**DOF**).
[2] Hot carcass weight
[3] Sum of the metatarsals and metacarpals
[4] Sum of the rumen, reticulum, omasum and abomasum
[5] Sum of the small intestine and the large intestine
[6] Gastrointestinal tract; Sum of the intestines, stomach, esophagus and bladder
[7] Sum of the kidneys and fat from the kidney, pelvic and heart region
[8] Gastrointestinal fat; comprised of omental and mesenteric fat
[9] Total internal fat; Sum of KPH, omental and mesenteric fat
[10] Total Sphlanchnic Tissue; sum of the GIT, liver, spleen and pancreas
[11] Sum of the oxtail, kidney, thymus, heart, lungs and trachea, GIT, pancreas, spleen, liver, gallbladder, lips, head, pizzle, hide and limbs
[a,b,c,d,e,f,g,h] DOF values with different superscripts differ ($P < 0.05$).

Table 4.4. Predictive regression equations for the proportionate growth (g•kg•d) of non-carcass components in implanted or non-implanted Charolais × Angus steers as estimated by a 378-d serial harvest study (x = feeding duration, DOF).

Item	Linear	Quadratic	Adjusted R^2	RMSE
HCW[1]	-	$y = -0.00070x^2 + 0.43x + 644$	0.56	19.4
Blood	-	$y = 0.00019x^2 – 0.11x + 44.4$	0.29	7.50
Head	-	$y = 0.00011x^2 – 0.067x + 37.8$	0.71	2.20
Pituitary, mg/kg•d	-	$y = 0.000027x^2 – 0.014x + 5.19$	0.22	0.99
Tongue	-	$y = 0.0000055x^2 – 0.0035x + 2.30$	0.47	0.19
Lips	-	$y = 0.0000043x^2 – 0.0016x + 0.81$	0.06	0.19
Hide	-	$y =0.00027x^2 – 0.17x + 105$	0.49	9.25
Pizzle	-	$y = -0.0000056x^2 + 0.0024x + 0.64$	0.03	0.32
Spinal cord	-	$y = 0.0.0000087x^2 – 0.0048x + 0.95$	0.59	0.17
Liver	-	$y = 0.000049x^2 – 0.034x + 17.5$	0.72	1.24
Lungs/Trachea	-	$y = 0.000043x^2 – 0.025x + 9.12$	0.59	1.07
Heart	$y = -0.0015x + 4.65$	-	0.06	0.66
Pancreas	-	$y = 0.0000062x^2 – 0.0027x + 1.03$	0.15	0.20
Esophagus	-	$y = 0.0000066x^2 – 0.0034x + 0.94$	0.47	0.14
Rumen	-	$y = 0.000081x^2 – 0.039x + 22.2$	0.15	3.24
Omasum	-	$y = 0.000022x^2 – 0.014x + 6.18$	0.45	0.86
Stomach[2]	-	$y = 0.00014x^2 – 0.076x + 35.6$	0.41	3.86
Small intestine	-	$y = 0.0001x^2 – 0.066x + 16.7$	0.86	1.45
Large intestine	-	$y = 0.000092x^2 – 0.049x + 9.97$	0.66	1.50
Intestines[3]	-	$y = 0.00019x^2 – 0.11x + 26.7$	0.86	2.26
GIT[4]	-	$y = 0.00034x^2 – 0.19x + 63.5$	0.77	5.01
GIT fat[5]	-	$y = -0.00049x^2 + 0.27x + 30.8$	0.58	10.1
TST[6]	-	$y = 0.0004x^2 – 0.23x + 84.1$	0.80	5.55
Total offal[7]	-	$y = 0.00092x^2 – 0.57x + 276$	0.80	14.5

[1] Hot carcass weight

[2] Sum of the rumen, reticulum, omasum and abomasum

[3] Sum of the small intestine and the large intestine

[4] Gastrointestinal tract; Sum of the intestines, stomach, esophagus and bladder

[5] Gastrointestinal fat; comprised of omental and mesenteric fat

[6] Total Splanchnic Tissue; sum of the GIT, liver, spleen and pancreas

[7] Sum of the oxtail, kidney, thymus, heart, lungs and trachea, GIT, pancreas, spleen, liver, gallbladder, lips, head, pizzle, hide and limbs

Table 4.5. Predictive regression equations for the proportionate growth (g•kg•d) of non-carcass components exhibiting treatment differences ($P \leq 0.05$) in implanted or non-implanted Charolais × Angus steers as estimated by a 378-d serial harvest study (x = feeding duration, DOF).

Item	Quadratic	Exponential	Adjusted R^2	RMSE
Brain				
CON[1]	$y = 0.000011x^2 – 0.0061x + 1.43$	-	0.88	0.12
REV[1]	$y = 0.0000011x^2 – 0.0063x + 1.44$	-	0.87	0.13
Limbs[2]				
CON	$y = 0.000085x^2 – 0.058x + 27.2$	-	0.79	1.93
REV	$y = 0.00012x^2 – 0.072x + 26.7$	-	0.83	1.92
Thymus				
CON	$y = -0.000020x^2 + 0.0059x + 1.29$	-	0.34	0.44
REV	$y = -0.000022x^2 + 0.0061x + 1.15$	-	0.4	0.40
Reticulum				
CON	$y = 0.000019x^2 – 0.011x + 3.08$	-	0.83	0.28
REV	$y = 0.000024x^2 – 0.012x + 3.07$	-	0.73	0.33
Abomasum				
CON	$y = 0.000018x^2 – 0.012x + 4.36$	-	0.74	0.44
REV	$y = 0.000023x^2 – 0.014x + 4.25$	-	0.68	0.51
KPH[3]				
CON	-	$12.25e^{0.003x}$	0.74	4.59
REV	$y = -0.00013x^2 + 0.084x + 10.44$	-	0.55	4.44
TIF[4]				
CON	$y = -0.00064x^2 + 0.39x + 38.5$	-	0.83	10.3
REV	$y = -0.00053x^2 + 0.31x + 39.7$	-	0.65	12.8

[1] Steers received no implant **(CON)** or a Revalor-XS **(REV;** Merck Animal Health, Summit, NJ**)** on d0 and d190 of the study; implant treatment effect occured ($P \leq 0.05$) if treatment is differentiated.

[2] Sum of the metatarsals and metacarpals

[3] Sum of the kidneys and fat from the kidney, pelvic and heart region

[4] Total internal fat; Sum of KPH, omental and mesenteric fat

CHAPTER V

CARCASS PERFORMANCE OF TBA + E2 IMPLANTED STEERS VS. NON-HORMONE TREATED STEERS ACROSS SERIAL HARVEST ENDPOINTS

5.1. Abstract

Growth promoting implants containing trenbolone acetate **(TBA)** and estradiol **(E_2)** are extensively used in the beef industry to improve rate of gain and feed efficiency. Improved efficiency associated with implants has been attributed to a shift in nutrient deposition away from fat toward the development of lean muscle. Though decreased waste fat will improve carcass cutability, a concurrent reduction in intramuscular fat and carcass quality often occurs in implanted animals marketed prior to achieving target composition. A serial-harvest study was designed to evaluate the development of traits contributing to carcass yield and quality in response to implant and days on feed **(DOF)**. Charolais × Angus steers (n = 80) were paired for similarity and pairs were randomized to 1 of 10 harvest dates corresponding to 0, 42, 84, 126, 168, 210, 252, 294, 336 or 378 DOF. Individuals were then randomized to 1 of 2 implant treatments; **REV** steers received a Revalor-XS (200mg trenbolone acetate/40mg estradiol) implant on d 0 and d 190, whereas **CON** steers received no implant, representing a non-hormone treated **(NHTC)** marketing strategy. Upon each feeding endpoint, 4-REV/CON pairs were harvested and the weight of kidney, pelvic and heart fat **(KPH)**, and hot carcass weight

(HCW) were obtained. Carcasses were chilled for 48 h and graded according to USDA quality and yield grade standards. All variables were analyzed using mixed models. While no TRT × DOF interactions ($P > 0.05$) occured in yield grade variables, a TRT × DOF interaction occurred ($P < 0.01$) for skeletal and overall maturity. Implanted steers had a larger (6%; $P < 0.01$) LM area than non-implanted counterparts. While REV carcasses had 17% less ($P < 0.01$) KPH as a percentage of the HCW than CON carcasses, no treatment effects ($P = 0.26$) were observed in marbling, suggesting sustained marbling quality throughout the 378-d feeding period. Marbling and 12th rib fat depth increased linearly ($P < 0.01$) across DOF; LM area, percentage KPH, USDA yield grade, and lean maturity increased whereas LM area:HCW decreased quadratically ($P < 0.06$) with additional DOF. These data support a shift in nutrient deposition from waste-fat accumulation to lean tissue development in response to TBA + E_2 implants compared to NHTC. Additionally, implanted steers exhibited advanced skeletal maturity, however no compromise in marbling was observed throughout the feeding period.

5.2. Introduction

Exogenous hormones such as trenbolone acetate **(TBA)** and estradiol-17β **(E_2)** are frequently administered to beef cattle via growth promoting implants and are extensively used in conventional cattle feeding to improve rate of gain and feed efficiency, essentially improving yield of red meat products by approximately 10% (Johnson et al., 1996; Guiroy et al., 2002). Improved efficiency associated with TBA + E_2 implants has been attributed to a shift in nutrient deposition away from fat deposits often trimmed from the final product, toward the development of lean muscle (Owens, 1995; Johnson et al.,

1996; Guiroy et al., 2002). Observed reductions in waste fat suggest improved carcass cutability and red meat yield, however, is also associated with a concurrent reduction in intramuscular fat and carcass quality in implanted animals marketed prior to achieving target composition (Morgan, 1991; Montgomery et al., 2001).

Quality and yield grading of beef carcasses is the premise of the price point received by producers and paid by consumers at purchase. Additionally, characteristics used in the determination of carcass quality and yield contribute to purchase decisions and consumer experience of a meat product. The objective of this experiment was to evaluate the development of carcass yield and quality attributes in conventional feedlot steers administered growth promoting implants in comparison to unconventional, non-hormone treated counterparts, across a 378-d feeding and growth period.

5.3. Materials & Methods

All experimental procedures associated with this study were executed humanely, following guidelines and had been approved by the West Texas A & M University Institutional Animal Care and Use Committee. (Protocol No. 01-08-18).

5.3.1. Animals and Treatments

Charolais × Angus steers (n = 80) that had been paired, fed and processed as described by Kirkpatrick (2020) and harvested as described by Pillmore (2020) were randomly designated to one of 10 harvest dates in 42 d increments, corresponding to 0, 42, 84, 126, 168, 210, 252, 294, 336 or 378 DOF and one of 2 implant treatments, **REV** or **CON.** While REV steers received a Revalor-XS (200mg trenbolone acetate/40mg estradiol; Merck Animal Health, Madison, NJ) on d 0 and d 190 of the study, CON cattle

received no implant throughout the study, representing non-hormone treated cattle (**NHTC**). Steers were humanely harvested in accordance to the standards described by Pillmore (2020). Following harvest procedures, hot carcass weight (**HCW**) was obtained and carcasses were chilled for 24 h at approximately -2°C, and subsequently for 24 h at approximately 1°C. Following the 48-h chill period, the right side of each carcass was ribbed between the 12th and 13th rib and evaluated in accordance to the USDA quality and yield grading standards for beef carcasses (USDA, 2017). The exposed ribeye was allowed to bloom for approximately 20 minutes prior to grading. The left side of the carcass was evaluated in the occurrence of a mis-split carcass that inhibited evaluation of grade characteristics.

5.3.2. Carcass Yield Grade

Carcass yield grade (YG) was determined in accordance to the USDA yield grading standards (USDA, 2017) via evaluation of HCW, 12th rib fat thickness (**FT**), longissimus muscle area (**LMA**), and kidney-pelvic-heart (**KPH**) fat as a percentage of HCW. The HCW used in the determination of carcass yield grade was the weight of the carcass at harvest including KPH, representing standard commercial procedures. Rib fat thickness was measured three-fourths the distance from the medial edge of 12th rib interface, perpendicular to the dorsal edge of the ribeye. Longissimus muscle area of the 12th rib interface was measured via USDA dot grid. The KPH was removed upon harvest for direct and objective weighing and was expressed as a percentage of HCW. Measurements of each component were then applied to the USDA equation (YG = 2.5 + {2.5 × FT, in} + {0.0038 × HCW, lbs} + {0.2 × KPH} – {0.32 × LM area, in^2}) for final

calculation of YG. Dressed carcass yield (**DY**) was calculated by dividing the weight of the HCW by SBW. Longissimus muscle area was also expressed in relation to HCW (LM:HCW).

5.3.3. Carcass Quality Grade

Carcasses were also assessed for quality using the USDA quality grading standards (USDA, 2017) via subjective evaluation of intramuscular fat, dentition, lean maturity and skeletal maturity. Intramuscular fat of the 12th rib interface was subjectively evaluated and assigned to the appropriate marbling score: 10-19 = practically devoid, 20-29 = traces, 30-39 = slight, 40-49 = small, 50-59 = modest, 60-69 = moderate, 70-79 = slightly abundant, 80-89 = moderately abundant, and 90-99 = abundant. Dentition was evaluated based on the number of erupted incisors; steers with 0, 1 or 2 permanent incisors were deemed eligible for Prime, Choice, Select and Standard, whereas steers with 3 or more permanent incisors were deemed over 30 mo of age and were no longer eligible for young quality grades. Carcasses were then subjectively evaluated for skeletal ossification of the sacral and lumbar vertebrae and lean color of the longissimus muscle, evaluated at the 12th and 13th rib interface. Overall maturity was calculated as the combination of degree of skeletal ossification and lean color (USDA, 2017) and assigned a maturity score (A, B, C, D, E).

5.3.3. Statistical Analysis

The study was a balanced incomplete block design with a 2 x 10 treatment structure. Pair served as a block (n = 40) and individual steer (n = 80) was the experimental unit. All variables were evaluated for the main effects of implant treatment

and DOF and the interaction between treatment × DOF with d-0 BW as a covariate and were analyzed using mixed models of SAS (SAS 9.3, SAS Institute, Cary, NC). Pair was included as a random effect. The Glimmix procedure of SAS was used and least squares means were used in the calculation of means and differences of each variable. The CONTRAST statement was used in the evaluation of linear and quadratic relationships of each variable across DOF.

Linear or quadratic regression equations were generated to estimate daily growth of each characteristic. Variables were analyzed using the REG procedure of SAS (SAS 9.3, SAS Institute, Cary, NC) with DOF and each variable of interest in the model. Data were also evaluated for exponential and power equations and the best fit model was determined by highest adjusted r^2 value. Feeding duration was represented by the x variable whereas non-component variables were represented y. Equations were developed for variables that exhibited linear or quadratic relationships across DOF ($P \leq 0.05$). Separate equations were developed for REV and CON for variables that exhibited effects of implant treatment ($P \leq 0.05$).

5.4. Results and Discussion

5.4.1. Carcass Yield

Longissimus muscle area was 6% larger (87.6 vs. 82.8 cm^2; $P < 0.01$) in REV steers than non-implanted counterparts, suggesting LMA as a factor influencing the increased SBW and HCW (Kirkpatrick, 2020; Pillmore, 2020). The 6% increase in LMA observed in the present study was observed to a similar degree by Reiling and Johnson (2003; 6%) and Carvalho et al., (2020; 6%) and Samber et al. (1996; 5-7%). A meta-

analysis of data from 37 independent implant studies (Duckett et al., 1996) suggested a 4% increase in ribeye area in implanted animals when compared to non-hormone treated animals. Scheffler et al. (2003) reported no change in the LMA of non-implanted Holstein steers and steers receiving a single combination implant, however, observed an increase in LMA when steers received 2 or more combination implants.

The increase in LMA in the present study and HCW of the same cattle as reported by Pillmore (2020), demonstrates the protein depository effects associated with growth promoting implants. Combination implants such as Revalor-XS used in the present study, are expected to elicit an additive response in protein deposition above that of single-hormone implants, due to the various mechanisms of estrogenic and androgenic compounds (Hutcheson et al., 1997; Cooper et al., 1999).

Carcasses of implanted steers in the present study also deposited 0.57 percentage points less (2.81 vs. 3.38%; $P < 0.01$) KPH than carcasses of non-hormone treated cattle. Johnson et al. (1996) reported a reduction of 0.12 percentage points in the KPH percentage of implanted steers, Reiling and Johnson (2003) observed a 0.22 percentage point reduction when steers received 2 Revalor-S implants and Kniffen et al. (1999) observed a reduction of 0.3 percentage point reduction in KPH of heifers recieving one or more estrogenic implants. In contrast, Duckett et al. (1996), Samber et al. (1996) and Cooper et al. (1999) reported no change in KPH percentage in response to implant administration, supporting the sustained fat percentage reported by Hutcheson et al. (1997). The reduction in KPH percentage between treatment groups observed in the present study is speculated to have occurred due to the prolonged feeding duration and

differences in fat accretion in implanted and non-implanted steers as the feeding duration progressed.

No main effects ($P > 0.13$) of implant treatment were observed for LMA:HCW (1.75 vs. 1.76), FT (1.17 vs. 1.24 cm) or USDA YG (3.04 vs. 3.28) between REV and CON cattle. The consistency in LMA:HCW among REV and CON cattle supports the consistent increase in LMA (6%) and HCW (6%; Pillmore, 2020) as independent variables in implanted steers vs. non-implanted counterparts.

Researchers have previously reported consistency in FT and YG between implanted and non-implanted cattle (Duckett et al., 1996; Samber et al., 1996; Kniffen et al. 1999; Roeber et al., 2000). Hutcheson et al. (1997) suggested that implanting feedlot steers increases protein accretion and total mass, while maintaining similar fat percentages to control steers, thus supporting increased LMA and similar FT and YG of implanted steers in the present study. A study comparing carcass performance in response to various implants reported steers implanted with Revalor-XS to have the most 12^{th} rib FT and greatest calculated USDA YG in comparison to other commercially available implants (Smith et al., 2018).

Main effects of DOF occurred for all yield variables ($P \leq 0.05$; **Table 5.1.**). Fat thickness and YG increased linearly ($P < 0.01$) across DOF. Fat thickness at the 12^{th} rib interface accrued at approximately 0.0051 cm per d ($r^2 = 0.61$; **Table 5.2.**), obtaining 1 cm of fat in approximately 196 d and YG accrued at 0.008 units per d ($r^2 = 0.66$), obtaining a complete YG score in approximately 125 d. Longissimus muscle area and KPH increased quadratically whereas LMA:HCW decreased quadratically ($P < 0.06$) with increasing DOF.

5.4.2. Carcass Quality

While no treatment × DOF interactions ($P > 0.05$) were observed in yield grade variables, a treatment × DOF interaction occurred ($P < 0.01$; **Fig. 5.1.**) for skeletal maturity, therefore driving the observed treatment × DOF interaction ($P < 0.01$; **Fig. 5.1.**) in overall maturity. While skeletal and overall maturity were similar ($P \geq 0.39$) for REV and CON carcasses from 0 to 126 DOF, REV carcasses displayed advanced maturity ($P = 0.01$) compared to CON carcasses, beginning at 168 DOF. Carcasses of implanted steers exceeded A-maturity following harvest at 252 DOF and gained approximately 0.32° of maturity per d, whereas CON carcasses gained approximately 0.14° of maturity per d.

The administration of steroidal implants has demonstrated advanced characteristics of skeletal and lean maturity and bone metabolism due to estrogenic effects on bone metabolism. Kniffen et al. (1999) reported advanced closure of the epiphyseal plate of implanted heifers in response to implant dose. Scheffler et al. (2003) reported implanted Holstein steers to display advanced skeletal maturity scores, and progressively more advanced maturity with additional implant administration. Reiling and Johnson (2003) also reported advanced skeletal maturity and increased ash content in thoracic buttons due to cartilaginous ossification.

Lean maturity did not differ between treatments ($P = 0.13$) however, the 12th rib interface became darker and lean maturity score increased quadratically ($P < 0.01$) as the feeding period progressed and as the animal aged. Similarly, Scheffler et al. (2003) reported no difference in L*a*b* values of the longissimus muscle of implanted or non-implanted steers though Herschler et al. (1995) observed carcasses of implanted cattle had darker longissimus muscle. Previous researchers have also suggested implant to

increase the declarative incidence of dark cutters, due to dark colored longissimus muscle, as a factor of implant administration and days from implant to harvest. Scanga et al. (1998) reported steers implanted and re-implanted with androgen and combination implants to increase dark cutting prevalence within pen to the highest degree in comparison to steers treated with other implant strategies. Because all steers had fewer than 3 permanent incisors, dentition results are not reported and all steers were deemed eligible for young quality grades.

Despite the decrease in fat depots in response to implantation observed in KPH in the present experiment and previously (Reiling and Johnson, 2003; Pillmore et al., 2019), and decrease in internal fat as demonstrated by Pillmore et al. (2019; 2020) and Johnson et al. (1996), marbling was similar (Sl^{94} vs. Sm^{08}; $P = 0.26$) for REV and CON in the present study, suggesting sustained marbling quality throughout the 378-d feeding period (**Table 5.1.**). Similar marbling, together with FT and YG for both treatment groups in the present study supports the sustained fat percentage and obtainment of similar finish at a heavier weight in implanted animals reported by Hutcheson et al. (1997). Marbling accrued in a linear fashion across DOF ($P < 0.01$; **Table 5.1.**) at approximately 0.078° of marbling per d ($r^2 = 0.72$; **Table 5.2.**), requiring approximately 128 d to accrue a complete marbling score (i.e. Sl^{00} to Sm^{00}).

Duckett et al. (1996) also reported implanted cattle from 37 independent trials to accrue similar marbling to non-implanted steers. Smith et al. (2018) also reported similar marbling in steers implanted with Revalor-XS and non-implanted steers, however, other implants evaluated in the study resulted in less marbling than non-implanted and Revalor-XS implanted steers. Bryant et al. (2010) and Smith et al. (2017) reported cattle that

received non-coated commercial implants had less marbling than cattle that received slow-release implants such as Revalor-XS, likely due to the flood-like release of hormones by non-coated implants. Pillmore et al. (2019) reported a decrease in marbling from Moderate^{80} to Small^{20} marbling in long-fed Jersey steers aggressively implanted with 200 mg TBA and 20 mg of E_2 every 70 d. Reiling and Johnson (2003) also reported decreased marbling in steers initially and re-administered with Revalor-S and Scheffler et al. (2003) reported a 10-18% increase in the number of Select grade carcasses from implanted, long-fed Holsteins compared to non-implanted counterparts. Gerken et al. (1995), Herschler et al (1995) and Montgomery et al. (2001) discussed decreased marbling as a common result in response to single estrogenic implants, however, to a lesser degree in response than androgenic or combination implants.

5.5. Conclusions

These data support a shift in nutrient deposition from waste-fat accumulation to lean tissue development in response to slow-release TBA + E_2 implants compared to NHTC. Additionally, implanted steers exhibited advanced skeletal maturity, however no concurrent compromise in marbling was observed throughout the 378-d feeding period. Steers accrued 12th rib fat and marbling within the longissimus muscle in a linear fashion across DOF, thus greatly influencing the USDA quality and yield grade of Charolais × Angus steers.

5.6. Literature Cited

Barham, B., P. Beck, J. Apple, W. Whitworth, M. Miller and S. Gadberry. 2012. Effect of age entering feedlot and implant regimen on beef cattle performance, carcass characteristics and sensory evaluation. Prof. Anim. Sci. 28:20-31. doi: 10.15232/S1080-7446(15)30312-0.

Bryant, T. C., T. E.Engle, M. L.Galyean, J. J.Wagner, J. D.Tatum, R. V.Anthony, and S. B. Laudert. 2010. Effects of ractopamine and trenbolone acetate implants with or without estradiol on growth performance, carcass characteristics, adipogenic enzyme activity, and blood metabolites in feedlot steers and heifers. J. Anim. Sci. 88:4102–4119. doi:10.2527/jas.2010-2901.

Carvalho, P. H. V., G. A. Perry and T. L. Felix. 2020. Effects of steroidal implants on feedlot performance, carcass characteristics and serum and meat estradiol-17β concentrations of Holstein steers. Transl. Anim. Sci. 2020.4:206-213. doi. 10.1093/tas/txz186.

Cooper, R., T. Milton, and F. Prouty. 1999. Implant strategies on performance and carcass characteristics of finishing steers. Nebraska beef Cattle Reports. 399. Available from: https://digitalcommons.unl.edu/animalscinbcr/399?utm_source=digitalcommons.unl.edu%2Fanimalscinbcr%2F399&utm_medium=PDF&utm_campaign=PDFCoverPages.

Duckett, S. K., D. G. Wagner, F. N. Owens, H. G. Dolezal, D. R. Gill. 1996. Effects of estrogenic and androgenic implants on performance, carcass traits and meat

tenderness in feedlot steers: A review. Prof. Anim. Sci. 22:205-214. doi: 10.15232/S1080-7446(15)32526-2.

Gerken, C. L., J. D. Tatum, J. B. Morgan, and G. C. Smith. 1995. Use of genetically identical (clone) steers to determine the effects of estrogenic and androgenic implants on beef quality and palatability characteristics. J. Anim. Sci. 73:3317–3324. doi: 10.2527/1995.73113317x

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

Herschler, R. C., A. W. Olmsted, A. J. Edwards, R. L. Hale, T. Montgomery, R. L. Preston, S. J. Bartle, and J. J. Sheldon. 1995. Production responses to various doses and ratios of estradiol benzoate and trenbolone acetate implants in steers and heifers. J. Anim. Sci. 73:2873–2881. doi: 10.2527/1995.73102873x.

Hutcheson, J. P., D. E. Johnson, C. L Gerken, J. B. Morgan and J. D. Tatum. 1997. Anabolic implant effects on visceral organ mass, chemical body composition and estimated energetic efficiency in cloned beef steers. J. Anim. Sci. 75:2620-2626. doi: 10.2527/1997.75102620x.

Johnson, B. J., P. T. Anderson, J. C. Meiske, and W. R. Dayton. 1996. Effect of a combined trenbolone acetate and estradiol implant on feedlot performance, carcass characteristics, and carcass composition of feedlot steers. J. Anim Sci. 74:363–371. doi: 10.2527/1996.742363x.

Kirkpatrick, T.J. 2020. The effect of growth-promoting implants and days on feed on live performance and behavioral characteristics, biometric measurements, empty body composition, and energy retention of serially harvested beef steers. Thesis. West Texas A&M University. Canyon, TX.

Kniffen, D. M., W. R. Wagner, P. E. Lewis. 1999. Effects of long-term estrogen implants in beef heifers. J. Anim. Sci. 77:2886-2892. doi: /10.2527/1999.77112886x

Montgomery, T. H., P. F. Dew, and M. S. Brown. 2001. Optimizing carcass value and the use of anabolic implants in beef cattle. J. Anim. Sci. 79:E296-E306. doi: 10.2527/jas2001.79E-SupplE296x.

Morgan, J. B. 1991. Tenderness problems and potential solutions. National Beef Quality Audit, Final Report, pp 180. National Cattlemen's Assoc., Englewood, CO.

Owens, F. N., P. Dubeski, C. F. Hanson. 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci. 71:3138–3150. doi: 10.2527/1993.71113138x.

Pillmore, S. P., T. J. Kirkpatrick, K. Wesley, K. Cooper, T. Tennant, and T. Lawrence. 2019. An aggressive implant program altered USDA yield and quality grade of long-fed Jersey steer Carcasses. J. Anim. Sci. 97:305. 10.1093/jas/skz258.616

Reiling, B. A. and D. D. Johnson. 2003. Effects of implant regimens (trenbalone acetate-estradiol administered alone or in combination with zeranol) and vitamin D_3 on fresh beef color and quality. J. Anim. Sci. 18:135-142. doi: 10.2527/2003.811135x.

Roeber, D. L., R. C. Cannell, K. E. Belk, J. D. Tatum, and G. C. Smith. 2000. Implant strategies during feeding: Impact on carcass grades and consumer acceptability. J. Anim. Sci. 78:1867–1874. doi: 10.2527/2000.7871867x.

Samber, J. A., J. D. Tatum, M. I. Wray, W. T. Nichols, J. B. Morgan and G. C. Smith. 1996. Implant program effects on performance and carcass quality of steer calves finished for 212 days. J. Anim. Sci. 74: 1470-1476. doi: 10.2527/1996.7471470x.

Scanga, J. A., K. E. Belk, J. D. Tatum. T. Grandin, and G. C. Smith. 1998. Factors contributing to the incidence of dark cutting beef. J. Anim. Sci. 76:2040-2047. doi: 10.2527/1998.7682040x.

Scheffler, J. M., D. D. Buskirk, S. R. Rust, J. D. Cowley, M. E. Doumit. 2003.Effect of repeated administration of combination trenbolone acetate and estradiol implants on growth, carcass traits, and beef quality of long-fed Holstein steers. J. Anim. Sci. 81:2395-2400.

Smith, Z. K., A. J. Thompson, J. P. Hutcheson, W. T. Nichols, and B. J. Johnson. 2018. Evaluation of coated steroidal implants containing trenbolone acetate and estradiol-17β on live performance, carcass traits, and sera metabolites in finishing steers. J. Anim. Sci. 96:1704-1723. doi: 10.1093/jas/sky095. doi:.10.2527/1998.7682040x

USDA. 2017. United States Standards for Grades of Carcass Beef. Federal Register. Available from: https://www.federalregister.gov/documents/2017/06/19/2017-12657/united-states-standards-for-grades-of-beef. Accessed on: 17 Mar 2020.

Table 5.1. USDA quality and yield grade characteristics of serially harvested steers (378-d) receiving no implant (CON) or Revalor-XS (REV).

	Implant Treatment[1]			DOF[2]											*P*-value		
Item	CON	REV	SEM	0	42	84	126	168	210	252	294	336	378	SEM	TRT × DOF	TRT	DOF
Steers	40	40	-	8	8	8	8	8	8	8	8	8	8	-	-	-	-
Days of age	406	409	3.12	213	254	300	339	393	434	476	521	550	597	-	-	-	-
USDA yield grade																	
LM area, cm^2	82.8	87.6	1.12	60.6^{f}	63.6^{f}	76.2^{e}	81.6^{de}	87.2^{cd}	93.0^{bc}	92.9^{bc}	90.9^{c}	99.4^{b}	106.7^{a}	2.62	0.60	<0.01	<0.01
LM:HCW	1.76	1.75	0.03	2.74^{a}	2.16^{b}	1.88^{c}	1.79^{c}	1.66^{cd}	1.54^{de}	1.56^{de}	1.37^{e}	1.46^{de}	1.44^{de}	0.08	0.95	0.81	<0.01
12^{th} rib fat depth, cm	1.24	1.17	0.07	0.20^{e}	0.46^{de}	0.66^{cd}	0.95^{bc}	0.94^{bc}	1.28^{b}	1.77^{a}	2.09^{a}	1.84^{a}	1.87^{a}	0.16	0.26	0.46	<0.01
KPH, %	3.38	2.81	0.11	1.65^{e}	2.06^{de}	2.51^{cd}	3.05^{bc}	3.32^{ab}	3.42^{ab}	3.38^{ab}	3.45^{ab}	4.07^{a}	4.05^{a}	0.26	0.30	<0.01	<0.01
USDA yield grade[3]	3.28	3.04	0.11	1.36^{g}	1.98^{fg}	2.31^{ef}	2.68^{e}	2.87^{de}	3.42^{cd}	3.82^{bc}	4.67^{a}	4.18^{ab}	4.30^{ab}	0.25	0.40	0.13	<0.01
USDA quality grade																	
Marbling score[4]	40.8	39.4	0.91	24.5^{f}	28.2^{ef}	31.9^{de}	34.0^{d}	42.5^{c}	42.6^{c}	44.9^{bc}	49.0^{ab}	49.4^{ab}	54.0^{a}	2.26	0.42	0.21	<0.01
Skeletal maturity[5]	40.7	69.6	2.52	15.6	19.8	25.1	40.9	48.3	60.6	72.9	83.7	94.3	90.4	6.15	<0.01	<0.01	<0.01
Lean maturity[5]	57.8	61.8	1.90	15.9^{d}	47.6^{c}	48.7^{c}	48.3^{c}	67.8^{b}	74.1^{ab}	69.8^{b}	71.4^{ab}	71.1^{ab}	83.0^{a}	4.70	0.40	0.12	<0.01
Overall maturity[5]	47.5	66.0	1.90	13.9	32.4	33.8	44.0	56.1	66.1	70.1	81.2	81.3	88.5	4.30	<0.01	<0.01	<0.01

[1] Steers received no implant **(CON)** or a Revalor-XS **(REV;** Merck Animal Health, Summit, NJ**)** on d0 and d190 of the study.

[2] Linear **(LIN)** and quadratic **(QUAD)** contrasts of the main effect of DOF.

[3] United States yield grade- YG = [2.5 (2.5 × 12^{th} rib fat, in.) + (0.0038 × HCW, lbs) + (0.2 × KPH %) – (0.32 × LMA, in^2)]

[4] 20 = Traces; 30 = Slight; 40 = Small; 50 = Modest; 60 = Moderate; 70 = Slightly Abundant

[5] Scores: 0 to 99 = A maturity; 100 to 199 = B maturity; > 200 = C maturity

[a,b,c,d,e,f,g,h] DOF values with different superscripts differ ($P < 0.05$)

Table 5.2. Predictive regression equations for the development of USDA quality and yield grade characteristics of serially harvested steers (378-d) implanted with Revalor-XS (**REV**) on d 0 and d 190, compared to non-hormone treated steers (**CON**) (x = feeding duration, DOF).

Item	Linear[1]	Quadratic[1]	Exponential[1]	Adjusted R^2	RMSE
USDA yield grade					
LM area, cm^2					
CON	-	$y = -0.00012x^2 + 0.15x + 60.2$	-	0.64	9.71
REV	-	$y = -0.00023x^2 + 0.21x + 58.7$	-	0.80	7.78
LM:HCW	-	$y = 0.000013x^2 – 0.0080x + 2.59$	-	0.77	0.21
12^{th} rib fat depth, cm	$y = 0.0051x + 0.239$	-	-	0.61	0.49
KPH, %					
CON	-	-	$1.996e^{0.0025x}$	0.65	0.69
REV	-	$y = -0.000017x^2 + 0.011x + 1.62$	-	0.40	0.68
USDA yield grade[3]	$y = 0.008x + 1.57$	-	-	0.66	0.73
USDA quality grade					
Marbling score[4]	-	-	$26.155e^{0.0021x}$	0.75	5.92
Lean maturity[5]	-	$y = -0.00046x^2 + 0.311x + 24.3$	-	0.65	12.85

[1] Linear, quadratic and exponential contrasts of the main effect of DOF.

[2] Steers received no implant **(CON)** or a Revalor-XS **(REV;** Merck Animal Health, Summit, NJ**)** on d0 and d190 of the study; implant treatment effect occured ($P \leq 0.05$) if treatment is differentiated.

[3] United States yield grade- YG = [2.5 (2.5 × 12^{th} rib fat, in.) + (0.0038 × HCW, lbs) + (0.2 × KPH %) – (0.32 × LMA, in^2)]

[4] 20 = Traces; 30 = Slight; 40 = Small; 50 = Modest; 60 = Moderate; 70 = Slightly Abundant

[5] Scores: 0 to 99 = A maturity; 100 to 199 = B maturity; > 200 = C maturity

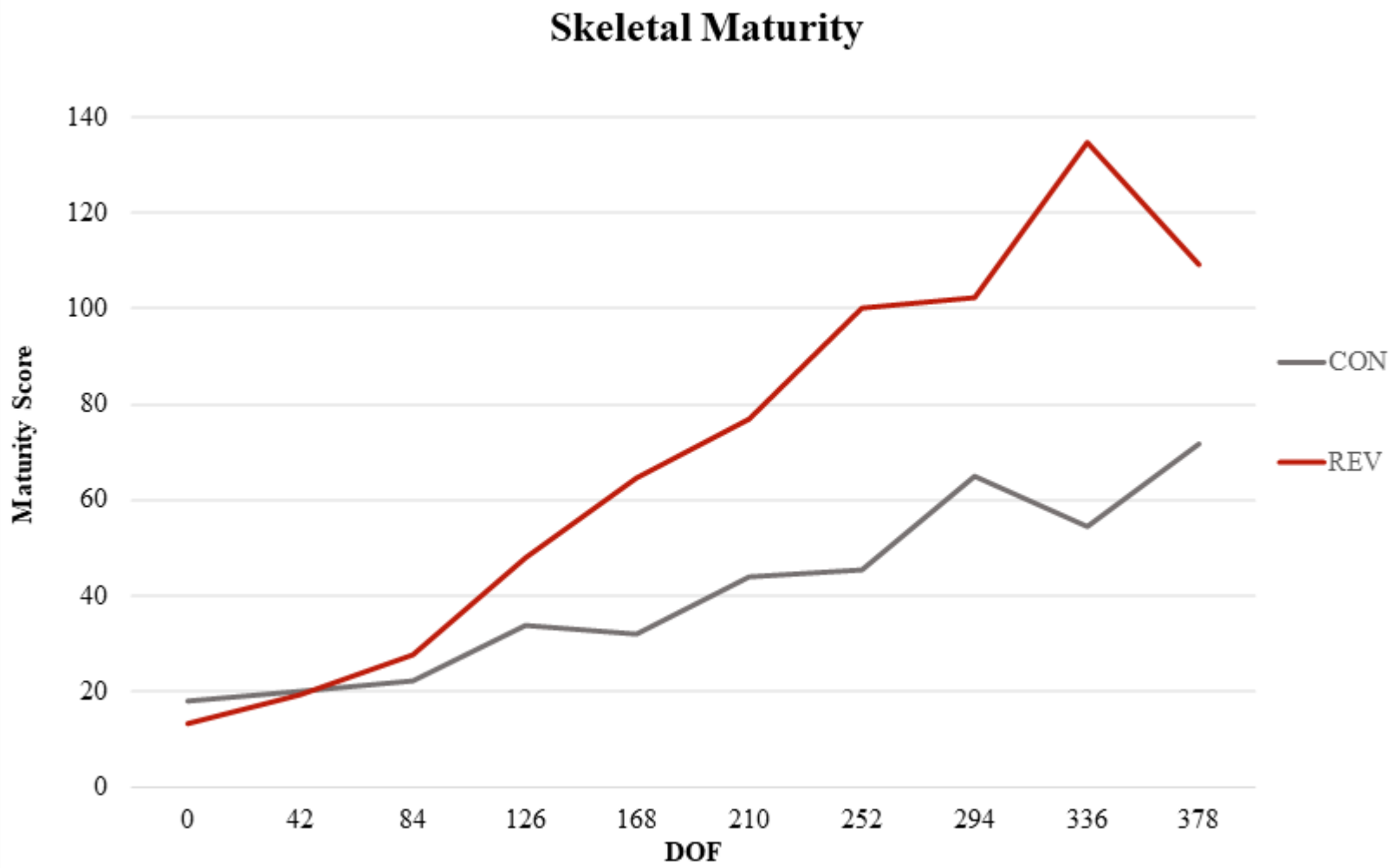

Figure 5.1. Interaction of implant treatment × DOF for skeletal maturity of serially harvested steers (378-d) implanted with Revalor-XS (**REV**) on d 0 and d 190, compared to non-hormone treated steers (**CON**).

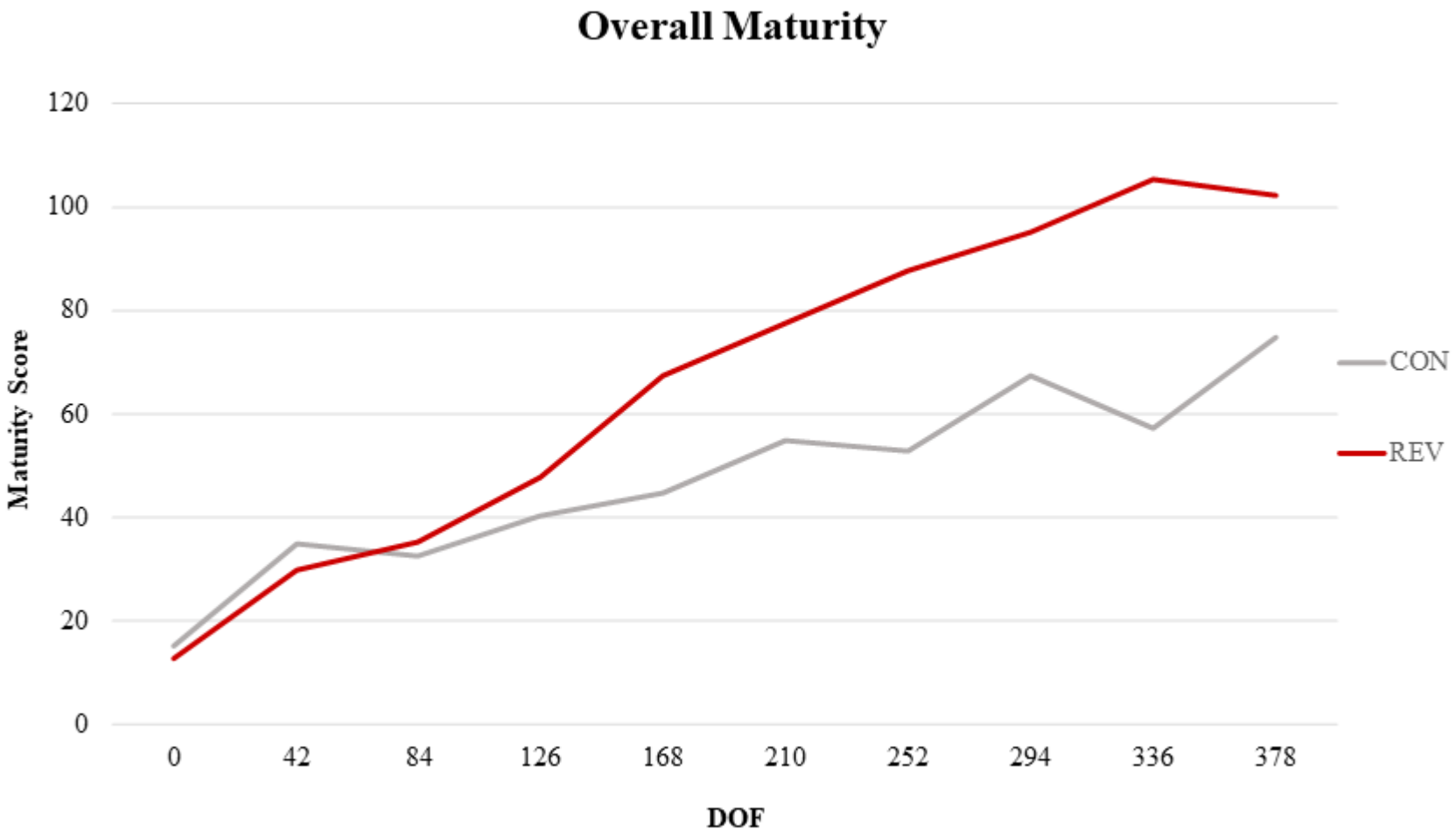

Figure 5.2. Interaction of implant treatment × DOF for overall maturity of serially harvested steers (378-d) implanted with Revalor-XS (**REV**) on d 0 and d 190, compared to non-hormone treated steers (**CON**).