IMPROVING THE VALUE OF CULL COWS THROUGH ANTEMORTEM MANAGEMENT PRACTICES AND POSTMORTEM ENHANCEMENT TECHNOLOGIES

by

SHANNA HUTCHISON

B.S., University of Arkansas, 2003
M.S., University of Arkansas, 2004

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department Of Animal Sciences and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2007

Abstract

Sixty cows were utilized to investigate the use of zilpaterol, implanting, and concentrate feeding on performance, carcass traits, subprimal yield, steak retail display, and meat palatability of cows fed for 70 d. The 5 treatments were: 1) grass-fed on pasture (**Grass**); 2) concentrate-fed (**C**); 3) concentrate-fed and implanted (**CI**) with a trenbolone acetate/estradiol implant, DE); 4) concentrate-fed and fed zilpaterol beginning on d 38 of the feeding period (**CZ**); and 5) concentrate-fed, implanted and fed zilpaterol (**CIZ**). Hot carcass weights and dressing percentages were higher ($P < 0.05$) for all concentrate-fed cows than grass-fed cows. The CIZ cows had the largest and grass-fed cows the smallest longissimus muscle (**LM**) areas. Total subprimal weights were lightest for cuts from the grass-fed cows; and CIZ cows had greater weights than those from C cows. Sensory panelists found LM steaks from C and grass-fed cows were more tender than steaks from CZ and CIZ cows; and steaks from CI cows were more tender than steaks from CIZ cows. However, no tenderness differences were observed among treatments for knuckle (**KN**) steaks. In another study, carcasses from 31 fed cows and 24 fed steers were used to investigate the effects of aging (7 or 28 d) on LM retail display; aging and enhancement (blade tenderization and enhancement solution injection) on LM tenderness; and aging on enhanced KN, top blade, and top sirloin steaks. Steaks (LM) aged 7 d had less discoloration and were more color stable than steaks aged for 28 d. A sensory panel found enhanced-cow LM steaks were more tender than non-enhanced steaks; and aging for 28 d improved tenderness compared to 7 d aging for non-enhanced steaks only. Aging for 28 d compared to 7 d improved Warner-Bratzler shear (more tender) for enhanced cow top sirloin, steer top sirloin, and steer top blade steaks. Feeding cull cows a concentrate diet improved lean meat yields. When feeding a concentrate diet a combination of an implant and feeding zilpaterol can further increase lean meat yields. Enhancement provides an opportunity to improve tenderness of steaks from fed cows and steers.

Key Words: Cows, β-agonist, Implants, Aging, Tenderness, Color, Enhancement

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Acknowledgements

I would like to thank the National Cattlemen's Beef Association (NCBA). Part of the research in this dissertation was funded, by beef and veal producers and importers through their $1-per-head checkoff and was produced for the Cattlemen's Beef Board and state beef councils by the National Cattlemen's Beef Association. Chapters 3 and 4 were funded by a grant that I wrote to NCBA in December 2006. In addition, Intervet donated the implants and the β-agonist for the research reported in these Chapters. I would also like to thank the BK Giulini Corporation for donation of the phosphate for Chapters 5 and 6 of my dissertation. In addition, thanks to Excalibur seasonings for donation of Bromelin for the research reported in Chapters 5 and 6.

I would like to thank those who pointed me down the path to more education. Dr. Jason Apple your words of support, encouragement and friendship are worth more than you will ever know! To Dr. Paul Beck and family who encouraged me to continue my education after finishing my master's degree, thank you, for your support and friendship. Lastly, Dr. Troy Wistuba thanks for your words of encouragement and friendship.

Doc it has been a privilege to work with you and learn from you. Thanks for your guidance and most of all your patience with me while completing this degree. Twig thanks for all of your help and patience with me. Thanks for helping me out with all the SAS questions. Hunter thanks for making me think outside of the box. Thanks to the three of you for all of your help in the meat lab with all of my projects. Dr. Higgins your statistics help was much needed and greatly appreciated. Thanks to my outside chair Dr. Adhikari for serving on my committee. While not on my committee, I could not have gotten the live animal portion of my research done without the great help from Dr. John Jaeger at the Western Agriculture Research Station, Hays. Dr. Jaeger thank you for all of your guidance with my cow project and for teaching me how to ultrasound my cows, without your help I would not have learned as much. I can say that I learned something new from you each time that I was in Hays to weigh the cows.

I would not have been able to complete my research without great help in the meat lab from John Wolf and “The Meat Lab Crew”. John thanks for always helping me, showing me how to do something multiple times until I figured it out, listening to me and for making sure that someone got me to the hospital all of those times! Thanks to Mark Seyfert for all of your help with my GEMS project. Without the lab expertise of Dave Trumble many parts of my research would not have been completed. Thanks to the “Cowboys” at the Western Agriculture Research Station, Hays for experimental animal care and for helping on weigh days.

Thanks to all of the graduate students that have helped out with all of my research projects. Thanks to the friends that I have made while here Melissa, Sara W., Sara L., Kelly, Jennifer, Amanda and Andrea for all of your help and words of encouragement. Melissa thank you for your friendship and hard work, without you all of my shears and many other parts of my research projects would not have gotten finished as quickly. Special thanks to Roxanne for always lending an ear and for your friendship. Thanks to Dr. Kropf for your friendship and words of encouragement. It was an honor to have you as an instructor. Your love and passion for your students and teaching are amazing. Also, thanks for being the most reliable color panelist that I had!

To my parents for all that they have done for me over the years Dad and Mom thanks for all that you have endured for me and with me. Thanks to my brother and his family Chayne, Candy, Garrett, Hunter and Moe for their support during this adventure and for lending an ear when I needed to talk. Thanks to my new extended family Robert and Karen Neill for listening to me or letting me come over to the farm to get out of town for a while. Thanks to Megan and Corey and Angie and Chad for all of their support.

Last but certainly not least to my husband Casey, thank you for all of your love and support without you some days would have been more difficult than they already were. Thanks for always being there for me whenever I needed you. I can’t wait to get moved to Tennessee to be with you, finally! It will be nice to be able to start the rest of our lives TOGETHER. I came to K-State to earn my Ph D and was lucky enough to find my best friend and love of my life in addition to earning my degree. Casey, I love you!

Dedication

I would like to dedicate this dissertation to my parents Thomas and Sandra Hutchison. I could not have completed this “chapter” of my life without your love and support. Thank you for instilling the values of honesty and hard work in me at a young age. Without these values I would not have been able to complete this or any of my degrees. Thank you!

CHAPTER 1 - GENERAL INTRODUCTION

Antemortem Management

Approximately 16% of the 31-million head of cattle harvested in the United States in 2005 were cull cows (USDA Market Report, 2006). Cows are "culled" from the herd for reasons such as reproductive inefficiency, performance, and age-related issues. Yager et al. (1980) reported that cull cows contribute 15-25% of the producer's revenue. However, selling cows in poor condition may decrease the potential value per cow by up to $27.50 (Roeber et al., 2001). The National Market Cow and Bull Beef Quality Audit of 1999 reported that there are challenges associated with the meat production of cull cows (Roeber et al., 2001). Among the challenges noted were dressing percentage and carcass leanness. Schnell et al. (1997) estimated that $20 per head could be recovered by feeding a high-energy diet to cull cows prior to harvest. Feeding cull cows a high concentrate diet could potentially be a viable option to improve cull beef cattle profitability.

In addition to feeding high-energy diets, implants and β-adrenergic agonist can potentially improve efficiency of cull cows and increase lean meat yields. Cranwell et al. (1996a) reported that implanted cows fed a concentrate diet for 56 d had increased longissimus muscle areas and increased dressing percentages. In addition, they found that implanted cows had more kilograms of total lean at harvest. In a study by Plascencia et al. (1999), the use of zilpaterol in feedlot steers increased live weight by 5.5% Steers fed zilpaterol had a 26% improvement in ADG compared to those fed ractopamine or grain only (Avendano-Reyes et al., 2006). Therefore, implanting and feeding β-agonists offer and opportunity to increase in live weight gains, dressing percentages, and lean meat yields.

Implanted fed cows had similar WBSF values compared to those that were not implanted (Faulkner et al., 1989; Cranwell et al., 1996b). Feeding steers' zilpaterol for 45 d until 48 h before harvest resulted in lower sensory tenderness, juiciness ratings and WBSF values for the longissimus muscle (Beermann, 2004). Shear force values were increased in steers fed zilpaterol and ractopamine when compared to steers that

were fed grain only (Avendano-Reyes et al., 2006). Implanting fed cows is believed to have minimal influence on tenderness; however the influence of feeding zilpaterol to fed cows is unknown.

Feeding cull cows high energy diets in combination with implants and feeding β-agonist may improve production efficiency. Young animals that are fed β-agonist have larger ribeye areas, increased dressing percentages and increased lean meat yields. However, their use alone or in combination with an aggressive implant is not well documented in cull cows. Therefore, a study was designed to determine the influence of implanting and the newly approved β-adrenergic agonist, zilpaterol, on performance and lean meat yields of fed cull cows and its effect on meat quality, palatability and shelf-life stability.

Postmortem Enhancement

Tenderness of beef is a major concern to most consumers as it is a primary determinant of their overall eating experience. Beef tenderness has been reported as the most important factor affecting consumer satisfaction for beef palatability (Dikeman, 1987; Savell et al., 1987, 1989; Smith et al., 1987). Consumers were able to differentiate levels of tenderness of top loin steaks and were willing to pay a premium for improved tenderness (Boleman et al., 1997). However, the National Beef Tenderness Survey conducted in 1990 reported that there were numerous problems with beef tenderness (Morgan et al., 1991).

Beef carcass maturity and tenderness are inversely related (Beridenstein et al., 1968; Cross et al., 1973). Compared to carcasses from young cattle, those with E and E+ maturity were less tender (Berry et al., 1974). Meat from older animals is tougher than meat from younger animals (Bouton et al., 1978). The decreased tenderness is linked to the formation of heat stable cross-linking in mature animal collagen (Cross et al., 1973). Meat from mature cows also tends to be drier and often has a mealy residue upon first bite (Shorthose et al., 1990). Therefore, the meat from cull cows is generally less acceptable to most consumers.

There are several postmortem tenderization techniques that are commonly used to provide a consistently tender product to consumers. Some of these technologies

include aging, blade tenderization, and enhancement containing phosphates and sometimes enzyme tenderizers. Aging occurs with the breakdown of the muscle structural proteins by endogenous enzymes termed calpains (Devine, 2004). Aging is generally accepted to improve WBSF values and meat tenderness (Miller et al., 1997). Multiple studies have indicated that blade tenderized meat has improved WBSF values than untreated muscles (Glover et al., 1975; Goldner and Madigo, 1974). The injection of beef strip loins with a phosphate/lactate/chloride solution improved WBSF values compared to controls injected with water only (Vote et al., 2000). The use of these postmortem tenderization methods have been proven to provide tender meat products. However, some of these methods such as aging increase the cost of the product and require increased storage space for the required aging times. It is uncertain if extended aging periods are needed to improve tenderness if a combination of these postmortem technologies is incorporated.

There are several postmortem tenderization techniques such as aging, blade tenderization and injection enhancement commonly used to ensure a tender product to the end consumer. However, the impact of these techniques to improve tenderness of meat from cull cows is not documented. Therefore, a study was designed to determine the effects of 7 or 28 d of aging and blade tenderization in combination with injection enhancement on tenderness of longissimus muscle from fed cows and steers. A second objective was to determine if aging for 28 d instead of 7 d is necessary to achieve optimal tenderness when blade tenderization and injection enhancement are used on several muscles from fed cows and steers.

CHAPTER 2 - REVIEW OF LITERATURE

Feeding

Performance:

The gain and efficiency of thin mature beef cows can often equal the performance of young growing cattle. When feeding cull cows the most rapid gains are usually noted during the first weeks of feeding. Feed efficiency (gain to feed) decreased with time on feed for cull cows fed 112 d (Graham and Price, 1982). These researchers noted greater gains in the first 8 weeks of the study compared to the following 8 weeks. In another trial Graham and Price (1982) noted that young cows (3 to 4 years of age) had higher ADG than mature cows (6 years of age or older). Cull cows with thin to moderate initial body condition scores (**BCS**) had increased live weights and average daily gains through the first 28 d of feeding, but were not significantly increased from 28 to 56 d on feed (Schnell et al., 1997). Greater weight gains and efficiency were achieved when cows were fed either 80% versus 40% concentrate or 40% versus 22% concentrate diets (Swingle et al., 1979). However, in this experiment no differences were noted in ADG. Performance of cull-cows is generally improved when they are placed on high-energy diets.

Lean Meat Yields:

Carcass weights and boneless forequarter and hindquarter weights were increased by feeding cull cows (Matulis et al., 1987). They reported that cows fed for 56 d or longer had higher marbling scores, quality grades, and percentage of kidney, pelvic, and heart fat (KPH). Feeding cows a high energy diet for 84 d compared to 42 d increased lean muscle mass and carcass fat (Faulkner et al., 1989). As days on concentrate diet were increased the hot carcass weights and carcass soft tissue weights of cull cows were increased (Cranwell et al., 1996a). Dressing percentages, marbling scores and longissimus dorsi areas were increased as a partial result of increased cow BCS (Apple et al., 1999). Consequently, carcass value increased

significantly. Carcass soft tissue weights of cull cows were increased from 42 to 84 d on feed (Faulkner et al., 1989). Boneless carcass weights were increased by feeding cull cows a high-energy diet 38 to 108 d (Wooten et al., 1979). These increases were found in the entire carcass, with highest weight increases in the plate, rib, loin, and flank. Cows that were fed for 28 d had increased weights of fat free lean compared to those that were fed for 0 or 14-d (Schnell et al., 1997). Cull cows with initial BCS of thin to moderate had increased carcass weights and dressing percentages through the first 28 d on feed, but were not increased from 28 to 56 d on feed (Schnell et al., 1997). Swingle et al. (1979) found that cows fed the 80% concentrate diet had heavier carcasses compared to those fed a 40% concentrate diet. Feeding thin cull cows high-energy diets can increase BCS and in turn increase muscle weights. These high-energy diets will increase total meat yields of cull cows, but may decrease the percentage of lean compared to fat.

Meat Quality:

Beef carcass maturity and tenderness are inversely related (Beridenstein et al., 1968; Cross et al., 1973). Compared to carcasses from young cattle, those with E and E+ maturity were less tender (Berry et al., 1974). Meat from older animals is known to be tougher than meat from younger animals (Bouton et al., 1978). Meat from cows also tends to be drier and often has a mealy residue upon first bite (Shorthose et al., 1990). Therefore, the meat from cull cows may be less acceptable to consumers.

Feeding aged cows a high concentrate diet can improve muscle tenderness. Warner-Bratzler shear force (WBSF) values of longissimus dorsi steaks from cull cows were decreased significantly (more tender) when cows were fed for 84 d compared to those only fed for 28 d (Matulis et al., 1987). Sensory panel scores revealed that realimentated cows had more tender *gluteus medius* and *biceps femoris* muscles (Dryden et al., 1979). When compared to forage-fed cows, longissimus dorsi steaks from grain-fed cows had lower WBSF values (Cranwell et al., 1996b). Faulkner et al., (1989), showed an improvement in sensory traits at 42 d on feed, but no other improvements were observed for additional days (84 d) on feed. Feeding cull cows concentrate diets can improve tenderness of several subprimal cuts.

Approximately 2% of skeletal muscle is composed of collagen (Bendall, 1967). Tenderness decreases with the formation of heat stable cross-linking collagen in more mature animals (Cross et al., 1973). As animals mature the amount of collagen-cross linking present tends to increase. Collagen is generally stabilized as animals mature to an insoluble, heat-resistant form. This results in a decrease in the amount of heat-liable collagen that may be solubilized during cooking (Hill, 1966; Bailey, 1972). As reported by Light et al. (1985) tenderness is influenced by the quantity of heat-stable collagen cross-linking. They also reported that greater amounts of these cross-links are present in tougher muscles. However, feeding cows increases the amount of heat-liable cross-links that are present, in turn allowing for a product that is less tough (Aberle et al., 1981). They reported that feeding cattle high-energy diets results in rapid rates of protein synthesis. Cows fed a high-energy diet compared to those fed a maintenance diet prior to harvest had increased percentage of heat-liable collagen, less sensory panel detectable connective tissue, and lower shear force values (Miller et al., 1987). Therefore, these animals would be expected to have a higher portion of newly synthesized heat-liable collagen present.

Animal age can potentially affect color stability. Shemeis et al. (1994) evaluated meat quality traits of Danish Friesian cull cows based on age and body condition score. While fat color darkened and became more yellow with age, minor changes in muscle color (M. longissimus dorsi steaks) were observed. Cull beef cows fed for 56 d compared to those fed for 28 d had improved longissimus muscle visual lean color, texture, and firmness (Cranwell et al., 1996b). Schnell et al. (1997) found improved (whiter) external fat color of cull cows fed for 28-56 d. Feeding a high concentrate diet to cull cows resulted in a brighter cherry red meat color when compared to those that were not fed (Price and Berg, 1981). Feeding cull-cows concentrate diets before harvest can improve lean and fat color characteristics.

Feeding cows for 28 and 42 d numerically increased marbling scores compared to those fed for 0 or 14 d on feed (Schnell et al., 1997). Fed cows had increased marbling scores compared to non-fed cows and the greatest increases were noted for cows fed for longer periods of time 56 and 87 d (Wooten et al., 1979). Therefore, cows can gain marbling scores, and it is likely to be a result of increased days on feed.

Utilization of concentrate feeding in cull-cows can increase meat quantity and improve meat quality. Feeding high-concentrate diets to cull-cows can improve weight gains, fat color, lean meat yields and meat quality including color and shelf-life stability. Mature thin cull cows can have early live weight gains that are very impressive due to realimentation of their bodies. To improve carcass value it is important to feed cows long enough to improve the white color of external fat. In most studies approximately 56 d of feeding was sufficient to achieve white external fat. Feeding cull cows will also decrease the WBSF, improving tenderness. This increase in tenderness is usually attributed to increases in muscle mass and the amount of soluble collagen present allowing for the dilution of the heat-stable collage present in the muscles (Miller et al., 1983). These increases in total meat yields and meat quality associated with feeding cull cows can improve the acceptability of cow meat and potential for increased cull cow value.

Steroid Implants

Mode of Action:

Steroid hormones have two proposed modes of action in muscle cells (Heitzman, 1981). The first occurs by direct entry into the muscle cells and affect protein synthesis and degradation (Lawrence and Fowler, 1997). The second is initiated by an indirect effect, by entry into other endocrine organs (the hypothalamus, the gonads, the pancreas or the thyroid) resulting in synthesis, metabolism, or secretion of other hormones which can exert an anabolic effect in muscle and also affect intermediary metabolism in other tissues including the liver and adipose tissues, (Lawrence and Fowler, 1997). Steroid implants stimulate proliferation of skeletal muscle satellite cells (Johnson et al., 1998). In the postnatal animal satellite cells are necessary for muscle growth (Moss and Leblond, 1970). These researchers noted that the nuclei within the muscle fiber are not capable of DNA synthesis. In addition, in order for hypertrophy to occur, satellite cells must be present as a source of DNA, it has been estimated that 60-90% of the total DNA in mature muscle fibers is from satellite cells (Allen et al., 1979). Steroid implants have also been noted to increase the amount of circulating insulin-like growth factor- I (Frey et al., 1995). Insulin-like growth factor-I is necessary for cell

proliferation. Utilization of implants results in an increase in muscle protein synthesis and decrease in protein degradation. Implants increase muscle fiber size through increased DNA synthesis.

Performance:

Implanting cull cows with anabolic steroids is a management practice available to cattle producers. Matulis et al. (1987) found Angus and Hereford cull cows implanted with Synovex-H and fed a high-energy diet for 56 or 84 d had similar ADG and feed efficiency compared to the non-implanted fed controls. In agreement, Price and Makarechian (1982) reported that mature cull cows implanted with 0, 36 or 72 mg of zeranol (Ralgro®) and fed for 75 d did not have increased growth rates. In contrast, cows that were grazing fescue and implanted with zeranol had 11.2% increases in weight gains during a 59 d feeding period than cows that were not implanted (Corah et al., 1980). Similarly, cull cows implanted with zeranol and grazing pasture or native range had increased gains of 10.3% in one trial and 17.1% in a second trail (Staigmiller and Brownson, 1984). Waggoner and Applegate (1984) found implanting fed cull cows with zeranol increased performance. Cows implanted with trenbolone acetate, testosterone propionate + estradiol (TBE), and a combination of TBA + TBE had increased weight gain and improved feed efficiency, and heavier final weights compared to cows fed grain only during realimentation (Cranwell et al., 1996a). Cows implanted with Revalor-200® had increased average daily gains compared to non-implanted cows during a 60-d feeding period (Harborth, 2006). Some studies reported no differences in cow performance with the use of steroid implants and other studies reported on average a 10% increase in gain with their use. However, aggressive implants and grain feeding result in increased performance. Therefore, the use of more aggressive steroid implants in cull-cow feeding systems is needed to improve weight gains.

Lean Meat Yields:

Implants have been shown to increase meat yields in cull cow realimentation programs (Simms, 1997; Matulis et al., 1987). Cows implanted with Finaplix-H, and Synovex-H had increased dressing percents and ribeye areas after 56 d of feeding than cows fed for 28 d (Cranwell et al., 1996a). Carcasses from cows implanted with zeranol

had larger longissimus muscle areas, higher dressing percentages, and higher yield grade values than non-implanted cows (Waggoner and Applegate, 1984). In contrast, Faulkner et al. (1989) reported that the only change due to implanting with testosterone was an increase in percentage of kidney, pelvic, and heart fat of carcasses from implanted cows. However, carcass soft tissue was increased with the use of TBA + TBE compared to grain feeding alone or those cows implanted with TBA alone (Cranwell et al., 1996a). Cows that were implanted had heavier hot carcass weights, leaner carcass soft tissue, and more kilograms of total lean than non-implanted cows (Cranwell et al., 1996a). In contrast, Price and Makarechain (1982), reported mature cull cows implanted with zeranol (either 36 or 72 mg) had similar carcass weights, dressing percentages, average fat thickness, and longissimus muscle areas than non-implanted cows. Harborth (2006) reported that cows implanted with Revalor-200® tended to have heavier hot carcass weights and dressing percentages than non-implanted controls. These implanted cows also tended to have increased longissimus muscle areas compared to the non-implanted cows (Harborth, 2006). In young fed animals, meat yields are commonly increased with implanting. Johnson et al. (1996) reported that steers implanted with trenbolone acetate and estradiol had more carcass protein on d 40 of feeding than non-implanted controls. Heifers that received a trenbolone acetate + estradiol implant had heavier carcasses than those that did not receive the implant (Kreikemeier and Mader, 2004). Johnson et al. (1996) reported that longissimus muscle area was increased in carcasses of animals that were implanted compared to those that were not implanted. The use of multiple implants during a steer's life did not significantly increase hot carcass weights compared to those that were not given multiple implants (Platter et al., 2003). The use of one trenbolone acetate + estradiol implant compared to two implants resulted in an additional 0.08 kg of hot carcass weight (Schneider et al., 2007). Lean meat yields of cull-cows can be increased with the use of aggressive steroid implants.

Meat Quality:

A study utilizing implants (Finaplix-H®, Synovex-H®) in cull cows by Cranwell et al. 1996a, did not improve marbling, fat color, or tenderness of cows fed for 56 d compared to 28 d. However, it is likely that this could be due to the cows only being fed

for 56 d. The cows that were implanted with TBA tended to have lower shear force values than cows implanted with TBA + TBE, TBE, and controls (Cranwell, 1996b). Testosterone administration in cows did not influence the WBSF values, but trained sensory panelists found steaks from implanted cows to have more acceptable tenderness than those that were not implanted (Faulkner et al., 1989). In young animals implanting studies have had variable results on tenderness. Pritchard et al. (2000) reported steers that received a trenbolone acetate implant and at re-implantation received trenbolone acetate had increased shear force compared to those not implanted. While Kerth et al. (2003) noted that heifers that were implanted with trenbolone acetate and not re-implanted had lower shear force values than controls (no implant). However, an increase in shear force was noted by Nichols et al. (1996) when trenbolone acetate only was used in heifers. Kerth et al. (2003) noted no significant increases in tenderness with the use of implants. The results vary in young animals, but when steroid implants are utilized in cull-cow realimentation trials meat quality is typically not compromised.

The use of steroid implants in cull cows promotes increased weight gains and lean meat yields. When these growth promotants are used in realimentated cull-cow feeding systems they increase ribeye areas, dressing percentages and carcass soft tissue weights which all lead to increased total lean meat yields. Therefore, it is beneficial to use steroid implants in cull cow feeding programs to increase weights and ultimately lean muscle mass.

Beta Agonists

Mode of Action:

Beta-agonists belong to a class of compounds known as phenethanolamines (Mersmann and Smith, 2004). These compounds are referred to as repartioning agents. They redirect nutrients used for growth toward increased rates of muscle protein synthesis, away from adipose tissue deposition resulting in larger muscles (Mersmann, 1998). Beta-agonists are orally-active compounds, added in the diet of animals in production settings. These compounds are typically added to the animal diets during the last phase of finishing and depending on the class of β-agonists, are fed

for 28-42 d prior to harvest. Beta-agonists act through β-adrenergic receptors on adipocytes and indirectly lead to decreased fat synthesis, decreased fat storage, and increased mobilization and hydrolysis of fat (Mersmann, 1998). When the β-adrenergic agonist binds to its receptor, the G_s protein is activated allowing the following series of events to occur: adenylyl cyclase is activated in order to produce cyclic adenosine monophosphate (cAMP), and cAMP in turn activates protein kinase A to stimulate enzyme phosphorylation that leads to metabolic modifications (Mersmann, 1998).

It has been shown that β-agonists increase muscle through increased protein synthesis and decreased protein degradation (Mersmann, 1998). Ractopamine fed to pigs increased the rate of fractional protein synthesis (Bergen et al., 1989). An increase in mRNA abundance of muscle-specific proteins is related to the increased muscle hypertrophy, potentially through alterations in protein synthesis (Johnson, 2004). Clenbuterol fed steers had increased myosin light-chain mRNA compared to control steers (Smith et al., 1995). The β_2-agonist L-644,969 caused a 27% decrease in rate of fractional protein degradation in treated steers compared to those fed grain only (Wheeler and Koohmaraie, 1992).

There are two commercially available β-agonists: Ractopamine-HCl (Optaflexx™) a β_1-agonist and Zilpaterol-HCl (Zilmax®) a β_2-agonist. Ractopamine has been reported to preferentially bind to β_1-adrenergic receptors (Moody et al., 2000). According to Mills and Mersman (1995), muscle promoting β-agonists have been classified as β_2 selective. β_2-aderenergic agonist receptors are the most abundant receptor subtype in beef skeletal muscle (Sillence and Matthews, 1994). β_2-agonists act more commonly on skeletal muscle receptors to increase muscle mass, while β_1-agonists act to increase lypolysis and decrease lipogenesis (Hausman et al., 1987). The use of zilpaterol, a β_2-agonist, was approved for use in the United States in 2006.

Performance:

In a study by Plascencia et al. (1999), the use of zilpaterol in feedlot steers increased live weight (5.5%). Steers fed zilpaterol had a 26% improvement in ADG compared to those fed ractopamine or grain only (Avendano-Reyes et al., 2006). Steers fed ractopamine had greater average daily gains and gain:feed values than control steers (Schroeder et al., 2003a). Schroeder et al. (2003b) reported that heifers

fed ractopamine had heavier final weights, greater average daily gains and greater gain to feed than non-ractopamine fed heifers. Harborth (2006) noted that cull cows fed ractopamine tended to have greater overall gains, but these gains were not significant. No significant increases were noted for average daily gain or gain to feed for cows fed ractopamine (Harborth, 2006). Feeding ractopamine to heifers resulted in increased average daily gains (Walker et al., 2006). However, using a β_2-adrenergic agonist such as zilpaterol should show more dramatic increases in weight gains, due to the greater known amount of β_2 receptors present in beef animals. When β-agonists are fed to cattle there is an increase in live weight gains.

Lean Meat Yields:

Feeding zilpaterol to steers increased carcass weight (4.8%), dressing percentage (2.2 percentage points) and ribeye area (2.7%) (Plascencia et al., 1999). When added to finishing diets zilpaterol improves carcass and muscle yields of finishing cattle (Beermann, 2004). Ractopamine-HCl and aggressive implants (Revalor-200®) in cull cows (Harborth, 2006) resulted in no significant increases in hot carcass weights. However, the implanted and ractopamine fed cows had higher numerical hot carcass weights (Harborth, 2006). Cows fed ractopamine had a tendency to have greater longissimus muscle areas than cows that were not fed ractopamine (Harborth, 2006). Final live weights and hot carcass weights were greater for heifers fed ractopamine (Walker et al., 2006). In addition, these researchers noted that marbling scores and yield grades were not affected by feeding ractopamine to heifers. The use of β-agonist in feeding systems of young animals has lead to increased lean meat yields.

Meat Quality:

Zilpaterol had no negative impacts on meat quality when fed for up to 30 d in steers (Beermann, 2004). However, feeding zilpaterol for 45 d until 48 h before harvest resulted in lower sensory tenderness, juiciness ratings and WBSF values in the longissimus muscle (Beermann, 2004). Shear force values were increased by feeding zilpaterol and ractopamine compared to steers that were fed grain only (Avendano-Reyes et al., 2006). The use of zilpaterol in young bulls 30 d prior to harvest resulted in higher WBSF values than controls that were not fed zilpaterol (Strydom et al., 2007).

The color of beef from zilpaterol fed steers and steers fed grain only was similar (Avendano-Reyes et al., 2006). While color is not affected by the use of β-agonist it seems that tenderness may be compromised in some instances.

Few studies on the use of β-agonist in cull-cow feeding systems have been conducted. The use of ractopamine in cull-cow feeding systems did not affect performance or individual muscle weights. However, this may be a result of the actions of the β_1-agonist on fat receptors and less on receptors that increase muscle mass. From steer and heifer data, we would expect that feeding zilpaterol to cull cows could improve performance and increase carcass weight and ribeye area.

Aging

Color:

Aging of meat for longer periods may cause adverse color effects. Wicklund et al. (2005) reported that strip steaks from young crossbred animals aged for 14 d, according to visual panelist had a brighter more cherry red color compared to steaks aged for 21or 28 d. However, these steaks were not displayed to determine shelf-life stability. The initial color readings of steaks determined that 7 d aged steaks were lighter than those aged for 28 d (Wicklund et al., 2005). Young heifer meat aged for 21 to 28 d was noted to have a shorter shelf-life than meat that was aged for 7 d (O'Keefe and Hood, 1980-81). These decreases in color stability after longer storage periods may be a result of less metmyoglobin reducing activity (MRA) of the muscles. Ledward (1985) reported that a muscle's enzymatic reducing activity was the most important factor determining the amount of metmyoglobin that accumulates in a cut of meat. Potentially the muscles aged for 28 d would have less NAD present to aid in MRA, needed to allow meat to return to the oxymyoglobin state. Metmyoglobin reductase activity was numerically lower at 21 d of aging compared to 7 d of aging and NAD present was significantly lower for 21-d aged longissimus muscles compared to 7-d aged muscles (Madhavi and Carpenter, 1993).

Color of meat that is aged for longer periods of time is generally less color stable. This decrease in color stability is a result of less MRA activity in the aged muscles. Therefore, aging of meat is usually detrimental to product shelf-life.

Tenderness:

Tenderness of beef is a major concern to most consumers as it determines their overall eating experience. Beef tenderness has been reported as the most important factor affecting consumer satisfaction for beef palatability (Dikeman, 1987; Savell et al., 1987, 1989; Smith et al., 1987). Consumers were able to differentiate levels of tenderness of top loin steaks and were willing to pay a premium for improved tenderness (Boleman et al., 1997). The National Beef Tenderness Survey conducted in 1990 reported that there were numerous problems with beef tenderness (Morgan et al., 1991). Postmortem aging of muscles has been shown to improve muscle tenderness.

Aging of meat, a known method of tenderization, is used to ensure a tender acceptable product to the end consumer (Davey et al., 1967). Aging occurs with the breakdown of the muscle structural proteins by endogenous enzymes termed calpains (Devine, 2004). The process known as aging of meat has been used since the beginning of the 20th century. Aging in large industry operations is typically done after subprimal cuts have been removed from the carcass, vacuum packaged, and stored at temperatures above freezing.

Findings from the National Beef Tenderness Survey's of 1991 and 1998 have determined that beef is very variable in tenderness (Morgan et al., 1991; Brooks et al., 2000). According to the National Beef Tenderness Survey the average postmortem aging time in 1991 for various muscles was found to be 17 d (Morgan et al., 1991). While the average postmortem aging time for subprimals in 1998 was found to be 19 d (Brooks et al., 2000). Furthermore, aging times ranged from 2 to 61 d, with 34.1% of the subprimals aged for less than 14 d (Brooks et al., 2000). Steaks that were destined for foodservice had an average aging time of 32 d with a minimum of 20 d before fabrication to maximize tenderness (Brooks et al., 2000). Postmortem aging is among the most popular options for improving tenderness, but it also increases cost and introduces the risk of meat spoilage (Dransfield, 1994).

Aging strip loin steaks for 14 d improved WBSF values (Miller et al., 1997). While not significant, postmortem aging of 7, 14, 21 or 28 d numerically improved Warner-Bratzler shear force (WBSF) and sensory panel myofibrillar tenderness scores (Wheeler et al., 1990). Top sirloin butts aged for 21 d had lower WBSF values than

those only aged for 7 or 14 d (George-Evins et al., 2004). Loin steaks aged for 3, 7 or 14 d compared to those aged for 1 d had lower WBSF values (more tender) (Shackelford et al., 1991). Crouse and Koohmaraie (1990) reported lower WBSF values for 6 d of aging compared to 2 d of aging. In contrast, aging top sirloins for 35 d had no effect on Warner-Bratzler shear force values (Harris et al., 1992).

Aging of meat has been successfully used to improve tenderness for decades. Data supports decreased WBSF values of either steaks or muscles that have been aged for 7 or more days. Aging allows the structural proteins to be degraded by the calpain enzymes resulting in a more tender muscle.

Water Binding:

Steaks aged for 3 d versus those aged for 14 d had a higher percentage of thaw loss (Wheeler et al., 1999). Thawing loss was greater for gluteus medius steaks aged for 7 d than those aged for 21 d (George-Evins et al., 2004). This could potentially be due to the increased amount of purge already lost from muscles aged for 14 or 21 d. Cooking losses were decreased for steaks aged for 21 or 28 d compared to those aged 7 or 14 d (Wheeler et al., 1990). Davis et al. (1975) also, reported higher cooking losses for steaks aged for 4 d compared to those aged for 12 or 16 d. However, in disagreement with these authors, Shackelford et al. (1991) and Wheeler et al. (1999) reported no differences in cooking losses for steaks that were aged up to 14 d.

Data on water binding of steaks that are aged is variable. Most authors reported a decrease in cooking losses of product that was aged for longer periods of time. This seems valid, as the muscles that were aged for longer periods of time should have already lost more purge. Therefore, these muscles would have a lower amount of moisture present when cooking occurs than the muscles that were aged fewer days.

Sensory:

Aging, either dry or wet, has been noted to produce a product that has more flavor and is more tender compared to those that are not aged (Warren and Kastner, 1992; Campbell et al., 2001). Aging strip steaks for 14 d improved all sensory traits, but Choice grade steaks had higher sensory values than Select steaks (Miller et al., 1997). Sensory panel scores for flavor, tenderness and overall palatability of oven-broiled loin

steaks were optimal after 11 d of aging, and aging for more than 11 d did not result in significant increases in tenderness (Smith et al., 1978). Top sirloin steaks had no significant increase in overall tenderness until 28 d of aging, while top loin steaks had increased tenderness after only 7 d of aging (Harris et al., 1992). However, this would be expected as more connective tissue is found in top sirloin steaks than top loin steaks. Therefore, top sirloin steaks would require more time for postmortem proteolysis to allow for potential breakdown of the connective tissue present. Amounts of detectable connective tissue of longissimus steaks were significantly less for steaks aged for 21 or 28 d compared to those only aged for 7 or 14 d (Wheeler et al., 1990). No differences were found due to postmortem aging times of 7, 14, 21 or 28 d for sensory panel juiciness or flavor intensity (Wheeler et al., 1990).

Sensory panel tenderness is shown to increase in steaks that are aged compared to those that are not. Aging of steaks also decreases the amount of connective tissue detectable to sensory panelist. However, panelist found no differences for juiciness of aged steaks. Aging of most muscles or steaks will increase tenderness of the product. However, different muscles require different aging periods to allow connective tissue to break down.

Enzymes needed for MRA are utilized during aging, resulting in fewer present during display to allow MRA to work. Thus, aging meat for prolonged periods results in decreased color stability. Water binding is usually decreased with increased storage periods. Aging of meat has been shown to increase sensory panel tenderness and decrease WBSF values. Therefore, aged meat will be less color stable and more tender.

Enhancement

Blade Tenderization

Tenderness:

Numerous studies have indicated that blade tenderized meat has lower WBSF values than untreated muscles (Glover et al., 1975; Goldner and Madigo, 1974). The increase in tenderness observed with blade tenderized product is most likely due to the

action of the blades severing both the muscle fibers and connective tissue in the muscles (Parrish, 1977). Triceps brachii and psoas major muscles that were aged and blade tenderized resulted in lower numerical WBSF values (Lyon et al., 1983).

Blade tenderization of muscles is typically done to ensure a tender product to the end consumer. Blade tenderized longissimus dorsi muscles from cow and bulls were comparable in WBSF values to steer muscles that had not been blade tenderized (Tatum et al., 1978). Blade tenderization of longissimus dorsi steaks numerically increased tenderness (lower WBSF values) with each pass through the tenderizer (Tatum et al., 1978). The use of blade tenderization in cow biceps femoris muscles utilizing two passes through the blade tenderizer or of steer semimembranosus muscles passed through the tenderizer once yielded steaks that were significantly more tender than the cow biceps femoris and steer semimembranosus controls (no blade tenderization), respectively (Tatum et al., 1978; George-Evins et al., 2004). One pass through the blade tenderizer decreased the WBSF values of longissimus muscles, and with an additional pass, it was further decreased (Savell et a., 1977). This is in agreement with findings by Bowling et al. (1976), which indicated that repeated passes through the blade tenderizer further decreased WBSF values. Ribeyes from young bulls that were tenderized with one pass through the blade tenderizer had decreased WBSF values (Savell et al., 1982). However, the use of blade tenderization on aged psoas major muscles only numerically decreased WBSF values (Lyon et al., 1983). This is in agreement with Seideman et al. (1977) who observed no benefit in WBSF values for the psoas major with one pass through the blade tenderizer.

One pass through the blade tenderizer resulted in steaks that were more tender and had less detectable connective tissue as found by sensory panelist (Savell et al., 1977; Wheeler et al., 1990). However, Savell and others (1977) noted that these traits were improved with an additional pass through the blade tenderizer. In addition, similar sensory scores were found for overall palatability of strip steaks that had been blade tenderized either zero, one, or two times. Binder et al. (1985) reported similar findings, improvements in tenderness and connective tissue of blade tenderized muscles. Tenderness and overall desirability ratings were improved for blade tenderized and control strips (Medeiros et al., 1989). Top sirloin butts that were blade tenderized zero

or one time and aged 4 d were found to be similar in juiciness by sensory panelist (Savell et al., 1982). However, they found a decrease in juiciness for steaks tenderized one time and aged for 18 d compared to steaks not blade tenderized or control steaks that were aged for 4 or 18 d. Higher ratings were noted for myofibrillar tenderness, connective tissue, overall tenderness, and overall palatability scores for steaks that were blade tenderized one time and aged for either 4 or 18 d compared to those that were not blade tenderized and aged for 4 or 18 d (Savell et al., 1982). Seideman et al. (1977) reported higher connective tissue scores (less perceived connective tissue), compared to non-tenderized samples. In addition, they also noted increased tenderness scores of steaks blade tenderized one time and a further increase when tenderized two times. However, they found no further increase in tenderness with blade tenderizing three times compared to one or two times.

Inside round roasts blade tenderized one time had improved tenderness and amount of connective tissue (less connective tissue) compared to controls that were not blade tenderized (Loucks et al., 1984). In agreement, Medieros et al. (1989) reported increased tenderness scores of inside round steaks that were blade tenderized one time compared to untenderized controls. Glover et al. (1977) reported no differences in sensory panel scores for tenderness of inside round roast and steaks that were tenderized one time compared to non-tenderized controls.

It appears that the benefit of blade tenderization is very muscle specific. Blade tenderization has been shown to improve sensory scores for myofibrillar tenderness, connective tissue amount, and overall tenderness. Blade tenderizing inside round steaks and top sirloin butt steaks, can improve sensory scores for myofibrillar tenderness and connective tissue amounts. Many studies have indicated that additional improvement in tenderness results when muscles were passed through the blade tenderizer more than once. This is most often noted in muscles that are known to be tougher initially (such as the biceps femoris, inside round and top sirloin butt) have more dramatic increases in tenderness. This increase in tenderness can be partially attributed to the blades severing the connective tissue that is present. Therefore, to see the most benefit from blade tenderization, it should be performed on muscles that are known to be tougher (those that contain more connective tissue).

Water Binding:

Bullock chuck meat with one or two passes through the blade tenderizer did not affect the percentage of thaw loss (Rolan et al., 1988). Savell et al., (1977) found no effect on thaw loss percentage for strip loins that were blade tenderized. Using psoas major (Seideman et al., 1977), biceps femoris (Tatum et al., 1978), or inside rounds (Savell et al., 1978; Schwartz and Mandigo, 1977; and Tatum et al., 1978) researchers found no differences in thaw losses from blade tenderized compared to non-blade tenderized product. In contrast, Seideman et al. (1977) reported an increase in thaw loss for semitendinosus muscles that were passed through the blade tenderizer three times compared to control muscles that were not blade tenderized.

The use of blade tenderization on longissimus muscles resulted in increased cooking losses of steaks compared to those that were not blade tenderized (Wheeler et al., 1990). This is in agreement with Davis et al. (1975) who reported an increase in cooking loss when tenderizing with one pass through the blade tenderizer. Savell et al. (1977) reported an increase in cooking loss with three passes through the blade tenderizer compared to controls and those passed through only one or two times. In contrast, gluteus medius muscles tenderized with one pass through the blade tenderizer resulted in lower cooking losses (Savell et al., 1977). Others (Davis et al., 1977; Glover et al., 1977 and, Tatum et al., 1978) found, blade tenderization did not affect cooking losses. Savell et al. (1977) also, reported that the use of either one or two passes through the blade tenderizer did not affect drip or cooking losses of muscles. Roasts that were blade tenderized with one pass resulted in a higher percentage of drip loss, but no differences in cooking losses were found (Glover et al., 1977). Blade tenderization either with one or two passes through the tenderizer did not increase cooking loss percentage of bullock chuck meat (Rolan et al., 1988).

Mixed results have been reported for thaw and cooking loss percentages of muscles that have been blade tenderized. However, the type of muscle may determine how blade tenderization will affect these losses. The muscles that have greater amounts of connective tissue present for the blades to sever would result in less cooking losses. This is potentially a result of less damage to the muscle fibers in these muscles. In muscles such as the strip where there is less connective tissue present

higher cooking losses have been reported. This is likely the result of damage to the muscle fibers allowing for a more open muscle structure, which would allow more moisture to be released.

Juiciness:

One pass through the blade tenderizer resulted in steaks that were less juicy as found by sensory panelist (Savell et al., 1977; Wheeler et al., 1990). With one pass through the blade tenderizer juiciness of strip steaks was decreased (Binder et al., 1985). However, Savell and others (1977) noted that this trait was improved with an additional pass through the blade tenderizer. In disagreement, steaks from muscles that were blade tenderized resulted in no significant differences in sensory panel juiciness (Tatum et al., 1978). Glover et al. (1977) found similar results, reporting no differences in sensory panel scores for juiciness of blade tenderized steaks. Strip steaks tenderized one time compared to untenderized controls aged for either 4 or 18 d resulted in a decrease in juiciness (Savell et al., 1982). Seideman et al. (1977) reported higher juiciness scores in semitendinosus steaks tenderized up to three times compared to those tenderized zero or one time. Inside round roasts blade tenderized one time resulted in no differences in juiciness compared to controls that were not blade tenderized (Loucks et al., 1984). In agreement, Medieros et al. (1989) reported no change in juiciness of inside round steaks that were blade tenderized one time compared to untenderized controls. Glover et al. (1977) reported no differences in sensory panel scores for juiciness of inside round roast steaks that were tenderized one time compared to non-tenderized controls.

Mixed results for juiciness of blade tenderized meat have been noted. This is in agreement with increased cooking losses. The blades tend to sever both the connective tissue and the muscle fibers causing the muscle fibers ability to bind water to decrease. Therefore, blade tenderized product would seem to be less juicy as a result of increased moisture loss.

Beef Flavor:

There were no differences found in flavor intensity of blade tenderized steaks (Wheeler et al., 1990). This is in agreement with a study by Davis et al. (1977) that

reported no differences in flavor intensity with the use of blade tenderization. Glover et al. (1977) found similar results reporting no differences in sensory panel scores for beef flavor of blade tenderized steaks. In disagreement, Binder et al. (1985) reported a decrease in beef flavor of muscles passed through the blade tenderizer once. Similar beef flavor ratings were noted for blade tenderized and control strips (Medeiros et al., 1989). Savell et al. (1982) found no differences in beef flavor in blade tenderized or control samples aged either 4 or 18 d.

Inside round roasts blade tenderized one time had decreased beef flavor scores compared to controls that were not blade tenderized (Loucks et al., 1984). Mendieros et al. (1989) reported no change in flavor of steaks that were blade tenderized compared to non-blade tenderized steaks. Glover et al. (1977) reported no differences in sensory panel scores for beef flavor of inside round roast and steaks that were tenderized one time compared to non-tenderized controls.

While there are mixed results for beef flavor of blade tenderized muscles, in most studies there was no difference in beef flavor of blade tenderized muscles. Since there is no injection of brine into the muscles there should be no negative effects of beef flavor associated with blade tenderization.

When blade tenderization is utilized on muscles that are considered tougher it results in a more tender product. There have been mixed results for water-binding ability of blade tenderized muscles, but increased water-binding capacity seems to result from muscles with a higher amount of connective tissue present. In addition, the same type of trend is noted with juiciness. Beef-flavor of blade tenderized muscles is usually not compromised. Muscles that are blade tenderized are more tender, sometimes less juicy and have similar beef-flavor to non-blade tenderized muscles. Therefore, blade tenderization is an effective postmortem tenderization technology.

Injection

Mechanism of Injection Enhancement:

Injection enhancement of muscles with solutions containing some form of phosphate is a very common practice in industry today. While this practice has been in recent years more common in the pork industry, the use of injection enhancement has

become more popular in the beef industry. The use of injection allows for a more consistent and repeatable end product for consumers. Phosphates are used because of their ability to increase water binding capacity and to solubilize proteins in the meat (Romans et al., 2001). The USDA-FSIS (1999) regulates the amount of sodium tripolyphosphate present in the final product in fresh meat and poultry. The maximum phosphate allowed by the FSIS is 0.5%.

The addition of phosphates increases the pH of the meat. Increasing the meat pH improves water-holding capacity by moving the meat pH further from the meat protein isoelectric point (Miller, 1998). The addition of phosphate moves the pH of red meat further away from the isoelectric point allowing water-holding capacity to increase, due to the amount of negative charges on the meat protein that can bind water (Miller, 1998).

Tenderness:

Injection of beef strip loins with a phosphate/lactate/chloride solution improved WBSF values compared to controls injected with water only (Vote et al., 2000). Beef strip steaks that were aged and then injection enhanced also had lower WBSF values than non-enhanced controls (Wicklund et al., 2005). Similar results were found by Robbins et al. (2003) for enhanced compared to non-enhanced controls. In contrast, Baublits et al. (2006a) reported no decrease in WBSF values with the addition of phosphate. Beef triceps brachii muscles injected with tetrasodium phosphate and sodium chloride had lower WBSF values than controls or those injected with water only (Baublits et al., 2006b). The inclusion of phosphate decreased WBSF values (more tender) of the end product (Zheng et al., 2000). The inclusion of phosphate in the injection solution applied to beef round and pork roasts decreased the WBSF values compared to controls injected with water (Smith et al., 1984). No differences in WBSF values were found for injected pork loins compared to non-injected controls (Sutton et al., 1997).

The inclusion of calcium chloride in hot-boned semimembranosus muscles from mature cow's improved WBSF values compared to hot and cold-boned control cuts (Eilers et al., 1994). Enhancement with calcium chloride in longissimus,

semimembranosus, and triceps brachii reduced WBSF values compared to non-enhanced controls (Wheeler et al., 1993).

Beef strip loins injected with a solution containing phosphate/lactate/chloride were found to be more tender by sensory panelist compared to controls injected with water (Vote et al., 2000). Baublits et al. (2006a) found that enhancement of biceps femoris muscles regardless of phosphate type or concentration did not improve sensory panel tenderness compared to non-enhanced controls. However, they reported that enhancement at an 18% pump inclusion allowed for improved overall tenderness, compared to a 12% pump. Sensory overall tenderness and myofibrillar tenderness were increased while perceived connective tissue amounts were decreased with the inclusion of phosphate and salt in triceps brachii muscles compared to controls or those injected with water (Baublits et al., 2006b). Strip loins that were injected with an 8% pump were found by sensory panelist to be more tender compared to the non-enhanced controls (Wicklund et al., 2005).

While some data is conflicting on the effects of injection on WBSF values, in most studies WBSF was decreased with the inclusion of some type of phosphate and salt enhancement. However, it is important to let the product age for more than one day to see these increases in tenderness. In addition, sensory panelist normally found injected product to have increased myofibrillar tenderness and less connective tissue present. There are a number of studies that support the use of injection as it decreases WBSF values and increases sensory panel tenderness. Therefore, the use of injection in muscles is beneficial to increase tenderness.

Water Binding:

Steaks enhanced with 0.2% phosphate resulted in greater cooking losses than for the non-enhanced controls (Baublits et al., 2006a). However, the authors found that steaks enhanced with 0.4% phosphate had similar cooking losses to the non-enhanced controls. These authors also found that steaks pumped at 18% of weight had greater cooking losses than controls, while steaks pumped at 12% had similar cooking losses to controls. The inclusion of phosphate in restructured beef rolls increased the water binding ability (Trout and Schmidt, 1986). Beef strip steaks that were injection enhanced had lower cooking losses at 7 d than the non-enhanced control samples

(Wicklund et al., 2005). In agreement, lower cooking losses were reported for chops from enhanced pork loins than those from non-enhanced loins (Sutton et al., 1997; Prestat et al., 2002). When compared to controls enhanced with water only, pork loins injected with phosphate had reduced cooking losses (Cannon et al., 1993; Detienne and Wicker, 1999). Purge loss was lower for muscles that were pumped and stored for 2 d compared to those stored for 14 or 28 d (Baublits et al., 2006b). Steaks from phosphate enhanced muscles had lower cooking losses compared to those that were not injected or those injected with water only (Baublits et al., 2006b). However, Robbins and others (2002) reported higher cooking losses for phosphate-injected semimembranosus muscles compared to muscles that were not injected.

Differences in the amount of water-binding in the different studies are likely a result of the use of differing types and levels of phosphate and inclusion of salt. Generally when salt and phosphate were used in combination, the water binding ability of muscles was increased. Phosphates are used to increase the yields of products and to help to ensure satisfaction of the consumer, as these products are generally juicier. Therefore, the addition of phosphates generally increases the water-binding ability of meat.

Juiciness:

Beef strip loins injected with a solution containing phosphate/lactate/chloride were found juicier by sensory panelist compared to controls injected with water (Vote et al., 2000). Baublits et al. (2006a) found that enhancement of biceps femoris muscles regardless of phosphate type or concentration did not improve sensory panel juiciness compared to non-enhanced controls. Juiciness was increased with the inclusion of phosphate and salt in triceps brachii muscles compared to controls or those injected with water (Baublits et al., 2006b). Beef round and pork loin roasts injected with phosphate had increased juiciness compared to controls injected with water only (Smith et al., 1984). Strip loins that were injected with an 8% pump were found by sensory panelist to be juicier compared to the non-enhanced controls (Wicklund et al., 2005). Kerth et al. (1995) reported increased juiciness of strip loins that were injected with a calcium chloride solution.

In general, injection with a solution containing phosphate improves perceived sensory panel juiciness. This can be attributed to the increased amount of water in the product. Since the pH was lower allowing for more water to bind, the product would seem to be juicer, because of the increased amount of water in the meat. The inclusion of phosphates and salt increase product yields and this allows processors to sell more water and the consumer to have a juicier end product.

Flavor:

Trained sensory panelist found no change in grain/cowy flavor of phosphate injected beef top rounds (Papadopoulos et al., 1991a). However, panelist detected a metallic/sweet aroma from injected top rounds. Sensory panelist detected decreased beef flavor intensity compared to controls or water enhanced only triceps brachii muscles (Baublits et al., 2006b). However, Baublits and others (2005) reported no differences in beef flavor for steaks enhanced at varying salt and phosphate levels or non-enhanced biceps femoris muscles.

Strip loins injected with a solution containing phosphate/lactate/chloride were found to have more cooked beef flavor when evaluated by sensory panelist compared to controls injected with water (Vote et al., 2000). Phosphate-injected strip steaks were found to be saltier than their non-injected controls (Wicklund et al., 2005). Vote and others (2000) noted that sensory panelist found the inclusion of phosphate containing salt increased the saltiness of enhanced beef compared to steaks only enhanced with phosphate. The enhancement of pork loins with sodium containing salt solutions increased the saltiness in enhanced chops compared to non-enhanced controls (Prestat et al., 2002).

Injection enhancement solutions are associated with some off-flavors that are often found in the products. Although, some studies have found increased beef flavor with the inclusion of injection, this can probably be attributed to the amount of salt in the product, as most consumers would use some amount of salt during or after cooking beef. These consumers would attribute the increase in flavor as a result of the salt as beef flavor. However, some steaks that are injection enhanced are found to be saltier than their non-injected controls. This would be expected as most injection solutions contain 0.5% sodium chloride as well as the phosphate.

Injection with a salt phosphate solution results in decreases in WBSF values and increase in sensory panel myofibrillar tenderness. Water-binding capacity and juiciness of injected muscles are generally increased. However, beef-flavor is sometimes compromised in injected products. Products that are injection enhanced are found by sensory panelist to be more tender and juicier. Injection is a postmortem tenderization technology that can be successfully used to help create a more consistent end product to the consumer.

Enzyme Tenderization

Mechanisms of Enzyme Tenderization:

Dransfiled and Etherington (1981) noted that the most widely used enzymes to improve meat tenderness are plant enzymes, papain, bromelin and ficin. These researchers also noted that these plant enzymes along with microbial proteases derived from Aspergillus species, are approved by the United States Department of Agriculture (USDA) for meat tenderization. These enzymes are commonly used in the forms of marinades, injection in brine, pre-slaughter injection into the animal's vascular system, and they can be incorporated into various spices as meat tenderizers (Dransfield and Etherington, 1981). Enzymes have broad specificities and indiscriminately break down major muscle proteins including (connective tissue or collagen and myofibrillar proteins), sometimes resulting in an over tenderized mushy-textured product (Miller et al., 1989).

Tenderness:

Injection solutions containing bromelin or papain resulted in decreased WBSF values of semitendinosus compared to controls (McKeith et al., 1994). Beef deep pectoral muscles treated with increasing levels of either papain or bromelin resulted in lower WBSF values when cooked at a slow rate or at a fast rate (Fogle et al., 1982). For both papain and bromelin slow cooking required much lower activity levels than the fast cooking regimens (Fogle et al., 1982). The use of papain or Aspergillus protease resulted in reduced maximum shear force of briskets and top rounds (Ashie et al., 2002). These researchers noted that papain continued to increase tenderness of both the brisket and round as its dose was increased. They noted that at doses greater than

0.01 AU/100g of meat resulted in meat that was mushy and could no longer be cored, for shear force evaluation. The inclusion of pancreatin in a phosphate salt solution resulted in decreased shear values compared to control solutions and enzyme and water solutions (Janz et al., 2005). The use of papain, bromelin, and ficin in breast muscles from hens resulted in more tender meat than those that were blade tenderized (DeVitre and Cunningham, 1985). Sensory panelist found steaks that were blade tenderized and enzyme enhanced to be more tender than controls that were not blade tenderized or enhanced (Schallenberger et al., 1980).

Shear force values were lowest in spent hen meat when papain was injected intravenously 30 min prior to slaughter (Mendiratta and Panda, 1995). Tenderness was significantly decreased in beef treated with ficin heated to 55ºC compared to beef heated to 70ºC (Bock and Won, 1994). Strip loins and top rounds from mature cow carcasses that were enzyme dipped, blade tenderized and aged for 7 or 14 d were found to be more tender than steaks that were not aged and those that were not enzyme dipped or blade tenderized (Berry et al., 1979).

The use of enzymes in meat results in an increase in product tenderness. This is likely the result of the enzymes degradation of connective tissue and muscle enzymes that increase product tenderness. The use of enzymes at the proper level for the product will result in a dramatic increase in tenderness. However, if the enzyme is added at too high a rate it can result in some negative textural properties such as a mushy product.

Water Binding:

Percentage of bound water was greater for steaks treated with a solution containing papain (McKeith et al., 1994). When water alone was used in combination with pancreatin an enzyme used for cheese making, an excessive amount of drip loss was noted (Janz et al., 2005). The solutions containing phosphate and enzyme had improved moisture retention. This can be attributed to the increases in water binding that are associated with phosphate containing solutions. Cooking losses were found to be greater for hen muscles that were enzyme tenderized, but this increase could be attributed to the use of blade tenderization with these treatments (DeVitre and Cunningham, 1985).

The increase in water binding associated with the use of enzymes can partially be attributed to the other ingredients utilized in the injection solution. It is common to use enzymes with phosphates and salt which would increase the water binding ability of the meat. Therefore, the increase in water-binding associated with enzymes is likely a result of the other products used in the injection solution.

Flavor:

Papain treated steaks by either injection or dipping resulted in greater off-flavors detected by sensory panelist (McKeith et al., 1994). No significant differences were noted for flavor or overall acceptability of hen meat, with the inclusion of papain, bromelin, or ficin (DeVitre and Cunningham, 1985).

These differences in flavor can probably be attributed to the differences in perceived taste of beef and chicken. Enzymes are normally incorporated into a dipping or injection solution that contains phosphate and salt. Therefore, the off-flavors or lack there of may be a result of the other ingredients in the dipping or injection brines.

Enzyme tenderizers increase product tenderness. When enzymes are added to a solution containing phosphate and salt the water-binding ability increases. In addition, steaks treated with enzymes have not been reported to have detectable off-flavors. Therefore, enzymes can be used to increase product tenderness without causing detrimental sensory results.

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CHAPTER 3 - Effects of feeding zilpaterol on cull cow performance and lean meat yields

Shanna Hutchison

Department of Animal Sciences and Industry
Kansas State University
Manhattan, Kansas

ABSTRACT

Sixty cull cows were utilized to determine the effects of feeding zilpaterol and implanting Revalor-200® on performance, carcass characteristics and subprimal yields of cull cows fed for 70 d. Cows were assigned to one of the following five treatments: 1) grass-fed on pasture (**Grass**); 2) concentrate-fed (**C**); 3) concentrate-fed and implanted (**CI**) with Revalor-200®; 4) concentrate-fed and fed zilpaterol beginning on d 38 of the feeding period (**CZ**); and 5) concentrate-fed, implanted and fed zilpaterol beginning on d 38 (**CIZ**). Cows in the CIZ treatment appeared to have the highest and grass fed the lowest numerical gains for the final 34 d and total feeding period. Ultrasound muscle depth gains for the first 36 d on feed were greater ($P < 0.05$) for the implanted cows (CI and CIZ) compared to C and grass-fed cows. In addition, hot carcass weights were heavier ($P < 0.05$) for the concentrate-fed (C, CI, CZ, and CIZ) cows than the grass-fed cows. Longissimus muscle area (**LMA**) was largest ($P < 0.05$) for CIZ cows and smallest for the grass-fed cows. Total subprimal weights from the chuck were heavier ($P < 0.05$) for CIZ cows compared to C and grass-fed cows, and CI and CZ cows had ($P < 0.05$) heavier chuck subprimal weights than grass-fed cows. Rib and round subprimal weights were higher ($P < 0.05$) for the concentrate-fed (CI, CIZ, CZ, and C) cows compared the grass-fed cows. Grass-fed cows had ($P < 0.05$) fewer kg of total subprimals and a lower percentage of total subprimals than the concentrate-fed cows. In addition, CIZ cows had ($P < 0.05$) heavier total subprimal weights and a greater percentage of total subprimals than those for C cows. Rib cut-out and total soft tissue weights from the 9-10-11 rib were lighter ($P < 0.05$) for the cows on grass than concentrate-fed cows. Feeding cull cows a concentrate diet improved carcass weight, dressing percentages, and subprimal yield compared to feeding cows a grass-based pasture diet. When feeding cows a concentrate diet, a combination of an implant and feeding zilpaterol can maximize lean meat yield as indicated by LMA and subprimal yields.

Key Words: Cows, Performance, β-agonists, Carcass Subprimal Yields

INTRODUCTION

Cows are culled for various reasons such as reproduction inefficiency and poor performance; and these cows are typically sold in poor condition. Yager et al. (1980) reported that cull cows contribute 15-25% of the producer's revenue. The National Market Cow and Bull Beef Quality Audit of 1999 reported that there are challenges associated with cull cows (Roeber et al., 2001). Among the challenges noted were dressing percentage and carcass leanness. An increase in lean tissue and lean quality of aged cows could increase their value. In 1999, producers could have recovered $27.50 by monitoring health and condition and $27.50 by marketing cows in a timely manner (Roeber et al., 2001). Feeding cull cows a high energy diet for 50 to 70 days can improve performance and carcass characteristics (Price and Berg, 1981; Matulis et al., 1987; Cranwell et al, 1996a; Schnell et al, 1997). In addition, growth implants have been shown to increase feed efficiency, average daily gains and lean meat yields of aged cows. Researchers (Simms, 1997; Cranwell et al., 1996ab; Matulis et al., 1987) reported an increase in rate of gain, feed efficiency, and lean meat yields in cull cow realimentation programs that utilized growth implants. In addition, β-agonists that are commercially available for use when feeding cattle are Ractopamine-HCl (Optaflexx™), primarily a β_1-agonist; and Zilpaterol-HCL (Zilmax®), primarily a β_2-agonist (Mersmann, 1998). Ractopamine and zilpaterol have been found to increase muscle growth. Zilpaterol improves carcass and muscle yields when fed to finishing cattle (Beermann, 2004). In a study by Plascencia et al. (1999), feedlot steers fed zilpaterol had increased live weights (5.5%), carcass weights (4.8%), dressing percentages (2.2 percentage points) and ribeye areas (2.7%). Cows fed ractopamine-HCl and implanted with Revalor-200® (Harborth, 2006) had no differences in carcass weights. However, few studies have been investigated the use of zilpaterol, a β_2-agonists in cull cows.

Implants and β-agonists impact growth primarily through two separate pathways. Implants increase growth hormones such as IGF-I, while β-agonists influence the cyclic adenosine monophosphate pathway. However, Johnson (2004) has shown that implants may elicit a response through receptors that use secondary messenger systems similar to those of β-agonists. Potentially a synergistic effect of implants and β-agonists could

allow for further increases of compensatory lean tissue gain of cull beef cows. Therefore, the objective of this study was to determine the effects of feeding concentrate diets, an aggressive implant, feeding zilpaterol, and the combination of an aggressive implant and zilpaterol on performance, carcass traits, and subprimal lean meat yields of cull cows fed for 70 d.

MATERIALS AND METHODS

Animals

Sixty crossbred, mature cows were obtained from sale barns in Northwest Kansas; the Kansas State University Cow/Calf herd, Manhattan; and the Western Agriculture Research Station, Hays. Experimental procedures were approved by the Kansas State University Institutional Animal Care and Use Committee. Seven cows were removed from the study due to health, pregnancy, or sickness.

Treatments

Cows were stratified by weight and allotted to 70-d feeding period treatments consisting of: 1) grass-fed on pasture (**Grass**); 2) concentrate-fed (**C**); 3) concentrate-fed and implanted (**CI**) with Revalor-200® (Intervet, DE); 4) concentrate-fed and fed zilpaterol (Zilmax®, 106.25 mg/head/d; Intervet, DE) beginning on d 38 of the feeding period (**CZ**); and 5) concentrate-fed, implanted and fed zilpaterol beginning on d 38 (**CIZ**). The implanted cows were implanted on d 0 in the right ear with Revalor-200® (200 mg of trenbolone acetate and 20 mg of estradiol) per the manufacturer's instructions. Zilpaterol (Zilmax®, Intervet, DE) was fed for 30 d during the final 32 d of the feeding period only. Cows were removed from zilpaterol for the last 3 d prior to harvest in accordance with required withdrawal time.

Management

All cows were initially weighed and ultrasounded on d 0 of the feeding period. The 12 grass-fed cows were turned out on 20.2 ha of native Northwest Kansas grass pasture. Concentrate-fed cows were randomly allotted by treatment to pens of six animals resulting in two pens per treatment. Pen area was 18.4 m^2 per cow,

each cow had 0.5 m of bunk space, and every two pens shared a water tank. Cows were fed a concentrate diet containing silage and ground grain sorghum (Table 1). On d 14 cows were reweighed, ultrasounded, and treated with Dectomax® Pour–On (Pfizer, Inc., La Jolla, CA) to eliminate internal and external parasites. Ears of implanted cows were palpated to confirm implant retention. Initial weight, initial ultrasound measurements, and harvest-day dentition are reported in Table 2. All cows were again weighted and ultrasounded on d 36 and 70 of the feeding period. On the following day (d 71), cows were transported 210 km to a commercial abattoir and humanely harvested.

Carcass Data

Hot carcass weights (**HCW**) were recorded at harvest and all other carcass data were recorded after 48 h postmortem. Carcass data collected included longissimus muscle area (**LMA**); adjusted fat thickness; and percentage of kidney, pelvic, and heart fat. After a 30 min bloom period, marbling score (scale of 100 to 999: 300 = Slight ^{00}; 400 = Small^{00}; 500 = Modest^{00}); marbling texture (scale 1 to 3: 1 = coarse; 3 = fine); skeletal, lean and final maturity (scale of 100 to 599: 200 = B^{00}; 300 = C^{00}; 400 = D^{00}; 500 = E^{00}); lean color (scale 1 to 7: 1 = black; 4 = moderately dark red; 7 = very light cherry red); lean texture (scale 1 to 7: 1 = very coarse; 4 = slightly fine; 7 = very fine); lean firmness (scale 1 to 7: 1 = extremely soft; 4 = slightly soft; 7 = very firm) subjective fat color (scale of 1 to 5: 1 = bleached white, 5 = canary yellow); muscle score (scale 1 to 5: 1 = extremely light muscled; 3 = average muscled; 5 = extremely heavy muscled) and instrumental fat and longissimus muscle color were recorded. Instrumental readings were recorded using a MiniScan® XE Plus Spectrophotometer (45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminant A; Hunter Associates Laboratory, Reston, VA) to determine CIE L* (lightness), a* (redness), and b* (yellowness). Two measurements were taken and averaged to determine instrumental color values. A Meat Probes Incorporated (MPI) pH meter with glass probe electrode (Meat Probes Inc., Topeka, KS) was used to determine longissimus muscle pH. Two readings from each longissimus dorsi muscle from each side were recorded and averaged to determine sample pH.

Subprimal Fabrication/Processing

Boneless, closely-trimmed subprimals were removed from the left side of each carcass and weighed at approximately 72 h postmortem. Subprimal weights were taken for the beef rib, ribeye roll form an eight-rib wholesale rib (modification of NAMP # 112); chuck, shoulder clod (NAMP # 114); chuck, chuck roll (NAMP # 116A, PSO 1); chuck, chuck tender with all external skin removed (modification of NAMP # 116B); brisket, boneless, trimmed of fat (modification of NAMP # 120); round, knuckle, peeled (NAMP # 167A); round, top, cap off (NAMP # 169B); round, outside round (NAMP # 171B); round, eye of round (NAMP # 171C); loin, strip loin, boneless (NAMP # 180, PSO 1); loin, top sirloin butt, boneless trimmed to 0.635 cm fat (NAMP # 184); loin, bottom sirloin butt, tri-tip, boneless, trimmed practically free of fat (NAMP # 185D); loin, tenderloin, full, side muscle off trimmed free of fat (NAMP # 190); and flank, flank steak (NAMP # 193) (NAMP, 2007).

9–10–11 Rib Cut Out

At approximately 72 h postmortem, the procedure developed by Hankins and Howe (1946) was used to remove the 9-10-11 rib section from the right side of each carcass. All tissue was removed from the bones, and soft tissue and bone weights were taken for each 9-10-11 rib section. Rib soft tissue was vacuum packaged and transported to the Kansas State University Meat Laboratory for grinding. The soft tissue was coarse ground through a 0.953 cm plate, mixed thoroughly, and fine ground through a 0.138 cm plate. A 250 g sub sample of the fine-ground soft tissue was frozen at -80ºC until it was pulverized. Moisture and fat were determined on a pulverized sample using the CEM SMART (moisture, CEM Smart System 5; CEM Corporation; Matthews, NC) and SMART Trac (fat, CEM Smart Trac System Rapid Fat Analysis; CEM Corporation; Matthews, NC) systems (AOAC PVM – 1:2003; Keeton et al., 2003), crude protein (AOAC, 990.03), and ash (AOAC, 942.05) analysis.

Statistical Analysis

The data were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC). The model statement contained the respective response variable and treatment. Satterthwaite adjustments were used for

the degrees of freedom. Means were separated ($P < 0.05$) using the Least Significant Difference procedure when the respective F-test were significant ($P < 0.05$).

RESULTS

Performance Traits

Least square means for live animal performance are reported in Table 3-3. Implanted cows that were fed concentrate diets (CI and CIZ) had higher ($P < 0.05$) gains for the first 36 d on feed compared to cows fed C only. Although not significantly different, CIZ cows appeared to have the greatest body weight gains for the second 34 d when they were fed zilpaterol. For the entire feeding period, implanted cows (CI and CIZ) appeared to have the highest gains and grass-fed cows the lowest gains. No differences were reported ($P > 0.05$) for feed efficiency among the treatments.

There were no differences ($P > 0.05$) among treatments in ultrasound backfat or marbling score gains. Except for the CZ treatment and grass-fed cows, the largest numerical gains in backfat were noted during the last 34 d on feed compared to the first 36 d on feed. During the first 36 d on feed, CIZ, CZ, and CI cows had ($P < 0.05$) greater ultrasound muscle depth gains than the grass-fed cows. Although not significant, the cows fed zilpaterol (CIZ and CZ) appeared to have greater ultrasound muscle depth gains during the second 34-d of the feeding period when they were fed zilpaterol. For the entire feeding period, CIZ cows had greater ($P < 0.05$) ultrasound muscle depth gains than C and CI cows; and CZ cows tended to have greater ultrasound muscle depth gains than C ($P = 0.17$) and CI ($P = 0.28$) cows. During the entire feeding period all concentrate-fed cows had ($P < 0.05$) greater ultrasound muscle depth gains than the grass-fed cows.

Carcass Traits

Least square means for carcass traits are reported in Table 3-4. Hot carcass weights and dressing percentages were higher ($P < 0.05$) for all concentrate-fed cows than cows on grass. As a percentage of initial BW, CIZ cows had ($P < 0.05$) a greater percentage of initial BW than C and grass-fed cows. The other three concentrate-fed cow treatments (CI, CZ, and C) also had ($P < 0.05$) greater

percentage of initial BW as HCW than grass-fed cows. The CIZ cows had the largest ($P < 0.05$) LMA compared to the other treatment groups. The other concentrate-fed cows (CI, CZ and C) had larger ($P < 0.05$) LMA than cows on grass. Adjusted fat thickness, kidney pelvic and heart fat, and yield grade were not affected ($P > 0.05$) by treatments.

Least square means for marbling, carcass maturity, longissimus lean characteristics, fat color and longissimus pH are reported in Table 3-5. No differences ($P < 0.05$) were observed for carcass quality and color characteristics. Although not significant, longissimus muscle lean appeared darkest and coarsest textured (lowest scores) with the least marbling for the grass-fed treatment group. Also, fat color appeared slightly more yellow (higher score) for the grass-fed cows carcasses.

Subprimal Weights

Least square means for closely-trimmed subprimal weights are reported in Table 3-6. Total chuck subprimals from CIZ cows were heavier ($P < 0.05$) than those from C and grass-fed cows. In addition, total chuck subprimals from CI and CZ cows were heavier ($P < 0.05$) than total chuck subprimals from cows on grass. However, individual subprimal weights from chucks were similar ($P \geq 0.18$) among treatments.

Total weight for rib subprimals (ribeye roll) was heavier ($P < 0.05$) for all concentrate-fed cow groups compared to grass-fed cows. There were no differences ($P > 0.05$) noted for total loin weights among treatments. The tenderloin weights were heavier ($P < 0.05$) from all concentrate-fed cows than those from the grass-fed cows. However, no differences ($P \geq 0.21$) were noted in weights among treatments for the strip loin, top sirloin, or tri-tip.

Total round weights were greater ($P < 0.05$) from cows fed concentrates compared to total round weights from the grass-fed cows. This is partially attributed to the inside and outside round weights being greater ($P < 0.05$) for the concentrate-fed cows compared to the grass-fed cows. However, there were no differences ($P \geq 0.13$) in weights for the eye of round or knuckle among the treatments.

Flank weights were similar (P = 0.24) among the treatments. Brisket weights were heavier (P < 0.05) for the CIZ treatment compared to the C and grass-fed treatments. Weights of the brisket were also heavier (P < 0.05) from CI and CZ cows than the grass-fed cows.

Total subprimal cut weights were lighter (P < 0.05) for cuts from the grass-fed cows compared to the concentrate-fed cows. In addition, subprimal cut weights from CIZ cows were greater (P < 0.05) than those from C cows. When expressed as a percentage of initial BW, percentage of subprimals was less (P < 0.05) for cuts from grass-fed cows than the concentrate-fed cows. The percentage of subprimals from CIZ cows was (P < 0.05) greater than those from CZ and C cows; and CI cows had (P < 0.05) a greater percentage of subprimals than C cows.

Least square means for closely-trimmed subprimal weights as a percentage of HCW are reported in Table 3-7. Total subprimal weights from the chuck, expressed as a percentage of HCW were greater (P < 0.05) from CIZ cows than from C and grass-fed cows. In addition, percentages of chuck subprimals from CI and CZ cows were greater (P < 0.05) than total percentages from cows on grass. However, individual subprimal weights from chucks were similar (P ≥ 0.17) among treatments.

From the rib, the percentage of ribeye roll was lower (P < 0.05) from grass-fed than the concentrate-fed cows. In addition, the ribeye roll as a percentage of HCW was higher (P < 0.05) from CIZ cows than from C cows.

The loin subprimals from grass-fed cows had (P < 0.05) a lower percentage of tenderloin subprimals than the concentrate-fed groups. Also, CIZ cows had (P < 0.05) a higher percentage of tenderloin subprimals than C cows. No differences (P > 0.05) were noted in percentage of weights among treatments for the strip loin, top sirloin or tri-tip subprimals.

Total round subprimals as a percentage of HCW were greater (P < 0.05) from cows fed concentrate compared to grass-fed cows. Grass-fed cows had (P < 0.05) a lower percentage of inside and outside round subprimals than the concentrate-fed groups. In addition, the outside round was (P < 0.05) a greater percentage of HCW

for CIZ cows than C cows. There were no differences (P ≥ 0.14) in the percentage of the eye of round or knuckle among the treatments.

Flank subprimal weights as a percentage of HCW were not different (P = 0.64) among treatments. However, grass-fed cows had (P < 0.05) a lower percentage of brisket than CIZ, CI and CZ cows. Also, CIZ cows had (P < 0.05) a greater percentage of brisket than C cows.

Total subprimal weights as a percentage of HCW were greater (P < 0.05) for cows from the CIZ treatment compared to the C and grass-fed treatments. In addition, the other concentrate-fed (CI, CZ, and C) cows had greater (P < 0.05) total subprimal percentages than grass-fed cows.

9-10-11 Rib

Least square means for cow 9-10-11 rib cut-out weights and percentages are reported in Table 3-8. The weights of the whole 9-10-11 rib and soft tissue weight from the 9-10-11 rib from cows on grass were lower (P < 0.05) than from the concentrate-fed cows. However, 9-10-11 bone weight; and percentages of moisture, crude protein, total fat, and ash were similar (P ≥ 0.26) among all treatments.

DISCUSSION

The lack of significant differences noted in gains for the concentrate-fed cows versus the grass-fed cows for the overall feeding period is likely the result of inherent variation in cull cows and an extremely good pasture. Rain throughout the summer allowed for abundant grass pasture. Therefore, the cows on grass had an ample source of nutrients allowing them to gain weight during the trial. For the second 34 d on feed and entire feeding period concentrate-fed cows had numerically greater gains than grass-fed cows. In other studies, feeding cull cows a high energy diet for 50 to 70 days has shown improvements in performance and carcass characteristics (Price and Berg, 1981; Matulis et al., 1987; Cranwell et al, 1996a; Schnell et al, 1997).

In our study, the cows fed concentrate diets and were implanted (CI and CIZ cows) had greater gains than those fed concentrates and not implanted. In agreement, others (Cranwell et al., 1996a and Harborth, 2006) found cows implanted with aggressive implants had higher gains than non-implanted cows. Cranwell and others

(1996a) reported that cows implanted with trenbolone acetate (TBA), testosterone propionate + estradiol (TBE), or the combination of TBA + TBE had increased weight gains and improved feed efficiency. Harborth (2006) also reported increased average daily gains for cows implanted with Revalor-200® compared to non-implanted controls.

Feeding β-agonists has been shown to increase performance in young cattle. Steers fed zilpaterol had increased (5.5%) live weights compared to controls (Plascencia et al., 1999). Avendano-Reyes and others (2006) noted a 26% increase in ADG of steers fed zilpaterol compared to those fed ractopamine and those fed grain. Harborth (2006) noted that cows fed ractopamine tended to have higher overall gains. Similar to this study, weight gains of cows fed zilpaterol in our study were not found to be statistically different for the entire feeding period. While implanting appeared to improve gains, additional feeding of zilpaterol appeared to increase gains for the last 34 d of the feeding period. This gain was not observed for the cows fed zilpaterol and not implanted. Therefore, to realize the potential performance benefit of feeding zilpaterol, it may be necessary to first implant these cows.

Hot carcass weights, dressing percentages, LMA, 9-10-11 rib cut-out weight, and 9-10-11 soft tissue weight were greater for concentrate-fed cows compared to the grass-fed cows. In agreement, cows fed a grain diet for 63 d had increased hot carcass weights and longissimus muscle areas compared to cows that were not fed (Price and Berg 1981).

While not significant, implanted cows and cows fed zilpaterol in our study appeared to have heavier HCW and higher dressing percentages. In agreement, cows fed a concentrate diet for 56 d had higher dressing percentages than cows not fed and fed for 28 d (Cranwell et al., 1996a). Waggoner and Applegate (1984) reported that implanted cows had greater dressing percentages than cows that were not implanted. Harborth (2006) noted cows implanted with Revalor-200® had heavier hot carcass weights and increased dressing percentages than non-implanted cows. In agreement with our study, no statistical differences in hot carcass weights were reported for cows fed ractopamine and implanted with Revalor-200® implants (Harborth, 2006).

In this study, cows from the CIZ treatment had the largest and grass-fed cows the smallest LMA. Implanting alone had numerical increases in LMA compared to

concentrate-fed non-implanted cows. This trend was also observed by Cranwell et al. (1996a) and, Waggoner and Applegate (1984) reported that implanted cows had larger LMA than cows that were not implanted. The use of zilpaterol in steers resulted in a 2.7% increase in LMA (Plascencia et al., 1999). In contrast, cows that were fed ractopamine had a tendency to have larger LMA than cows that were not fed ractopamine (Harborth, 2006).

Subprimal weights and percentage of subprimals were numerically greater for the CIZ cows than the CI and CZ cows and statistically greater than the C and grass-fed cows. Although not significant Harborth (2006), found individual muscle weights for cows that were implanted and those that were fed ractopamine compared to non-implanted cows or those not fed ractopamine were increased. An increase in the size of type I fibers was evident in cows treated with ractopamine or trenbolone acetate (Gonzalez et al., 2007). This increase in fiber size may indicate that LMA and total muscle weights would be increased with the administration of implants and β-agonists.

In our study, implants and zilpaterol appeared to work synergistically to increase hot carcass weights, ribeye areas, and several subprimals weights. This could be partially due to implants stimulating quiescent satellite cells to begin proliferating again, resulting in an increased amount of DNA available to increase muscle hypertrophy when zilpaterol was administered. Steroid implants stimulate proliferation of skeletal muscle satellite cells (Johnson et al., 1998). In the postnatal animal satellite cells are necessary for muscle growth (Moss and Leblond, 1970). These researchers noted that the nuclei within the muscle fiber are not capable of DNA synthesis. In order for hypertrophy to occur, satellite cells must be present as a source of DNA. It has been estimated that 60-90% of the total DNA in mature muscle fibers is from satellite cells (Allen et al., 1979). Mersmann (1998) concluded that β-agonists redirect nutrients toward increased rates of muscle protein synthesis and away from adipose tissue deposition resulting in muscle accretion. Beta agonist work by binding to their receptors and signaling events that lead to increased protein synthesis and decreased protein degradation in the muscle. Therefore, as seen in this study, an implant may need to be administered first (d 0 of feeding period) to increase DNA synthesis prior to protein and muscle accumulation due to feeding zilpaterol.

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Table 3-1 Ingredient composition (%, DM) of experimental diets

Item	Diet
Ingredient	
Silage	19.7
Ground Sorghum	77.3
Protein/Mineral Supplement[1]	3.0

[1]Supplement formulated to deliver the following per/head/day: Soybean meal = 226.8 g; Trace mineral = 2.61 g; Vitamin A = 0.6504 g; Calcium = 10 g; Urea = 60 g; Salt = 25 g. Rumensin added at 0.3 g; Tylan® added at 0.09 g for cows on control diets and Zilmax® cows until Zilmax® was added in diet the last 30 d of the trial. Zilmax® was added at 0.10625 g.

Table 3-2 Live cow traits at the initiation of the 70 d feeding trial

	Treatment[1]					
Trait	CI	CIZ	CZ	C	Grass	SE
Number of Cows	10	9	10	12	11	
Body Weight, kg	508	507	519	523	515	18.9
Ultrasound Fat Thickness, mm	4.1	5.6	4.1	4.9	4.6	0.75
Ultrasound Muscle Depth, mm	53.8	52.4	52.6	50.9	53.9	2.63
Ultrasound Marbling Score[2]	4.4	4.4	4.8	5.2	5.3	0.33
Dentition[3]	4.0	6.4	4.7	6.0	6.6	1.28

[1]CI = fed concentrate and implanted with Revalor-200®; CIZ = fed concentrate, implanted with Revalor-200®, and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = fed concentrate; Grass = grazed native pasture.
[2]Marbling score: 4.0 = Slight[00]; 5.0 = Small[00], etc.
[3]Age was determined by visual dentition inspection at slaughter, number of permanent teeth.

Table 3-3 Live weight gain, ultrasound back fat gain, ultrasound marbling score gain data, and muscle depth gain for cows fed for 70 d

	Treatment[1]						
Trait	CI	CIZ	CZ	C	Grass	SE	P-value
Weight Gain							
Initial 36 d, kg	70.8[a]	56.5[ab]	50.1[bc]	40.9[c]	56.1[ab]	5.92	0.006
Second 34 d, kg	54.0	72.1	52.7	59.4	21.0	10.00	0.12
Total, kg	124.9	128.8	103.0	100.3	77.2	15.19	0.23
Feed Efficiency	8.2	8.1	8.2	8.3	---	0.19	0.97
Ultrasound Back Fat Gain							
Initial 36 d, mm	0.97	1.1	1.8	1.5	1.7	0.57	0.74
Second 34 d, mm	2.6	2.6	0.9	2.8	0.10	1.40	0.52
Overall, mm	3.6	3.7	2.7	4.3	1.8	1.58	0.76
Ultrasound Marbling Score Gain							
Initial 36 d[2]	-0.23	0.35	-0.12	-0.07	-0.23	0.338	0.71
Second 34 d	0.53	-0.15	0.41	0.14	0.23	0.268	0.40
Overall	0.30	0.20	0.29	0.08	-0.02	0.322	0.92
Ultrasound Muscle Depth Gain							
Initial 36 d, mm	2.7[a]	7.5[a]	5.2[a]	1.6[ab]	-5.4[b]	2.94	0.02
Second 34 d, mm	0.7	5.2	4.7	2.4	0.4	3.17	0.69
Overall, mm	3.4[b]	12.6[a]	9.9[ab]	3.9[b]	-5.0[c]	3.07	0.002

[1]CI = fed concentrate and implanted with Revalor-200®; CIZ = fed concentrate, implanted with Revalor-200®, and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = fed concentrate; Grass = grazed native pasture.

[2]Marbling score as determined by ultrasound, scores of 4.0 = Slight[00], 5.0 = Small[00].

[ab]Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 3-4 Carcass yield data for cows fed for 70 d

	Treatment[1]						
Trait	CI	CIZ	CZ	C	Grass	SE	P-value
Hot Carcass Weight, kg	376.7[a]	380.9[a]	371.7[a]	364.8[a]	315.9[b]	11.61	0.004
Dressing Percentage, %	59.6[a]	60.1[a]	59.8[a]	58.5[a]	52.6[b]	0.71	<0.001
HCW/Initial BW, %	74.3[ab]	75.4[a]	71.8[ab]	69.8[b]	61.6[c]	1.59	0.06
Longissimus Muscle Area, cm^2	92.0[b]	101.4[a]	87.5[b]	87.8[b]	73.3[c]	3.83	<0.001
Adjusted Fat Thickness, cm	0.92	1.03	0.95	1.07	0.68	0.152	0.33
Kidney Pelvic Heart Fat, %	1.5	1.6	1.5	1.5	1.3	0.09	0.15
Yield Grade	2.5	2.2	2.7	2.8	2.7	0.28	0.51
Muscle Score[2]	3.3	3.2	2.9	2.7	2.3	0.46	0.54

[1]CI = fed concentrate and implanted with Revalor-200®; CIZ = fed concentrate, implanted with Revalor-200®, and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = fed concentrate; Grass = grazed native pasture.
[2]Muscle Score 1-5: 1 = extremely light muscled; 3 = average muscled; 5 = extremely heavy muscled.
[abc]Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 3-5 Carcass quality and color characteristics for cows fed for 70 d

	Treatment[1]						
Trait	CI	CIZ	CZ	C	Grass	SE	P-value
Marbling Score[2]	435	414	459	426	354	39.2	0.42
Bone Maturity[3]	396	489	437	471	494	51.5	0.59
Lean Maturity[4]	196	235	188	183	266	34.1	0.39
Final Maturity[5]	340	414	367	390	419	38.5	0.51
Marbling Texture[6]	1.8	1.8	1.8	2.0	1.9	0.14	0.88
Lean Color[7]	5.9	5.2	6.1	6.1	4.9	0.63	0.47
Lean Texture[8]	4.9	4.8	5.2	5.3	4.4	0.33	0.22
Lean Firmness[9]	5.2	5.4	5.5	5.3	5.3	0.26	0.84
Fat Color[10]	2.0	2.4	2.0	2.3	2.8	0.28	0.34
Lean L*	39.3	39.9	38.1	38.8	38.7	0.93	0.64
Lean a*	29.0	30.4	29.7	30.8	29.9	0.89	0.56
Lean b*	19.5	21.1	20.5	21.4	20.9	0.94	0.51
Fat L*	74.4	74.0	74.4	74.2	74.0	0.77	0.99
Fat a*	16.7	16.5	17.6	17.0	17.1	0.81	0.88
Fat b*	23.8	24.6	25.7	25.1	25.6	1.27	0.74
pH	5.6	5.7	5.6	5.6	5.6	0.07	0.53

[1]CI = fed concentrate and implanted with Revalor-200®; CIZ = fed concentrate, implanted with Revalor-200®, and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = fed concentrate; Grass = grazed native pasture.
[2]Marbling score: 300 = Slight^{00}; 400 = Small^{00}, etc.
[3]Bone Maturity: 300 = C^{00}; 400 = D^{00}; 500 = E^{00}.
[4]Lean Maturity: 300 = C^{00}; 400 = D^{00}; 500 = E^{00}.
[5]Final Maturity: 300 = C^{00}; 400 = D^{00}; 500 = E^{00}.
[6]Marbling Texture: 1 = coarse; 3 = fine.
[7]Lean Color 1-7: 1 = black; 4 = moderately dark red; 7 = very light cherry red.
[8]Lean Texture 1-7: 1 = very coarse; 4 = slightly fine; 7 = very fine.
[9]Lean Firmness 1-7: 1 = extremely soft; 4 = slightly soft; 7 = very firm.
[10]Fat Color 1-5: 1 = bleached white; 3 = slightly yellow; 5 = canary yellow.

Table 3-6 Closely-trimmed subprimal weights per carcass side from cows fed for 70 d

	Treatment[1]						
Trait	CI	CIZ	CZ	C	Grass	SE	P-value
Chuck Subprimals, kg	16.0^{ab}	16.3^{a}	15.8^{ab}	14.6^{bc}	13.4^{c}	0.61	0.003
Shoulder Clod, kg	7.6	7.9	7.6	7.2	6.5	0.43	0.34
Chuck Tender, kg	1.1	1.1	1.0	0.98	0.92	0.06	0.27
Chuck Roll, kg	7.3	7.4	7.2	6.5	6.0	0.39	0.18
Ribeye Roll, kg	5.6^{a}	5.9^{a}	5.4^{a}	5.4^{a}	4.6^{b}	0.21	0.002
Loin Subprimals, kg	14.9	15.9	14.6	14.6	12.7	0.72	0.16
Tenderloin, kg	2.1^{a}	2.2^{a}	2.1^{a}	2.0^{a}	1.7^{b}	0.08	0.005
Strip Loin, kg	5.6	5.9	5.4	5.6	4.8	0.29	0.21
Top Sirloin, kg	6.6	6.9	6.4	6.5	5.6	0.38	0.26
Tri Tip, kg	0.67	0.79	0.70	0.65	0.48	0.08	0.24
Round Subprimals, kg	19.7^{a}	20.5^{a}	20.0^{a}	18.8^{a}	16.4^{b}	0.73	0.002
Knuckle, kg	4.1	3.9	4.2	4.1	3.5	0.32	0.58
Inside Round, kg	7.1^{a}	7.6^{a}	7.4^{a}	6.8^{a}	5.8^{b}	0.31	0.001
Outside Round, kg	5.9^{a}	6.3^{a}	5.9^{a}	5.6^{a}	4.9^{b}	0.23	0.002
Eye of Round, kg	2.6	2.8	2.5	2.3	2.0	0.16	0.13
Flank, kg	0.78	1.3	0.79	0.72	0.64	0.24	0.41
Brisket, kg	3.6^{ab}	3.9^{a}	3.4^{ab}	3.2^{bc}	2.5^{c}	0.16	0.01
Total Subprimals, kg	60.6^{ab}	63.7^{a}	60.1^{ab}	57.3^{b}	48.7^{c}	2.1	<0.001
% Initial Body Weight[2]	23.9^{ab}	25.3^{a}	23.3^{bc}	21.9^{c}	19.0^{d}	0.64	<0.001

[1]CI = fed concentrate and implanted with Revalor-200®; CIZ = fed concentrate, implanted with Revalor-200®, and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = fed concentrate; Grass = grazed native pasture.

[2]Percentage of initial body weight = total subprimal weight/(initial body weight/2)*100.

[abcd]Within a row, means without a common superscript letter differ (P < 0.05).

Table 3-7 Closely-trimmed subprimal weights as a percentage of hot carcass weight per carcass side from cows fed for 70 d

	Treatment[1]						
Trait	CI	CIZ	CZ	C	Grass	SE	P-value
Chuck Subprimals, %	8.1[ab]	8.2[a]	8.0[ab]	7.4[bc]	6.7[c]	0.31	0.003
Shoulder Clod, %	4.0	4.2	4.1	4.0	4.1	0.11	0.73
Chuck Tender, %	0.57	0.57	0.54	0.53	0.58	0.03	0.67
Chuck Roll, %	3.7	3.7	3.6	3.3	3.0	0.20	0.17
Ribeye Roll, %	2.8[ab]	3.0[a]	2.73[ab]	2.70[b]	2.3[c]	0.10	0.002
Loin Subprimals, %	7.9	8.3	7.9	8.0	8.0	0.32	0.79
Tenderloin, %	1.0[ab]	1.1[a]	1.0[ab]	0.98[b]	0.87[c]	0.04	0.006
Strip Loin, %	2.8	3.0	2.7	2.8	2.4	0.14	0.21
Top Sirloin, %	3.3	3.5	3.2	3.3	2.8	0.19	0.25
Tri Tip, %	0.34	0.40	0.35	0.33	0.24	0.04	0.24
Round Subprimals, %	9.9[a]	10.3[a]	10.1[a]	9.5[a]	8.3[b]	0.37	0.002
Knuckle, %	2.1	2.0	2.1	2.0	1.8	0.16	0.58
Inside Round, %	3.6[a]	3.8[a]	3.7[a]	3.4[a]	2.9[b]	0.16	0.001
Outside Round, %	3.0[ab]	3.2[a]	3.0[ab]	2.8[b]	2.4[c]	0.10	0.002
Eye of Round, %	1.3	1.4	1.3	1.2	1.0	0.08	0.14
Flank, %	0.39	0.64	0.40	0.36	0.32	0.64	0.42
Brisket, %	1.8[ab]	2.0[a]	1.7[ab]	1.6[bc]	1.2[c]	0.08	0.01
Total Subprimal, %	45.9[ab]	48.2[a]	45.6[ab]	43.5[b]	37.3[c]	1.5	<0.001

[1]CI = fed concentrate and implanted with Revalor-200®; CIZ = fed concentrate, implanted with Revalor-200®, and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = fed concentrate; Grass = grazed native pasture.
[abcd]Within a row, means without a common superscript letter differ (P < 0.05).

Table 3-8 Cut-out weights and percentages from the 9-10-11 rib of cows fed for 70 d

	Treatment[1]						
Trait	CI[1]	CIZ[2]	CZ[3]	C	Grass	SE	P-value
9-10-11 Rib, kg	6.8[a]	6.8[a]	6.5[a]	6.3[a]	5.5[b]	0.27	0.007
Bone, kg	1.5	1.4	1.4	1.4	1.4	0.06	0.66
Soft Tissue, kg	5.4[a]	5.4[a]	5.1[a]	4.9[a]	4.2[b]	0.27	0.004
Moisture, %	52.7	53.4	52.1	51.2	55.2	2.19	0.72
Crude Protein, %	16.4	16.7	16.8	15.7	17.5	0.62	0.26
Total Fat, %	29.7	29.1	30.2	31.9	25.7	2.98	0.58
Ash, %	0.82	0.83	0.86	0.77	0.84	0.395	0.46

[1]CI = fed concentrate and implanted with Revalor-200®; CIZ = fed concentrate, implanted with Revalor-200®, and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = fed concentrate; Grass = grazed native pasture.
[ab]Within a row, means without a common superscript letter differ (P <0.05).

CHAPTER 4 - Effects of implanting and feeding zilpaterol on retail display stability and palatability of longissimus and knuckle steaks from fed cows

Shanna Hutchison

Department of Animal Sciences and Industry
Kansas State University
Manhattan, Kansas

ABSTRACT

The effects of using zilpaterol, Revalor-200® implants and the combination of zilpaterol and Revalor-200® on steak retail display and palatability were evaluated using strip loins and knuckles from 53 cull cows. Treatments were 1) grass-fed on pasture (**Grass**); 2) concentrate-fed (**C**); 3) concentrate-fed and implanted (**CI**) with Revalor-200®; 4) concentrate-fed and fed zilpaterol beginning on d 38 of the feeding period (**CZ**); and 5) concentrate-fed, implanted and fed zilpaterol beginning on d 38 (**CIZ**). Trained visual panelist evaluated strip loin (longissimus muscle, **LM**) and knuckle (**KN**) steaks daily from 0 to 5 d of display for overall color and discoloration. On d 0 only, LM steaks from CIZ cows were darker ($P < 0.05$) than steaks from CZ cows. No differences ($P = 0.19$) in LM steak discoloration were observed among treatments. For KN steaks, no differences ($P > 0.05$) were detected among treatments early in the display period (0-2 d). However, steaks from CI and CIZ cows were darker ($P < 0.05$) than those from grass-fed cows on d 5. Discoloration was also similar ($P > 0.05$) among treatments early in the display period (0 – 1 d). However, on d 5 KN steaks from CI and CZ cows were ($P < 0.05$) more discolored than steaks from the CZ, C and grass-fed cows; and steaks from CZ cows were more discolored than those from grass-fed cows. Sensory panelist found LM steaks from CIZ cows had lower ($P < 0.05$; tougher) overall tenderness scores compared to steaks from CI, C, and grass-fed cows; and steaks from CZ cows had ($P < 0.05$) lower overall tenderness than steaks from C and grass-fed cows. In agreement, LM steaks from the CIZ cows had the highest ($P < 0.05$; tougher) Warner-Bratzler shear force (**WBSF**) scores; and steaks from CZ cows had higher ($P < 0.05$) WBSF scores than steaks from CI, C and grass-fed cows. Off-flavors for LM steaks were highest ($P < 0.05$) for the grass-fed treatment compared to the other treatments. No sensory panel tenderness or WBSF differences ($P > 0.05$) were reported for KN steaks among any of the treatments. Knuckle steaks from the grass and C cows were juicier ($P < 0.05$) than the CI treatment. Beef flavor was higher ($P < 0.05$) for KN steaks from the grass and CI treatments than the CIZ and CZ treatments. Feeding zilpaterol to implanted cows resulted in LM steaks, but not KN steaks, that were considered tougher as evaluated by WBSF and sensory panelists.

Key Words: Cows, Implants, β-agonist, Color, Tenderness

INTRODUCTION

Approximately 16% of the 31-million head of cattle harvested in the United States in 2005 were aged cows (USDA, 2006). Due to toughness and variation in tenderness, meat from cows is commonly used in Food Service and/or ground beef production. Color and tenderness of beef from cull cows could potentially be improved with proper management of fed cows such as short-term feeding, potentially creating other opportunities for beef from these cull cows (Matulis et al., 1987; Boleman et al., 1996; Cranwell et al., 1996).

Animal age can potentially affect color stability. Shemeis et al. (1994) evaluated meat quality traits of Danish Friesian cull cows based on age and body condition score. While fat color darkened and became more yellow with age, minor changes in longissimus muscle steak color were observed. Beef color of longissimus steaks from steers was not affected by feeding zilpaterol (Avendano-Reyes et al., 2006). Meat from older animals is known to be tougher (Bouton et al., 1978). Meat from mature animals also tends to be drier and often has a mealy residue upon first bite, compared to meat from younger animals (Shorthose et al., 1990). Connective tissue characteristics and increased collagen cross-linking are age-related traits that influence tenderness; but, feeding a high-concentrate diet, may increase meat tenderness because of an increase in muscle protein turnover and more newly synthesized collagen.

Carcasses from cows that were implanted had larger longissimus muscle areas and higher dressing percentages than those that were not implanted (Cranwell et al., 1996a; Waggoner and Applegate, 1984). Tenderness was not influenced with the use of implants in cows fed for 56 d compared to those fed for 28 d (Cranwell et al., 1996b). In addition, cows that were implanted with trenbolone acetate (**TBA**) tended to have lower shear force values than cows implanted with TBA + trenbolone acetate estradiol (**TBE**) and controls.

In addition to feeding high-concentrate diets, producers may now use β-agonists to increase carcass yields of cull cows. The use of zilpaterol had no negative impacts on meat quality when steers were fed for up to 30 d before slaughter (Beermann, 2004). However, feeding zilpaterol for 45 d until 48 h before harvest resulted in lower sensory

tenderness, juiciness ratings and WBSF values in the longissimus muscle (Beermann, 2004). Shear force values were increased by feeding zilpaterol and ractopamine compared to steers that were fed grain only (Avendano-Reyes et al., 2006).

The influence of feeding the β_2-agonist zilpaterol to cull cows on retail display stability and palatability has not been previously reported. Therefore, the objectives of this study were to determine the effects concentrate feeding, implanting, and feeding zilpaterol on retail display and meat palatability of longissimus dorsi and knuckle steaks from cull cows fed for 70 d prior to harvest.

MATERIALS AND METHODS

Treatments

Sixty cows were stratified by weight and allotted to 70-d feeding period treatments consisting of: 1) grass-fed on pasture (**Grass**); 2) concentrate-fed (**C**); 3) concentrate-fed and implanted (**CI**) with Revalor-200® (Intervet, DE); 4) concentrate-fed and fed zilpaterol (Zilmax®, 106.25 mg/head/d; Intervet, DE) beginning on d 38 of the feeding period (**CZ**); and 5) concentrate-fed, implanted and fed zilpaterol beginning on d 38 (**CIZ**). The implanted cows were implanted on d 0 in the right ear with Revalor-200® (200 mg of trenbolone acetate and 20 mg of estradiol) per the manufacturer's instructions. Zilpaterol (Zilmax®, Intervet, DE) was fed for 30 d during the final 32 d of the feeding period only. Cows were removed from zilpaterol for the last 3 d prior to harvest in accordance with required withdrawal time. Cow performance and carcass data are reported in Chapter 3.

Steak Fabrication

Strip loin and knuckle (**KN**) subprimals were removed from the carcass left sides and vacuum packaged at approximately 72 h postmortem. On d 14 postmortem, strip loins and KN were removed from their vacuum bags and cut into steaks. Subprimals were faced and the faced portion was retained for Thiobarbituric Acid Reactive Substances (**TBARS**) analysis. Five 2.54-cm thick longissimus muscle (**LM**) steaks

were cut from the strip loins. The first steak removed was used for display, the second steak was cut for sensory panel analysis, and the third, fourth and fifth steaks were randomly assigned to 14, 21, and 28 d WBSF analysis. Three 2.54-cm thick steaks were cut from the KN subprimals. The first steak cut was for display, the second for sensory panel analysis and the third steak was for 14 d WBSF analysis.

Display

At 14 d postmortem, display steaks were packaged in polyvinyl chloride (PVC) on 20.32 cm x 14.61 cm x 1.74 cm foam trays (2S, Cryovac Sealed Air, Duncan, SC) and over-wrapped with oxygen permeable film (MAPAC M film, 23,250 cc/m2/24h, 72 gauge, Resinite Packaging Films, Borden, Inc., North Andover, MA). Steaks were displayed under 2152 lux ± 54 (200 ± 5 foot candles; 34 watt, Ultralume 30, 3000K) light intensity to stimulate retail display in open top display cases. Display case (Unit Model DMF8; Tyler Refrigeration Corp., Niles, MI) temperatures (2 ± 5°C) were monitored using temperature loggers (RD-TEMP-XT; Omega Engineering, Inc., Stamford, CT). Cases defrosted twice daily at 12-h intervals. Steaks were kept in display and evaluated (visual and instrumental) each day for a 5-d period. On d 5 steaks were removed from display and the top half of each steak was removed, packaged and stored at -80ºC for TBARS analysis.

Visual Color

Visual color panelist (n=8) who had passed the Farnsworth-Munsell® 100 Hue Test (MacBeth; Newburgh, NY) were trained for retail display color analysis. Color of LM and KN steaks were evaluated to the nearest 0.5 point where 1= very bright red, 2= bright red, 3= dull red, 4= slightly dark red, 5= slightly dark red to reddish tan, 6= moderately dark red to tannish red, 7= tan to brown. A score of 5.5 was used as a benchmark when steaks were considered unacceptable in retail color by visual panelists. The panelists' scores were averaged for statistical analyses.

Visual color panelist also evaluated discoloration indicated by the presence of metmyoglobin formation on the surface of the LM and KN steaks. Discoloration was evaluated as a percentage of the steak surface on a scale to the nearest 0.5 point where 1 = no discoloration (0%), 2 = slight discoloration (1-19%), 3 = small discoloration

(20-39%), 4 = modest discoloration (40-59%), 5 = moderate discoloration (60-79%), 6 = extensive discoloration (80-99%), 7 = total discoloration (100%). Panelists' scores were averaged for statistical analyses.

Instrumental Color Measurement

MiniScan® XE Plus Spectrophotometer (45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminant A; Hunter Associates Laboratory, Reston, VA) was used for instrumental color analysis. Three readings were taken at different locations on each LM and KN steak. The three readings for each muscle were averaged for CIE L*, a*, and b*. Hue angle $(b^*/a^*)\tan^{-1}$ and saturation index (**SI**) $(a^{*2} + b^{*2})^{1/2}$ were calculated from the CIE L*, a*, and b* readings. Instrumental color was used to further characterize color and confirm visual panel evaluations.

Oxidation (TBARS)

Both prior to, and following the completion of display (5 d of display), lipid oxidation was assessed using the TBARS test using the following procedures. Faced portions from each muscle at the beginning of display and at the end of display the top half of each steak (where oxidation should be greatest) were removed, frozen in liquid nitrogen, and then pulverized using a Waring 700 tabletop blender (model 33BL79; Waring Products, New Hartford, CT). After pulverizing, a 10-g sample was blended for 30 sec with 10 ml of water and 15 ml of perchloric acid. Samples were then filtered through filter paper (Cat No. 1002, 125mm dia; Whatman International Ltd, Maidstone, England) and 5 ml of thiobarbituric acid solution was added to the filtrate, and samples were allowed to react for 18 h. Absorbance was then measured on a Spectophic 21 spectrophotometer (Bausch & Lomb, Rochester, NY). Control solutions of known concentration of malonaldehyde were read on the spectrophotometer and regression equations were plotted to calculate TBARS concentration.

Warner-Bratzler Shear Force

Steaks (2.54-cm thick) for WBSF analysis were weighed and cooked in a dual-air-flow, convection gas oven (model DFG-201; G. S. Blodgett Co., Inc., Burlington, VA) preheated to 163ºC. Steaks were cooked to 40ºC, turned, and cooked to a final internal

temperature of 70ºC. Internal temperature was monitored using a 30-gauge, copper-constantan type T thermocouple inserted into the geometric center of each steak and attached to a Doric temperature recorder (model 205; Vas Engineering, San Francisco, CA). After, cooking steaks were cooled and re-weighed to calculate cooking loss percentages and then stored overnight at 1°C, before 1.27-cm cores were removed parallel to the muscle fiber orientation. Then, each core was sheared once perpendicular to the muscle fibers using the Warner-Bratzler attachment to the Instron Universal Testing Machine (model 4201; Instron Corp., Canton, MA) with a 50 kg load cell and a crosshead speed of 250 mm/min. The eight core values for the LM steak samples were averaged for statistical analysis. Cores (n=4) from each muscle were averaged for statistical analysis for the *rectus femoris* (**RF**) and *vastus lateralis* (**VL**) muscles within the KN steaks. Percentage of cooking loss was calculated as 100 × (initial steak weight – cooked steak weight) / initial steak weight.

Sensory Panel

Sensory steaks were thawed at 2°C for 24 h in vacuum-packaged bags. Steaks were then cooked in a Blodgett oven (model DFG-102, The G. S. Blodgett Company, Inc. Burlington, VT) set at 163°C. Thermocouple wires (thirty-gauge copper and constantan, Omega Engineering, Stamford, CT) were inserted into the geometric center of each steak and internal temperature monitored using a Doric Minitrend 205 (VAS Engineering, San Francisco, CA). Steaks were turned at 40°C and removed from the oven when the internal temperature reached 70°C. Cooked steaks were cut into 2.54 × 1.25 × 1.25 cm cubes. Cubes were placed in double boilers and held on burners set to 107°C. The procedures for this trained sensory panel were conducted according to the guidelines of AMSA (1995). Each panelist received two cubes from each sample in random order. Each session included a warm-up sample (sample was an extra steak from a muscle from one of the treatments) and samples from all treatments (5 cows) of either LM or KN steaks. Panelists were provided Premium Unsalted Tops Saltine Crackers (Nabisco, Inc., East Hanover, NJ) and filtered water (The Brita Products Company, Oakland, CA) to cleanse their pallets between samples. Traits evaluated by the sensory panel included myofibrillar tenderness, juiciness, beef flavor intensity, off-

flavor intensity, connective tissue amount, and overall tenderness. An eight point scale with 0.5 point increments was used for scoring sample traits. Myofibrillar tenderness and overall tenderness were evaluated on a scale from 1=extremely tough to 8=extremely tender. Connective tissue was based on a scale of 1=abundant to 8=none. Juiciness was scored on a scale of 1=dry to 8=extremely juicy. Beef flavor intensity was determined on a scale from 1=extremely bland to 8=extremely intense. Off-flavor intensity was scored on a scale of 1=extremely intense to 8=none. Panelists were asked to make comments when off-flavors were detected.

Fatty Acids

A modified gas chromatography procedure of Sukhija and Palmquist (1988) was used for fatty acid analysis. Muscle samples (raw) for fatty acid analysis were pulverized in liquid nitrogen in order to facilitate fatty acid extraction and sample uniformity. Approximately 250 mg of the pulverized sample was mixed in tubes with 2 ml of internal standard solution (2 mg methyl tridecanoic acid/ml benzene) and 3 ml of methanolic-HCl (20 ml acetyl chloride in 100 ml of methanol). The tubes were gassed with nitrogen, capped tightly, and heated fro 2 h in a 70ºC water bath (ISO Temp 228; Fisher Scientific, Fairlawn, NJ). Samples were removed and allowed to cool to room temperature, and then 5 ml of 6% potassium carbonate and 2 ml benzene were added to each tube. Tubes were centrifuged (J-6B; Beckman Instruments Inc., Palo Alto. CA, USA) at 500 × *g* for 5 min, the upper layer of organic solvent was removed and placed in a gas chromatograph vial.

The fatty acid methyl esters were separated with a gas chromatograph (model GC17-A, Columbia, MD) equipped with a flame ionization detector and a Supelco column (SP 2560, Fused Silica Capillary Colum, 100 m x 0.25 mm x 0.2 µm film thickness; Supelco, Bellefonte, PA) by using high-purity helium as the carrier gas, with a hydrocarbon trap and carrier gas purifier at a 60 ml/min flow rate and 20 cm/s velocity, and a split ratio of 48:1, with a sample injection volume of 1-µl. Samples were injected and held for 5 min at 140°C, and then increased to 240°C at a rate of 4°C per min and held there for 15 min.

Statistical Analysis

Color data were analyzed as a completely randomized design with day of display as a repeated measure, using the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC, 2007). The model statement contained treatment, day and treatment × day. Warner-Bratzler Shear Force, moisture losses, and fatty acids were analyzed as a completely randomized design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC). The model statement included treatment. Sensory data were analyzed as a completely randomized block design using the MIXED procedure of SAS. Panel session was used as a block to account for the potential variation due to session. Satterthwaite adjustments were used for the degrees of freedom. All interaction and main effect means were separated ($P < 0.05$) using the Least Significant Difference procedure when the respective F-test were significant ($P < 0.05$).

RESULTS

Display

Treatment × day interactions ($P < 0.05$) were observed for visual color, a* and hue angle for LM steaks from cows (Table 4-1). Visual color on d 0 was greater ($P < 0.05$) for LM steaks from cows in the CIZ treatment than those from the CZ treatment. Visual color for all treatments was similar ($P > 0.05$) on each day from 1 to 5 d of display. Although not significant, steaks from cows in the CIZ and grass treatments appeared somewhat darker than those from the other treatments from 0 to 3 d of display. As expected steaks from all treatments darkened as d of display increased.

Longissimus muscle steaks from cows in all treatments had similar ($P > 0.05$) a* values at 0 to 3 d of display. Steaks from the C and grass treatments were redder ($P < 0.05$; higher a* value) on d 4 than steaks from the CIZ and CZ treatments. On d 5 steaks from the C and grass treatments were redder ($P < 0.05$) than steaks from the other treatments. Over the display period steaks from all treatments became less red (lower a* values).

Hue angle values for LM steaks in all treatments were similar ($P > 0.05$) for 0 to 3 d of display. On d 4 of display, steaks from CZ cows had higher ($P < 0.05$) hue angle values than steaks from the CIZ, C and grass treatments. Steaks from CZ cows had

the highest ($P < 0.05$) hue angle values on d 5 of display compared to the other treatments.

Main-effect treatment means for LM discoloration, L*, b*, SI and TBARS are reported in Table 4-2. Treatments had similar ($P > 0.05$) values for discoloration, L*, b*, saturation index and TBARS values for LM steaks.

Day of display means for discoloration, L*, b*, SI and TBARS are reported in Table 4-3. Longissimus muscle steaks were similar ($P > 0.05$) on all d of display for discoloration, L*, b* and saturation index values. As expected, TBARS values were ($P < 0.05$) higher on d 5 than d 0 of display.

Treatment × day interactions ($P < 0.05$) were observed for visual color, discoloration, a*, hue angle, saturation index and TBARS values for KN steaks. These treatment means are reported in Table 4-4. Visual color scores for KN steaks were similar ($P > 0.05$) for all treatments on d 0 to 2. Steaks from CIZ cows had lower ($P < 0.05$; less dark red) visual color scores on d 3 of display compared to the other treatments. On d 5, steaks from grass-fed cows were considered by visual panelist to be less ($P < 0.05$) dark red than those from the CI and CIZ treatments.

Discoloration scores for KN steaks were similar ($P > 0.05$) for all treatments on d 0 to 1 of display. Steaks from the CI treatment were more ($P < 0.05$) discolored on d 2 of display than steaks from the C and grass-fed cows. On d 3 more ($P < 0.05$) discoloration was noted for the CI steaks compared to the CZ, C and grass treatments. Steaks from the CI and CIZ treatments had the most ($P < 0.05$) discoloration on d 5, and steaks from CZ cows had more ($P < 0.05$) discoloration than grass-fed cows. Steaks in all treatments discolored over the display period.

Knuckle steaks from grass-fed animals were redder ($P < 0.05$; higher a* value) on d 0 of display than steaks from CI and CZ cows. On d 5 of display, KN steaks from the CI treatment were less red ($P < 0.05$) than all other treatments. Over the display, steaks from all treatments became less red (lower a* values).

Hue angle values for KN steaks were higher ($P < 0.05$) on d 3 for the CIZ treatment steaks compared to CZ treatment steaks. On d 4 and 5 of display steaks from the CI treatment had higher ($P < 0.05$) hue angle values than all the other treatments.

Saturation index values on 0 to 1 d were similar (P > 0.05) for KN steaks from all treatments. On d 3 of display, KN steaks from the CIZ treatment had lower (P < 0.05) SI values than steaks from the C treatment. On d 5, SI values were lower (P < 0.05) for CI steaks compared to steaks from the CZ and grass-fed cows.

On d 0 of display, TBARS values were similar (P < 0.05) for KN steaks from all treatments. On d 5 of display, KN steaks from the grass-fed cows had similar (P > 0.05) TBARS to steaks from all treatments on d 0 of display. Steaks from the grass-fed cows had lower (P < 0.05) TBARS values on d 5 compared to steaks from CI cows.

Main-effect treatment means for KN L* and b* values are reported in Table 4-5. Treatments had similar (P > 0.05) values for L* and b* of KN steaks.

Day of display means for L* and b* values are reported in Table 4-6. Treatment means were similar (P > 0.05) on all d of display for L* and b* values from the KN.

Sensory Panel

Sensory panel, WBSF and cooking loss means for LM steaks are reported in Table 4-7. Sensory panelist found steaks from CIZ cows to have lower (P < 0.05; lower score indicates a tougher steak) myofibrillar tenderness than steaks from the CI, C and grass-fed cows. In addition, steaks from CZ cows had (P < 0.05) lower scores than steaks from C and grass-fed cows. No differences were noted for juiciness or beef flavor among the treatments.

The amount of detectable connective tissue found by sensory panelist was greater (P < 0.05; lower score) for LM steaks from the CIZ treatment compared to those from CI, C and grass-fed cows. Steaks from CZ cows had lower (P < 0.05) scores for detectable connective tissue than steaks from C cows.

Sensory panelist found LM steaks from cows in the CIZ treatment had lower (P < 0.05; lower score indicates a tougher steak) overall tenderness than CI, C and grass-fed cows, and steaks from CZ cows had (P < 0.05) lower scores than steaks from C and grass-fed cows. Off-flavors were highest (P < 0.05) for steaks from grass-fed cows.

Warner-Bratzler shear force values were highest (P < 0.05; indicates tougher steaks) for LM steaks from cows from the CIZ treatment compared to all other treatments. The WBSF values for steaks from the CZ cows were higher (P < 0.05) than

steaks from the C, grass-fed, or CI cows. Cooking losses for LM steaks were similar (P > 0.05) among all treatments.

Sensory panel, WBSF and cooking losses for KN steaks are reported in Table 4-8. Sensory panelist did not find any differences (P > 0.05) in myofibrillar tenderness, connective tissue amount, or overall tenderness of KN steaks. Steaks from CI cows were less juicy (P < 0.05; lower score) than steaks from the C and grass-fed cows. Beef flavor was found to be higher (P < 0.05) for steaks from the CI and grass-fed cows compared to steaks from the CIZ and CZ cows. No differences (P > 0.05) were noted by sensory panelist for off-flavor of KN steaks. Knuckle steaks from all treatments had similar (P > 0.05) WBSF values and cooking losses.

Fatty Acids

Least square means for percentages of fatty acids in the LM and KN muscles are reported in Tables 4-9 and 4-10, respectively. No differences (P > 0.05) among treatments for any fatty acids were noted. However, total (C16:0, and C18:1) fatty acid means appeared lower for the LM from grass-fed cows than the other treatments. Also, *n-6* appeared lower for both muscles from grass-fed cows than the other treatments resulting in a lower numerical *n-6/n-3* ratio.

Discussion

Longissimus muscle steaks from the grass and CIZ treatments were among the visually darker steaks for 0 to 3 d of display. Forage-based diets may promote oxidative metabolism rather than anaerobic muscle metabolism and glycogen storage (Vestergaard et al., 2000). These researchers reported that bulls fed forage-based restricted diets had less glycogen, higher muscle pH and darker muscle color than bulls fed ad libitum concentrate diets. In our study, LM steak a* values were lower for the CIZ and CZ treatments compared to the C and grass treatments. In agreement, a* values of zilpaterol fed steers were lower than controls or those fed ractopamine (Avendano-Reyes et al., 2006).

While there were no differences for TBARS values on d 5 for LM steaks, KN steaks from grass-fed animals had lower TBARS values on d 5 than those from the CI cows. This may be potentially attributed to the increased amount of α-tocopherol that

may be present in the muscle and fat of the grass-fed animals (O' Sullivan et al., 2004). Studies have shown that supplementation of vitamin E to steers results in accumulation α-tocopherol in muscle tissue (Arnold et al., 1992, 1993; Liu et al., 1996). This accumulation in α-tocopherol results in delayed oxymyoglobin and lipid oxidation of beef (O'Sullivan et al., 2004). Therefore, we could expect less oxidative rancidity (lower TBARS values) in grass-fed animals, due to a potentially increased level of α-tocopherol in the muscle acting as an antioxidant.

The combined use of zilpaterol and Revalor-200® resulted in LM steaks that had the highest WBSF values indicating that the steaks were tougher. Sensory panelist agreed with the WBSF values for the CIZ treatment, as they found these steaks and those from the CZ treatment to have the lowest myofibrillar and overall tenderness scores (lower score indicates tougher steaks). In addition, sensory panelist found the CIZ and CZ treatments to have the most detectable connective tissue (lower scores). Avendano-Reyes et al. (2006) found similar WBSF values for meat from steers that were fed zilpaterol compared to those fed a grain-only diet. However, these researchers did not conduct a sensory panel. Vestergaard et al. (1994) reported that shear values were dramatically increased in young bulls with the addition of cimaterol. While the combination of implant and zilpaterol resulted in increased toughness, the use of the implant alone resulted in tenderness values that were similar to the C and grass-fed treatments. In agreement, implanted cows had no increases in sensory panel tenderness or connective tissue (Cranwell et al., 1996). Therefore, the use of implants in combination with zilpaterol may result in a toughening of LM steaks. However, there were no differences in tenderness noted for the KN muscle. The differences observed for muscles could be related to the increases in muscle mass (weight) for the LM, while there was no increase noted in weight of the KN muscle (Chapter, 3). This may indicate that protein accumulation may not have occurred to the same extent in the KN, as in the LM.

Aging of meat allows for the breakdown of structural proteins by endogenous enzymes termed calpains (Devine, 2004). Vestergaard et al. (1994) speculated that the reduced protein degradation and reduced proteolytic activity in combination with the changes in muscle fiber size and proportion are major contributors to the decreased

tenderness when β-agonists are fed to ruminants. The decreases noted in tenderness with the use of zilpaterol may be a result of the zilpaterol decreasing protein degradation. Therefore, the decrease in degradation could carry-over postmortem, accounting for increased meat toughness.

While both muscles acted differently in terms of tenderness, the sensory panel and shear force values of these steaks from both muscles would indicate they range from slightly tough to slightly tender. Aging alone for 14 d did not result in what would be considered consistently tender. Therefore, both muscles would need some type of postmortem tenderization technology applied to increase tenderness. Two options for increasing tenderness could be injection enhancement and blade tenderization of the muscles.

Connective tissue in the grain-fed treatment was found to be the lowest, while the CIZ treatment was found to have the most. It has been documented by others that feeding cows a high energy diet prior to harvest results in increased amount of heat-liable collagen, less sensory panel detectable connective tissue and lower shear force values (Miller et al., 1987; Boleman et al., 1996). However, it has also been noted that the total amount of collagen was lowest in muscles from animals fed cimaterol, a β-agonist, compared to those that were not fed cimaterol (Vestergaard et al., 1994).

Off-flavors for the LM steaks were greatest from cows that were grass-fed. The off-flavor descriptors used most often for this treatment were grassy and livery. However, there were no differences in off-flavors of KN steaks. Boleman et al. (1996) noted that cows that were not fed concentrate had higher off-flavors than those that were fed for 28, 56, or 84 d. The flavor attribute of cowy was higher for cows that were fed for 0 or 14 d than those fed 56 d (Schnell et al., 1997).

Fatty acid profiles were not altered for either the LM or KN steaks. The *n–6* ratios for the LM tended to increase for cows in the CI, CIZ, CZ and C treatments compared to steaks from cows on grass. In agreement, cattle on pasture had higher levels of *n–6* fatty acids than those that were fed grain (Ponnampalam et al., 2006). In addition, short-term grain feeding (80 d) resulted in similar levels of saturated, monounsaturated and *n–6* fatty acids compared to cattle on grass. In agreement, cattle in this study were only fed for 70 d and, therefore, the grass-fed cows did not have

higher amounts of the more favorable fatty acids such as CLA and *n–3*. Noci et al. (2005) found the polyunsaturated fatty acid to saturated fatty acid ratio was increased with increased 0, 40, 99, and 158 d of grazing in heifers compared to those on grain diets. The increase in grazing also led to a linear decrease in the *n–6/n–3* ratio (Noci et al., 2005). In our study, fatty acid profiles were likely not found to be significantly increased or decreased, due to the relatively short time the cows were on the concentrate diets.

The two muscles were affected very differently by the treatments in this study. The results from Chapter 3 show a numerical increase in individual muscle weight from the LM when the combination of zilpaterol and Revelor-200® implants was used. However, there was no difference in muscle weight noted for the KN for any of the treatments. This lack of increase in muscle weight of the KN from implanted and zilpaterol-fed cows may be related to no influence in tenderness, while an increase in weight and a decrease in tenderness were noted for the LM.

The use of zilpaterol, implants, or the combination had minimal affect on retail display life of LM or KN steaks. However, the combination treatment (zilpaterol and implant) resulted in increased lean meat yields (Chapter 3) and increased toughness of LM steaks, but not KN steaks. Postmortem tenderization technologies may need to be incorporated for both LM and KN steaks from fed cows, regardless of treatment, to improve tenderness acceptability.

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Table 4-1 Treatment × days of display interaction means for visual and instrumental color of longissimus steaks from fed cull cows

	Display, d						
Trait	0	1	2	3	4	5	SE
Visual Color							
CI[1]	3.2^{efg}	3.5^{efg}	3.6^{defg}	3.8^{defg}	4.6^{bcd}	5.2^{ab}	0.32
CIZ[1]	4.0^{def}	4.1^{cdef}	4.1^{cdef}	4.2^{cde}	5.1^{abc}	5.5^{a}	0.31
CZ[1]	2.9^{g}	3.3^{efg}	3.4^{efg}	3.8^{defg}	5.1^{abc}	5.2^{ab}	0.32
C[1]	3.0^{fg}	3.3^{efg}	3.7^{defg}	3.6^{defg}	4.2^{cde}	5.0^{abc}	0.31
Grass	3.8^{defg}	4.1^{cdef}	4.3^{bcde}	4.3^{bcde}	4.8^{bcd}	5.3^{a}	0.36
a*							
CI	31.1^{ab}	30.7^{abc}	30.3^{abcd}	28.8^{bcd}	25.5^{ef}	21.9^{gh}	1.10
CIZ	29.2^{abcd}	29.4^{abcd}	29.2^{abcd}	27.6^{de}	24.8^{fg}	20.4^{h}	1.06
CZ	31.7^{ab}	31.1^{ab}	30.6^{abc}	28.9^{abcd}	23.5^{fg}	19.8^{h}	1.10
C	31.7^{ab}	31.8^{ab}	31.1^{ab}	29.8^{abcd}	27.9^{cde}	25.2^{ef}	1.06
Grass	30.4^{abcd}	31.4^{ab}	31.2^{ab}	29.8^{abcd}	27.9^{cde}	25.6^{ef}	1.10
Hue Angle[2]							
CI	36.5^{def}	37.3^{cdef}	37.5^{cdef}	36.4^{def}	38.6^{bcd}	40.3^{b}	0.81
CIZ	35.7^{f}	36.4^{def}	36.6^{def}	36.0^{ef}	37.2^{cdef}	40.6^{b}	0.79
CZ	36.6^{def}	37.6^{cdef}	37.7^{cdef}	37.1^{def}	41.0^{b}	43.7^{a}	0.81
C	36.7^{def}	37.8^{cdef}	37.9^{cdef}	37.1^{def}	38.1^{cde}	39.5^{bc}	0.79
Grass	36.2^{def}	37.6^{cdef}	37.6^{cdef}	36.3^{def}	36.7^{def}	38.1^{cde}	0.90

[1]CI = fed concentrate for 70 d and implanted with Revalor-200®; CIZ = fed concentrate for 70 d, implanted with Revalor-200® and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = concentrate; Grass = grazed native pasture for 70 d.
[2]Calculated using the equation: Hue Angle = $(b^*/a^*)\tan^{-1}$.
[abcdefgh]Within a trait, means without a common superscript letter differ ($P < 0.05$).

Table 4-2 Treatment means for fed cull cow longissimus steaks displayed for 5 d on L*, b* and TBARS values

	Treatment[1]						
Trait	CI	CIZ	CZ	C	Grass	SE	P-value
Discoloration	1.6	1.8	1.9	1.4	1.5	0.17	0.19
L*	39.4	36.3	38.8	40.0	36.7	1.12	0.32
b*	21.5	20.1	21.8	22.9	22.2	0.90	0.29
Saturation Index[2]	35.4	33.5	35.2	37.4	36.8	0.98	0.13
TBARS[3]	0.43	0.29	0.41	0.43	0.30	0.053	0.08

[1]CI = fed concentrate for 70 d and implanted with Revalor-200®; CIZ = fed concentrate for 70 d, implanted with Revalor-200® and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = concentrate; Grass = grazed native pasture for 70 d.
[2]Calculated using the equation: Saturation Index = $(a^{*2} + b^{*2})^{1/2}$.
[3]Thiobarbituric Acid Reactive Substances.

Table 4-3 Main effect means for days of display (0 to 5 d) for cull cow longissimus steaks on L*, b* and TBARS values

	Display, d						
Trait	0	1	2	3	4	5	SE
Discoloration	1.0	1.0	1.0	1.2	2.2	3.5	0.13
L*	40.3	38.2	38.0	39.0	37.6	36.4	0.60
b*	22.7	23.6	23.4	21.5	20.2	18.7	0.40
Saturation Index[1]	38.3	38.9	38.4	36.1	32.9	29.4	0.57
TBARS[2]	0.15[b]	---	---	---	---	0.60[a]	0.03

[1]Calculated using the equation: Saturation Index = $(a^{*2} + b^{*2})^{1/2}$.
[2]Thiobarbituric Acid Reactive Substances.

Table 4-4 Treatment × days of display means for visual and instrumental color of knuckle steaks from fed cull cows

	Display, d						
Trait	0	1	2	3	4	5	SE
Visual Color							
CI[1]	2.8^{h}	3.6^{fg}	4.6^{bcd}	4.4^{cde}	4.9^{bc}	5.4^{a}	0.22
CIZ[1]	3.3^{h}	3.7^{fg}	4.5^{cd}	3.4^{gh}	4.8^{bcd}	5.4^{a}	0.21
CZ[1]	3.4^{gh}	3.4^{gh}	4.1^{def}	4.0^{ef}	4.5^{cd}	5.1^{ab}	0.22
C[1]	3.0^{h}	3.5^{g}	4.1^{def}	4.1^{def}	4.4^{cde}	5.0^{abc}	0.21
Grass	3.3^{h}	3.7^{fg}	4.4^{cde}	4.3^{cde}	4.6^{bcd}	4.9^{bc}	0.22
Discoloration							
CI	1.0^{i}	1.1^{hi}	1.8^{fg}	2.2^{de}	2.7^{bc}	3.3^{a}	0.15
CIZ	1.0^{i}	1.1^{hi}	1.5^{gh}	1.9^{efg}	2.4^{bcd}	3.2^{a}	0.14
CZ	1.0^{i}	1.1^{hi}	1.5^{gh}	1.8^{fg}	2.3^{cde}	2.9^{b}	0.15
C	1.0^{i}	1.0^{i}	1.3^{hi}	1.8^{fg}	2.1^{def}	2.4^{bcd}	0.14
Grass	1.0^{i}	1.0^{i}	1.1^{hi}	1.4^{ghi}	1.8^{fg}	2.3^{cde}	0.15
a*							
CI	31.1^{bc}	28.9^{de}	26.4^{fghi}	25.5^{hi}	24.2^{ij}	21.0^{k}	0.95
CIZ	31.3^{abc}	28.0^{def}	26.9^{defghi}	24.8^{hij}	25.7^{hi}	23.8^{j}	0.92
CZ	29.6^{bcd}	28.5^{def}	27.3^{defgh}	27.0^{defghi}	26.8^{defghi}	25.8^{hi}	0.95
C	31.4^{ab}	29.3^{cde}	27.8^{defg}	27.2^{defgh}	25.7^{hi}	23.9^{ij}	0.91
Grass	31.6^{a}	29.6^{bcd}	27.9^{def}	26.0^{ghi}	26.3^{fghi}	26.5^{efghi}	1.07
Hue Angle[2]							
CI	36.8^{f}	38.8^{bcd}	39.2^{bc}	38.4^{bcdef}	38.6^{abcd}	42.0^{a}	0.61
CIZ	36.9^{ef}	38.8^{bcd}	38.8^{bcd}	39.3^{b}	37.6^{cdef}	39.2^{bc}	0.60
CZ	36.8^{f}	38.2^{bcdef}	38.6^{bcde}	37.6^{cdef}	37.9^{bcdef}	38.1^{bcdef}	0.62
C	37.3^{def}	39.2^{bc}	39.5^{b}	38.1^{bcdef}	38.3^{bcdef}	38.5^{bcdef}	0.59
Grass	37.8^{bcdef}	38.8^{bcd}	39.1^{bcd}	38.7^{bcde}	38.0^{bcdef}	38.2^{bcdef}	0.69
Saturation Index[3]							
CI	38.9^{ab}	37.2^{abcd}	34.0^{defgh}	32.5^{ghi}	31.0^{i}	28.1^{j}	1.12
CIZ	39.2^{ab}	35.9^{bcdef}	34.5^{cdefg}	32.0^{hi}	32.4^{hi}	30.7^{ij}	1.08
CZ	37.0^{abcde}	36.3^{abcde}	35.0^{cdefg}	34.1^{defgh}	34.0^{defgh}	32.8^{fghi}	1.12
C	39.6^{a}	37.8^{abc}	36.0^{bcde}	34.6^{cdefg}	32.8^{fghi}	30.7^{ij}	1.08
Grass	39.9^{a}	38.0^{ab}	35.9^{bcdef}	33.2^{efghi}	33.3^{efghi}	33.7^{defghi}	1.24
TBARS[4]							
CI	0.19^{c}	----	----	----	----	1.3^{a}	0.14
CIZ	0.14^{c}	----	----	----	----	0.94^{ab}	0.14
CZ	0.14^{c}	----	----	----	----	1.0^{ab}	0.14
C	0.20^{c}	----	----	----	----	0.98^{ab}	0.13
Grass	0.18^{c}	----	----	----	----	0.61^{bc}	0.17

[1]CI = fed concentrate for 70 d and implanted with Revalor-200®; CIZ = fed concentrate for 70 d, implanted with Revalor-200® and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = concentrate; Grass = grazed native pasture for 70 d.

[2]Calculated using the equation: Hue Angle = $(b^*/a^*)\tan^{-1}$.

[3]Calculated using the equation: Saturation Index = $(a^{*2} + b^{*2})^{1/2}$.

[4]Thiobarbituric Acid Reactive Substances

[abcdefghij]Within a trait, means without a common superscript letter differ ($P < 0.05$).

Table 4-5 Treatment means for fed cull cow knuckle steaks displayed for 5 d on L*, b* and TBARS values

	Treatment[1]						
Trait	CI	CIZ	CZ	C	Grass	SE	P-value
L*	39.8	39.8	40.3	41.1	40.4	0.84	0.71
B*	21.0	21.1	21.4	21.9	22.1	0.58	0.58

[11]CI = fed concentrate for 70 d and implanted with Revalor-200®; CIZ = fed concentrate for 70 d, implanted with Revalor-200® and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = concentrate; Grass = grazed native pasture for 70 d.

Table 4-6 Main effect means for days of display (0 to 5 d) for cull cow knuckle steaks on L*, b* and TBARS values

	Display, d						
Trait	0	1	2	3	4	5	SE
L*	41.2	40.7	39.7	40.8	40.0	39.3	0.45
b*	23.5	23.2	22.1	20.6	20.1	19.6	0.31

Table 4-7 Treatment means for sensory panel traits, Warner-Bratzler shear force (WBSF) and cooking loss for steaks from the longissimus muscle of fed cull cows

	Treatments[1]						
Trait	CI	CIZ	CZ	C	Grass	SE	P-value
Myofibrillar tenderness[2]	4.5[ab]	3.7[c]	4.0[bc]	5.1[a]	4.9[a]	0.26	0.003
Juiciness[3]	5.3	5.6	5.5	5.5	5.6	0.13	0.36
Beef Flavor[4]	5.6	5.4	5.6	5.6	5.4	0.10	0.34
Connective Tissue[5]	5.8[ab]	5.0[c]	5.4[bc]	6.1[a]	5.8[ab]	0.23	0.01
Overall Tenderness[2]	4.7[ab]	3.8[c]	4.2[bc]	5.3[a]	4.9[a]	0.25	0.004
Off Flavor[6]	7.6[a]	7.5[a]	7.4[a]	7.3[a]	6.9[b]	0.15	0.02
Strip WBSF, kg	4.4[c]	6.6[a]	5.5[b]	4.1[c]	4.5[c]	0.29	<0.001
Strip Loin Cooking Loss, %[7]	25.3	25.6	26.4	26.3	22.9	1.22	0.26

[1]CI = fed concentrate for 70 d and implanted with Revalor-200®; CIZ = fed concentrate for 70 d, implanted with Revalor-200® and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = concentrate; Grass = grazed native pasture for 70 d.
[2]Myofibrillar and overall tenderness evaluated on an 8 point scale 8 = extremely tender, 1 = extremely tough.
[3]Juiciness evaluated on an 8 point scale 8 = extremely juicy, 1 = dry.
[4]Beef flavor evaluated on an 8 point scale 8 = extremely intense, 1 = extremely bland.
[5]Connective tissue evaluated on an 8 point scale 8 = none, 1 = abundant.
[6]Off-flavor evaluated on an 8 point scale 8 = none, 1 = extremely intense.
[7]Cooking loss was calculated by 100 × (initial steak weight – cooked steak weight)/initial steak weight.
[abc]Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 4-8 Treatment means for sensory panel traits, Warner-Bratzler shear force (WBSF) and cooking loss for steaks from the knuckle muscle of fed cull cows

	Treatments[1]						
Trait	CI	CIZ	CZ	C	Grass	SE	P-value
Myofibrillar tenderness[2]	4.7	4.7	4.4	4.7	4.1	0.25	0.33
Juiciness[3]	5.0[b]	5.3[ab]	5.3[ab]	5.4[a]	5.6[a]	0.17	0.04
Beef Flavor[4]	5.9[a]	5.4[b]	5.4[b]	5.5[ab]	5.7[a]	0.07	0.003
Connective Tissue[5]	5.9	5.7	5.6	5.3	5.3	0.21	0.13
Overall Tenderness[2]	4.9	4.8	4.5	4.7	4.2	0.25	0.19
Off Flavor[6]	7.4	7.6	7.4	7.4	7.1	0.12	0.07
Knuckle WBSF, kg	4.5	5.5	5.6	5.1	5.2	0.55	0.37
Knuckle Cooking Loss, %[7]	30.9	32.0	31.7	32.7	29.3	2.30	0.82

[1]CI = fed concentrate for 70 d and implanted with Revalor-200®; CIZ = fed concentrate for 70 d, implanted with Revalor-200® and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = concentrate; Grass = grazed native pasture for 70 d.
[2]Myofibrillar and overall tenderness evaluated on an 8 point scale 8 = extremely tender, 1 = extremely tough.
[3]Juiciness evaluated on an 8 point scale 8 = extremely juicy, 1 = dry.
[4]Beef flavor evaluated on an 8 point scale 8 = extremely intense, 1 = extremely bland.
[5]Connective tissue evaluated on an 8 point scale 8 = none, 1 = abundant.
[6]Off-flavor evaluated on an 8 point scale 8 = none, 1 = extremely intense.
[7]Cooking loss was calculated by 100 × (initial steak weight – cooked steak weight)/initial steak weight.
[ab]Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 4-9 Percentages of fatty acids in the longissimus muscle from cows

	Treatment[1]						
Trait	CI	CIZ	CZ	C	Grass	SE	P-value
SFA[2]							
C14:0	0.06	0.06	0.08	0.08	0.05	0.015	0.52
C16:0	0.60	0.61	0.75	0.74	0.52	0.133	0.67
C17:0	0.03	0.04	0.04	0.04	0.03	0.006	0.42
C18:0	0.31	0.34	0.38	0.37	0.30	0.044	0.66
Other[3]	0.03	0.03	0.03	0.03	0.03	0.003	0.65
MUFA[4]							
C16:1	0.10	0.09	0.13	0.13	0.07	0.030	0.57
C17:1	0.03	0.02	0.02	0.03	0.02	0.005	0.51
C18:1	0.96	0.96	1.2	1.1	0.74	0.21	0.60
Other[5]	0.02	0.02	0.03	0.03	0.02	0.005	0.44
PUFA[6]							
CLA[7]	0.005	0.005	0.005	0.005	0.005	0.0001	0.91
n–3[8]	0.02	0.02	0.02	0.02	0.03	0.003	0.38
n–6[9]	0.14	0.13	0.14	0.14	0.11	0.008	0.06
Total	2.3	2.3	2.8	2.8	1.9	0.46	0.63
PUFA/SFA	0.19	0.17	0.14	0.16	0.16	0.019	0.48
n–6/n-3	8.5	7.7	7.9	8.1	4.4	0.71	0.15

[1]CI = fed concentrate for 70 d and implanted with Revalor-200®; CIZ = fed concentrate for 70 d, implanted with Revalor-200® and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = concentrate; Grass = grazed native pasture for 70 d.
[2]SFA = saturated fatty acid.
[3]C8:0, C11:0, C12:0, C15:0, C20:0, C21:0, C22:0 and C24:0.
[4]MUFA = monounsaturated fatty acid.
[5]C14:1, C15:1, C20:1 and C24:1.
[6]PUFA = polyunsaturated fatty acid.
[7]Conjugated linoleic acid (C18:2) isomers 9 *cis* 11 *cis*, 9 *cis* 11 *trans*, 9 *trans* 11 *trans* and 10 *trans* 12 *cis*.
[8]C18:3, C20:5, C 22:5 and C22:6.
[9]C18:2, C18:3, C20:3 and C20:4.

Table 4-10 Percentages of fatty acids in the knuckle muscle from cows

	Treatment[1]						
Trait	CI	CIZ	CZ	C	Grass	SE	P-value
SFA[2]							
C14:0	0.06	0.04	0.06	0.07	0.05	0.015	0.64
C16:0	0.62	0.45	0.58	0.71	0.52	0.161	0.75
C17:0	0.04	0.03	0.03	0.04	0.03	0.010	0.72
C18:0	0.32	0.26	0.30	0.36	0.30	0.075	0.85
Other[3]	0.04	0.03	0.03	0.04	0.03	0.004	0.79
MUFA[4]							
C16:1	0.09	0.06	0.09	0.11	0.07	0.024	0.56
C17:1	0.03	0.02	0.02	0.03	0.02	0.005	0.51
C18:1	0.93	0.67	0.84	1.1	0.69	0.240	0.67
Other[5]	0.02	0.02	0.02	0.02	0.02	0.004	0.49
PUFA[6]							
CLA[7]	0.006	0.005	0.006	0.006	0.006	0.002	0.88
n–3[8]	0.02	0.02	0.02	0.02	0.03	0.003	0.25
n–6[9]	0.16	0.13	0.14	0.15	0.12	0.012	0.35
Total	2.3	1.7	2.1	2.6	1.9	0.56	0.71
PUFA/SFA	0.20	0.21	0.20	0.20	0.18	0.03	0.96
n–6/n-3	8.0	8.3	8.0	7.9	4.6	0.77	0.15

[1]CI = fed concentrate for 70 d and implanted with Revalor-200®; CIZ = fed concentrate for 70 d, implanted with Revalor-200® and fed zilpaterol for 30 d prior to slaughter; CZ = fed concentrate and zilpaterol; C = concentrate; Grass = grazed native pasture for 70 d.
[2]SFA = saturated fatty acid.
[3]C8:0, C11:0, C12:0, C15:0, C20:0, C21:0, C22:0 and C24:0.
[4]MUFA = monounsaturated fatty acid.
[5]C14:1, C15:1, C20:1 and C24:1.
[6]PUFA = polyunsaturated fatty acid.
[7]Conjugated linoleic acid (C18:2) isomers 9 *cis* 11 *cis*, 9 *cis* 11 *trans*, 9 *trans* 11 *trans* and 10 *trans* 12 *cis*.
[8]C18:3, C20:5, C 22:5 and C22:6.
[9]C18:2, C18:3, C20:3 and C20:4.

CHAPTER 5 - Effects of 7 or 28 d of aging on retail display of strip loins from fed mature cull cows and fed steers and 7 or 28 d of aging, blade tenderization and injection enhancement on palatability

Shanna Hutchison

Department of Animal Sciences and Industry
Kansas State University
Manhattan, Kansas

ABSTRACT

Strip loins from thirty-one fed mature cull cows and twenty-four fed steers were used to determine the effects of 7 or 28 d of aging on retail shelf-life. These muscles were also used to determine the effects of aging 7 or 28 d in addition to blade tenderization and with injection enhancement. Strip loins were removed from both carcass sides and randomly assigned to 7 or 28 d of aging. Following aging, retail shelf-life steaks were removed and strip loins were divided in half. Half sections were randomly assigned to enhancement or non-enhancement and frozen. Enhancement solutions were formulated to contain 0.5% sodium chloride, 0.35% phosphate and 0.023% bromelin (cows only). Sections were passes once through a blade tenderizer and injected to retain a 10% pump. Both cow and steer steaks aged for 28 d were less ($P < 0.05$) color stable than steaks aged for 7 d. Steaks aged 7 d had less ($P < 0.05$) discoloration over the 6 d of retail display compared to 28-d aged steaks and did not reach a score of 5.5 (unacceptable) for the display period. In addition, steaks aged for 7 d had lower ($P < 0.05$) hue angle values than those aged for 28 d. Aging for 28 d decreased ($P < 0.05$) Warner-Bratzler shear force (WBSF) values for both cow and steer steaks compared to 7-d of aging. Furthermore, enhanced steaks had lower ($P < 0.05$) WBSF values than non-enhanced steaks. Cow steaks that were enhanced had WBSF values that would be considered extremely tender. Enhanced cow and steer steaks had lower ($P < 0.05$) cooking losses than non-enhanced steaks. Cow steaks that were enhanced had higher ($P < 0.05$) myofibrillar tenderness compared to non-enhanced steaks. Enhanced cow steaks aged for 28 or 7 d resulted in similar ($P > 0.05$) overall tenderness as determined by sensory panelist. Enhanced cow steaks had lower ($P < 0.05$) overall firmness as determined by a sensory panel. Sensory panel overall tenderness values from this study indicate that the use of blade tenderization and enhancement of products aged for 7 d results in similar overall tenderness to steaks aged for 28 d. This indicates that blade tenderization and enhancement of 28-d aged steaks may not be necessary to achieve increased tenderness.

Key Words: Cow, Aging, Enhancement, Enzyme, Color, Tenderness

INTRODUCTION

In 2005, approximately 16% or (5 million) of the 31-million head of cattle harvested in the United States were mature cows (USDA, 2006). However, mature cull cows tend to have inferior palatability traits compared to young cattle (Tuma et al., 1963; Dikeman and Tuma, 1971). Tenderness of meat is a very important palatability factor to consumers (Dikeman, 1987; Morgan et al., 1991). Cow meat tends to be tougher due to the increased amounts of collagen cross-linking that is associated with age (Beridenstein et al., 1968; Cross et al., 1973; Berry et al., 1974). With inferior palatability and the potential for color instability, cow meat is often used in the food service and institutional sectors of the meat industry. However, feeding cull cows prior to harvest improves lean color and tenderness (Cranwell et al., 1996). Longissimus dorsi (strip) steaks are more tender, brighter colored, and more color stable than many other retail cuts, and are typically used in the retail sector of the meat industry (Brooks et al., 2000; McKenna et al., 2005). Therefore, strip steaks from fed cull cows could potentially be used in the retail sector of the meat industry.

Postmortem methodologies such as aging, blade tenderization, and injection enhancement are often utilized to improve product tenderness. Meat is often aged to enhance tenderness (Smith et al, 1978; Savell et al, 1981). However, aging of meat can be very costly, requiring increased storage space, increased labor, and delayed returns on investments. The use of enhancement solutions has been noted to improve beef tenderness and juiciness (Vote et al., 2000; McGee et al., 2003). In addition, injection enhancement containing enzymes have been shown to increase product tenderness (McKeith et al., 1994). Blade tenderization is another postmortem tenderization method used in the industry to ensure a tender product. Parrish (1977) noted that blade tenderization disrupts skeletal muscle tissue to improve product tenderness. Therefore, the combination of aging, enhancement and blade tenderization should result in a more tender product.

Aging effects on retail color stability of cow strip steaks is unknown. In addition, aging products for extended periods of time when combined with blade tenderization and enzyme enhancement may not be necessary. Therefore, the objectives of this

study were to 1) determine if aging time (7 or 28 d) affects retail color stability of longissimus muscle steaks and 2) determine the effects of 7 or 28 d of aging with or without enhancement or aging in combination with enhancement on tenderness and sensory traits of longissimus steaks from fed cull cows and steers.

MATERIALS AND METHODS

Animals

Experiment 1: Thirty-one cull cows were fed a high-energy diet for 60 d prior to harvest at the Kansas State University Meat Laboratory. Carcass quality and yield grade data were taken at 48 h postmortem and carcasses were fabricated starting at 72 h postmortem. Fed-cow performance, carcass traits, and carcass composition are reported by Harborth (2006).

Experiment 2: Twenty-four steers were fed a high-energy diet prior to harvest at the Kansas State University Meat Laboratory. Carcass quality and yield grade data were taken at 48 h postmortem. Carcasses were fabricated into subprimal cuts starting at 72 h postmortem. Steer performance, carcass traits and carcass composition are reported by Winterholler (2006).

Fabrication

Strip loins were removed from both carcass sides starting at 72 h postmortem, weighed, and vacuum packaged in Prime Source Vacuum Pouches (Koch Equipment, Kansas City, MO). Strip loins from each carcass side were randomly assigned to 7 or 28 d of vacuum aging at a temperature of 0 ± 2ºC. After aging they were removed from vacuum package bags, the anterior end was faced, and one 2.54-cm thick steak was removed for display. Following the display steak removal, the strip loins were divided into posterior and anterior sections at approximately the third and fourth lumbar vertebrae region. The sections from each carcass side (7 or 28 d of aging) were then randomly assigned to treatments of no enhancement or a combination of blade tenderization and injection enhancement, and were frozen at -40ºC until further processing.

Enhancement

Experiment 1: Strip loin sections (7 or 28 d aging) from 31 fed cull cows were randomly assigned to non-enhancement or enhancement treatments. The enhanced sections were thawed for 36 h prior to processing and passed once through a blade tenderizer (model TC700, Ross Industries Inc., Midland, VA) prior to passing through a Wolftec multiple-needle injector (model N30; Wolftec, Inc.; Werther, Germany). Sections were injected at 10% of their weight with a solution containing 0.35% phosphate (BRIFISOL 85 Instant; BK Giulini, Corp.; Simi Valley, CA), 0.5% sodium chloride, and 0.023% Bromelin1000 (Excalibur Seasoning, Pekin, IL). Bromelin was included in the formulation for the cow strip loins to breakdown additional collagen cross-linking due to increased animal age. These sections were allowed a five-minute drip time, vacuum packaged, and refrozen at -40ºC. Actual pump percentages for 7 d aged strip loins were 10.8% and 10.3% for 28 d of aging. Frozen non-enhanced and enhanced sections were removed from the freezer and three 2.54-cm thick steaks were cut using a BIRO band saw (model 3334, The BIRO Mfg. Co.; Marblehead, OH). The three steaks nearest the center of the strip loin were randomly assigned to Warner-Bratzler shear force (WBSF), pH, and sensory analysis.

Experiment 2: The strip loin sections (7 or 28 d aging) from 24 fed steers were randomly assigned to non-enhancement or enhancement treatments. Procedures in experiment 1 were used except the injection solution did not contain Bromelin. Bromelin was not added to the formulation for steer longissimus muscles, as steers were less than 24 mo of age. The strip loins were injected at 10% of their weight with a solution containing 0.35% phosphate (BRIFISOL 85 Instant; BK Giulini, Corp.; Simi Valley, CA) and 0.5% sodium chloride. Actual pump percentages for steer strip loins aged for 7 d were 10.3% and 9.6% for 28-d aged muscles.

Retail Display

On d 7 or 28 of aging strip loins were removed from vacuum package bags, the anterior end was faced and one 2.54-cm thick steak was removed for retail display. The faced portion of the strip was packaged for d 0 Thiobarbituric Acid Reactive Substances (**TBARS**) analysis. The display steaks were packaged in polyvinyl chloride (PVC) on

20.32 cm x 14.61 cm x 1.74 cm foam trays (2S, Cryovac Sealed Air, Duncan, SC) and over-wrapped with oxygen permeable film (MAPAC M film, 23,250 cc/m2/24h, 72 gauge, Resinite Packaging Films, Borden, Inc., North Andover, MA). Steaks were displayed under 2152 lux ± 54 (200 ± 5 foot candles; 34 watt, Ultralume 30, 3000K) light intensity to stimulate retail display in open top display cases. Display case (Unit Model DMF8; Tyler Refrigeration Corp., Niles, MI) temperatures (2 ± 5°C) were monitored using temperature loggers (RD-TEMP-XT; Omega Engineering, Inc., Stamford, CT). Cases defrosted twice daily at 12-h intervals. Steaks were kept in display for a 7-d period. On d 7 steaks were removed from display and the top half of the steak was removed and vacuum packaged for TBARS analysis.

Visual Color

Visual color panelist (n=7) who had passed the Farnsworth-Munsell® 100 Hue Test (MacBeth; Newburgh, NY) were trained for retail-display color analysis. Color of longissimus muscle within the strip steak was evaluated on a seven-point scale to the nearest 0.5 point where 1= very bright red, 2= bright red, 3= dull red, 4= slightly dark red, 5= slightly dark red to reddish tan, 6= moderately dark red to tannish red, 7= tan to brown. A score of 5.5 was used as a benchmark when steaks were considered unacceptable in retail color by the visual panelists. The panelists' scores were averaged for statistical analyses.

Visual color panelists also evaluated discoloration indicated by the presence of metmyoglobin formation on the surface of the longissimus steaks during display. Discoloration was evaluated as a percentage of the steak surface on a seven-point scale to the nearest 0.5 point where 1 = no discoloration (0%), 2 = slight discoloration (1-19%), 3 = small discoloration (20-39%), 4 = modest discoloration (40-59%), 5 = moderate discoloration (60-79%), 6 = extensive discoloration (80-99%), 7 = total discoloration (100%). Panelists' scores were averaged for statistical analyses.

Instrumental Color

MiniScan® XE Plus Spectrophotometer (45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer, Illuminant A; Hunter Associates Laboratory, Reston, VA) was used for instrumental color analysis. Three readings were taken at different locations

on each longissimus muscle. The three readings for each muscle were averaged for CIE L*, a*, and b*. Hue angle $(b^*/a^*)\tan^{-1}$ and saturation index (**SI**) $(a^{*2} + b^{*2})^{1/2}$ were calculated from the CIE L*, a*, and b* readings. Instrumental color was used to confirm visual panel evaluations.

Oxidation (TBARS)

Both prior to, and following the completion of display, lipid oxidation was assessed using the TBARS test. The top half of each steak (where oxidation should be greatest) was removed, frozen in liquid nitrogen, and then pulverized using a Waring 700 tabletop blender (model 33BL79; Waring Products, New Hartford, CT). A 10-g pulverized sample was blended for 30 sec with 10 ml of water and 15 ml of perchloric acid before filtration (Cat No. 1002, 125mm dia; Whatman International Ltd, Maidstone, England) and addition of 5 ml of thiobarbituric acid solution to the filtrate. Samples were allowed to react for 18 h before absorbance was measured on a Spectophic 21 spectrophotometer (Bausch & Lomb, Rochester, NY). Control solutions of known concentration of malonaldehyde were read on the spectrophotometer and regression equations were plotted to calculate TBARS concentration.

Palatability

Warner-Bratzler Shear Force

Steaks (2.54-cm thick), were cooked in a dual-air-flow, convection gas oven (model DFG-201; G. S. Blodgett Co., Inc., Burlington, VA) preheated to 163ºC. Steaks were cooked to 40ºC, turned, and cooked to a final internal temperature of 70ºC. Internal temperature was monitored using a 30-gauge, copper-constantan type T thermocouple inserted into the geometric center of each steak and attached to a Doric temperature recorder (model 205; Vas Engineering, San Francisco, CA). After cooking, steaks were cooled, re-weighed to calculate cooking loss percentages, and then stored overnight at 1°C. Six 1.27-cm cores were removed parallel to the muscle fiber orientation and sheared once perpendicular to the muscle fibers using the Warner-Bratzler attachment to the Instron Universal Testing Machine (model 4201; Instron Corp., Canton, MA) with a 50 kg load cell and a crosshead speed of 250 mm/min. The

six core values for each sample were averaged for statistical analysis. Percentage of cooking loss was calculated by 100 × (thawed steak weight – cooked steak weight)/thawed steak weight.

Sensory Panel Analysis

Sensory steaks were thawed at 2°C for 24 h in their vacuum-packaged bags. Steaks were then cooked in a Blodgett oven (model DFG-102, The G. S. Blodgett Company, Inc. Burlington, VT) set at 163°C. Thermocouple wires (thirty gauge copper and constantan, Omega Engineering, Stamford, CT) were inserted into the geometric center of each steak and internal temperature was monitored using a Doric Minitrend 205 (VAS Engineering, San Francisco, CA). Steaks were turned at 40°C and removed from the oven when the internal temperature reached 70°C. Cooked steaks were cut into 2.54 × 1.25 × 1.25 cm cubes, placed in double boilers, and held on burners set to 107°C. The procedures for this trained sensory panel were conducted according to the guidelines set by the AMSA (1995). Panelists received eight or fewer samples per sensory panel session. Each session included samples from all treatments (4) from two fed cows. Panelists were provided Premium Unsalted Tops Saltine Crackers (Nabisco, Inc., East Hanover, NJ) and filtered water (The Brita Products Company, Oakland, CA) to cleanse their pallets between samples. Traits evaluated by the sensory panel included myofibrillar tenderness, juiciness, beef flavor intensity, off-flavor intensity, connective tissue amount, and overall tenderness. An eight point scale with 0.5 point increments was used for scoring sample traits. Myofibrillar tenderness and overall tenderness were evaluated on a scale from 1=extremely tough to 8=extremely tender. Connective tissue was based on a scale of 1=abundant to 8=none. Juiciness was scored on a scale of 1=dry to 8=extremely juicy. Beef flavor intensity was determined on a scale from 1=extremely bland to 8=extremely intense. Firmness was scored on a scale of 1=extremely soft to 8=extremely firm. Off-flavor intensity was scored on a scale of 1=extremely intense to 8=none.

pH analysis

One steak from each treatment (strip loin) was cut and frozen to determine pH. Steaks were thawed for 48 h at 4.4 ± 1 ºC. A Meat Probes Incorporated (MPI) pH meter

with glass probe electrode (Meat Probes Inc., Topeka, KS) was used to determine pH. Three readings from the longissimus muscle from each steak were recorded and averaged to determine pH.

Statistical Analysis

Color data were analyzed as a completely randomized block design with animal used as the blocking factor and day of display as a repeated measure, using the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC). The model statement contained aging, day, and aging × day. Warner-Bratzler Shear Force and moisture losses were analyzed as a split plot using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC, 2006). The whole plot aging period was a completely randomized block with animal used as the blocking factor and enhancement as the subplot. The model statement included aging, injection and aging × injection. Sensory data were analyzed as a split plot in a randomized complete block design using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC, 2006). Panel session was used as the block to account for the variation due to session. The model statement included aging, injection and aging × injection. Satterthwaite adjustments were used for the degrees of freedom. All interaction and main effect means were separated ($P < 0.05$) using the Least Significant Difference procedure when the respective F-test were significant ($P < 0.05$).

RESULTS

Display Color

Experiment 1: Day × aging interactions ($P < 0.05$) were observed for all color measures and TBARS of longissimus steaks from fed cull cows. Therefore, interaction means are reported in Table 5-1. Visual color for steaks aged 7 and 28 d were similar ($P > 0.05$) on 0 and 1 d of display. Steaks aged for 7 d were ($P < 0.05$) brighter red than steaks aged for 28 d at 2 through 6 d of display. As expected, steaks generally became progressively darker as days of display increased. Steaks aged for 7 d did not reach an unacceptable score of 5.5 during the entire 6 d of display. However, the 28-d aged steaks exceeded a score of 5.5 on d 4 and were moderately dark red to tannish red for the remainder of the panel.

Discoloration scores were initially (d 0) similar ($P > 0.05$) for steaks aged 7 or 28 d. Thereafter (1-6 d of display), steaks aged for 7 d had less ($P < 0.05$) discoloration than steaks aged for 28 d. Steaks aged 7 d had less ($P < 0.05$) discoloration at 0 and 1 d of display than they did at 2-6 d of display. After 2 d of display, steaks aged 7 d became progressively more discolored ($P < 0.05$) with each additional d of display. For steaks aged 28 d, discoloration progressively increased ($P < 0.05$) for every additional d of display. This indicates that cow steaks that are aged for 28 d are less color stable than those aged for 7 d.

Steaks aged for 7 d had higher ($P < 0.05$; were lighter) L* values than steaks aged for 28 d, except at d 1 when they were similar. For steaks aged for 7 d, steaks displayed for 6 d were darker ($P < 0.05$) than all other d of display. Steaks aged for 28 d, became progressively darker from d 0 to d 3 with each additional d of display ($P < 0.05$). After 3 d of display, steaks displayed 3 and 4 d were ($P < 0.05$) lighter than steaks displayed for 5 and 6 d.

Steaks aged for 7 d had higher ($P < 0.05$; were redder) a* values than steaks aged for 28 d, except at d 0 when they were similar ($P > 0.05$). For steaks aged 7 d, a* values were similar ($P > 0.05$) for the first 3 d of display. After which, steaks displayed 3 and 4 d were redder ($P < 0.05$) than steaks displayed at 5 and 6 d. For steaks aged 28 d, steaks became less red ($P < 0.05$) with each additional d of display.

Steaks aged for 7 d had higher ($P <0.05$) b* values than 28 d aged steaks. For steaks aged for 7 d, 0-1 d of display had ($P < 0.05$) higher b*values than d 3-6 of display. On d 2 of display, 7-d aged steaks had higher ($P <0.05$) b* values than d 4-6. Steaks aged for 7 d on d 3 and 4 d of display had higher ($P < 0.05$) b* values than d 5-6 of display. For steaks aged for 28 d, 0-1 d of display had ($P < 0.05$) higher b*values than d 3-6 of display. On d 2 of display, 28-d aged steaks had higher ($P <0.05$) b* values than on d 4-6 of display.

Hue angle values were higher ($P < 0.05$, more orange) for steaks aged 28 d than steaks aged 7 d on 3-6 of display. Steaks aged for 7 d had similar ($P > 0.05$) hue angles on all d of display. Steaks aged for 28 d had similar ($P > 0.05$) hue angles on d 0-2 of display and became progressively higher with each d of display thereafter.

Saturation index values were higher ($P < 0.05$) for 7-d aged steaks at all d of display than steaks aged for 28 d. Steaks aged for 7 d had reasonably stable SI values for the first 3 d of display and lowest ($P < 0.05$) SI values at d 5 and 6 of display. Steaks aged for 28 d progressively worsened for each d of display.

Steaks aged for 7 and 28 d had similar ($P > 0.05$) TBARS values on both d 0 and 6 of display. Steaks aged for 7 and 28 d had increased ($P < 0.05$) TBARS values from d 0 to 6 of display.

Experiment 2: Steaks from young fed steers display day × aging interactions were ($P < 0.05$) observed for visual color, discoloration, a* values, hue angle and saturation index values and are reported in Table 5-2. Visual color for steaks aged 7 and 28 d were similar ($P > 0.05$) on d 0 to 2 of display. Steaks aged for 7 d were ($P < 0.05$) brighter red than steaks aged for 28 d at 3 through 5 d of display. For steaks aged either 7 or 28 d, steaks were brightest red ($P < 0.05$) on 0 and 1 d of display, but became progressively darker as days of display increased. Steaks aged for 7 d reached a score of unacceptable 5.5 on d 5 of display. However, the 28-d aged steaks exceeded a score of 5.5 on d 4 of display and were moderately dark red to tannish red for d 5 to 6 of display.

Discoloration scores for 7 and 28-d aged steaks were similar ($P > 0.05$) on d 0 to 2 of display. Steaks aged for 7 d had less discoloration on d 3-6 of display than steaks aged 28 d. For steaks aged both 7 and 28 d, discoloration progressively increased ($P < 0.05$) after d 1 with each additional d of display.

Steaks aged for 7 d had higher ($P < 0.05$; were redder) a* values on d 1, 3, 4, and 5 d than steaks aged for 28 d. For steaks aged 7 d, a* values were highest ($P < 0.05$) on d 0 and 1 of display, and lowest ($P < 0.05$) at d 6 of display. In general, a* values for 7-d aged steaks declined from d 2-5 of display. Steaks aged for 28 d had their highest ($P < 0.05$) a* values at 0-2 d of display and lowest ($P < 0.05$) at 5 and 6 d of display. The a* values for steaks aged 28 d progressively ($P < 0.05$) declined from 2 to 6 d of display.

Steaks aged for 7 d had ($P < 0.05$) greater hue angles than steaks aged for 28 d on 3 to 5 of display. Steaks aged for 7 d had similar ($P > 0.05$) hue angle values on d 0-3, and were similar to 28-d aged steaks on d 0. Hue angle values for 28-d aged steaks

were similar (P > 0.05) to 7 d aged steaks initially (d 0). For steaks aged 28 d, hue angle values were higher (P < 0.05) for each additional d of display from 3 to 5 of display.

Steaks aged for 7 and 28 d had similar (P > 0.05) SI values from 0 to 2 d of display. Saturation index values for 28-d aged steaks were lower (P < 0.05) than 7-d aged steaks on d 3 to 5 of display. However, both 7 and 28-d aged steaks were similar (P > 0.05) on d 6 of display.

Main effect means of aging for L*, b* and TBARS are reported in Table 5-3. Aging either 7 or 28 d resulted in similar (P > 0.05) L*, b* and TBARS values.

Day of display means for L*, b* and TBARS values for steer steaks are reported in Table 5-4. Steaks in display on d 0 and 1 had the highest (P < 0.05; lightest) L* values and the lowest (P < 0.05) L* values on d 6 of display compared to all other d of display. Steaks on d 2 and 3 had higher (P < 0.05) L* values than steaks on d 4 and 5 of display.

Steak b* values were highest (P < 0.05) at d 1 of display and lowest at 6 d of display. Steak b* values were higher (P < 0.05) on d 0 and 2 of display than d 3-5 of display. Steaks on d 3 and 4 of display had higher (P < 0.05) b* values than those on d 5 of display.

Strip steak TBARS values were greater (P < 0.05) on d 6 of display than on d 0 of display. The increased values indicate that the steaks had increased oxidative rancidity over the display time.

Sensory Panel

Experiment 1: Palatability-trait means comparing longissimus steaks from fed cows aged for 7 and 28 d are presented in Table 5-5. Sensory panelist found (P < 0.05) steaks aged for 7 d were more juicy, had more detectable connective tissue (lower scores), and were firmer than steaks aged for 28 d. Steaks aged for 7 d also tended (P = 0.06) to have more sensory panel beef flavor than steaks aged for 28 d. Steaks aged for 7 d had (P < 0.05) higher WBSF (less tender) and lower pH than steaks aged for 28 d. No differences (P = 0.43) were noted in vacuum package losses for 7 or 28 d aged steaks.

Palatability-trait means comparing enhanced and non-enhanced longissimus steaks from fed cows are presented in Table 5-6. Steaks both enhanced and non-enhanced were found by sensory panelist to have similar ($P > 0.05$) juiciness scores. Sensory panelist found ($P < 0.05$) enhanced steaks had less beef flavor (lower score), were less firm, and had less ($P < 0.05$) detectable connective tissue than non-enhanced steaks. Steak WBSF values were lower ($P < 0.05$, more tender) for enhanced steaks compared to non-enhanced steaks. Vacuum package losses were not different ($P = 0.48$) for enhanced and non-enhanced steaks. Steak pH was higher ($P < 0.05$) for enhanced steaks compared to non-enhanced steaks.

Aging × enhancement interactions ($P < 0.05$) were observed for sensory panel myofibrillar and overall tenderness, and off flavors; and percentage of cooking loss (Table 5-7). Enhanced steaks (7 or 28 d of aging) had ($P < 0.05$) higher myofibrillar and overall tenderness scores (more tender), more off-flavor (lower scores) and lower percentages of cooking loss than non-enhanced steaks aged for (7 or 28 d). Comparing the non-enhanced steaks, steaks aged for 28 d had ($P < 0.05$) higher myofibrillar tenderness scores than steaks aged for 7 d. Comparing the enhanced steaks, steaks aged for 28 d had ($P < 0.05$) higher myofibrillar scores, less off-flavors (higher score) and a higher percentage of cooking loss than steaks aged for 7 d.

Experiment 2: Main effect means for WBSF, vacuum package loss, cooking loss and pH of steer strip loin steaks aged 7 and 28 dare reported in Table 5-8. Steaks aged for 28 d had ($P < 0.05$) lower WBSF and higher pHs; and tended to have a greater percentage of vacuum package loss ($P = 0.07$) and cooking loss ($P = 0.05$) than steaks aged for 7 d.

Main effect means for WBSF, vacuum package loss, cooking loss and pH of enhanced and non-enhanced steer steaks are reported in Table 5-9. Enhanced steaks had ($P < 0.05$) lower WBSF values and higher pH values than steaks that were non-enhanced. Percentage of vacuum package losses and cooking losses were not different ($P \geq 0.17$) due to enhancement.

DISCUSSION

Cow and steer steaks aged for 7 d were brighter red and more color stable than those aged for 28 d over the 6 d of retail display. Wicklund et al. (2005) reported that strip steaks from young crossbred animals aged for 14 d, according to visual panelist, had a brighter, more cherry-red color compared to steaks aged for 21 or 28 d. However, these steaks were not displayed to determine shelf-life stability. In our study, steaks aged for 7 d had higher L* values indicating that they were lighter in color than the steaks aged for 28 d. In agreement, initial color readings of steaks determined that steaks aged for 7 d were lighter than those aged for 28 d (Wicklund et al., 2005). Steer steaks aged for 7 d had higher a* values than those aged for 28 d.

Aging of cow and steer steaks for 28 d decreased retail display life. In agreement, young heifer meat aged for 21 to 28 d was noted to have a shorter shelf-life than meat that was aged for 7 d (O'Keefe and Hood, 1980-81). These decreases in color stability after longer storage periods may be a result of less metmyoglobin reducing activity (MRA) of the muscles. Ledward (1985) reported that a muscle's enzymatic reducing activity was the most important factor determining the amount of metmyoglobin that accumulates in a cut of meat. Potentially the muscles aged for 28 d have less NAD present to aid in MRA, needed to allow meat to return to the oxymyoglobin state. Metmyoglobin reductase activity was numerically lower at 21 d of aging compared to 7 d of aging and NAD present was significantly lower for 21-d aged longissimus muscles compared to those aged 7 d (Madhavi and Carpenter, 1993).

Aging cow steaks for 7 d resulted in a juicier product that had more detectable connective tissue and higher WBSF values compared to those aged for 28 d. In disagreement, aging steaks for 14-d compared to 7-d resulted in improvement of sensory panel juiciness (Miller et al, 1997). However, in agreement tenderness, beef flavor intensity, and overall mouth feel were increased in 14 d aged steaks compared to 7 d aged steaks (Miller et al., 1997).

Steaks aged for 28 d had lower WBSF values (more tender) than those aged for 7 d. In agreement Gruber et al. (2006), found that WBSF was decreased with increased aging periods. Aging of strip steaks for 14 d compared to 7 d resulted in lower WBSF values (Miller et al., 1997). Huff and Parrish (1993) found that steaks aged for 3, 7, 14, or 28 had additional increases in tenderness with additional days of aging. Strip loin

steaks had numerical decreases in WBSF with additional d aging of steaks aged for 6, 12, 18, and 24 d (Eilers et al., 1996).

In the current study, cow steaks aged for 7 d had more sensory panel detectable connective tissue than those aged for 28 d. In agreement, Huff and Parrish (1993) reported that steaks aged for 3 d had the most detectable connective tissue and those aged for 28 d had the least detectable connective tissue. In addition, Harris et al. (1992) noted decreased amounts of connective tissue for steaks aged for 35 d compared to those aged for 0 d. However, these researchers did not report differences in connective tissue for steaks aged for 7 or 28 d.

Detectable sensory panel connective tissue in cow steaks was dramatically decreased with the inclusion of the enhancement solution. Strip steaks from cows that were enhanced had less sensory panel detectable connective tissue than cow steaks that were non-enhanced. This can be attributed to the use of bromelin in the enhancement solution allowing for the break down of collagen. In agreement, McKeith et al. (1994), reported that semitendinosus steaks injected with bromelin had less detectable connective tissue compared to control steaks that were not injected. In addition, enhanced cull cow steaks were found by sensory panelist to have less residue than non-enhanced steaks (Hoffman, 2006). However, these steaks were not enzyme enhanced.

Enhanced steaks for both cows and steers had lower WBSF (more tender) than non-enhanced steaks. Cow steaks had WBSF values that would be considered extremely tender. In addition, enhanced (with bromelin) cow steaks were more tender (lower WBSF values) than enhanced (without bromelin) steer steaks. These cow WBSF values were similar to those often found in the psoas major muscle (2.95 kg, Rhee et al., 2004), which are noted to be extremely tender. Cow longissimus steaks aged for 7 d, injected, and aged an additional 7 d were found to have lower shear force values than non-enhanced steaks aged for 14 d (Hoffman, 2006). The use of an enhancement solution containing bromelin (Kolle et al., 2004) resulted in decreased WBSF of steaks from the adductor muscle, but their decreases were not as dramatic for this muscle and others that they studied, as they were in our present study. However, these researchers used bromelin in a water solution that did not contain salt and

phosphate and they used a lower concentration of bromelin than in our study. Triceps brachii steaks from young animals injected with phosphate and salt had lower WBSF values than non-enhanced control steaks (Baublits et al., 2006). McKeith et al. (1994) reported that semitendinosus steaks injected with a solution containing bromelin resulted in decreased shear force values compared to non-enhanced controls.

Enhanced cow steaks aged for either 7 or 28 d were more tender overall as determined by a sensory panel than non-enhanced steaks aged for 7 or 28 d. In agreement, tenderness of semitendinosus steaks injected with bromelin had increased sensory panel tenderness compared to non-injected controls (McKeith et al., 1994). Injection of strip loins with a phosphate/lactate/chloride solution resulted in increased sensory tenderness and juiciness (Vote et al., 2000.) Furthermore, sensory panel tenderness and additional juiciness were increased for cow longissimus steaks that were aged 14 d and enhanced compared to non-enhanced controls (Hoffman, 2006). In addition, Baublits et al. (2005) reported that NaCl enhanced steaks received higher sensory tenderness ratings compared to non-enhanced controls. Phosphate and salt enhancement resulted in improved sensory tenderness and juiciness compared to non-enhanced controls (Baublits et al., 2006). Furthermore, the non-enhanced steaks aged for 28 d were more tender overall than non-enhanced steaks aged for 7 d. Harris et al. (1992) reported increased overall tenderness from 0 d aging to 35 d aging. Campo et al. (1999) found increases in sensory panel tenderness with additional aging periods from 1 to 21 d of aging.

It is also, important to note in our study that overall firmness, as determined by sensory panelist, was decreased in enhanced compared to non-enhanced samples. We speculate that this is a result of the inclusion of the enzyme at a greater level than was necessary. In agreement, semitendinosus steaks injected with bromelin resulted in steaks that were determined by sensory panelist to be mushy (McKeith, 1994). This indicates that the use of an enzyme may result in a product that is less firm, as a result of the degradation of connective tissue in the muscle.

While aging for 28 d compared to 7 d resulted in less desirable color and a shorter display life, tenderness of strip loin steaks from both cows and steers were improved. Injection enhancement containing an enzyme resulted in a dramatic increase

in tenderness of cow strip steaks. When cow steaks were enhanced, sensory panel tenderness was not improved by aging for 28 d compared to 7 d. Therefore, if using the combination of blade tenderization and injection enhancement containing an enzyme, aging cow muscles for 28 d may not be necessary to achieve optimal tenderness. Food service suppliers could age for fewer days when using these tenderization methodologies on longissimus muscle steaks.

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Table 5-1 Effects of aging 7 or 28 d on visual and instrumental color scores and TBARS values of longissimus steaks from fed cull cows

	Display, d							
Trait	0	1	2	3	4	5	6	SE
Visual Color								
7	3.3^{a}	3.7^{b}	3.9^{b}	4.5^{c}	4.5^{c}	4.8^{cd}	5.0^{d}	0.14
28	3.2^{a}	4.0^{b}	4.5^{c}	5.1^{d}	6.0^{e}	6.4^{f}	6.7^{f}	
Discoloration								
7	1.0^{a}	1.2^{a}	1.5^{b}	1.9^{c}	2.3^{d}	2.7^{e}	3.2^{f}	0.15
28	1.0^{a}	1.5^{b}	2.4^{d}	3.5^{g}	4.9^{h}	5.6^{i}	6.4^{j}	
L*								
7	41.8^{e}	42.0^{e}	42.0^{e}	41.7^{e}	41.8^{e}	41.6^{e}	41.1^{d}	0.57
28	44.5^{f}	41.4^{de}	40.5^{c}	39.2^{b}	38.9^{b}	37.9^{a}	37.4^{a}	
a*								
7	31.1^{h}	31.3^{h}	30.2^{h}	29.7^{gh}	29.0^{g}	27.7^{f}	26.9^{ef}	0.60
28	29.5^{gh}	27.5^{f}	25.4^{e}	21.5^{d}	19.7^{c}	16.8^{b}	14.4^{a}	
b*								
7	23.0^{h}	23.8^{h}	22.8^{gh}	22.6^{fg}	22.0^{f}	21.2^{e}	20.7^{de}	0.42
28	22.2^{e}	21.2^{e}	19.7^{d}	18.0^{c}	17.4^{c}	16.0^{b}	14.9^{a}	
Hue Angle[1]								
7	36.5^{a}	37.1^{a}	37.0^{a}	37.1^{a}	37.1^{a}	37.4^{a}	37.6^{a}	0.02
28	37.0^{a}	37.6^{a}	37.9^{a}	40.5^{b}	42.3^{c}	44.5^{d}	46.5^{e}	
Saturation Index[2]								
7	38.7^{hi}	39.3^{i}	37.9^{h}	37.3^{gh}	36.4^{g}	34.9^{f}	33.9^{ef}	0.69
28	36.9^{g}	34.8^{f}	32.2^{e}	28.0^{d}	26.4^{c}	23.3^{b}	20.9^{a}	
TBARS[3]								
7	0.13^{a}	---	---	---	---	---	0.40^{b}	0.45
28	0.19^{a}	---	---	---	---	---	1.0^{b}	

[1]Calculated using the equation: Hue Angle = $(b^*/a^*)\tan^{-1}$.
[2]Calculated using the equation: Saturation Index = $(a^{*2} + b^{*2})^{1/2}$.
[3]Thiobarbituric Acid Reactive Substances
[abcdefghij]Within a trait, means without a common superscript letter differ ($P < 0.05$).

Table 5-2 Effects of aging 7 or 28 d, on retail display for 6 d on visual and instrumental color scores of longissimus steaks from fed steers

	Display, d							
Trait	0	1	2	3	4	5	6	SE
Visual Color								
7	3.3^{a}	3.5^{a}	4.0^{b}	4.4^{c}	4.8^{d}	5.7^{f}	6.4^{gh}	0.16
28	3.0^{a}	3.4^{a}	4.2^{bc}	5.3^{e}	6.1^{g}	6.6^{h}	6.6^{h}	
Discoloration								
7	1.0^{a}	1.4^{a}	1.7^{b}	2.3^{c}	3.4^{d}	4.9^{e}	5.7^{f}	0.15
28	1.0^{a}	1.1^{a}	1.8^{b}	3.5^{d}	5.1^{e}	6.0^{fg}	6.4^{g}	
a*								
7	28.2^{hi}	29.0^{i}	25.7^{fg}	24.4^{efg}	22.5^{de}	18.3^{bc}	12.7^{a}	0.64
28	26.2^{fgh}	26.3^{gh}	24.2^{ef}	20.6^{cd}	16.6^{b}	13.9^{a}	12.8^{a}	
Hue Angle[1]								
7	35.8^{a}	36.7^{ab}	37.9^{abc}	38.5^{abc}	39.8^{cd}	44.5^{e}	52.0^{g}	1.05
28	38.5^{abc}	38.9^{bc}	39.9^{cd}	42.4^{de}	47.5^{f}	51.0^{g}	52.0^{g}	
Saturation Index[2]								
7	34.8^{hi}	36.2^{i}	32.6^{fg}	31.1^{ef}	29.2^{de}	25.2^{bc}	20.1^{a}	0.93
28	33.4^{fgh}	33.7^{ghi}	31.4^{f}	27.6^{cd}	24.1^{b}	21.7^{a}	20.6^{a}	

[1]Calculated using the equation: Hue Angle = $(b^*/a^*)\tan^{-1}$.
[2]Calculated using the equation: Saturation Index = $(a^{*2} + b^{*2})^{1/2}$.
^{abcdefghi}Within a row, means without a common superscript letter differ ($P < 0.05$).

Table 5-3 Main effect means of aging 7 or 28 d for steer steaks displayed for 6 d on L*, b* and TBARS values

	Aging			
Trait	7 d	28 d	SE	P-value
L*	43.9	43.7	0.58	0.83
b*	18.9	18.5	0.31	0.39
TBARS[1]	0.71	0.68	0.06	0.75

[1]Thiobarbituric Acid Reactive Substances.

Table 5-4 Main effect means of d of display 0 to 6 for steer steaks aged 7 or 28 d on L*, b* and TBARS values

	Display, d							
Trait	0	1	2	3	4	5	6	SE
L*	45.9^{d}	45.5^{d}	44.2^{c}	43.8^{c}	42.9^{b}	42.7^{b}	41.8^{a}	0.45
b*	20.5^{d}	21.4^{e}	20.0^{d}	18.8^{c}	18.0^{c}	16.8^{b}	15.7^{a}	0.32
TBARS[1]	0.16^{b}	---	---	---	---	---	1.2^{a}	0.05

[1]Thiobarbituric Acid Reactive Substances.
^{abcde}Within a row, means without a common superscript letter differ ($P < 0.05$)

Table 5-5 Sensory panel traits and Warner-Bratzler shear force (WBSF) for cull cow meat aged for 7 or 28 d

Trait	7 d	28 d	SE	P-value
Number	31	31		
Juiciness[1]	5.5	5.2	0.07	0.002
Beef Flavor[2]	5.1	5.0	0.04	0.06
Connective Tissue[3]	6.3	6.7	0.07	<0.001
Firmness[4]	5.0	4.6	0.08	0.004
WBSF, kg	3.7	2.9	0.10	<0.001
Vacuum Package Loss, %[5]	2.6	2.7	0.08	0.43
pH	5.7	5.8	0.01	<0.001

[1]Juiciness evaluated on an 8 point scale 8 = extremely juicy, 1 = dry.
[2]Beef flavor evaluated on an 8 point scale 8 = extremely intense, 1 = extremely bland.
[3]Connective tissue evaluated on an 8 point scale 8 = none, 1 = abundant.
[4]Firmness evaluated on an 8 point scale 8 = extremely firm, 1 = extremely soft.
[5]Vacuum package loss was calculated by 100 × (thawed steak in package weight – thawed steak weight)/thawed steak in package weight.

Table 5-6 Injection main effect means for sensory panel traits and Warner-Bratzler shear force (WBSF) of cull cow meat aged for 7 or 28 d

Trait	NE[1]	ENH[2]	SE	P-value
Number	31	31		
Juiciness[3]	5.4	5.3	0.07	0.10
Beef Flavor[4]	5.4	4.6	0.04	<0.001
Connective Tissue[5]	5.6	7.3	0.07	<0.001
Firmness[6]	6.2	3.5	0.08	<0.001
WBSF, kg	4.7	1.9	0.10	<0.001
Vacuum Package Loss, %[7]	2.6	2.7	0.08	0.48
pH	5.7	5.9	0.01	<0.001

[1]NE = Non-enhanced steaks.
[2]ENH = Enhanced steaks.
[3]Juiciness evaluated on an 8 point scale 8 = extremely juicy, 1 = dry.
[4]Beef flavor evaluated on an 8 point scale 8 = extremely intense, 1 = extremely bland.
[5]Connective tissue evaluated on an 8 point scale 8 = none, 1 = abundant.
[6]Firmness evaluated on an 8 point scale 8 = extremely firm, 1 = extremely soft.
[7]Vacuum package loss was calculated by 100 × (thawed steak in package weight – thawed steak weight)/thawed steak in package weight.

Table 5-7 Injection × aging interaction means for sensory panel traits of cull cow meat aged for 7 or 28 d

Trait	7d NE[1]	28d NE[1]	7d ENH[2]	28d ENH[2]	SE
Number	31	31	31	31	
Myofibrillar Tenderness[3]	4.2[a]	4.9[b]	7.3[c]	7.6[d]	0.11
Overall Tenderness[3]	4.4[a]	5.0[b]	7.6[c]	7.6[c]	0.15
Off-Flavor[4]	6.9[c]	6.6[c]	5.7[a]	5.9[b]	0.07
Cooking Loss, %[5]	29.4[c]	29.4[c]	26.3[a]	28.4[b]	0.62

[1]NE = Non-enhanced.
[2]ENH = Enhanced.
[3]Myofibrillar and overall tenderness evaluated on an 8 point scale 8 = extremely tender, 1 = extremely tough.
[4]Off-flavor evaluated on an 8 point scale 8 = none, 1 = extremely intense.
[5]Cooking loss was calculated by 100 × (thawed steak weight – cooked steak weight)/thawed steak weight.
[abcd]Within a row, means without a common superscript letter differ (P < 0.05).

Table 5-8 Main effect means for Warner–Bratzler shear force (WBSF), pH and package loss for steer strip loins aged for 7 or 28 d

Trait	7d	28d	SE	P-value
Number	24	24		
WBSF, kg	3.4	2.8	0.10	< 0.001
Vacuum Package Loss, %[1]	2.5	2.6	0.79	0.07
Cooking Loss, %[2]	26.3	24.6	0.63	0.05
pH	5.7	5.8	0.01	<0.001

[1]Vacuum package loss calculated by 100 × (thawed steak in package weight – thawed steak weight)/thawed steak in package weight.
[2]Cooking loss was calculated by 100 × (thawed steak weight – cooked steak weight)/thawed steak weight.

Table 5-9 Main effect means for Warner–Bratzler shear force (WBSF), pH and package loss for enhanced steer steaks

Trait	NE	ENH	SE	P-value
Number	24	24		
WBSF, kg	3.9	2.3	0.09	< 0.001
Vacuum Package Loss, %[3]	2.5	2.6	0.01	0.43
Cooking Loss, %[4]	26.0	24.9	0.61	0.17
pH	5.7	5.8	0.01	< 0.001

[1]NE = Non-enhanced steaks.
[2]ENH = Enhanced steaks.
[3]Vacuum package loss calculated by 100 × (thawed steak in package weight – thawed steak weight)/thawed steak in package weight.
[4]Cooking loss was calculated by 100 × (thawed steak weight – cooked steak weight)/thawed steak weight.

CHAPTER 6 - Influence of 7 and 28 d aging of fed mature cow and steer knuckle, *gluteus medius* and *infraspinatus* muscles that were blade tenderized and injection enhanced

Shanna Hutchison

Department of Animal Sciences and Industry
Kansas State University
Manhattan, Kansas 66502

ABSTRACT

Thirty-one fed mature cows and twenty-four fed steer knuckle, *gluteus medius*, and *infraspinatus* muscles were used to determine the effects of aging 7 or 28 d on tenderness and cooking losses of blade tenderization and injection enhanced steaks. Muscles were removed from both carcass sides and randomly assigned to 7 or 28 d of aging. Following the aging period, muscles were frozen until further processing. All, muscles were thawed, passed once through a blade tenderizer and injected to retain a 10% pump. The enhancement solution contained 0.5% sodium chloride, 0.35% phosphate and 0.023% bromelin (cow muscles only). No differences ($P > 0.05$) were reported in Warner-Bratzler shear force (WBSF) for knuckle steaks from either cows or steers. However, the *rectus femoris* required less force to shear ($P < 0.05$) (more tender) than the *vastus lateralis* for steaks from both cows and steers. *Gluteus medius* steaks from cows aged for 28 d had ($P < 0.05$) lower WBSF values than those aged for 7 d. For *gluteus medius* steaks from steers, steaks aged for 28 d tended ($P = 0.06$) to have lower WBSF values than steaks aged for 7 d. Cow *infraspinatus* steaks had similar ($P > 0.05$) WBSF for steaks aged 7 and 28 d. However, steer *infraspinatus* steaks aged for 28 d had lower ($P < 0.05$) WBSF values than those aged for 7 d. Even though aging improved tenderness for the gluteus medius from cows and steers, and the infraspinatus from steers, WBSF values for all enhanced muscles were relatively low indicating a tender product. Therefore, additional aging of muscles that are blade tenderized and enhanced may not be necessary to achieve desirable tenderness.

Key Words: Cow, Steer, Aging, Enhancement, Tenderness

INTRODUCTION

Cull cows accounted for approximately 5 million of the 31-million head of cattle harvested in the United States in 2005 (USDA, 2006). However, meat from mature cull cows tends to have inferior palatability traits compared to meat from young cattle (Tuma et al., 1963; Dikeman and Tuma, 1971). Therefore, steaks from fed cows are often tenderized postmortem.

National beef tenderness surveys (Morgan et al. 1991; Brooks et al., 2000) have indicated that there is a large amount of variability in tenderness of muscles in retail and food service settings. Large emphasis has recently been placed on the variability in beef tenderness. This is a result of the increasing number of consumers that can differentiate tender from tough meat, and those that are willing to pay a premium for tender beef (Miller et al., 2001). Several value-added approaches including new fabrication techniques have been utilized to increase demand for cuts from the chuck and round (NCBA, 2001). Some subprimals that have been identified as having the potential to be upgraded for use as steaks include the *infraspinatus* (**INF**) from the chuck top blade and round knuckle (**KN**). The *gluteus medius* (**GM**) from the top sirloin butt is commonly used in restaurants as a medium-priced steak cut. In addition, the GM has problems with respect to consistency of tenderness (McKeith et al., 1981). These subprimals from fed cows have the potential to be upgraded using several postmortem technologies.

Postmortem technologies of aging, injection enhancement, and blade tenderization are commonly used in industry to decrease the variation in tenderness and improve palatability of several beef cuts. Aging of beef cuts increases tenderness, strip steaks aged for 14 d compared to 7 d had lower WBSF values (more tender) (Miller et al., 1997). The utilization of enhancement solutions has been noted to improve beef sensory tenderness and juiciness (Vote et al., 2000; McGee et al., 2003) and to produce a product that is more acceptable to consumers (Robbins et al., 2003). Blade tenderization improves tenderness (George-Evins et al., 1999), by disruption of the skeletal tissue (Parrish, 1977). Individually or a combination of these technologies can be used to improve steak tenderness.

Meat industry suppliers utilize variable aging times depending upon their customer specifications. Variable aging times are commonly used in combination with blade tenderization and injection enhancement solutions. However, aging of meat for extended periods of time results in increased cooler space needed, increased labor, and delayed returns on investments. Extended aging periods, when used in combination with blade tenderization and injection enhancement may not be necessary. Therefore, the objective of this study was to determine if aging time (7 or 28 d) of blade tenderized and injection-enhanced knuckle, top blade, and top sirloin affects tenderness of steaks from fed cull cows and steers.

MATERIALS AND METHODS

Animals

Experiment 1: Thirty-one cull cows were fed a high-energy diet for 60 d prior to harvest at the Kansas State University Meat Laboratory. Carcass quality and yield grade data were taken at 48 h postmortem and carcasses were fabricated starting at 72 h postmortem. Fed-cow performance, carcass traits, and carcass composition are reported by Harborth (2006).

Experiment 2: Twenty-four steers were fed a high-energy diet prior to harvest at the Kansas State University Meat Laboratory. Carcass quality and yield grade data were taken at 48 h postmortem and carcasses were fabricated into subprimal cuts starting at 72 h postmortem. Steer performance, carcass traits and carcass composition are reported by Winterholler (2006).

Subprimal Fabrication/Processing

Experiment 1: Beef round, knuckle (tip), peeled (**KN**, NAMP # 167A); loin, top-sirloin butt (NAMP # 184); and chuck shoulder, top blade (NAMP # 114D) subprimals were fabricated in accordance with the National Association of Meat Processors guidelines (NAMP, 1997). Subprimals from both carcass sides of 31 fed cows were weighed, and vacuum packaged in Prime Source Vacuum Pouches (Koch Equipment, Kansas City, MO). Subprimals from each carcass side were randomly assigned to 7 or 28 d of

vacuum aging at a cooler temperature of 0 ± 2ºC. On d 7 or 28, subprimals were frozen at -40ºC until further processing.

All processing was conducted in the Meat Laboratory processing facility under chilled conditions (4 ± 1ºC) at Kansas State University. At 36 h prior to processing, subprimals were thawed at a room temperature of (2.2 ± 2ºC), removed from packages and weighed to determine percentage of freeze-thaw loss. Percentage of freeze-thaw loss was calculated by 100 × (initial subprimal weight – thawed subprimal weight) / initial subprimal weight. The subprimals were passed once through a blade tenderizer (model TC700, Ross Industries Inc., Midland, VA) and then passed through a Wolftec multiple-needle injector (model N30; Wolftec, Inc.; Werther, Germany). Subprimals were injected at 10% of their weight with a solution containing 0.35% phosphate (BRIFISOL 85 Instant; BK Giulini, Corp.; Simi Valley, CA), 0.5% salt, and 0.023% Bromelin 1000 (Excalibur Seasoning, Perkin, IL). Bromelin was included in the formulation for the cow subprimals to breakdown collagen cross-linking due to increased animal age. The subprimals were allowed a five min drip time vacuum packaged and refrozen at -40ºC. Frozen subprimals were removed from the freezer and three 2.54-cm thick steaks were cut with a BIRO band saw (model 3334, The BIRO Mfg. Co.; Marblehead, OH). Steaks from each subprimal were randomly assigned to Warner-Bratzler shear force (**WBSF**) and pH analysis. Two 2.54-cm thick steaks were removed from the cranial end of the KN before three 2.54-cm thick steaks representing the center portion of the KN were removed for analysis. For the top sirloin butt, two 2.54-cm thick steaks from the cranial portion of the GM were removed and two 2.54-cm thick steaks (near the center of the subprimal) were removed for analysis. Two 2.54-cm thick INF steaks were removed from the dorsal end of the top blade before two 2.54-cm thick steaks were removed for analysis.

Experiment 2: The same subprimals used in experiment 1 were utilized in experiment 2. Subprimals (knuckle, top sirloin butt, and top blade) were removed from both carcass sides of 24 steer carcasses. Procedures used were identical to those in experiment 1 except the injection solution did not contain Bromelin. The subprimals were injected at 10% of their weight with a solution containing 0.35% phosphate (BRIFISOL 85 Instant;

BK Giulini, Corp.; Simi Valley, CA) and 0.5% salt. Bromelin was not added to the formulation for steer subprimals as steers were less than 24 mon of age.

Warner-Bratzler Shear Force

Steaks (2.54-cm thick) for WBSF analysis were cooked in a dual-air-flow, convection gas oven (model DFG-201; G. S. Blodgett Co., Inc., Burlington, VA) preheated to 163ºC. Steaks were cooked to 40ºC, turned, and cooked to a final internal temperature of 70ºC. Internal temperature was monitored using a 30-gauge, copper-constantan type T thermocouple inserted into the geometric center of each steak and attached to a Doric temperature recorder (model 205; Vas Engineering, San Francisco, CA). After, cooking steaks were cooled and re-weighed to calculate cooking loss percentages and then stored overnight at 1°C, before 1.27-cm cores were removed parallel to the muscle fiber orientation. Then, each core was sheared once perpendicular to the muscle fibers using the Warner-Bratzler attachment to the Instron Universal Testing Machine (model 4201; Instron Corp., Canton, MA) with a 50 kg load cell and a crosshead speed of 250 mm/min. The six core values for the GM and INF steak samples were averaged for statistical analysis. Cores (n=4) from each muscle were averaged for statistical analysis of the *rectus femoris* (**RF**) and *vastus lateralis* (**VL**) muscles within the KN steaks. Vacuum package loss was calculated as 100 × [((thawed steak weight in the bag - bag weight) – steak weight prior to cooking))]/(thawed steak weight in bag - bag weight). Percentage of cooking loss was calculated as 100 × (thawed steak weight – cooked steak weight)/thawed steak weight.

pH analysis

One steak from each muscle was cut to determine pH of the samples. The steaks were left frozen until removal for pH determination. Steaks were thawed for 48 h at 4.4 ± 1 ºC. A Meat Probes Incorporated (MPI) pH meter with glass probe electrode (Meat Probes Inc., Topeka, KS) was used to determine sample pH. Three readings from each steak were recorded and averaged to determine sample pH.

Statistical Analysis

For the GM and INF steaks data were analyzed as a completely randomized block design using the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC) with cow utilized as a blocking factor. The model statement included aging. The KN was analyzed as a split plot in a completely randomized block design with cow used as the blocking factor. Aging period was used as the whole plot and muscle (RF and VL) was the subplot. The model included aging, muscle and aging × muscle. Satterthwaite adjustments were used for the degrees of freedom. Means were separated ($P < 0.05$) using the Least Significant Difference procedure when the respective F-test were significant ($P < 0.05$).

RESULTS

Experiment 1

Knuckle: No differences ($P \geq 0.06$) due to aging (7 or 28 d) were detected for KN steak traits (Table 6-1). However, the RF had lower shear force values ($P < 0.05$) than the VL. Also, steaks aged 28 d tended ($P = 0.09$) to have higher pH values than steaks aged for 7 d.

Gluteus medius: *Gluteus medius* steaks aged for 28 d had lower ($P < 0.05$) WBSF values than those aged for 7 d Table 6-1. No differences ($P > 0.05$) were observed for freeze-thaw, vacuum package, or cooking loss of GM steaks. *Gluteus medius* muscles aged for 7 or 28 d had similar ($P > 0.05$) pH values.

Infraspinatus: Traits for the INF muscle are reported in Table 6-1. No differences ($P \geq 0.09$) were noted in WBSF values. There were no freeze-thaw, vacuum package, cooking loss or pH differences ($P > 0.05$) for steaks from the INF. However, steaks aged 28 d tended to ($P = 0.09$) to have higher pH values than steaks aged 7 d.

Experiment 2

Knuckle: Steer KN data is reported in Table 6-2. Warner-Bratzler shear force, cooking losses, vacuum package losses or pH of round tip steaks were not different ($P \geq 0.05$) due to aging (7 or 28 d). However, 28 d aged KN steaks had greater ($P < 0.05$) freeze-thaw losses than those aged for 7 d. The RF was more ($P < 0.05$) tender than the VL.

Gluteus medius: Warner-Bratzler shear force values and vacuum package losses of top sirloin steaks were not ($P > 0.05$) affected (Table 6-2) by postmortem aging of 7 or 28 d. Steaks that were aged for 28 days had higher ($P < 0.05$) cooking losses than those that were only aged for 7 days. *Gluteus medius* muscles aged for 7 d had ($P \geq 0.05$) higher pH values than steaks aged 28 d.

Infraspinatus: Top blade steaks that were aged for 28 d required less force to shear ($P < 0.05$) than those aged for 7 d (Table 6-2). Cooking, freeze-thaw, package losses and pH were not different ($P > 0.05$) due to d of aging of the INF muscle.

DISCUSSION

In our study, aging cow and steer KN steaks for 7 or 28 d resulted in the similar WBSF values. However, the RF within the KN was found to be more tender than the VL. While, not compared statistically Gruber et al. (2006) also found the RF required less force to shear than the VL at 2, 4, 6, 10, 14, 21, and 28 d of aging. However, these researchers only used aging as a postmortem tenderization technique.

Gluteus medius steaks from cows and steers aged for 28 d resulted in lower WBSF values than those aged for 7 d. In agreement, steaks from the GM aged for 21 d were found to have lower WBSF values compared to those aged 7 or 14 d (George-Evins et al., 2004). Gruber and others (2006) noted that GM tenderness was numerically decreased with additional aging time from 2 to 28 d. Furthermore, Harris and others (1992) reported that top sirloin steaks showed no significant increases in overall tenderness until 28 d of storage. In contrast, Baublits et al. (2006) reported that there were no differences in WBSF values in steaks aged for 2, 14 or 28 d after injection enhancement in young fed animals. Furthermore, other researchers have not detected improvements in WBSF for top sirloin steaks that were aged compared to those that were not aged (Savell et al., 1982; Harris et al., 1992).

In our study, aging the INF muscle from cows for 28 d did not result in increased tenderness. However, steer INF muscles aged for 28 d resulted in lower WBSF values than 7 d of aging. In agreement, Gruber and others (2006) reported that with additional aging *infraspinatus* WBSF values were decreased for 2, 4, 6, 10, 14, 21, and 28 d of aging. Bratcher and others (2005) reported that aging of *infraspinatus* muscles resulted

in decreased WBSF values of steaks sampled. Jones et al. (2005) reported that the INF had 18.26 mg/g of collagen. However, in our study the heavy connective tissue through the center of the muscle was removed.

In agreement with this study blade tenderized and enzyme injection enhanced cow strip loin steaks were extremely tender (Chapter 5). Sensory panelist and WBSF values from that study noted steaks were very tender. In addition, cow steaks that were enzyme tenderized resulted in WBSF values comparable to young steer steaks.

Consistently the psoas major muscle is noted as the most tender beef muscle. Rhee et al. (2004) noted that the psoas major aged for 14 d compared to other muscles had the lowest WBSF (most tender) with 2.95 kg of shear force. In addition, they noted that the WBSF for INF was 3.27 kg; RF, 3.86 kg; longissimus 3.99, kg; and GM, 4.44 kg, respectively. In our study, steaks that were blade tenderized and injection enhanced resulted in low shear values.

All steaks in this study were blade tenderized and enhanced with an injection solution. This process most likely had a greater impact on tenderness (WBSF) than aging. The use of bromelin in the injection solution for cow steaks (Exp. 1) resulted in numerically lower WBSF values (more tender) for all muscles than those observed for young steer steaks (Exp. 2). The bromelin was included in the injection solution to breakdown the anticipated greater collagen cross-linking in cows steaks. No significant differences were observed for enhanced cow and steer KN steaks and cow INF steaks. However, aging for 28 d versus 7 d did significantly decrease WBSF for enhanced cow and steer GM steaks and steer INF steaks. This additional decrease due to aging may not be necessary considering that all steaks were very tender. Therefore, the 21 d of additional aging to 28 s may not be necessary to result in acceptable tenderness. However, to maximize tenderness (reduce WBSF), aging does reduce WBSF for the GM steaks from both cows and steers, and INF steaks from steers.

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Table 6-1 Effects of days of aging on Warner-Bratzler shear force (WBSF) and moisture loss from the beef knuckle (round tip), *gluteus medius* and *infraspinatus* of fed cull cows

	Days of Aging			
Trait	7	28	SE	P-value
Knuckle				
WBSF, kg[1]	2.93	2.83	0.11	0.53
Freeze-Thaw Loss, %[2]	4.3	4.6	0.25	0.39
Vacuum Package Loss, %[3]	2.3	2.4	0.04	0.18
Cooking Loss, %[4]	34.1	32.8	0.97	0.33
pH	5.88	5.92	0.018	0.09
Gluteus medius				
WBSF, kg	2.11	1.48	0.121	0.004
Freeze-Thaw Loss, %	5.3	6.1	0.377	0.10
Vacuum Package Loss, %	2.5	2.5	0.070	0.83
Cooking Loss, %	32.0	31.8	0.931	0.85
pH	5.78	5.84	0.011	0.004
Infraspinatus				
WBSF, kg	1.66	1.69	0.105	0.81
Freeze-Thaw Loss, %	3.7	3.8	0.209	0.71
Vacuum Package Loss, %	3.6	3.7	0.113	0.46
Cooking Loss, %	27.6	25.4	1.10	0.17
pH	5.88	5.92	0.018	0.09

[1]Within the knuckle, the *rectus femoris* muscle (2.60 kg) had lower ($P < 0.05$) WBSF than the *vastus lateralis* muscle (3.17 kg).
[2]Freeze-thaw loss = 100 × (initial weight -thaw weight/initial weight).
[3]Vacuum package loss was calculated by 100 × (thawed steak in package weight – thawed steak weight)/thawed steak in package weight.
[4]Cooking loss was calculated by 100 × (thawed steak weight – cooked steak weight)/thawed steak weight.

Table 6-2 Effects of days of aging on Warner-Bratzler shear force (WBSF) and moisture loss from the beef knuckle (round tip), *gluteus medius* and *infraspinatus* of fed steers

	Days of Aging			
Trait	7	28	SE	P-value
Knuckle				
WBSF, kg[1]	3.07	2.99	0.131	0.69
Freeze-Thaw Loss, %	6.2	6.9	0.254	0.03
Vacuum Package Loss, %	2.3	2.3	0.057	0.95
Cooking Loss, %	31.7	32.0	0.133	0.79
pH	5.91	5.87	0.016	0.06
Gluteus medius				
WBSF, kg	2.87	2.57	0.115	0.06
Freeze-Thaw Loss, %	8.8	8.2	0.333	0.12
Vacuum Package Loss, %	2.6	2.5	0.058	0.14
Cooking Loss, %	31.3	33.8	0.680	0.01
pH	5.79	5.81	0.009	0.05
Infraspinatus				
WBSF, kg	2.08	1.88	0.075	0.03
Freeze-Thaw Loss, %	4.9	4.2	0.540	0.21
Vacuum Package Loss, %	3.9	3.9	0.118	0.61
Cooking Loss, %	23.3	24.7	0.500	0.07
pH	6.04	6.05	0.012	0.74

[1]Within the knuckle, the *rectus femoris* muscle (2.75 kg) had lower ($P < 0.05$) WBSF than the *vastus lateralis* muscle (3.31 kg).
[2]Freeze-thaw loss = 100 × (initial weight -thaw weight/initial weight).
[3]Vacuum package loss was calculated by 100 × (thawed steak in package weight – thawed steak weight)/thawed steak in package weight.
[4]Cooking loss was calculated by 100 × (thawed steak weight – cooked steak weight)/thawed steak weight.

Appendix A - Carcass data descriptors associated with Chapter 3

Color of Lean	
Very light cherry red	7
Cherry red	6
Slightly dark red	5
Moderately dark red	4
Dark red	3
Very dark red	2
Black	1

Texture of Marbling	
Fine	3
Medium	2
Coarse	1

Texture of Lean	
Very fine	7
Fine	6
Moderately fine	5
Slightly fine	4
Slightly coarse	3
Coarse	2
Very coarse	1

Firmness of Lean	
Very firm	7
Firm	6
Moderately firm	5
Slightly soft	4
Soft	3
Very soft	2
Extremely soft	1

Maturity

A-00	100
B-00	200
C-00	300
D-00	400
E-00	500

Muscle Score

Extremely heavy muscled	5
Slightly heavy muscled	4
Average muscled	3
Slightly light muscled	2
Extremely light muscled	1

Fat Color

Canary yellow	5
Yellow	4
Slightly yellow	3
White	2
Bleached white	1

Appendix B - Color panel descriptors associated with Chapters 4 and 5

Muscle Color Score Scale

1= Very bright red

2= Bright red

3= Dull red

4= Slightly dark red

5= Slightly dark red to reddish tan

5.5= Borderline acceptable

6= Moderately dark red to tannish red

7= Tan to brown

***May be used in half-point increments**

Discoloration Scale (%Metmyoglobin)

1 = None (0%)

2 = Slight discoloration (1-19%)

3 = Small discoloration (20-39%)

4 = Modest discoloration (40-59%)

5 = Moderate discoloration (60-79%)

6 = Extensive discoloration (80-99%)

7 = Total discoloration (100%)

***Use in whole point increments only**

Appendix C - All Treatment Means for Chapter 5

Table C-1 Treatment means for the effects of aging 7 or 28 d on visual and instrumental color scores and TBARS values of longissimus steaks from fed cull cows

	Display, d								
Trait/Aging Time	0	1	2	3	4	5	6	SE	P-value
Visual Color									
7 d	3.3	3.7	3.9	4.5	4.5	4.8	5.0	0.1398	<.0001
28 d	3.2	4.0	4.5	5.1	6.0	6.4	6.7		
Discoloration									
7 d	1.0	1.2	1.5	1.9	2.3	2.7	3.2	0.1492	<.0001
28 d	1.0	1.5	2.4	3.5	4.9	5.6	6.4		
L*									
7 d	41.8	42.0	42.0	41.7	41.8	41.6	41.1	0.5743	<.0001
28 d	44.5	41.4	40.5	39.2	38.9	37.9	37.4		
a*									
7 d	31.1	31.3	30.2	29.7	29.0	27.7	26.9	0.6043	<.0001
28 d	29.5	27.5	25.4	21.5	19.7	16.8	14.4		
b*									
7 d	23.0	23.8	22.8	22.6	22.0	21.2	20.7	0.4161	<.0001
28 d	22.2	21.2	19.7	18.0	17.4	16.0	14.9		
Hue Angle									
7 d	36.5	37.1	37.0	37.1	37.1	37.4	37.6	0.01822	<.0001
28 d	37.0	37.6	37.9	40.5	42.3	44.5	46.5		
Saturation Index									
7 d	38.7	39.3	37.9	37.3	36.4	34.9	33.9	0.6900	<.0001
28 d	36.9	34.8	32.2	28.0	26.4	23.3	20.9		
TBARS									
7 d	0.13	---	---	---	---	---	0.40	0.4472	<.0001
28 d	0.19	---	---	---	---	---	1.0		

Table C-2 Treatment means for the effects of aging 7 or 28 d on visual and instrumental color scores and TBARS values of longissimus steaks from fed steers

	Display, d								
Trait/Aging Time	0	1	2	3	4	5	6	SE	P-value
Visual Color									
7 d	3.3	3.5	4.0	4.4	4.8	5.7	6.4	0.1573	<.0001
28 d	3.0	3.4	4.2	5.3	6.1	6.6	6.6		
Discoloration									
7 d	1.0	1.4	1.7	2.3	3.4	4.9	5.7	0.1492	<.0001
28 d	1.0	1.1	1.8	3.5	5.1	6.0	6.4		
L*									
7 d	45.7	45.9	44.1	43.9	43.0	43.0	41.8	0.6401	0.69
28 d	46.0	45.2	44.3	43.7	42.7	42.5	41.8		
a*									
7 d	28.2	29.0	25.7	24.4	22.5	18.3	12.7	0.9098	0.002
28 d	26.2	26.3	24.2	20.6	16.6	13.9	12.8		
b*									
7 d	20.4	21.6	19.9	19.3	18.6	17.1	15.4	0.4518	0.13
28 d	20.6	21.1	20.0	18.3	17.4	16.4	15.9		
Hue Angle									
7 d	35.8	36.7	37.9	38.5	39.8	44.5	52.0	1.0452	0.0002
28 d	38.5	38.9	39.9	42.4	47.5	51.0	52.0		
Saturation Index									
7 d	34.8	36.2	32.6	31.1	29.2	25.2	20.1	0.9254	0.009
28 d	33.4	33.7	31.4	27.6	24.1	21.7	20.6		
TBARS									
7 d	0.13	---	---	---	---	---	0.40	0.0767	0.38
28 d	0.19	---	---	---	---	---	1.0		

Table C-3 Treatment means for cow sensory panel, Warner-Bratzler shear force (WBSF), moisture loss and pH for fed cull cows

Aging	7		28		SE	P-value
Injection	No	Yes	No	Yes		
Trait						
Myofibrillar Tenderness	4.2	7.3	5.0	7.6	0.10	0.0036
Juiciness	5.6	5.4	5.3	5.2	0.09	0.78
Beef Flavor	5.5	4.7	5.4	4.6	0.05	0.49
Connective Tissue	5.4	7.3	5.8	7.5	0.08	0.07
Overall Tenderness	4.32	7.6	5.1	7.6	0.16	0.02
Firmness	6.3	3.7	6.0	3.3	0.11	0.38
Off-Flavor	6.9	5.7	6.8	5.9	0.07	0.02
WBSF, kg	5.2	2.2	4.2	1.7	0.14	0.07
Vacuum Package Loss, %	2.5	2.7	2.6	2.7	0.11	0.82
Cooking Loss, %	29.4	26.3	29.4	28.4	0.62	0.05
pH	5.7	5.8	5.7	5.9	0.01	1.0

Table C-4 Treatment means for steer Warner-Bratzler shear force (WBSF), moisture loss and pH

Aging	7		28		SE	P-value
Injection	No	Yes	No	Yes		
WBSF, kg	4.3	2.5	3.5	2.1	0.11	0.06
Vacuum Package Loss, %	2.4	2.5	2.6	2.7	0.11	0.71
Cooking Loss, %	27.6	25.0	24.3	24.8	0.83	0.05
pH	5.6	5.8	5.7	5.8	0.01	0.21

Appendix D - Sensory Panel Descriptors Chapter 4

Myofibrillar Tenderness

1 = Extremely tough
2 = Very tough
3 = Moderately tough
4 = Slightly tough
5 = Slightly tender
6 = Moderately tender
7 = Very tender
8 = Extremely tender

Juiciness

1 = Extremely dry
2 = Very dry
3 = Moderately dry
4 = Slightly dry
5 = Slightly juicy
6 = Moderately juicy
7 = Very juicy
8 = Extremely juicy

Beef Flavor Intensity

1 = Extremely bland
2 = Very bland
3 = Moderately bland
4 = Slightly bland
5 = Slightly intense
6 = Moderately intense
7 = Very intense
8 = Extremely juicy

Connective Tissue Amount

1 = Abundant
2 = Moderately abundant
3 = Slightly abundant
4 = Moderate
5 = Slight
6 = Traces
7 = Practically none
8 = None

Overall Tenderness

1 = Extremely tough
2 = Very tough
3 = Moderately tough
4 = Slightly tough
5 = Slightly tender
6 = Moderately tender
7 = Very tender
8 = Extremely tender

Off-Flavor Intensity

1 = Abundant
2 = Moderately abundant
3 = Slightly abundant
4 = Moderate
5 = Slight
6 = Traces
7 = Practically none
8 = None

Appendix E - Sensory Panel Descriptors Chapter 5

Myofibrillar Tenderness
1 = Extremely tough
2 = Very tough
3 = Moderately tough
4 = Slightly tough
5 = Slightly tender
6 = Moderately tender
7 = Very tender
8 = Extremely tender

Juiciness
1 = Extremely dry
2 = Very dry
3 = Moderately dry
4 = Slightly dry
5 = Slightly juicy
6 = Moderately juicy
7 = Very juicy
8 = Extremely juicy

Beef Flavor Intensity
1 = Extremely bland
2 = Very bland
3 = Moderately bland
4 = Slightly bland
5 = Slightly intense
6 = Moderately intense
7 = Very intense
8 = Extremely juicy

Connective Tissue Amount
1 = Abundant
2 = Moderately abundant
3 = Slightly abundant
4 = Moderate
5 = Slight
6 = Traces
7 = Practically none
8 = None

Overall Tenderness
1 = Extremely tough
2 = Very tough
3 = Moderately tough
4 = Slightly tough
5 = Slightly tender
6 = Moderately tender
7 = Very tender
8 = Extremely tender

Overall Firmness
1 = Extremely soft
2 = Very soft
3 = Moderately soft
4 = Slightly soft
5 = Slightly firm
6 = Moderately firm
7 = Very firm
8 = Extremely firm

Off-Flavor Intensity
1 = Abundant
2 = Moderately abundant
3 = Slightly abundant
4 = Moderate
5 = Slight
6 = Traces
7 = Practically none
8 = None