INFLUENCE OF ENHANCEMENT AND BLADE TENDERIZATION ON BEEF SUBPRIMALS OF KNOWN CATERGORIES OF TENDERNESS.

By

MEGAN LEIGH MCMICHAEL

Bachelor of Science in Animal Science

Oklahoma State University

Stillwater, OK

2004

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2005

INFLUENCE OF ENHANCEMENT AND BLADE

TENDERIZATION ON BEEF SUBPRIMALS

OF KNOWN CATEGORIES

OF TENDERNESS

Thesis Approved:

Dr. J. Brad Morgan

Thesis Adviser

Dr. Christina DeWitt

Dr. Roy Escoubas

Dr. A. Gordon Emslie

Dean of the Graduate College

ACKNOWLEDGEMENTS

First I would like to thank Dr. Brad Morgan for allowing me to continue my education under his guidance and for accepting me into graduate school. I have not only learned more knowledge about meat science, but have gained a tremendous amount of knowledge about life in general. Thank you for always pushing me to make the next step, never letting me take the easy way out, always keeping me busy, and most of all always being there through one of the hardest times of my life. Also, I would like to thank Dr. Deb Roeber for answering all of the questions and helping guide me in the right direction at times.

A special thank you is extended to Kris Novotny, Betty Rothermel, and Linda Guenther. Without the help of each one of these three ladies, neither I nor any other graduate student that has came thru this program would have made it. They are like your mothers away from home that know when to push you and know when to comfort you, I can not express how much each one of you mean to me. Each one of you holds a special place in heart and always will. Without the help of Jake Nelson, Russell Nabors, Marcia Dalton, Lily Ramos and Dustin Vann, I would still be trying to complete my research. Also, thank you to the student workers in the Food and Agricultural Products Center meat lab and student workers in the muscle biology lab, the many hours, early mornings and late nights you helped with my research is greatly appreciated. Through one of the toughest times of my life, it was all of the people mentioned above that kept me on track and keep my research going, thank you very much.

Much appreciation goes to the National Cattleman's Beef Association for funding this project. This project was funded, by beef and veal producers and importers through their $1 per-head check off and was produced for the Cattlemen's Beef Board and state beef councils by the National Cattlemen's Beef Association. I would also like to thank National Steak and Poultry, for providing the use of their facilities.

Most importantly, I would like to thank my family for the love support they have given me over the years. To my parents, Ken and the late Karen, thank you for always believing in me and instilling in me the beliefs and values you did. To my sister, Maura, thank you for always listening to me and for the many memories we have shared together. Mom, the completion of my Masters work is for you as you were always my driving force when I was down and you were always the first to understand the stress of school. I miss you and love you dearly. Lastly, without the guidance of my Lord and Savior, Jesus Christ, the completion of this work would have been impossible.

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 1

II. REVIEW OF LITERATURE

Introduction 3
The Beef Carcass 6
Postmortem Treatments 8
Blade Tenderization 8
Postmortem Aging 10
Enhancement 13
US Quality Grade 16
Warner-Bratzler Shear Force 18

III. INFLUENCE OF ENHANCEMENT AND BLADE TENDERIZATION ON BEEF SUBPRIMALS OF KNOWN CATEGORIES OF TENDERNESS 20

Abstract 20
Introduction 21
Materials and Methods 23
Sample Collection 23
Postmortem Handling 24
Warner-Bratzler shear force 24
Statistical Analysis 25
Results and Discussion 26
Implications 38

LITERATURE CITED 80
APPENDIX A 87

LIST OF TABLES

Table Page

1. Least square means and standard errors for Warner-Bratzler shear values (kg) of subprimal steaks with a significant main effect for postmortem aging 39

2. Least square means and standard errors for Warner-Bratzler shear values (kg) of subprimal steaks with significant main effects for grade…………………………………………………………………….…….. 40

3. Least square means and standard errors for Warner-Bratzler shear values (kg) for subprimal steaks with a significant main effect for treatment……………………………………………………………………… 41

4. Least square means and standard errors for Warner-Bratzler shear values (kg) for subprimal steaks with a postmortem aging (d) x treatment interaction………………………………………………………… 42

5. Least square means and standard error for Warner-Bratzler shear force values (kg) for subprimal steaks with a grade x treatment interaction……………………………………………………………………... 43

6. Least square means and standard errors for Warner-Bratzler shear values (kg) for subprimal steaks with significant main effects for tenderness category………………………………………………………… 44

7. Least square means and standard errors for Warner-Bratzler shear values (kg) for subprimal steaks with a treatment x tenderness category interaction…………………………………………………………….. 45

8. Least square means and standard errors for Strip Loin steaks with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction……………………………………………… 46

9. Least square means and standard errors for Knuckle steaks[2] with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction. ……………………………………………… 47

10. Least square means and standard errors for Clod steaks[2] with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction………………………………………………….. 48

11. Least square means and standard errors for Top Sirloin steaks[2] with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction………………………………………………….. 49

12. Least square means and standard errors for Inside Round steaks[2] with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction……………………………………………….. 50

13. Least square means and standard errors for Eye of Round steaks[2] with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction…………………………………… 51

LIST OF FIGURES

Figure Page

1. Influence of postmortem aging on Warner-Bratzler shear force values stratified by subprimal. 52

2. Influence of US quality grade on Warner-Bratzler shear force values stratified by subprimal…… 53

3. Influence of postmortem treatment on Warner-Bratzler shear force values of strip loin steaks. 54

4. Influence of postmortem treatment on Warner-Bratzler shear force values of top sirloin steaks. 55

5. Influence of postmortem treatment on Warner-Bratzler shear force values of clod steaks. 56

6. Influence of postmortem treatment on Warner-Bratzler shear force values of inside rounds steaks. 57

7. Influence of postmortem treatment on Warner-Bratzler shear force values of knuckles steaks....58

8. Influence of postmortem treatment on Warner-Bratzler shear force values of eye of rounds steaks....59

9. Influence of postmortem treatment and postmortem aging on Warner-Bratzler shear force values of strip loin steaks. 60

10. Influence of postmortem treatment and postmortem aging on Warner-Bratzler shear force values of inside round steaks. 61

11. Influence of postmortem treatment and postmortem aging on Warner-Bratzler shear force values of clod steaks. 62

12. Influence of US quality grade and postmortem treatment on Warner-Bratzler shear force values of strip loin steaks. 63

13. Influence of US quality grade and postmortem treatment on Warner-Bratzler shear force values of top sirloin steaks. 64

14. Influence of US quality grade and postmortem treatment on Warner-Bratzler shear force values of inside round steaks 65

15. Influence of US quality grade and postmortem treatment on Warner Bratzler shear force values of clod steaks. 66

16. Influence of US quality grade and postmortem treatment on Warner-Bratzler shear force values of eye of round steaks. 67

17. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough strip loin steaks. 68

18. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough top sirloin steaks. 69

19. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough knuckle steaks. 70

20. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough inside round steaks.....................................71

21. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough eye of round steaks. 72

22. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough clod steaks. 73

23. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender strip loin steaks. 74

24. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender knuckle steaks...75

25. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender clod steaks. 76

26. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender top sirloin steaks. 77

27. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender inside round steaks. 78

28. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender eye of round steaks. 79

NOMENCLATURE

AMSA	American Meat Science Association
°C	degree (s) Celsius
cm	centimeter (s)
d	day
h	hour
IMPS	Institutional Meat Purchasing Specifications
kg	kilogram (s)
MARC	Meat Animal Research Center
N	sample size
NaCl	Sodium Chloride
NAMP	North American Meat Processors Association
NCBA	National Cattlemen's Beef Association
USDA	United States Department of Agriculture
WBSF	Warner-Bratzler shear force
>	greater than
<	less than
≥	greater than or equal to

CHAPTER I

INTRODUCTION

The beef industry today is at a tenderness disadvantage and is continuously in a battle with other meat industries. Total beef consumption on a carcass basis, from year 2000 to 2004 has declined by 3.63 kg, where total poultry consumption has increased by 1.36 kg (USDA, 2005). In order to bring beef consumption back to where it was, new innovations, technologies and marketing programs have to be implemented in this industry since the proportion of tender cuts in the beef carcass is limited. Our goal is and should always be to satisfy the consumers who spend the dollar. A lack of a consistent tender beef product could cost the beef industry $250 million annually (Smith et al. 1995). The meat industry ranks first in total business receipts accounting for 28% of the total food industry, thus making it a large part of the US food economy (Aberle, 2001). Demand for meeting consumer's needs and expectations of beef products with product quality and consistency is an area that continuously needs to be improved (NCBA, 1998). The National Cattlemen's Beef Association (NCBA) set forth a goal of "reducing consumer dissatisfaction due to variability in eating quality (tenderness) by 50% by the year 2005" (Tatum et al., 1999). Insurance that beef products will be consistently high in quality and consistently tender must be transferred from producer to processor. If this “palatability insurance” fails and undesirable eating experiences occur, the perception of our products quality will be lost. Several studies have shown that consumers who purchase beef are concerned with tenderness. Boleman et al. (1997) showed consumers were willing to pay more for a “guaranteed tender” product and Miller et al. (2001) demonstrated that 78% of consumers are more willing to buy steaks if “guaranteed tender”. Amount of variation in tenderness with the beef industry is often reported as a concern by consumers (Morgan et al., 1991; NBQA, 2000; Brooks et al., 2000). Tenderness is an important part of meat acceptability (Dransfield, 1994) and is the primary determinant of good eating experience according to consumers (Neely et al., 1999; Savell et al., 1989; Lorenzen et al., 1999). Morgan et al. (1991) found that product tenderness was a problem in the beef industry and has resulted in a targeted focus on new and improved methodologies for benefiting beef tenderness. For the beef industry to maintain the level of customer acceptance, commercially acceptable or applicable methods must be developed and consistently used to ensure that maximum tenderness of cooked beef is achieved. If the beef industry can consistently market a tender product, revenues will be increased and consumers will be satisfied. The current research was conducted to determine the influence of blade tenderization and enhancement on six subprimals of beef of known categories of tenderness.

CHAPTER II

REVIEW OF LITERATURE

With consumer satisfaction and price being the driving force behind the purchase of beef products, focusing on tenderness must be a primary goal, which can be done on a guaranteed basis. Moeller and Courington (1998) provided information that led the beef industry to focus on the following areas to improve tenderness and consistency; 1) taste and tenderness are the primary decision makers for consumer purchases, 2) consumers are displeased with the beef products available, and 3) improvements in the consistency and quality would increase beef consumption. It is obvious the demand for meeting consumer's needs and expectations of beef products with product quality and consistency is an area within the industry that is continuously looking for improvement (NCBA, 1998). However measuring consumer's wants and reactions to meat tenderness is complicated due to other influences on their decisions (Savell and Shackelford 1992).

Several factors are associated with beef tenderness, including marbling, subcutancaneous fat thickness, catheptic enzymes, calcium-dependent proteases and their inhibitors. All have been suggested as influences associated with meat tenderness (Koohmaraie, 1988). Improving tenderness can be done in a variety of pre-harvest methods. Such methods include increasing the level of vitamin D_3 fed in the ration (Karges et al., 2001), biological type of cattle (*Bos indicus* vs. *Bos taurus*) (Koohmaraie et al., 1994), and high grain rations (Dikeman et al., 2003). Prerigor injection or infusion of calcium chloride has proved to be a way of increasing and accelerating tenderness (Koohmaraie and Shackelford, 1991; Wheeler et al., 1990).

For postmortem interventions, Tatum et al. (1997), listed several interventions that would increase tenderness of beef. Those mentioned were electrical stimulation, calcium infusion into the carcass or cuts, suspension of the carcass by the pelvis, high temperature conditioning of the carcass, blade/needle tenderization, use of tropical plant enzymes, wet or dry aging of the carcass or cuts, and marinating in salt/acid solutions. Of these eight interventions, our primary focus was blade/needle tenderization, marination, and postmortem aging. Incorporating these technologies can significantly help increase the value of the beef carcass at little expense as well as making other methods of improving beef tenderness invaluable. The strategy workshop of the National Beef Quality Audit 2000 (NBQA, 2000), brought forth the idea that the industry needs to encourage post-harvest product enhancement technologies and manage pre-harvest production practices, in hopes for a tender flavorful product. If failure occurs in one or more of these pre-rigor and/or postmortem areas, an increase in the risk of a poor eating experience for the consumer could occur. By incorporating these methods, they can aid in increasing tenderness which allows for the opportunity to maximize tenderness of underutilized cuts (i.e., chuck and round) of the beef carcass. With roughly two-thirds of the beef carcass being made up of the chuck and round, there is a need for improving the tenderness values of these subprimals. Meats from these underutilized cuts have usually been marketed as lower priced roasts and steaks. Postmortem treatments such as blade tenderization and enhancement along with postmortem aging will enable processors to achieve maximum tenderness levels in these under utilized cuts. Savell and Shackelford (1992) expressed the need for implementation of methods to eliminate the variation in tenderness, which would help increase consumers satisfaction with beef. Miller et al. (2001) found that if a retailer can guarantee steaks to be tender, consumers would purchase them. Boleman et al. (1997) showed that consumers will actually pay a premium if guaranteed tender. Palatability is often defined as the perceived eating satisfaction that is influenced by flavor, juiciness, and tenderness. With tenderness being the primary factor of palatability. Some tools to measure tenderness include consumer taste panels, trained sensory panels and the most commonly used measurement is Warner-Bratzler shear force (WBSF). Tenderness is the predominant quality determinant and probably the most organoleptic characteristic of red meat in general (Koohmaraie, 1988). It has been a practice of some time in the beef industry to control the attributes that reflect consumer acceptable of products. Controlling can be done through postmortem treatments and the use of the United States Department of Agriculture (USDA) quality grading system.

THE BEEF CARCASS

Belew et al. (2003) reported a wide range of tenderness variation between individual beef muscles. The beef carcass is made up of muscles that differ in composition, aging response, amount of connective tissue, marbling, and sarcomere length. Collagen protein is the most abundant protein and more is present in the more active (locomotion) muscles, which largely affect the tenderness value of the particular muscle.

The main cause of tenderness variation is collagen (Dransfield, 1994). This is due to the fact that carcasses originate from multiple breeds and various production systems which make for variation in tenderness outcomes. Stuby-Souva et al. (1994) reported that tenderness differences can occur between carcasses, between muscles from the same carcass, and within individual muscles. In agreement, Rhee et al. (2004) also found a variation in tenderness in different muscles and implied a need for specific muscle strategies for improving quality and value. They identified a need for cut specific tenderness improvement strategies, since muscles vary greatly in proteolysis, rigor shortening, and connective tissue, all of which contribute to tenderness variations. Kirchofer, Calkins, and Gwartney (2002) reported a wide variation in chuck muscles and found this to impact tenderness and functional properties due to fiber type composition of the muscles. They also reported that muscles from the round does not have the same variation in fiber type as the chuck and exhibit little variation in functional properties. The chuck and round portions of the carcass roughly make up two-thirds of the beef carcass, therefore offering tender steaks and roasts from these cuts would improve value. As the meat industry isolates individual muscles from the chuck and round for merchandizing as steaks, more knowledge about how these muscles respond to postmortem aging is required to assure tenderness (Bratcher et al., 2005). Further research is needed to focus on more pre-rigor/postmortem techniques to improve these underutilized cuts. Steaks and roasts of lower value face challenges in terms of palatability (Baublits et al., 2005). Rhee et al. (2004) provided solutions to improve tenderness in different lower values cuts. The semimembranosus (rigor shortening) could be improved by a stretching method. The rectus femoris, triceps brachii, and semitendinosus (limited postmortem proteolysis) tenderness values could be increased by marination treatments. The semitendinosus, semimembranosus, triceps brachii, rectus femoris (excess collagen) could improve tenderness by genetics. Charges from industry leaders, producers, and retailers have been to increase the value of the carcass; it must become part of our utmost attention. As a result, the industry today has started marketing cuts traditionally used for roasts as steaks in an attempt to add value. Miller et al. (2001) found that 78% of consumers would purchase steaks if the retailer could guarantee them to be tender. The strip loin, shoulder clod, knuckle, eye of round, inside round, and top sirloin are subprimals of practical interest. However it is the shoulder clod, knuckle, eye of round, and inside round, all subprimals originating from the chuck and round, that offer the most potential for added value.

POSTMORTEM TREATMENTS

In today's beef industry, numerous postmortem treatments or interventions are being researched and utilized to aid in the prevention of nonconforming (i.e., "tough") beef carcasses to reach the end consumer. Prevention of beef carcasses that could be "tough" can be reduced at numerous steps through out the production line. Through incorporation of postmortem treatments or interventions during the chain of production, the chance of increasing tenderness is improved. There is a need for prevention strategies as 15-20% of the steaks sold to consumers are considered to be "tough" (Miller et al., 2001). Miller et al. (2001) and George et al. (1999) found that 21% of top sirloins steaks and 13% of strip loins steaks purchased at supermarkets had Warner-Bratzler shear force (WBSF) values of 4 kg or greater. These tenderness values reported are approaching the "intermediate" (3.9 > WBSF < 4.6 kg) and "tough" categories (WBSF > 4.6 kg) used by Belew et al. (2003) in a tenderness categorization study of individual muscles. From the research listed, it is obvious the need for improvements.

Blade Tenderization. It has been well documented that blade tenderization will increase tenderness values. The process of blade tenderization can often be referred to as mechanical tenderization or needling. Blade tenderization involves a machine with multiple blades and/or needles that penetrate meat as it passes through on a conveyor. The multiple blades disrupt the surface structure by penetrating the muscle. This allows for physical disruption of muscle fibers and muscle connective tissues. Disrupting muscle tissues has been an applicable way to increase tenderness (Parrish, 1977).

Blade tenderization has a long history of being used within the beef industry. Blade tenderization is still being used in the industry today, as 50% of the foodservice establishments surveyed in the 1998 National Beef Tenderness Survey utilize some form of mechanical tenderization for products that are wet aged (Brooks et al., 2000). Pietrasik and Shand (2003) supported other research that blade tenderization of tough cuts (i.e., round) could increase tenderness with the cutting action of the mechanical blades causing disruption of muscle fibers and connective tissue. Blade tenderization has been used to decrease WBSF values of strip loins (Jeremiah et al., 1999; Pringle et al., 1998; Wheeler et al., 1990; Davis 1977), chuck roasts (Shackelford,1989), inside rounds or semimembranosus (Kolle et al., 2004; Jeremiah, 1999; Loucks et al., 1984; Mandigo and Olsen, 1982; and Davis, 1977), top sirloins (George-Evins et al., 2004; Jeremiah et al. 1999; Savell 1977), eye of rounds (Seideman et al., 1977), knuckles (Kolle et al., 2004), pork loins (Goldner and Mandigo 1974), goat wholesale cuts (McMillin and Brock, 2005; Bowling, 1976) and lamb (Bowling, 1976). Pringle et al. (1998) reported the use of needle tenderization had a positive influence on beef steak palatability and could ensure acceptable palatability in strip loin steaks. If meat is already tender, blade tenderization does not have an advantage in added tenderness (Davis et al., 1975) and although tenderness of tough meat can be improved, it will not be improved to the palatability standpoint of tender beef (Smith et al., 1979). Bowling et al. (1976)

and Seideman et al. (1977) reported that WBSF values of blade tenderized meat may over-estimate the real effects of blade tenderization, such as organoleptic tenderness.

Blade tenderization after completion of a postmortem aging period has been reported by several researchers to produce consistent reductions of shear force values. Also blade tenderization provides greater uniformity of tenderness within the subprimals or cuts. Previous research has used only a single pass through the blade tenderizer. However, Savell et al. (1977) reported a decrease in shear force values with each pass through the blade tenderizer. Tatum et al. (1978) reported that cow biceps femoris blade tenderized twice and steer semimembranosus tenderized once were significantly more tender than control counter parts. Additionally, Tatum (1978) failed to reduce WBSF values of cow longissimus dorsi to values comparable to that of control longissimus muscles of steers with blade tenderization. The values of the cow longissimus dorsi reported were still undesirable in tenderness. On the other hand, Seideman et al. (1986) reported that bullock beef muscle palatability ratings were improved to levels comparable to untenderized steer beef by utilizing one pass through the mechanical tenderizer. Regardless of their initial tenderness, blade tenderization and 18 d of postmortem aging are probably most effective in reducing WBSF values of steaks from any population of carcasses (Savell et al., 1982).

Postmortem Aging. Postmortem aging assists in the improvement in palatability that occurs in the muscle by manipulating myofibriliar components. Postmortem aging results in enzymatic degradation of muscle fibers, thus, increased tenderness. Aging is an effective way of enhancing tenderness (Dransfield, 1994) and has been used and researched extensively over the last decade. There are two different types of postmortem aging, wet aging and dry aging. Wet aging, the more commonly used of the two, involves the steak or roast being aged in a vacuum bag. Dry aging, is less common in the industry today due to a shortage of space and limited capacity in the plants, as well as it involves the aging of the entire carcass or subprimal while being exposed to air. It has long been acknowledged that aging meat for 14 d or longer can achieve positive influence in tenderness. Nishimura et al. (1998) found that beef should be aged for more than 14 d to obtain maximum tenderness while Koohmaraie (1996) reported the optimum length to maximize tenderness is 10 to 14 d. Although muscles respond positively to postmortem aging, the guarantee of tenderness is limited, as the muscle could still remain tough. The effect postmortem aging has on overall tenderness is still debatable. The relationship between calpains and ultimate meat tenderness are highly related, as calpains are believed to be the main protease system involved in the tenderization process. It is historically believed that the natural enzymes and calpains found in muscles improve tenderness by degrading sarcomere boundaries, which in turn disrupts the myofibrillar structure. Koohmaraie (1996) stated proteases must meet certain criteria and calpains, especially μ-calpains, are the only proteases to do so. The criteria was that the protease must be endogenous to skeletal muscle cells, must have the ability to reproduce postmortem changes in myofibrils in an in-vitro setting under optimum conditions and must have access to myofibrils in the tissue. The μ-calpains will decrease more rapidly and quickly during of postmortem aging than the M-calpains (Boehm et al., 1998). According to Dransfield (1994), all μ-calpains are activated postmortem by calcium ions and serve a role in most natural tenderization. Aside from calpains, connective tissue may also play a role in the tenderization affect. According to Nishimura et al. (1998) intramuscular connective tissue has an effect on beef tenderness in extended aging periods. The structural weakening of intramuscular connective tissue can have an effect on the final decrease in shear force, but it was not until 35 d that the significant of changes in connective tissue occurred. Koohmaraie et al. (1994) hypothesized that the difference in the rate and extent of postmortem aging is responsible for most of the variation of tenderness. In agreement with other researchers, Miller et al. (1997) reported that aging beef for 14 d would improve the consistency of beef tenderness and should be recommended as a processing control point for the beef industry to improve consumer acceptance of beef regardless of breed, fatness, or processing variables.

In the beef industry the time prearranged for aging varies extremely from retail to the foodservice industry. Savell and Shackelford (1992) reported that most retailers and purveyors have relied on aging as a means of controlling the quality of the beef being marketed. Brooks et al. (2000) determined that only 34% of subprimals in retail stores had been aged for less than 14 d and the average postmortem aging period was approximately 19 d. Due to differences in subprimals, muscle location or steak; various aging periods may need to be cut dependent to ensure maximum tenderness. However, there is little information on aging muscles other than the strip loin and ribeye subprimals. The question that needs further research is how effective is aging of muscles originating from the round. Lorenzen et al. (1998) reported that in order to maximize the tenderness of the short loin, rib, and chuck roll, a postmortem aging time of 14 d must be utilized. Differences in aging requirements goes beyond muscle type, subprimal location, and steak. Bratcher et al. (2005) used muscles of locomotion and found that the upper US Choice needed to be aged for 7 d, while US Select cuts should be aged for at least 14 d, thus suggesting quality grade may be an indicator of required postmortem aging time.

Enhancement. Enhancing beef products through injection of a phosphate based solution may be one of the best methods used to date. That offers the consumer a more consistent eating experience and this insurance of that the industry is looking for. The purpose of beef enhancement solutions should be to provide a product palatable enough to meet the consumer’s expectations. Enhancing is an accepted process that often requires minimal processing to achieve the desired increase in tenderness. Not only is meat tenderized by solubilization of the protein as a result of injection of the enhancement solution, but the needle injection itself acts as a mechanical tenderization method. Incorporation of non-meat ingredients into meat products is a simple and inexpensive alternative to increasing tenderness and adding value to cuts. Non-meat ingredients typically used when enhancing whole muscle are sodium tripolyphosphate, sodium chloride and a natural antioxidant (i e., rosemary oleoresin). Sodium chloride is the most common salt used in the industry as it serves several purposes. The incorporation of sodium chloride in the beef industry today is used to enhance the natural beef flavor, which enhances the palatability characteristics of beef products (Pearson and Gillett, 1996). The increased water holding capacity benefits come with the addition of sodium chloride. The addition of a phosphate into the enhancement solutions by dipping or injecting has been used to increase tenderness (Carpenter, 1961). The primary purpose of the addition of antioxidants is to delay the onset of lipid oxidation (oxidation of oils and fats of phospholipids). Rosemary and sage are two common antioxidants used in the red meat industry; however rosemary is commonly used in the beef industry. In the pork industry it is common to find fresh pork injected with solutions containing sodium tripolyphosphate, sodium/potassium lactate, and sodium chloride and other flavorings to maintain tenderness and enhance palatability traits (Vote et al., 2000). The injection of various salts and phosphate formulations into primal meats cuts is routinely practiced to enhance tenderness (Dhanda, 2002; Carpenter et al., 1961). The pork and poultry industries have extensively used enhancement in their products; however enhancement of beef subprimals is advancing quickly as the need to focus more attention on the consumer's desire for a consistent eating experience.

From the 1998 National Beef Tenderness Survey (Brooks et al., 2000), inadequate tenderness, flavor, juiciness, and overall palatability are all quality challenges ranked among the top 10 that restaurateurs, purveyors, and retailers consider as challenges that must be overcame. Addition of the enhancement process into the production of beef cuts, may serve as a way to face these challenges. Research has shown that through the incorporation of a solution containing phosphate, salt, and an antioxidant or a mixture of such all palatability attributes can be improved (Vote et al., 2000; Lawrence et al., 2004). However, many other factors play a role in the overall tenderness of the final product. Consumers often cook steaks past the degree of doneness that would ensure adequate tenderness (varies with muscle type), when doing so most moisture is lost in the product. When lean becomes heated, moisture is lost as the contractile proteins within the muscle become tougher. However the enhanced product which contains injected phosphate, such as sodium tripolyphosphate, are not as susceptible to drying out due to over cooking. A phosphate, such as sodium tripolyphosphate, is used in the enhancement solution which has a primary function of increasing water holding capacity and can aid in prevention of too dry of products. Increased water holding capacity is due proteins that are unfolded and exposed to more sites thus allowing for more water binding. Sheard et al. (1999) injected pork loin steaks with phosphate concentrations and showed an increase in the water holding capacity, tenderness and juiciness of pork loin steaks that were superior to the control. Moeller and Courington (1998) found that consumers will purchase beef if a solution is added to increase product palatability.

US QUALITY GRADE

Quality and yield grades are the primary determinants of profitability if a producer markets their cattle on a grid basis. The primary method used to differentiate between tenderness levels of beef carcasses is the US quality grading system. Muscle type and location is certainly dependent on the role US quality grades will play in predicting tenderness. Unless sold as a guaranteed tender product, products could be sold based on the quality grade. Quality grade may not be an accurate predictor of tenderness (eating quality), as some research has shown that quality grade has little to no effect on tenderness of various muscles and more costly effects on others (Nelson et al., 2004). Quality grades are determined by the combination of estimating physiological age and the amount of marbling distributed in the longissimus muscle cross section between the 12th and 13th rib, with the intent to segment carcasses based on their expected cooked palatability. The challenge with quality grades is, they are used as a measure of tenderness. Typically, tenderness increases as marbling increases. Researchers have shown a positive relationship between marbling and beef palatability, however the relationship is weak (Koohmaraie, 1996). There is a low to moderate relationship between marbling and tenderness according to Tatum et al. (1981). Marbling can explain about 5% of the variation in palatability traits, however, there was “tough” and “tender” products, according to WBSF, remaining within each marbling degree (Wheeler et al., 1994). Since producers may be paid by carcass quality grades and research has shown that even though adequate marbling is present, carcasses may still need a postmortem intervention. Smith et al. (1987) found that US quality grade was not useful in determining the palatability of the round steaks evaluated. In contrast, Nelson et al. (2004) reported that palatability could be determined by US quality grade. In the 1998 National Beef Tenderness Survey (Brooks et al., 2000), no difference in WBSF between chuck and round cuts from Choice and Select carcasses existed. In retail cuts originating from the clod, chuck roll, top round, bottom round, eye of round, top loin, top sirloin, and ribeye steaks no difference was found in WBSF either. The emphasis of the Choice quality grade has primarily been used for merchandising the rib and loin steaks only, while for other cuts the value of the Choice quality grade is neutral to negative (Dikeman, 1987). US quality grades are more accurate in predicting ribeye or strip loin tenderness than tenderness from a round or chuck muscle. Research (Kukowski et al., 2003; Neely et al., 1999), has shown that US quality grade had little effect on consumer evaluation and the difference in quality grade could not be determined, but according to Nelson et al. (2004) the effect of marbling on tenderness seems to be more evident with “middle beef cuts” (i.e. rib and loin) than in “end cuts” (i.e. chuck and round). In disagreement, Vote et al. (2000), found no quality grade effect between enhanced Choice and Select strip loins. In addition, Smith et al. (1984) reported that marbling is much more closely related to the palatability of loin steaks versus that of top round steaks. Most of the postmortem interventions being utilized are aimed at increasing tenderness, thus it can be expected (as some research has shown) that the effect of US quality grade on the subprimal may be lost when an intervention is utilized. US Choice and Select are the primary quality grades that are being marketed in the retail case, 90% of all strip loins in the retail case fell into these two grades (Tatum et al., 1997). Therefore more focus should remain on the effects of palatability attributes from these two quality grades.

WARNER BRATZLER SHEAR FORCE

The use of Warner-Bratzler shear force (WBSF) has proven to be an effective method of classifying and comparing the tenderness attributes of specific muscles for the last decade. There are currently two commonly used methods to evaluate beef tenderness of the cooked product, Warner-Bratzler shear force (WBSF) and slice shear force (SSF). The most commonly used method and the method that is most widely accepted to objectively measure beef tenderness of the cooked meat is WBSF. This standardized process uses six to eight 1.27 cm diameter cores, removed parallel to the muscle fibers, from each steak. Warner-Bratzler shear force can be utilized on all muscles. Upon core removal, a V-shaped blade is used to measure tenderness by cutting the core perpendicular to the length of the steak (McKenna, 2003). The shear force value produced by the WBSF is the amount of force (measured in kilograms or pounds) to shear a one half inch core of meat (McKenna, 2003). Shackelford et al. (1997) showed that WBSF longissimus shear force measurements at the time of carcass grading can serve as a valid predictor of cooked longissimus WBSF following a postmortem aging period of 14 d. Warner-Bratzler shear force values are used to determine the difference in tenderness among samples within individual muscles and can be used to compares tenderness among muscles.

Even though WBSF is a commonly used method and the AMSA guidelines are typically followed, Wheeler et al. (1997) found that comparisons of actual shear force values should not be made due to very low correlations between institutions using this procedure. WBSF values can effectively be used to classify tenderness of specific muscles. But, the question is how do WBSF values correlate with consumer's needs and acceptability levels. If a WBSF value of < 3.0 kg can be achieved, then 100% consumer satisfaction can be achieved; 3.4 kg, 99% consumer satisfaction; 4.0 kg, 94% satisfaction; 4.3 kg, 86%, and > 4.9 kg, only 25% consumer satisfaction (Miller et al., 2001). At the same time, Miller (2001) showed the transition from tender to tough beef took place between 4.3 and 4.9 kg of WBSF, with the average being 4.6 kg. If a WBSF value of 4.1 kg is used as a threshold (Huffman et al., 1996), 98% of the time steaks will be considered acceptable in tenderness. For the National Beef Tenderness Survey in 1998, a threshold of 4.6 kg was used for the intermediate and tough categories, and 3.9 kg was used as the baseline for acceptable tender product (Brooks et al., 2000). A threshold of WBSF of > 4.54 kg was set for defining nonconformance "tough" when developing a quality management to ensure beef tenderness by Tatum et al., 1997. The question that must be posed is whether WBSF is an accurate correlation to consumer perception of tenderness and palatability their (i.e. cooking methods, degree of doneness, flavor, seasonings).

CHAPTER III

INFLUENCE OF ENHANCEMENT AND BLADE TENDERIZATION ON BEEF SUBPRIMALS OF KNOWN CATERGORIES OF TENDERNESS

M. L. McMichael, J.B. Morgan, D.R. Roeber, J.L. Nelson

Oklahoma State University, Stillwater, OK 74078

ABSTRACT

Six paired subprimals (strip loin, knuckle, clod, inside round, eye of round and top sirloin) from US Choice and Select carcasses were enhanced, blade tenderized or aged to increase their tenderness values. Subprimal pairs were randomly assigned to blade tenderization, enhancement or postmortem aging. N=4, steaks were fabricated for postmortem aging of 7 d, 10 d, 14 d, and 21 d . N=2, steaks were fabricated from subprimals and assigned to blade tenderization (two passes) or enhancement and were conventionally aged for 7 d and 14 d. Upon conclusion of each storage period, each steak was frozen (-20ºC) until WBSF analysis was conducted. Subprimal pairs with a conventionally aged 7 d steak that exhibited a WBSF ≥ 4.50 kg were classified as "tough." US Choice and Select enhanced strip loin steaks displayed a lower ($P < 0.05$) WBSF than blade tenderized or conventionally aged steaks. Enhanced "tough" strip loin, knuckle, and clod steaks possessed lower ($P < 0.05$) WBSF than blade tenderized or conventionally aged steaks regardless of postmortem aging. Blade tenderized and enhanced "tough" eye of round and top sirloin steaks displayed lower

(P < 0.05) WBSF regardless of postmortem aging compared to steaks that were controls. Enhancement of “tender” clod steaks lowered WBSF values (P < 0.05) compared to control and blade tenderized counterparts. Postmortem aging up to 14 d for “tough” strip loin and knuckles steaks proved to be effective (P < 0.05). US Choice and Select “tough” blade tenderized and enhanced clod steaks possessed lower WBSF values (P < 0.05) as well as US Select “tender” enhanced clod steaks. US Choice and Select blade tenderized and enhanced eye of round steaks exhibited lower WBSF values (P < 0.05) than postmortem aging, however, WBSF values would still be considered “tough”. It was concluded postmortem aging, enhancement, or blade tenderization or combinations of were significantly effective in increasing overall tenderness in strip loins, knuckles, clods, eye of rounds and top sirloins in the “tough” category.

INTRODUCTION

The beef industry has been one of the most challenged segments in the agriculture industry in recent years. Trying to increase beef sales for today’s consumer has the entire industry searching for ways to meet consumer needs and expectations. Meeting consumer needs and expectations of beef products with product quality and consistency is an important concern for the beef industry (NCBA, 1998). As a result, many branded beef programs and value added marketing strategies have emerged. The main focus of these programs is to consistently provide high quality, palatable product. Positive effects associated with procedures such as enhancement, blade tenderization, and postmortem aging, have improved palatability attributes which assist in providing consumers with a desirable dining experience. However, Vote et al. (2000) demonstrated that quality grade is not effected by enhancement of strip loins. Enhancement solutions containing NaCl and phosphate have been implemented in the pork industry for some time to improve palatability in the final product. With the beef industry promoting value added products and striving to increase value throughout the entire carcass, there is a need to characterize the effects of enhancement solutions on the end product.

Today, most beef that is sold to food service establishments in the United States has been blade or needle tenderized (Brooks et al., 2002). Brooks et al. (2002) found that mechanically tenderized steaks from chuck and round muscles ranked significantly higher than non-treated control steaks in all consumer sensory attributes. Some benefits in which enhancement and blade tenderization offer the beef industry are added value to beef cuts from the entire carcass and improvements in palatability resulting in higher consumer acceptance of once lower valued cuts. The need for more research to determine if differences in U.S. quality grades effect the tenderness of enhanced, blade tenderized, and control beef steaks from subprimals throughout the carcass is a necessity. Adding value to the carcass to increase tenderness will tremendously effect the value of the end products. Kolle et al. (2004) reported a larger decrease in WBSF values for beef muscles injected with a salt and phosphate solution compared to blade tenderization and enzymatic tenderization.

The focus of this study was to determine the impact enhancement and blade tenderization has on the shear force value of multiple beef subprimals throughout the carcass. Steaks were classified into two tenderness categories, if WBSF was < 4.5 kg then that was considered “tender” and if WBSF was ≥ 4.5 kg then that was considered “tough”.

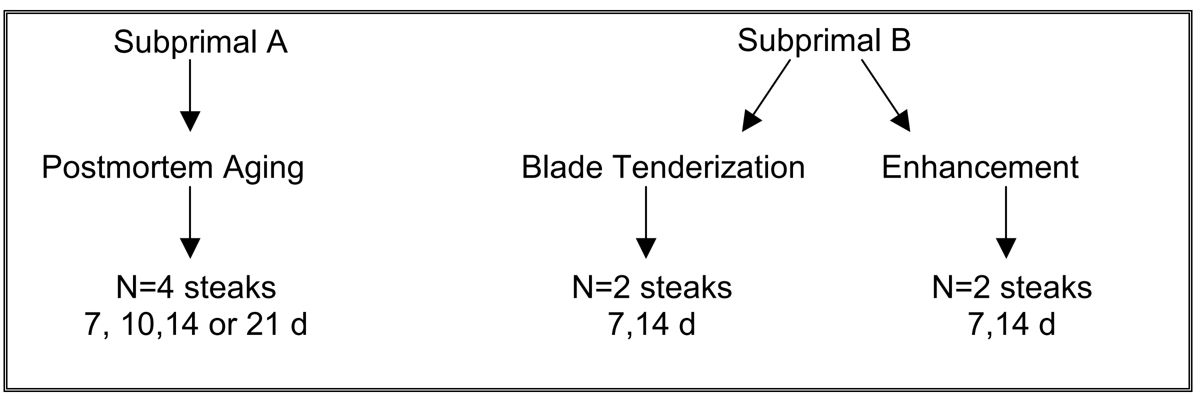
Materials and Methods

Sample Collection

US Choice and Select paired beef carcass subprimals consisting of strip loin (US choice n=75, US select n=78) , Institutional Meat Purchase Specifications IMPS # 180 (North American Meat Processors, 2002); knuckle (US choice n=27, US select n=43), IMPS # 167; should clod (US choice n=49, US select n=60), IMPS # 114; eye of round (US choice n=63, US select n=50), IMPS # 171C; inside round (US choice n=42, US select n-62), IMPS # 169; and top sirloin (US choice n=22, US select n=28), IMPS # 184 were obtained from federally inspected beef processing plants in Corpus Christi and Dumas, TX and Dodge City, KS and shipped to the Food and Agricultural Products Center (FAPC) at Oklahoma State University.

Postmortem Handling

Upon arrival to the Food and Agricultural Products Center located in Stillwater, Oklahoma on the campus of Oklahoma State University, paired samples were assigned randomly into two equal groups (Figure 1). Group A (the control) was aged (7, 10, 14 or 21 d). Group B (treatments) were enhanced or blade tenderized with postmortem aging of either 7 or 14 d. Two equal halves were obtained from subprimal samples in group B and were randomly assigned to either enhancement or blade tenderization treatment groups. Subprimal halves were randomly assigned to enhancement were enhanced to 110% of their original weight with solution to provide 0.36% sodium chloride, 0.45% sodium tripolyphosphate (Brifisol 512, BK Giulini Co, Simi Valley, CA), and 0.1% rosemary oleoresin solution in the final product. The remaining subprimal halves were randomly assigned to blade tenderization and were mechanically tenderized; with two passes, through the ROSS® needle tenderizer (Ross Industries, Inc., Midland VA). For group B, steaks (N=2) from each treatment group were then randomly assigned to a postmortem aging treatment of 7 or 14 d upon completion of treatment. Samples were allowed to age for their respective storage periods at refrigeration temperatures (4ºC ± 1ºC) under a vacuum pressure of 3 torr. At the conclusion of each storage period, each steak was frozen to -20ºC until Warner-Bratzler shear force analysis was conducted.



Warner-Bratzler Shear Force

A measurement of tenderness for each sample was determined using the Warner-Bratzler shear force method (McKenna, 2003). All steaks were tempered for 24 h at 4°C prior to cooking. Individual subprimal steaks were randomly sorted, cooked and tested on assigned days to eliminate cooking variation. Steaks were broiled on an impingement oven (Lincoln Impinger, Model 1132-00-A) at approximately 180°C to a core temperature of 70°C (medium degree of doneness). Temperature was measured using a Versa Tuff 386 type T thermocouple (Model 38653-T, Atkins Technical INC, Gainesville, FL). Steaks were allowed to cool to room temperature (21°C) prior to coring. Upon cooling to approximately 21°C, a minimum of six cores (1.27 cm diameter) were removed parallel to muscle fiber orientation and sheared using the Warner-Bratzler shear head attachment on an Universal Instron Testing Machine (Model 4502, Instron, Canton, MS) at a cross head speed of 200 mm per min. The peak load of each core was recorded by a Dell Opti-plex (Model GX 400) utilizing Instron Program software. Mean peak load for each sample was calculated and further analyzed.

Statistical Analysis

Shear force data were analyzed by individual subprimal using the ordinary least squares method for the analysis of variance (PROC GLM; SAS Institute, Cary, NC). The model included treatment (enhancement, blade tenderization), US quality grade, tenderness category, postmortem aging, and interactions as main effects to evaluate their effect on shear force. Means were separated using least significant difference. Means, standard errors, and standard deviations were generated using SAS procedures (version 9.1, SAS Institute, Cary, NC).

Results and Discussion

As anticipated, differences in WBSF associated with subprimals were present in the study for treatment (enhancement or blade tenderization), US quality grade, and postmortem aging. Variations in WBSF were also present when steaks were divided into tenderness categories. The tenderness categories used were “tender” (i.e. WBSF < 4.5 kg) and “tough” (i.e. WBSF ≥ 4.5 kg).

Within the beef industry, the amount of time a steak takes to reach retail stores or foodservice establishments often varies. With postmortem aging of product prior to retail sale, an increase in tenderness may be achieved. From Figure 1, it can be suggested to age each subprimal differently to achieve maximum tenderness. Results of this study showed, an increase in tenderness can be achieved when steaks from each subprimal are aged differently. Strip loin, top sirloin, and knuckle steaks all possessed lower WBSF values at 21 d. Inside round steaks had the lowest WBSF at 10 d. The least square means and standard errors presented in Table 1, suggest that only WBSF values similar to the findings of Rhee et al. (2004) are longissimus and semimembranosus muscles. Rhee et al. (2004) found the following WBSF values after 14 d of aging; longissimus 3.99 kg, rectus femoris 3.86 kg, gluteus medius 4.44 kg, triceps brachii 3.98 kg, semitendinosus 4.29 kg, and semimembranosus 4.64 kg. Potential differences in the values could be due to uncontrollable issues (i.e. endpoint cooking temperature or muscle location). The findings for top sirloins were consistent with George-Evins et al. (2004), as they reported lower WBSF at 21 d versus 14 d. To contrast the findings of this research Harris et al. (1992)

and Savell et al. (1982), reported that as postmortem aging time increased, tenderness did not increase in top sirloin steaks. Tenderness values exhibited by the eye of round, inside round and clod in our findings would be considered undesirable by consumers. Morgan et al. (1991), who found that according to WBSF values, steaks coming from the round were less tender than steaks coming from the chuck, rib and loin subprimals. According to Denoelly and Lebihan, (2003) and Rhee et al. (2004), at 14 d knuckles were more tender than clods. However the findings are in agreement, as it is consistent throughout all aging periods, but greater at 21 d. Results of this research agrees with the findings of Parrish et al. (1991), who reported that postmortem aging enhances the potential of increasing tenderness. However it does not insure a 100% tender product as other ante- and postmortem factors can play a role on tenderness.

Least square means and standard errors for Warner-Bratzler shear force values for subprimals with a significant main effect for US Quality grade are presented in Table 2. From this research only three (strip loin, knuckle and eye of round) of the six subprimals had US Quality grade effects on WBSF values (Figure 2). US Choice eye of round and knuckle steaks exhibited a lower, more acceptable WBSF value than their US Select counterparts. Eye of round steaks from both US quality grades displayed WBSF values that would be considered undesirable in tenderness. In contrast to the findings of the eye of round, Brooks et al. (2000) reported no grade effect on eye of round steaks. However, some of the results from Brooks et al. (2000) do concur with the findings presented, as they found no grade effect on the top sirloin, inside round, and clod. Furthermore on an individual muscle basis, Goodson et al. (2002) and Kukowski et al. (2003) found no US grade effect for clod steaks. Romans et al. (1965) reported no difference in top sirloins steaks. Neely et al. (1999) concluded no difference in US grade effect for consumer evaluation of the inside round. In partial disagreement to our findings, Nelson et al. (2004), reported the effect of marbling on tenderness to be more evident in “the middle cuts” than in “the end cuts”, such as cuts originating from the round.

All six subprimals exhibited a decrease in WBSF when either postmortem treatment (enhancement or blade tenderization) was applied (Table 3). As shown in Figures 3 thru 8, enhancement had the greatest impact on WBSF, in that WBSF values from all six subprimals significantly decreased with the incorporation of the enhancement solution. Top sirloin, inside round, knuckle, clod and eye of round all exhibited WBSF values that would be considered undesirable prior to incorporating any of the investigated postmortem treatments. However, following enhancement, all WBSF values were improved and would be considered desirable, except for the eye of round steaks which had a mean WBSF value of 4.51 kg. Blade tenderization was effective in decreasing WBSF values from the control WBSF value in only the strip loin, top sirloin, and clod subprimals. In contrast to our research, Savell et al. (1982) and Tatum et al. (1978) reported no effect on WBSF when strip loin steaks were blade tenderized. Findings in this study are consistent with the findings of Kolle et al. (2004), who reported that tenderization strategies may not be effective when utilized on the whole subprimal (such as our research) as individual muscles will responded differently to the treatments, also Kolle et al. (2004) was able to produce the lower WBSF values with a phosphate salt solution compared to blade tenderization. Vote et al. (2000) and Molina et al. (2005) were able to lower WBSF in strip loin and clod steaks, respectively, when enhancing with a salt phosphate solution as well.

The use of blade tenderization was effective in producing lower WBSF values in only three subprimals (strip loin (Figure 3), top sirloin (Figure 4) and clod (Figure 5)). This could be due to the process by which blade tenderization was performed. For our research, it should be noted that blade tenderization occurred prior to postmortem aging. Others (Kolle et al., 2004; Jeremiah et al., 1999; George-Evins et al., 2004), conducted investigations that applied blade tenderized upon the completion of postmortem aging. Furthermore, the subprimals were passed through the blade tenderizer twice, where other research typically only used one pass. One can assume findings in this study should have produced lower WBSF values, than recorded. However, George-Evins et al. (2004) reported that the number of passes typically used for middle cuts is one to two passes, where as in the food service industry round subprimals may be passed through the blade tenderizer beyond three passes. According to Jeremiah et al. (1999) and Mandigo and Olson (1982), mechanical tenderization was effective in increasing meat tenderness, especially in round muscles. However, this is in disagreement with findings in the present study, as only very little differences in WBSF values were found in control steaks and blade tenderized steaks from the round subprimals.

A significant interaction existed between postmortem aging time and treatment application on WBSF of strip loin, inside round and clod subprimals (Table 4). Incorporation of an enhancement solution and postmortem aging up to 14 d significantly decreased all WBSF values compared to the control and blade tenderized counterparts, thus indicating improved tenderness ($P < 0.05$). It appeared that strip loin samples which were enhanced resulted in WBSF values more tender after only 7 d of postmortem aging compared to control and blade tenderized samples aged for 14 d (Figure 9). Researchers at Colorado State University (Vote et al., 2000) reported the similar findings on strip loins enhanced with a phosphate solution. Similar findings were observed for inside round (Figure 10) and clod (Figure 11) samples in that postmortem aging had little impact on WBSF following the enhancement treatment compared to control and blade tenderized treatments. Unexplainably, WBSF value for inside rounds increased with the application of blade tenderization. Perhaps the lack of an increase in tenderness from blade tenderization was due to the fact blade tenderized prior to aging as mentioned previously. Absent from findings of this study was the relationship between blade tenderization and postmortem aging, that George-Evins et al. (2004) reported with top sirloins, as they reported a decrease in WBSF values. The potential cause of the lack of this finding could be George-Evins et al. (2004) performed blade tenderization upon the completion of the postmortem aging periods.

A significant interaction occurred between US quality grade and postmortem treatment (Table 5). All subprimals except knuckles exhibited a significant effect. As anticipated, strip loin, top sirloin, inside round, eye of round, and clod steaks all displayed lower WBSF values for enhanced steaks than their control and blade tenderized counterparts. For strip loin steaks, no difference in tenderness was observed between US Choice and Select steaks for control and blade tenderization; however a marked improvement (on average a 10.4% and 16% for Choice and Select, respectively) in tenderness was observed when strip loins were enhanced (Figure 12). Vote et al. (2000), reported an increase in tenderness when strip loins were enhanced which is in agreement with our results. Regardless of US quality grade, enhancement and blade tenderization of top sirloin steaks (Figure 13) produced higher WBSF values than the control steaks. The enhancement of top sirloin steaks produced the lowest WBSF values. An increase in tenderness was observed for only enhancement in inside round steaks, as blade tenderization and control offered no improvement in WBSF values (Figure 14). To contrast findings of this study, Jeremiah et al. (1999) increased tenderness when inside rounds were mechanically tenderized, regardless of US quality grade. In order to improve WBSF values of US choice and select clod steaks, it appears (Figure 15) that incorporating blade tenderization and enhancement will improve tenderness. As previously observed in other subprimals, both enhancement and blade tenderization effectively lowered WBSF values in eye of round steaks (Figure 16).

Incorporation of enhancement improved US Choice and Select eye of round steaks approximately 20% and 15%, respectively.

For the data presented, two tenderness categories were used, “tender” included all steaks with a 7 d WBSF < 4.5 kg, and “tough” included steaks with a 7 d WBSF of ≥ 4.5 kg. Miller et al. (2001) found that the transition from “tender” to “tough” took place between 4.3 and 4.9, with the average being 4.6 kg. To adequately capture “tough” product, the threshold of ≥ 4.5 kg was used. Subprimals with a main effect for tenderness category are present in Table 6. Differences between tenderness categories were clearly present in all subprimals except for eye of rounds, which is consistent with the findings of Shackelford et al. (1997).

Once subprimals were categorized according to tenderness values, postmortem treatments decreased WBSF values (Table 7). Enhancement improved all subprimal WBSF values from both “tender” and “tough” categories compared to control and blade tenderized counterparts. Strip loin steaks displaying WBSF values categories as “tender” and “tough” can be improved with the incorporation of an enhancement solution (Figure 17). Additionally, the most significant improvement was seen with top sirloins of both tenderness categories, as both enhancement and blade tenderization proved to be most effective in this subprimals for improving overall tenderness (Figure 18). George-Evins et al. (2004) reported similar findings for the blade tenderized top sirloin steaks; however no tenderness category was used. Enhancement of knuckle steaks from both tenderness categories significantly decreased WBSF compared to control and blade tenderized counterparts (Figure 19). Once “tough” inside round steaks were enhanced, a decrease in WBSF occurred (Figure 20). However it should be mentioned that WBSF values for enhanced “tough” inside round and eye of round steaks were still above our threshold of ≥ 4.5 kg. Interestingly, enhanced “tough” eye of round steaks decreased almost 1 kg from the control and blade tenderized counterparts (Figure 21). Enhanced “tender” clod steaks exhibited the lowest WBSF, however enhanced “tough” clod steaks expressed WBSF values equal to control “tender” steaks (Figure 22). Top sirloins that were “tough” and “tender”, “tough” eye of rounds and “tough” clods all displayed increases in tenderness when blade tenderization was used. Blade tenderization was not effective in lowering WBSF values of the “tough” strip loin, knuckle, inside round, and eye of round steaks below the threshold of 4.5 kg. The “tough” top sirloin, strip loin, knuckle and clod steaks exhibited WBSF values that would classify as “tender” after the use of a postmortem intervention.

All subprimals exhibited a significant effect for the postmortem treatment by tenderness category by postmortem aging interaction. After 14 d, enhanced “tough and tender” strip loin steaks displayed lower, more desirable WBSF than did blade tenderized and control steaks (Figure 23). It is obvious that enhancement proved to be most effective regardless of aging period. With the exception of 7 d “tough” steaks, blade tenderization displayed minimal ($P > 0.05$) improvements in strip loin steaks (Table 8).

For “tough” knuckle steaks, it appeared that a minimum of 14 d of postmortem aging was required to improve WBSF (Table 9). On the other hand, regardless of postmortem aging period, enhancement of knuckle steaks significantly improved tenderness. Enhancement could be the most beneficial process in order to improve knuckle steak consistency (Figure 24). Attention should be focused on the fact that enhanced knuckle steaks aged for 7 d, were more tender than control steaks aged for 14 d.

For clod steaks, blade tenderization offered no influence on WBSF of “tender” steaks (Table 10). Tender clod steaks which were enhanced were approximately 20% more tender than their control steak counterparts. However blade tenderization did not influence WBSF values of “tender” steaks. (Figure 25) Enhancement and blade tenderization improved WBSF for “tough” steaks, agreeing with Molina et al. (2005) who reported a decrease in WBSF when clod steaks were injected with a salt phosphate solution.

Least square means and standard errors for top sirloin steaks with a significant effect for a postmortem treatment by tenderness category by aging interaction are shown in Table 11. On day 14 of postmortem aging, top sirloin steaks categorized as “tender” based on their initial shear force values displayed an unexplainable increase in WBSF values (Figure 26). However, the use of blade tenderization and enhancement proved invaluable in that the shear force value was lowered below the “tough” threshold due to a corresponding lowering (> 1 kg) of treated top sirloin steak shear force measurements. A similar response was observed for “tough” top sirloin steaks in that regardless of aging time, WBSF values were improved by the application of blade tenderization and enhancement.

It appears that inside round steaks categorized as being "tender" based on initial shear force values did not become more tender with increased postmortem aging as well as did not respond to either of the tested tenderness improvement technologies (Table 12). Additionally, "tough" inside round steaks exhibited a similar trend in that once they were categorized as being "tough" neither the control, blade tenderization nor enhancement were very effective in improving tenderness as shown in Figure 27.

Eye of round steaks classified as "tender" did not respond to postmortem aging and did not improve tenderness with the application of a postmortem tenderization method (Table 13). Unlike "tender" eye of round steaks, the "tough" eye of round steaks did respond to blade tenderization and enhancement (Figure 28). The enhancement process could be beneficial in improving eye of round consistency and marketability. No improvements in tenderness were observed by Kolle et al. (2004) when eye of rounds were subjected to blade tenderization or salt/phosphate injection, thus agreeing with the results of the present study and disagreeing with Jeremiah et al. (1999) who improved WBSF in eye of rounds with blade tenderization.

From these findings it can be suggested that the six subprimals rank from tender to tough in the following order: strip loin > top sirloin > knuckle > clod > inside round > eye of round. This is consistent with findings by Lorenzen et al. (2003), where they ranked strip loin, top sirloin, and top round, respectively, from tender to tough. Nonetheless, it is obvious that improvements in tenderness in muscles originating from the chuck and round are still needed. When comparing muscles of locomotion to support muscles, differences in WBSF values will appear possibly due to different aging patterns and different responses to postmortem treatments within each subprimal, thus accounting for some of our vast differences in WBSF values. Muscle location in a subprimal could potentially play a role in WBSF values as well, as numerous researchers have concluded muscle location effects. Recommendations from the findings of the present research to achieve maximum tenderness are in the following table.

Recommendations to achieve maximum tenderness for “Tough” beef.		
Subprimal	**Treatment**	**Recommendation**
Strip loin (IMPS # 180)	Enhancement	Incorporate an enhancement solution containing salt and phosphate to achieve maximum tenderness.
	Blade Tenderization	No recommendations.
	Conventional aging	To maximize tenderness age ≥ 14 days.
Knuckle (IMPS # 167)	Enhancement	To increase tenderness, incorporate an enhancement solution (salt/phosphate).
	Blade Tenderization	No recommendations.
	Conventional aging	To maximize tenderness, should age ≥ 14 d.
Clod (IMPS #114)	Enhancement	Incorporate an enhancement solution containing salt and phosphate to achieve maximum tenderness.
	Blade Tenderization	To increase tenderness, utilize two passes through a blade tenderizer.
	Conventional aging	To maximize tenderness, should age ≥ 14 d.
Eye of Round (IMPS # 171C)	Enhancement	To maximize tenderness, utilize an enhancement solution (salt/phosphate).
	Blade Tenderization	Utilize two passes through a blade tenderized to increase tenderness.
	Conventional aging	No recommendation.
Inside Round (IMPS # 169)	Enhancement	No recommendation.
	Blade Tenderization	No recommendation.
	Conventional aging	No recommendation.
Top Sirloin (IMPS # 184)	Enhancement	Incorporate an enhancement solution containing salt and phosphate to achieve maximum tenderness.
	Blade Tenderization	To increase tenderness, utilize two passes through a blade tenderizer.
	Conventional aging	Age ≥ 14 d to achieve improvements in tenderness.

Implications

Since tenderness is the most desirable factor in consumer acceptance, providing a tender product is something the beef industry is constantly trying to do. With the incorporation of blade tenderization or enhancement, tenderness can be improved and often guaranteed. Furthermore, as "tough" product is acquired, the incorporation of a postmortem treatment will increase tenderness, thus putting the product into the "tender" category. Henceforth, the results suggest integration of a postmortem treatment of blade tenderization or enhancement to increase tenderness, thus potentially increasing consumer acceptance.

Table 1. Least square means and standard errors for Warner-Bratzler shear values (kg) of subprimal steaks with a significant main effects for postmortem aging.

	Postmortem Aging, d			
Subprimal	7	10	14	21
Strip Loin (n=153)	4.61[a] ± 0.04	4.23[b] ± 0.04	4.05[c] ± 0.04	3.86[d] ± 0.04
Top Sirloin (n=50)	4.53[a] ± 0.08	4.29[bc] ± 0.09	4.75[a] ± 0.08	4.19[c] ± 0.08
Inside Round (n=104)	4.73[a] ± 0.05	4.42[b] ± 0.05	4.58[ab] ± 0.05	4.63[a] ± 0.05
Knuckle (n=70)	4.64[a] ± 0.06	4.56[ab] ± 0.06	4.46[ab] ± 0.06	4.38[b] ± 0.07
Clod (n=109)	4.70[a] ± 0.05	4.67[a] ± 0.05	4.58[a] ± 0.05	4.56[a] ± 0.05
Eye of Round (n=115)	5.20[a] ± 0.17	5.30[a] ± 0.17	5.45[a] ± 0.18	5.38[a] ± 0.18

[a,b,c,d] Within a row, means without a common superscript differ ($P < 0.05$)

Table 2. Least square means and standard errors for Warner-Bratzler shear values (kg) of subprimal steaks with significant main effects for quality grade.

	US Quality Grade			
Subprimal	Choice	n	Select	N
Strip Loin	$4.14^{a} \pm 0.02$	75	$3.99^{b} \pm 0.02$	78
Knuckle	$4.23^{b} \pm 0.05$	27	$4.45^{a} \pm 0.04$	43
Eye of Round	$4.85^{b} \pm 0.04$	63	$5.09^{a} \pm 0.11$	50

[a,b] Within a row, Means without a common superscript differ ($P < 0.05$)

Table 3. Least square means and standard errors for Warner-Bratzler shear values (kg) of subprimal steaks with a significant main effect for treatment.

		Postmortem Treatment		
Subprimal	n	Control	Blade Tenderization	Enhancement
Strip Loin	153	$4.33^{a} \pm 0.03$	$4.23^{b} \pm 0.03$	$3.62^{c} \pm 0.03$
Top Sirloin	50	$4.64^{a} \pm 0.05$	$4.07^{b} \pm 0.06$	$4.02^{b} \pm 0.06$
Inside Round	104	$4.66^{b} \pm 0.04$	$5.01^{a} \pm 0.04$	$4.44^{c} \pm 0.04$
Knuckle	70	$4.55^{a} \pm 0.05$	$4.59^{a} \pm 0.05$	$3.88^{b} \pm 0.05$
Clod	109	$4.64^{a} \pm 0.03$	$4.30^{b} \pm 0.03$	$3.81^{c} \pm 0.03$
Eye of Round	113	$5.27^{a} \pm 0.11$	$5.09^{a} \pm 0.10$	$4.51^{b} \pm 0.10$

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

Table 4. Least square means and standard errors for Warner-Bratzler shear values (kg) for subprimal steaks with a postmortem aging (d) x treatment interaction.

Subprimal	Postmortem Treatment		
	Control	Blade Tenderization	Enhancement
Strip Loin (n=153)			
7 d	$4.61^{a} \pm 0.04$	$4.44^{b} \pm 0.04$	$3.79^{d} \pm 0.04$
14 d	$4.05^{c} \pm 0.04$	$4.03^{c} \pm 0.04$	$3.46^{e} \pm 0.04$
Inside Round (n=104)			
7 d	$4.73^{b} \pm 0.06$	$4.97^{a} \pm 0.06$	$4.20^{c} \pm 0.06$
14 d	$4.58^{b} \pm 0.06$	$5.05^{a} \pm 0.06$	$4.61^{b} \pm 0.06$
Clod (n=109)			
7 d	$4.70^{a} \pm 0.05$	$4.28^{b} \pm 0.05$	$3.95^{c} \pm 0.05$
14 d	$4.58^{a} \pm 0.05$	$4.33^{b} \pm 0.05$	$3.67^{d} \pm 0.05$

^{a,b,c,d} Within a subprimal, means without a common superscript differ ($P < 0.05$)

Table 5. Least square means and standard errors for Warner-Bratzler shear values (kg) for subprimal steaks with a grade x treatment interaction.

	US Quality Grade	
Subprimal	Choice	Select
Strip Loin	n=75	n=78
Control	$4.33^{a} \pm 0.04$	$4.33^{a} \pm 0.04$
Blade Tenderization	$4.31^{ab} \pm 0.04$	$4.16^{b} \pm 0.04$
Enhancement	$3.76^{c} \pm 0.04$	$3.49^{d} \pm 0.04$
Top Sirloin	n=22	n=28
Control	$4.67^{a} \pm 0.08$	$4.61^{a} \pm 0.07$
Blade Tenderization	$3.93^{b} \pm 0.08$	$4.21^{b} \pm 0.07$
Enhancement	$3.96^{b} \pm 0.08$	$4.08^{b} \pm 0.08$
Inside Round	n=42	n=62
Control	$4.60^{bc} \pm 0.06$	$4.71^{b} \pm 0.05$
Blade Tenderization	$5.10^{a} \pm 0.06$	$4.91^{a} \pm 0.05$
Enhancement	$4.47^{c} \pm 0.06$	$4.41^{c} \pm 0.05$
Eye of Round	n=63	n=50
Control	$5.16^{a} \pm 0.06$	$5.37^{a} \pm 0.20$
Blade Tenderization	$5.03^{a} \pm 0.06$	$5.15^{a} \pm 0.19$
Enhancement	$4.23^{a} \pm 0.06$	$4.78^{ab} \pm 0.19$
Clod	n=49	n=60
Control	$4.64^{a} \pm 0.05$	$4.65^{a} \pm 0.05$
Blade Tenderization	$4.29^{b} \pm 0.05$	$4.31^{b} \pm 0.05$
Enhancement	$3.91^{c} \pm 0.05$	$3.71^{d} \pm 0.05$

[a,b,c,d] Within a subprimal, means without a common superscript differ ($P < 0.05$)

Table 6. Least square means and standard errors for Warner-Bratzler shear values (kg) of subprimal steaks with significant main effect for tenderness category[1].

	Tenderness category	
Subprimal	Tender	Tough
Strip Loin (n=153)	$3.64^{b} \pm 0.02$	$4.49^{a} \pm 0.02$
Top Sirloin (n=50)	$4.12^{b} \pm 0.05$	$4.37^{a} \pm 0.03$
Inside Round (n=104)	$4.44^{b} \pm 0.03$	$4.97^{a} \pm 0.03$
Knuckle (n=70)	$4.13^{b} \pm 0.05$	$4.55^{a} \pm 0.03$
Clod (n=109)	$3.87^{b} \pm 0.03$	$4.64^{a} \pm 0.02$
Eye of Round (n=113)	$4.52^{b} \pm 0.13$	$5.39^{b} \pm 0.02$

[a,b] Within a row means without a common superscript differ ($P < 0.0002$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

Table 7. Least square means and standard error for Warner-Bratzler shear force values (kg) for subprimal steaks with a treatment x tenderness category interaction.

Subprimal	Postmortem Treatment		
	Control	Blade Tenderization	Enhancement
Strip Loin (n=153)			
Tender	$3.76^{d} \pm 0.04$	$3.84^{cd} \pm 0.04$	$3.33^{e} \pm 0.04$
Tough	$4.90^{a} \pm 0.04$	$4.63^{b} \pm 0.04$	$3.92^{c} \pm 0.04$
Top Sirloin (n=50)			
Tender	$4.39^{b} \pm 0.09$	$4.00^{c} \pm 0.09$	$3.97^{c} \pm 0.10$
Tough	$4.89^{a} \pm 0.06$	$4.14^{bc} \pm 0.06$	$4.07^{c} \pm 0.06$
Knuckle (n=104)			
Tender	$4.16^{cd} \pm 0.09$	$4.47^{bc} \pm 0.09$	$3.74^{e} \pm 0.09$
Tough	$4.94^{a} \pm 0.06$	$4.70^{ab} \pm 0.06$	$4.02^{de} \pm 0.06$
Inside Round (n=103)			
Tender	$4.28^{c} \pm 0.06$	$4.77^{b} \pm 0.06$	$4.27^{a} \pm 0.06$
Tough	$5.03^{a} \pm 0.05$	$5.25^{a} \pm 0.05$	$4.61^{b} \pm 0.05$
Eye of Round (n=113)			
Tender	$4.57^{cd} \pm 0.23$	$4.90^{cd} \pm 0.20$	$4.08^{d} \pm 0.20$
Tough	$5.97^{a} \pm 0.03$	$5.27^{b} \pm 0.03$	$4.93^{c} \pm 0.03$
Clod (n=109)			
Tender	$4.11^{c} \pm 0.06$	$4.12^{c} \pm 0.06$	$3.37^{d} \pm 0.06$
Tough	$5.17^{a} \pm 0.04$	$4.48^{b} \pm 0.04$	$4.26^{c} \pm 0.04$

[a,b,c,d] Within a subprimal, means without a common superscript differ ($P < 0.05$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

Table 8. Least square means and standard errors for Strip Loin steaks with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction.

Tenderness Category	Postmortem Treatment		
	Control	Blade Tenderization	Enhancement
Tender			
7 d	$3.81^{ef} \pm 0.06$	$4.03^{de} \pm 0.06$	$3.46^{g} \pm 0.06$
14 d	$3.71^{fg} \pm 0.06$	$3.65^{fg} \pm 0.06$	$3.19^{h} \pm 0.06$
Tough			
7 d	$5.41^{a} \pm 0.06$	$4.86^{b} \pm 0.06$	$4.11^{d} \pm 0.05$
14 d	$4.40^{c} \pm 0.05$	$4.40^{c} \pm 0.06$	$3.74^{f} \pm 0.05$

[a,b,c,d,e,f,g,h] Means without a common superscript differ ($P < 0.05$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

n=153

Table 9. Least square means and standard errors for Knuckle steaks[2] with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction.

Tenderness Category	Postmortem Treatment		
	Control	Blade Tenderization	Enhancement
Tender			
7 d	$4.07^{d} \pm 0.13$	$4.65^{bc} \pm 0.12$	$3.77^{d} \pm 0.12$
14 d	$4.25^{cd} \pm 0.13$	$4.30^{cd} \pm 0.13$	$3.71^{d} \pm 0.12$
Tough			
7 d	$5.20^{a} \pm 0.08$	$4.84^{ab} \pm 0.09$	$4.12^{d} \pm 0.08$
14 d	$4.66^{bc} \pm 0.09$	$4.56^{bc} \pm 0.08$	$3.93^{d} \pm 0.08$

^{a,b,c,d} Means without a common superscript differ ($P < 0.05$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

[2] n=70

Table 10. Least square means and standard errors for Clod steaks[2] with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction.

Tenderness Category	Postmortem Treatment		
	Control	Blade Tenderization	Enhancement
Tender			
7 d	$3.98^{e} \pm 0.08$	$4.16^{de} \pm 0.08$	$3.52^{f} \pm 0.08$
14 d	$4.25^{de} \pm 0.08$	$4.08^{e} \pm 0.08$	$3.21^{f} \pm 0.08$
Tough			
7 d	$5.42^{a} \pm 0.05$	$4.39^{cd} \pm 0.05$	$4.38^{cd} \pm 0.05$
14 d	$4.92^{b} \pm 0.05$	$4.57^{c} \pm 0.05$	$4.13^{e} \pm 0.05$

[a,b,c,d,e,f] Means without a common superscript differ ($P < 0.001$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

[2] n=109

Table 11. Least square means and standard errors for Top Sirloin steaks[2] with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction.

	Postmortem Treatment		
Tenderness Category	Control	Blade Tenderization	Enhancement
Tender			
7 d	$3.96^{d} \pm 0.13$	$4.20^{cd} \pm 0.13$	$3.94^{d} \pm 0.14$
14 d	$4.81^{ab} \pm 0.13$	$3.80^{d} \pm 0.13$	$3.99^{d} \pm 0.14$
Tough			
7 d	$5.10^{a} \pm 0.08$	$4.09^{d} \pm 0.08$	$4.04^{d} \pm 0.08$
14 d	$4.68^{bc} \pm 0.08$	$4.18^{d} \pm 0.08$	$4.09^{d} \pm 0.08$

[a, b,c,d,e] Means without a common superscript differ ($P < 0.05$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

[2] n=50

Table 12. Least square means and standard errors for Inside Round steaks[2] with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction.

	Postmortem Treatment		
Tenderness Category	Control	Blade Tenderization	Enhancement
Tender			
7 d	$4.14^{e} \pm 0.08$	$4.63^{cd} \pm 0.08$	$4.10^{e} \pm 0.08$
14 d	$4.41^{de} \pm 0.08$	$4.91^{bc} \pm 0.08$	$4.45^{de} \pm 0.08$
Tough			
7 d	$5.32^{a} \pm 0.08$	$5.31^{a} \pm 0.08$	$4.45^{de} \pm 0.08$
14 d	$4.74^{cd} \pm 0.08$	$5.19^{ab} \pm 0.08$	$4.78^{cd} \pm 0.08$

[a,b,c,d,e] Means without a common superscript differ ($P < 0.001$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

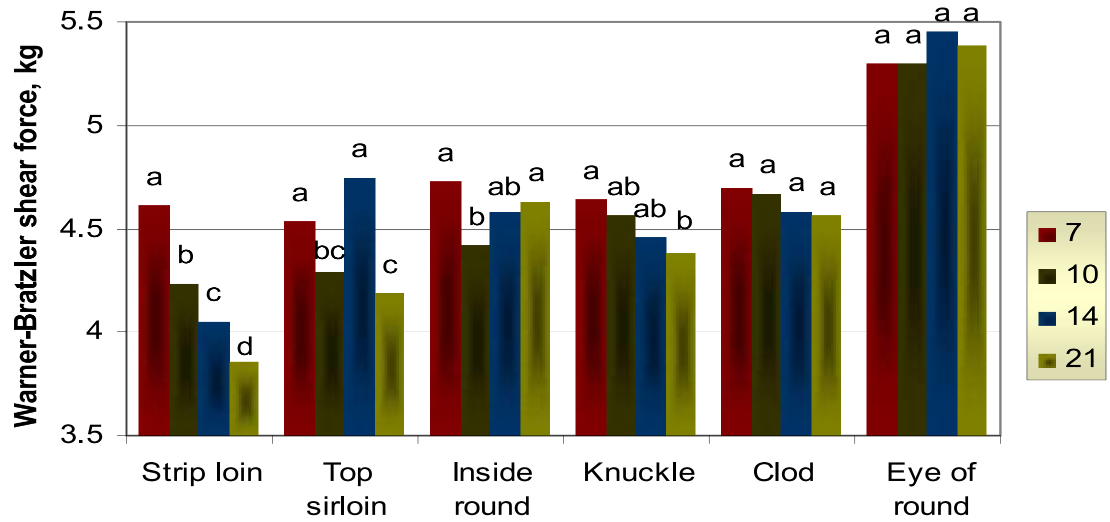
[2] n=104

Table 13. Least square means and standard errors for Eye of Round steaks[2] with a significant effect for a postmortem treatment x tenderness category[1] x postmortem aging interaction.

Tenderness Category	Postmortem Treatment		
	Control	Blade Tenderization	Enhancement
Tender			
7 d	$4.21^{c} \pm 0.29$	$4.60^{c} \pm 0.28$	$4.15^{c} \pm 0.29$
14 d	$4.91^{c} \pm 0.31$	$5.21^{bc} \pm 0.28$	$4.00^{c} \pm 0.28$
Tough			
7 d	$6.07^{a} \pm 0.05$	$5.36^{b} \pm 0.05$	$4.91^{c} \pm 0.05$
14 d	$5.86^{a} \pm 0.05$	$5.17^{b} \pm 0.05$	$4.95^{c} \pm 0.05$

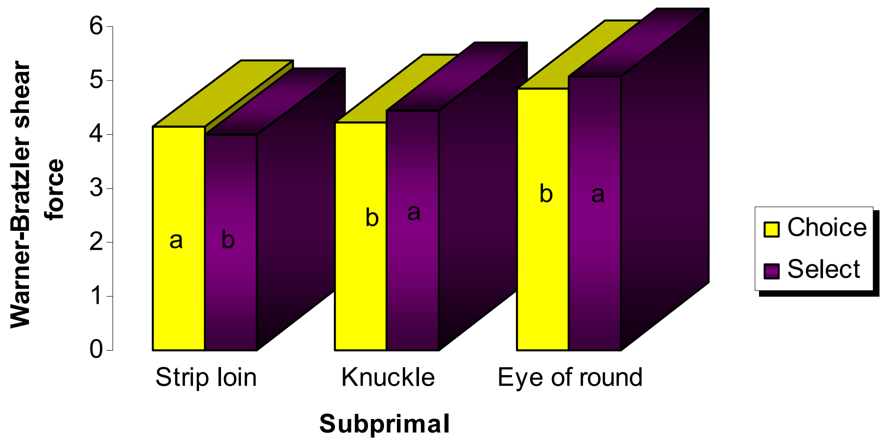
[a,b,c] Means without a common superscript differ ($P < 0.005$)
[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg
[2] n=113

Figure 1. Influence of postmortem aging on Warner-Bratzler shear force values stratified by subprimal.



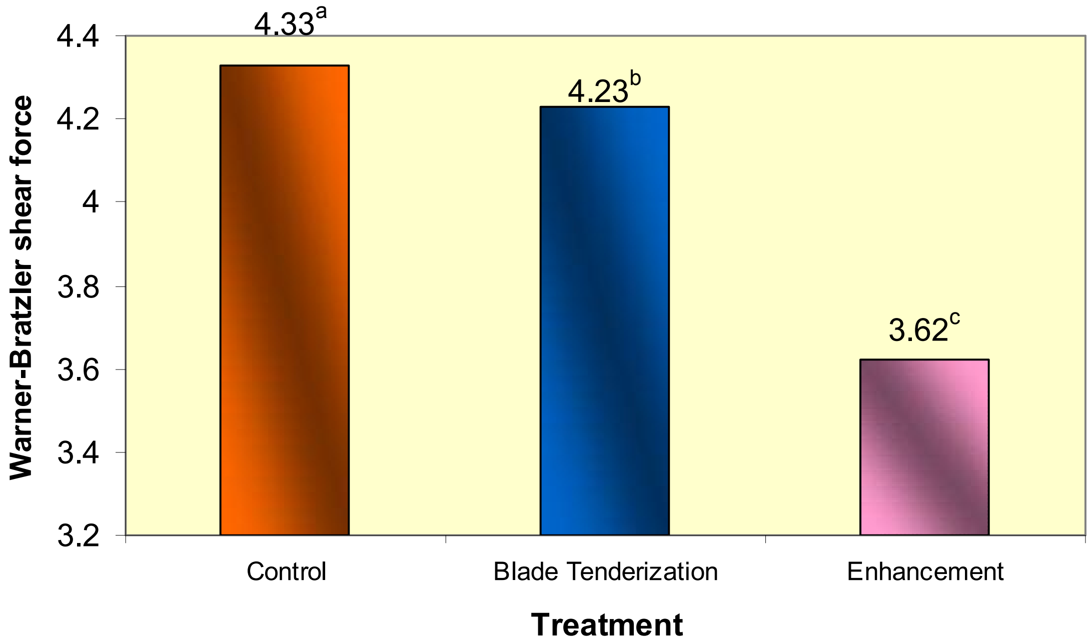
[a,b,c,d] Means within a subprimal, lacking a common superscript differ ($P < 0.05$)

Figure 2. Influence of US quality grade on Warner-Bratzler shear force values stratified by subprimal.



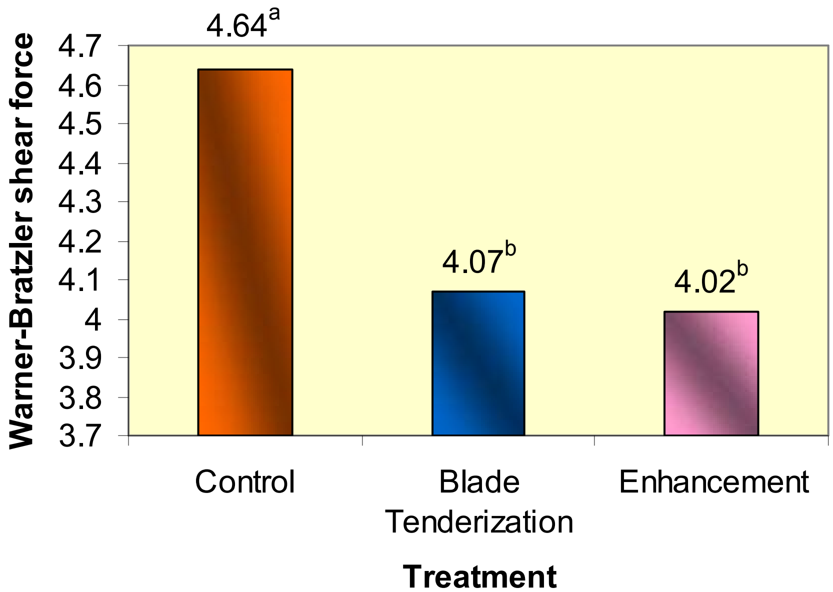
[a,b] Means within a subprimal, lacking a common superscript differ ($P < 0.05$)

Figure 3. Influence of postmortem treatment on Warner-Bratzler shear force values of strip loin steaks.



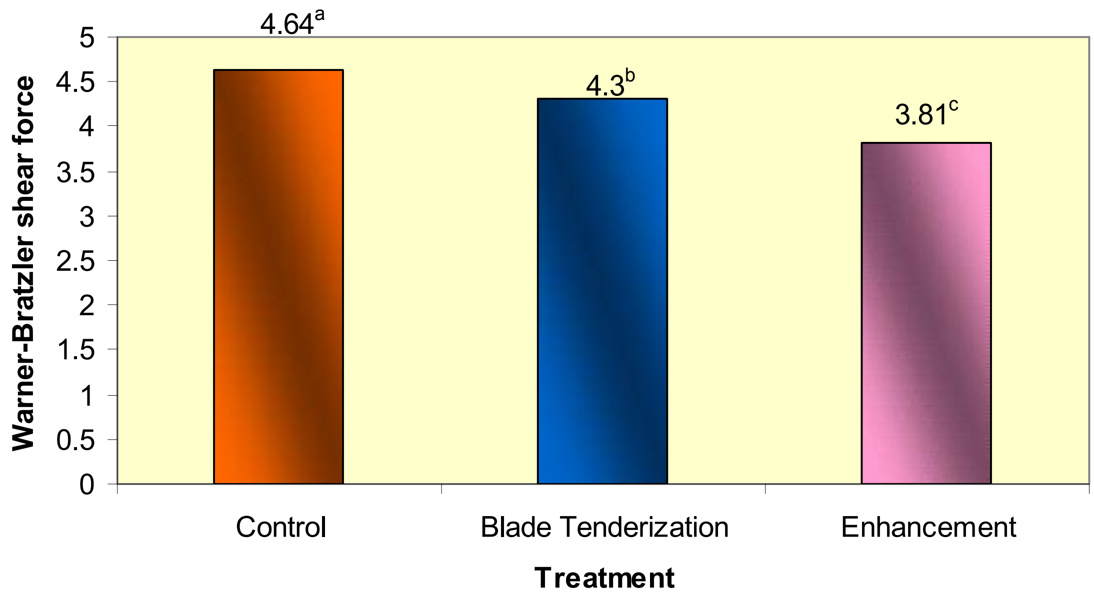
[a,b,c] Means without a common superscript differ ($P < 0.05$)

Figure 4. Influence of postmortem treatment on Warner-Bratzler shear force values of top sirloin steaks.



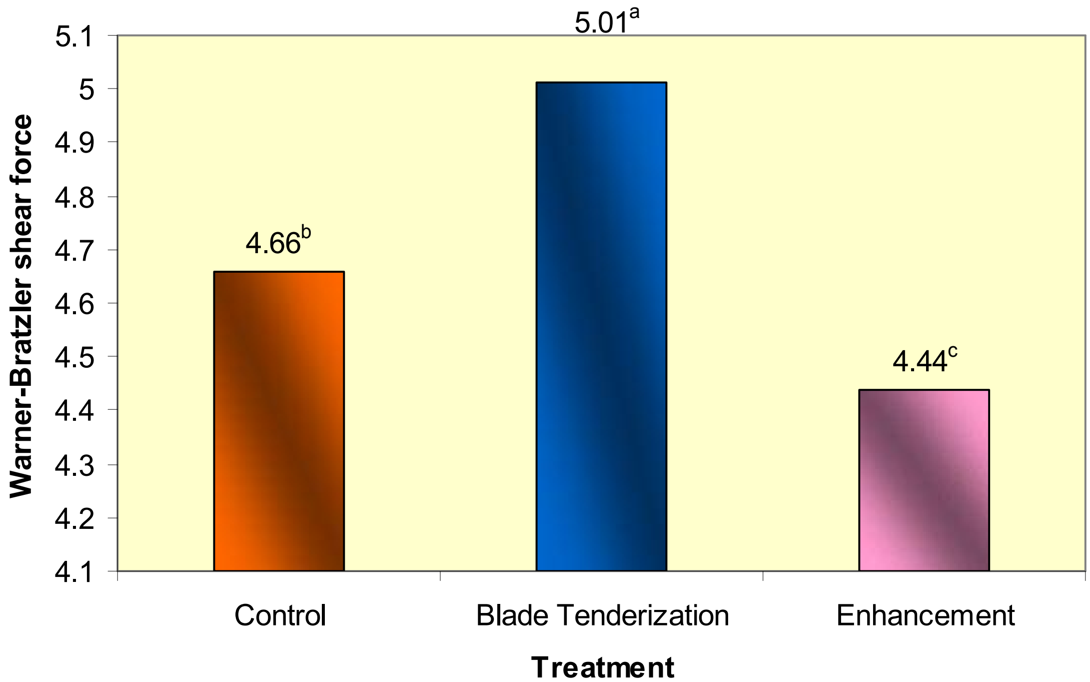
[a,b] Means without a common superscript differ ($P < 0.05$)

Figure 5. Influence of postmortem treatment on Warner-Bratzler shear force values of clod steaks.



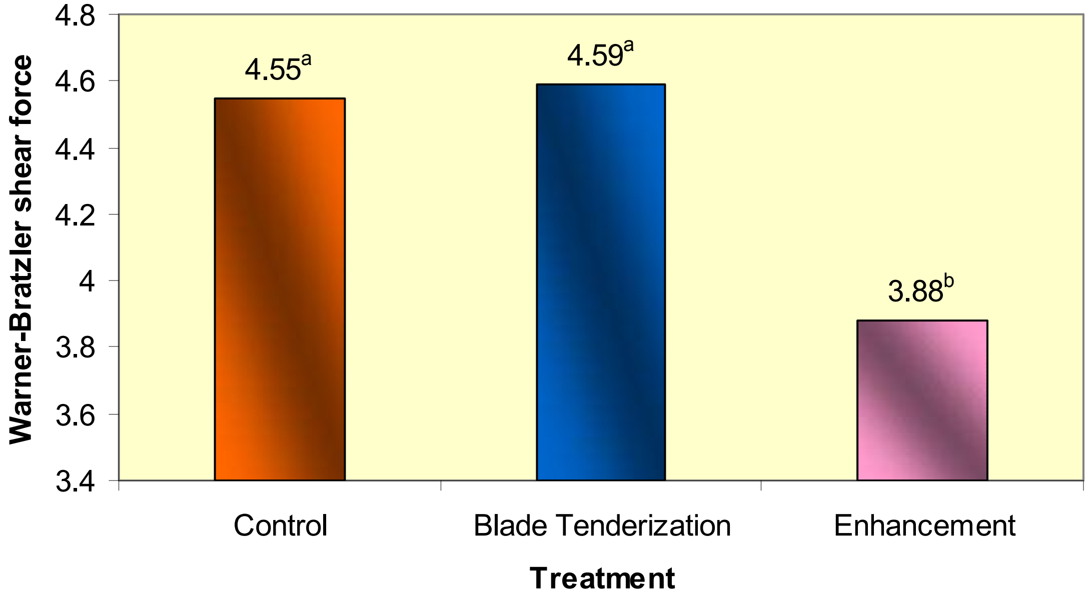
[a,b,c] Means without a common superscript differ ($P < 0.05$)

Figure 6. Influence of postmortem treatment on Warner-Bratzler shear force values of inside round steaks.



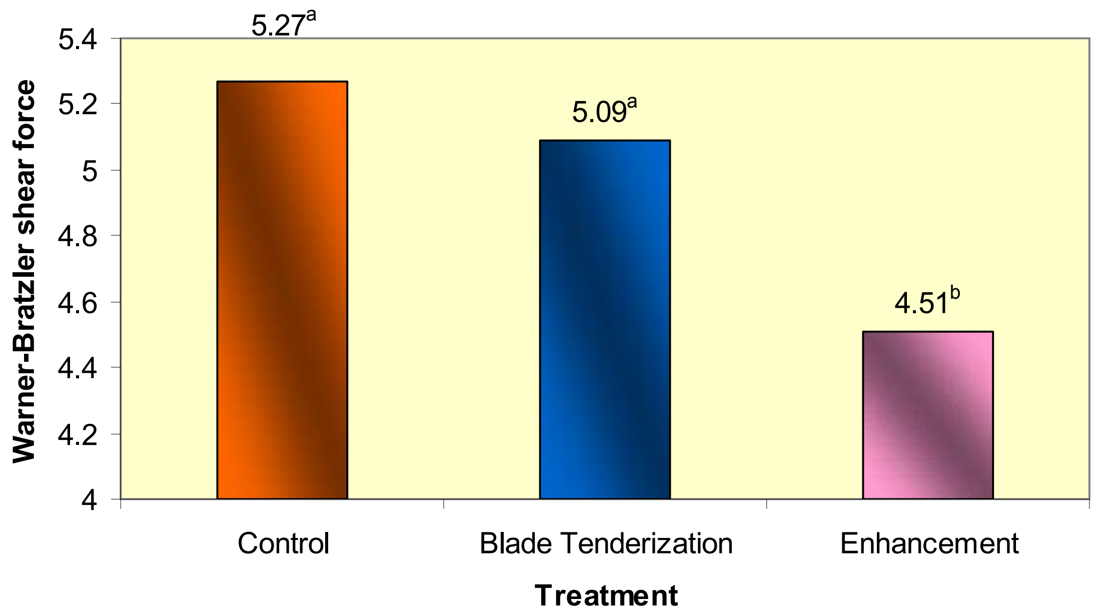
[a,b,c] Means without a common superscript differ ($P < 0.05$)

Figure 7. Influence of postmortem treatment on Warner-Bratzler shear force values of knuckle steaks.



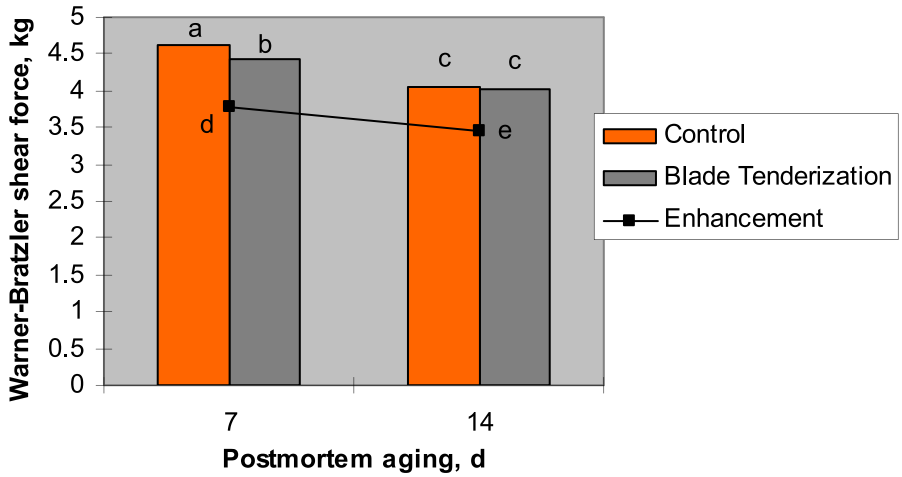
[a,b] Means without a common superscript differ ($P < 0.05$)

Figure 8. Influence of postmortem treatment on Warner-Bratzler shear force values of eye of round steaks.



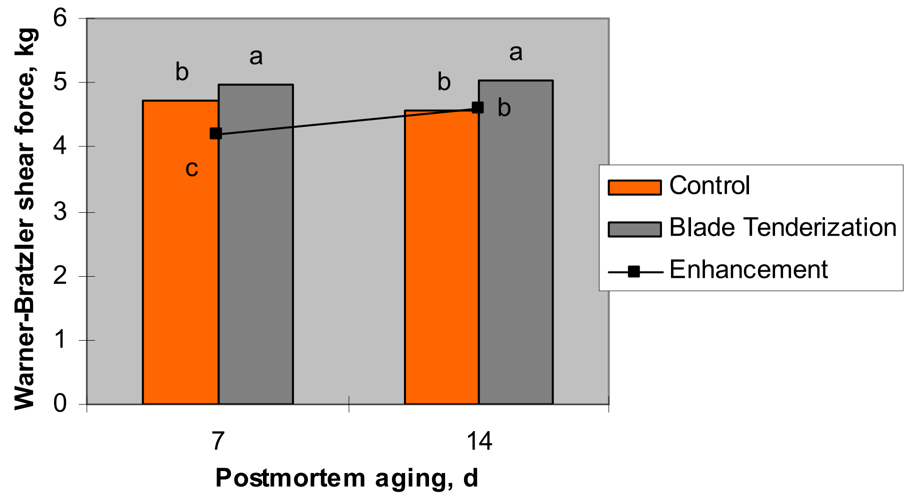
[a,b] Means without a common superscript differ ($P < 0.05$)

Figure 9. Influence of postmortem treatment and postmortem aging on Warner-Bratzler shear force values of strip loin steaks.



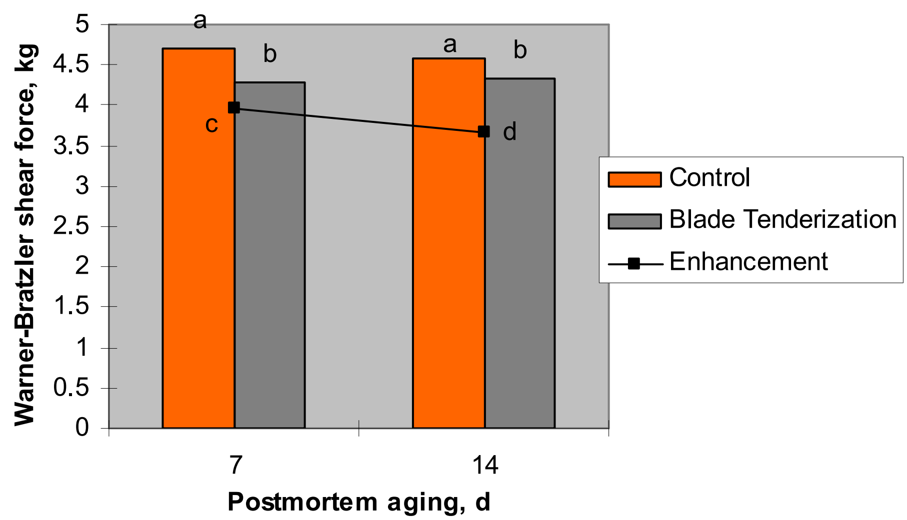
a,b,c,d,e Means without a common superscript differ ($P < 0.05$)

Figure 10. Influence of postmortem treatment and postmortem aging on Warner-Bratzler shear force values of inside round steaks.



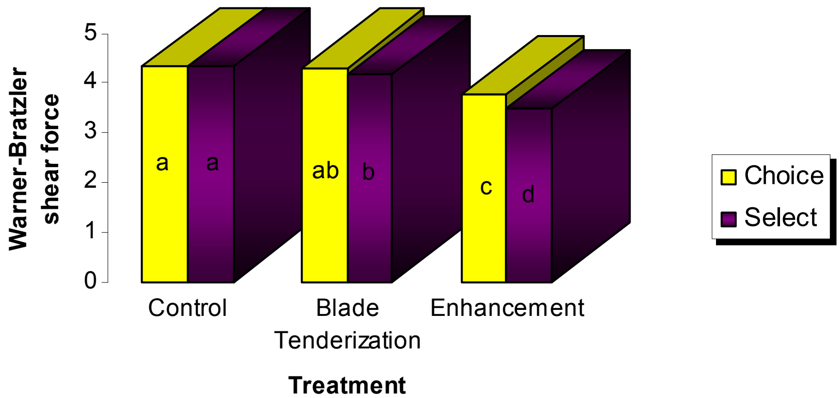
[a,b,c] Means without a common superscript differ ($P < 0.05$)

Figure 11. Influence of postmortem treatment and postmortem aging on Warner-Bratzler shear force values of clod steaks.



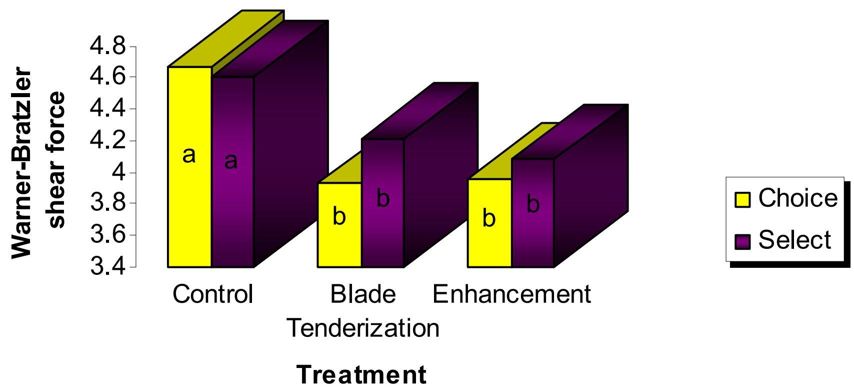
[a,b,c,d] Means without a common superscript differ ($P < 0.05$)

Figure 12. Influence of US quality grade and postmortem treatment on Warner-Bratzler shear force values of strip loin steaks.



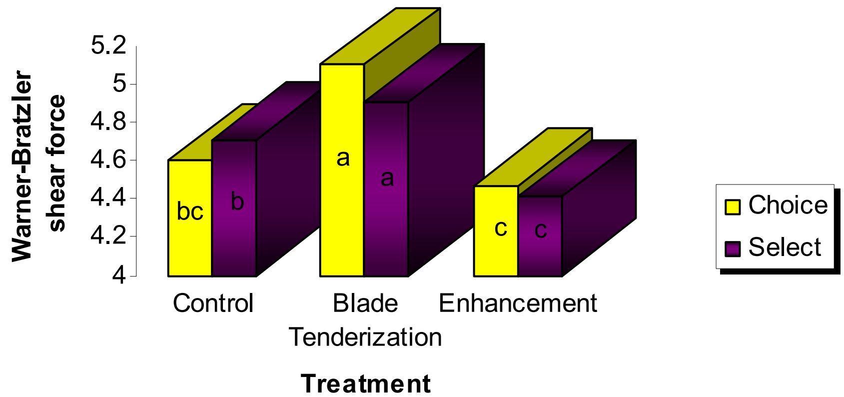
a,b,c,d Means without a common superscript differ (P < 0.05)

Figure 13. Influence of US quality grade and postmortem treatment on Warner-Bratzler shear force values of top sirloin steaks.



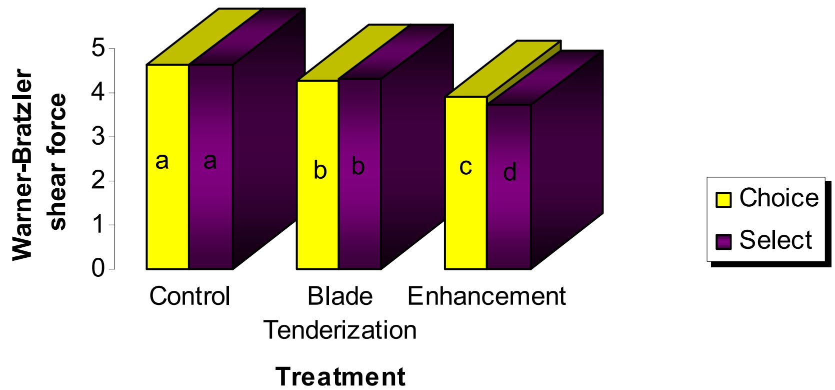
[a,b] Means without a common superscript differ ($P < 0.05$)

Figure 14. Influence of US quality grade and postmortem treatment on Warner-Bratzler shear force values of inside round steaks.



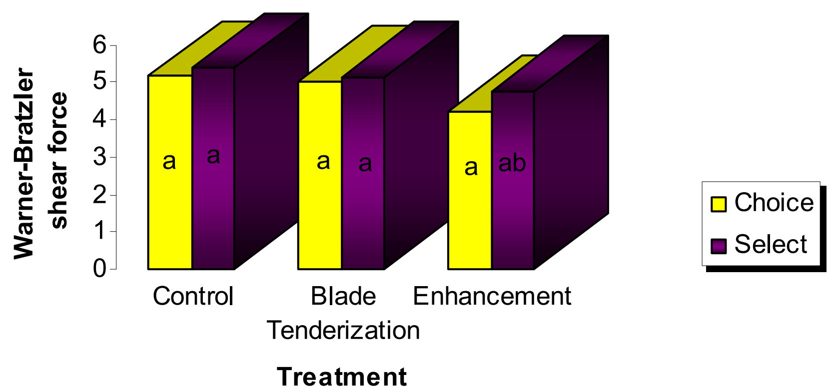
[a,b,c] Means without a common superscript differ ($P < 0.05$)

Figure 15. Influence of US quality grade and postmortem treatment on Warner-Bratzler shear force values of clod steaks.



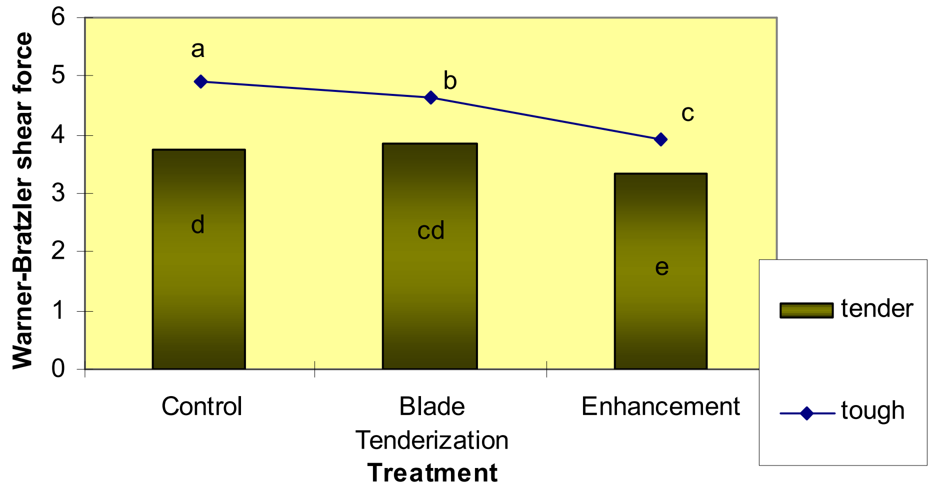
[a,b,c,d] Means without a common superscript differ ($P < 0.05$)

Figure 16. Influence of US quality grade and postmortem treatment on Warner-Bratzler shear force values of eye of round steaks.



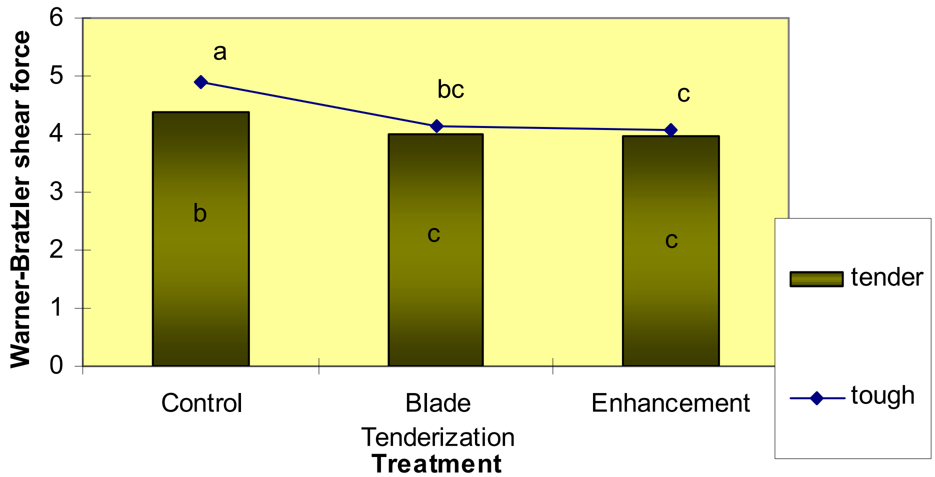
[a,b] Means without a common superscript differ ($P < 0.05$)

Figure 17. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough[1] strip loin steaks.



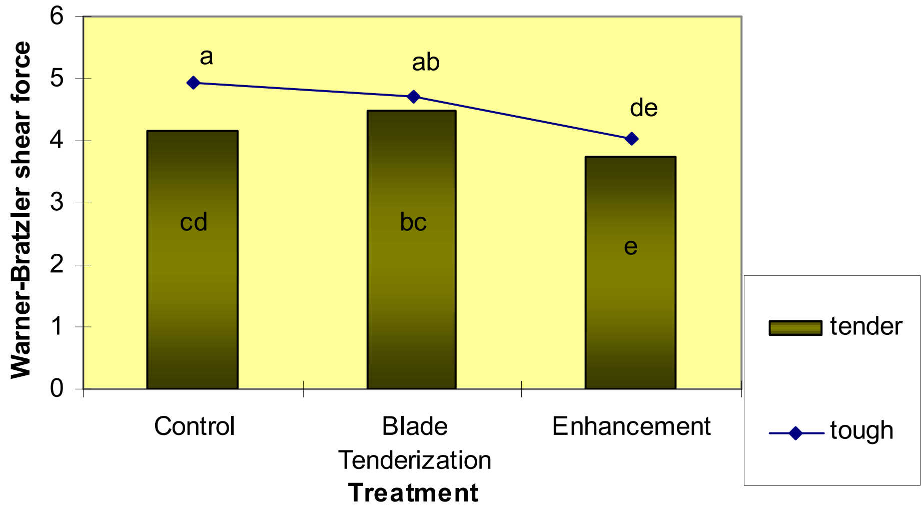
[a,b,c,d,e] Means without a common superscript differ ($P < 0.05$)
[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

Figure 18. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough[1] top sirloin steaks.



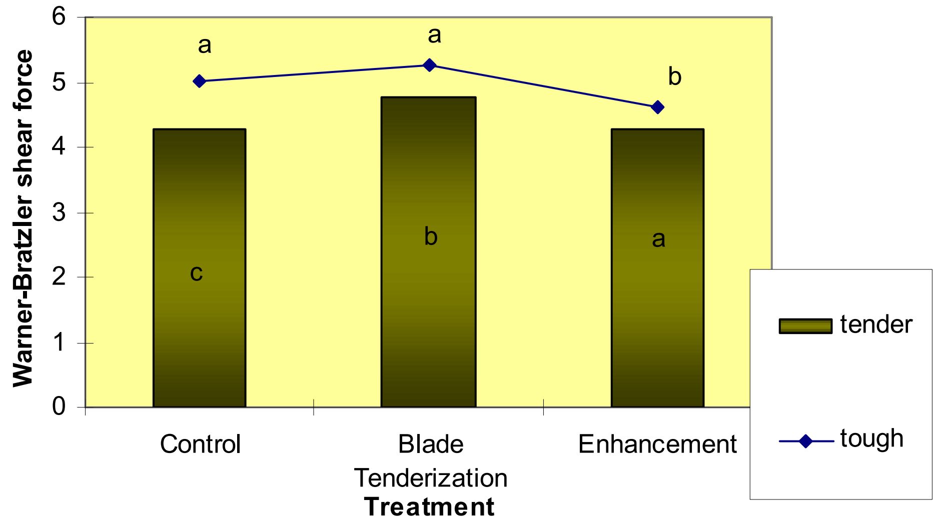
a,b,c Means without a common superscript differ ($P < 0.05$)
[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

Figure 19. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough[1] knuckle steaks.



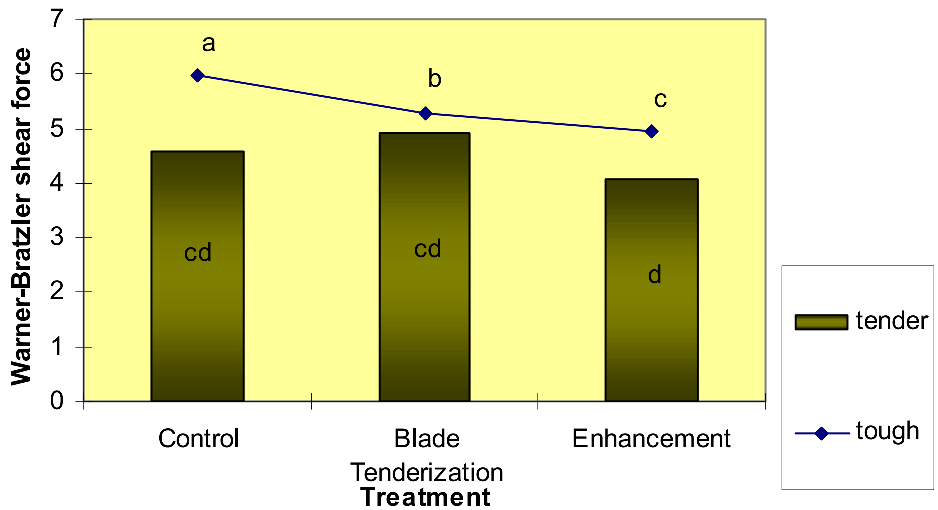
[a,b,c,d,e] Means without a common superscript differ (P < 0.05)
[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

Figure 20. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough[1] inside round steaks.



[a,b,c] Means without a common superscript differ (P < 0.05)
[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

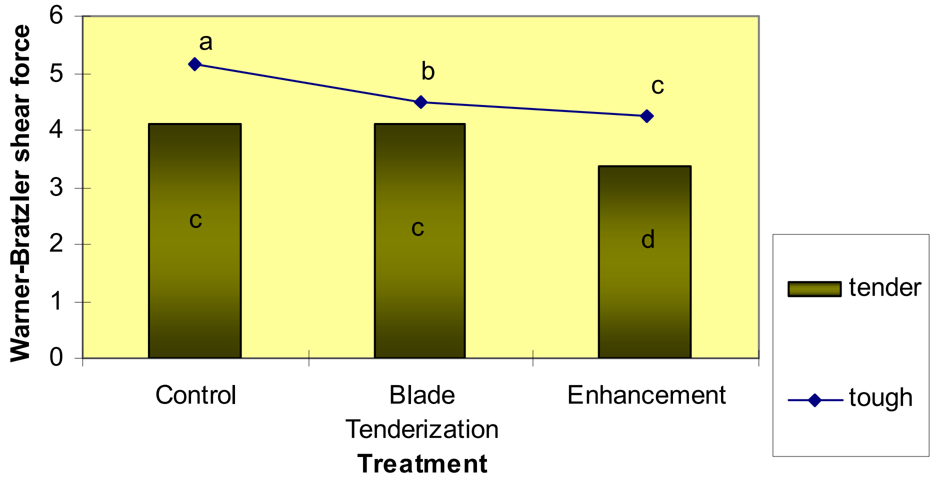
Figure 21. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough[1] eye of round steaks.



[a,b,c,d] Means without a common superscript differ ($P < 0.05$)

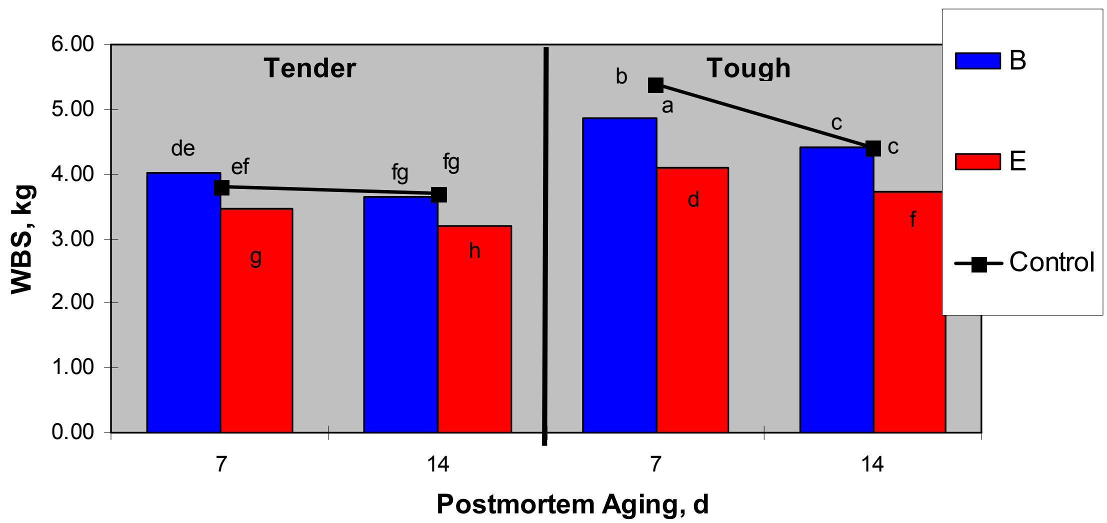
[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

Figure 22. Influence of postmortem treatments on Warner-Bratzler shear force values of tender and tough[1] clod steaks.



a,b,c,d Means without a common superscript differ ($P < 0.05$)
[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

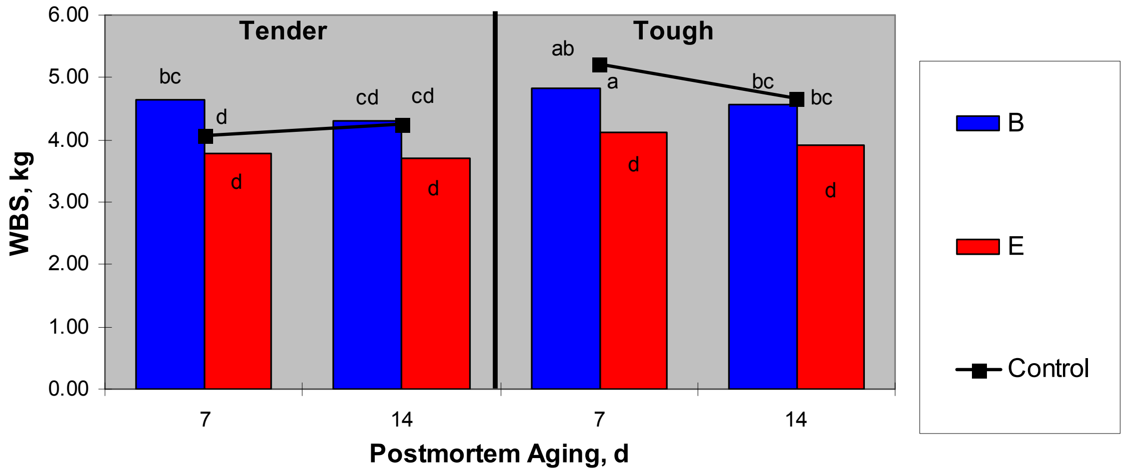
Figure 23. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender strip loin steaks.



a,b,c,d,e,f,g,h Means without a common superscript differ ($P < 0.05$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

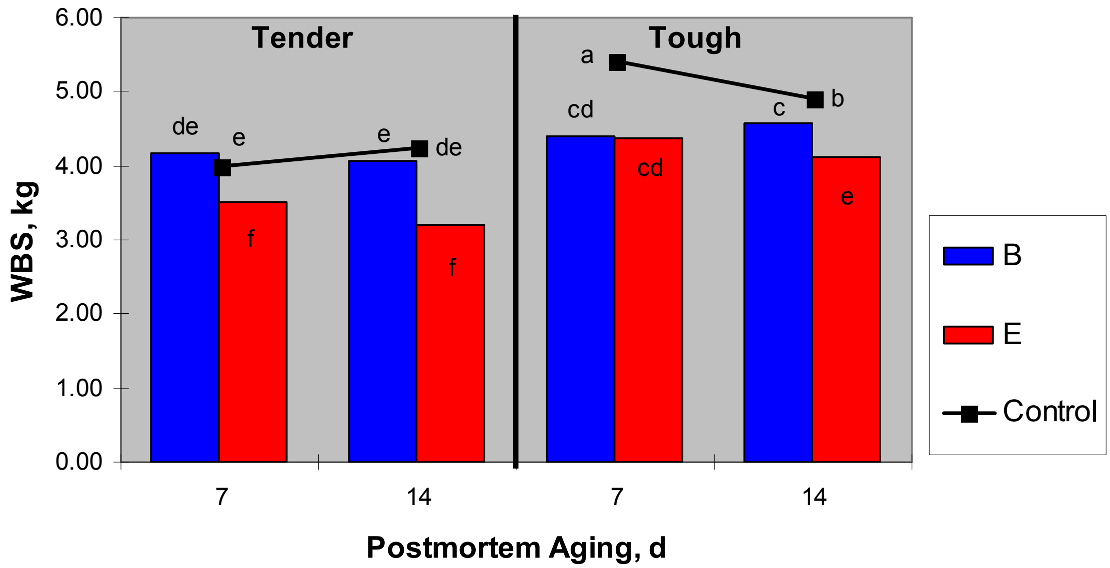
Figure 24. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender knuckle steaks.



[a,b,c,d] Means without a common superscript differ ($P < 0.05$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

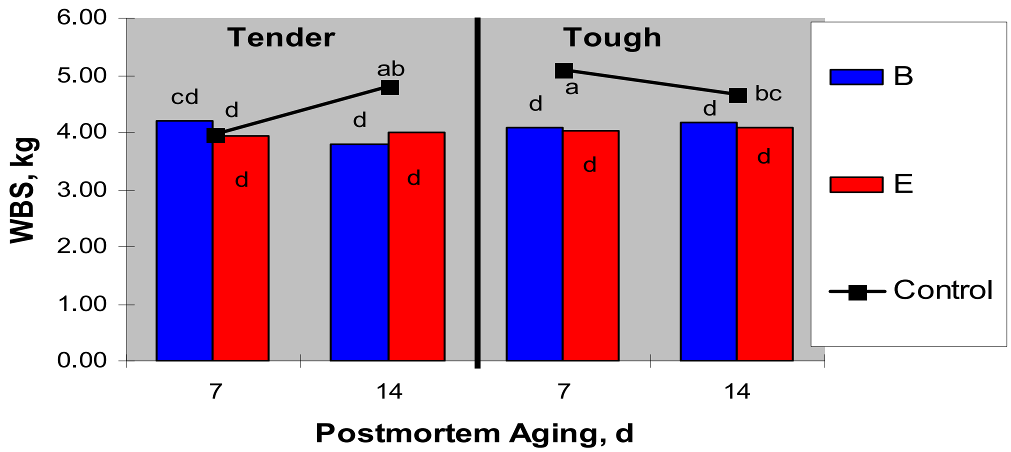
Figure 25. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender clod steaks.



[a,b,c,d,f] Means without a common superscript differ ($P < 0.05$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

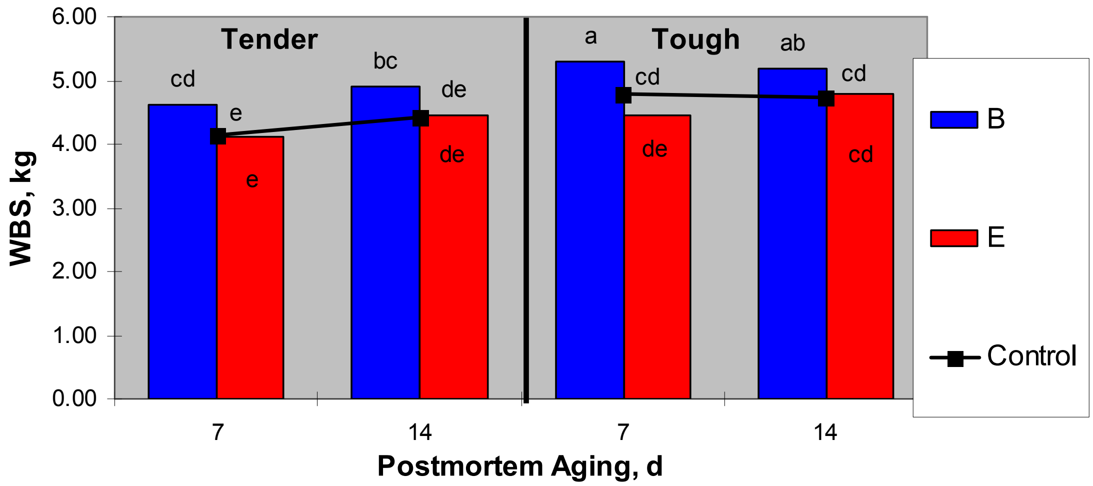
Figure 26. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender top sirloin steaks.



[a,b,c,d] Means without a common superscript differ ($P < 0.05$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

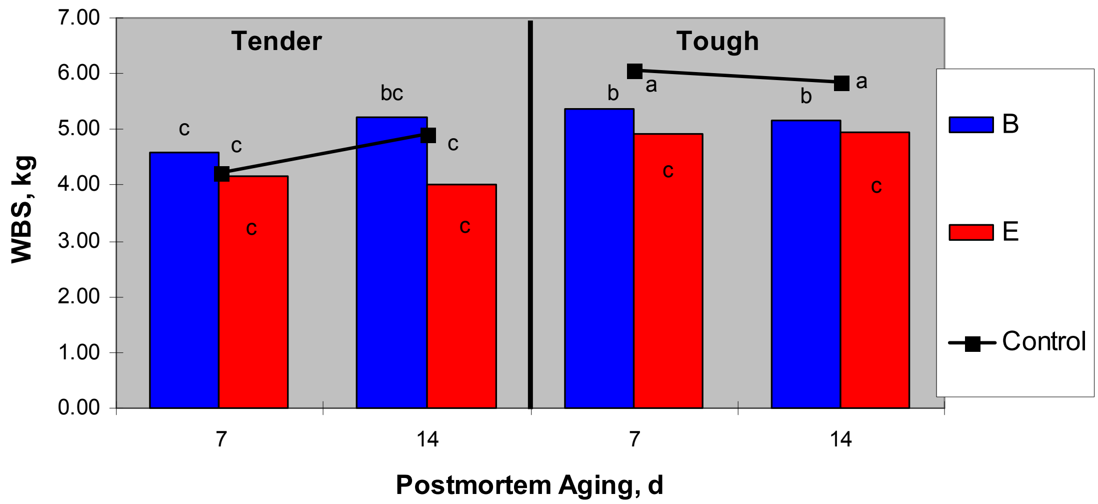
Figure 27. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender inside round steaks.



^{a,b,c,d,e} Means without a common superscript differ ($P < 0.05$)

[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

Figure 28. Influence of postmortem aging, blade tenderization (B) or enhancement (E) on Warner-Bratzler shear force values of tough[1] and tender eye of round steaks.



[a,b,c] Means without a common superscript differ ($P < 0.05$)
[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

LITERATURE CITED

Aberle, E.D., J.C. Forrest, D.E. Gerrad, and E.W. Mills. 2001. Principles of Meat Science. 4th ed. Kendall-Hunt Publishing, Dubuque, IA.

Belew, J.B. J.C. Brooks, D.R. McKenna, and J.W. Savell. 2003. Warner-Bratzler shear force comparisons of 40 bovine muscles. Meat Sci. 64:507-512.

Boehm, M.E., T.L.Kendall, V.F. Thompson, D.E. Goll. 1998. Changes in the calpains and calpastatin during postmortem storage of bovine muscle. J. Anim. Sci. 76:2415-2435.

Boleman, S.J., R. K. Miller, J.F. Taylor, H.R. Cross, T.L. Wheeler, M. Koohmaraie, S.D. Shackelford, M.F. Miller, R.L. West, D. D. Johnson and J.W. Savell. 1997. Consumer evaluation of beef of known categories of tenderness. J. Anim. Sci. 75:1521-1524.

Bowling, R.A., G.C. Smith, Z.L. Carpenter, W.H. Marshall, and M.Shelton. 1976. Blade tenderization of wholesale cuts from ram lambs and kid goats. J. Anim. Sci. 43:122-130.

Bratcher, C.L., D.D. Johnson, R.C. Littell and B.L. Gwartney. 2005. The effects of quality grade, aging, and location within muscle on Warner-Bratzler shear force in beef muscle of locomotion. Meat Sci. 70:279-284.

Brooks, JC., J.B. Belew, D.B. Griffin, B.L. Gwartney, D.S. Hale, W.R. Henning, D.D. Johnson, J.B. Morgan, F.C. Parrish, Jr., J.O. Reagan and J.W. Savell. 2000. National beef tenderness survey – 1998. J. Anim. Sci. 78:1852-1860

Davis, G.W., G.C. Smith and Z.L. Carpenter. 1977. Effect of blade tenderization on storage life, retail caselife and palatability of beef. J. Food Sci. 42:330.

Denoyelle, C. & Lebihan, E. (2003). Intramuscular variation in beef tenderness. Meat Science, 66, 241-247. (Denoyelle and Lebihan, 2003)

Dhanda, J.S., R.B. Pegg, J.A.M., Janz, J.L. Aalhus, P.J. Shand. 2002. Palatability of bison semimembranosus and effects of marination. Meat Sci. 62:19-26.

Dikeman, M.E., R.D. Green, and D.M. Wulf. 2003. Effects of Genetics vs Management on Beef Tenderness. Beef Improvement Federation.

Dikeman, M.E. 1987. Fat reduction in animals and effects on palatability and consumer acceptance of meat products. Proc.Recip. Meat Conf. 40:93-103.

Dransfield, E. 1994. Optimisation of tenderization, ageing, and tenderness. Meat Sci. 36:105-121

George, M.H., J.D. Tatum, K.E. Belk, and G.C. Smith. 1999. An audit of retail beef loin steak tenderness conducted in eight U.S. cities. J. Anim. Sci. 77:11735-1741.

George-Evins, C.D., J.A. Unruh, A.T. Waylan, J.L. Marsden. 2004. Influence of quality classification, aging period, blade tenderization, and endpoint cooking temperature on cooking characteristics and tenderness of beef gluteus medius steaks. J. Anim. Sci. 82:1863-1868.

Golder, W.J. and R.W. Mandigo. 1974. The effect of mechanical tenderization on fresh and tempered boneless pork loins. J. Anim. Sci. 39:169.

Harris, J.J., R.K. Miller, J.W. Savell, H.R. Cross, and L.J. Ringer. 1992. Evaluation of tenderness of beef top sirloin steaks. J. Food Sci. 57:6-9.

Huffman, K.L., M.F. Miller, L.C. Hoover, C.K. Wu. 1996. Effect of beef tenderness on consumer satisfaction with steaks consumed in the home and restaurant. J. Anim. Sci. 74:91

Jeremiah, L. E., L.L. Gibson, and B. Cunningham. 1999. The influence of mechanical tenderization on the palatability of certain bovine muscles. Food Res. Inter. 32:585-591.

Karges, K., J.C. Brooks, D.R. Gill, J.E. Breazile. 2001. Effects of supplemental vitamin D3 on feed intake, carcass characteristics, tenderness, and muscle properties of beef steers. J. Anim. Sci. 79:2844-2851.

Kirchofer, K.S., C.R. Calkins, and B.L. Gwartney. 2002. Fiber type composition of muscles of the beef chuck and round. J. Anim. Sci. 80:2872-2878.

Kolle, B.K., D.R. McKenna, J.W. Savell. 2004. Methods to increase tenderness of individual muscles from beef rounds when cooked with dry or moist heat. Meat Sci. 68:145-154.

Koohmaraie, M. 1996. Biochemical factors regulating the toughening and tenderization process of meat. Meat Sci. 43:S193-201

Koohmaraie, M., K.E. Gregory, L.V. Cundiff, R.M. Koch, M.E. Dikeman, 1994. Breed effects and retained heterosis for growth, carcass, and meat traits in advanced generations of composite populations of beef cattle. J. Anim. Sci. 72:833.

Koohmaraie, M, S.D. Shackelford. 1991. Predictors of beef tenderness: Development and verification. J. Food Sci. 56:1130

Koohmaraie, M. 1988. The role of endogeneous proteinases in meat tenderness. Proc. Recip. Meat Conf. 41:89-100.

Kukowski, A.C., R.J. Maddock, and D.M. Wulf. 2004. Evaluating consumer acceptability of various muscles from the beef chuck and rib. J. Anim. Sci. 82:521-525.

Lamkey, J.M., K.A. Dunlavy, and H.G. Dolezal. 1993. Changes in the palatability of beef chuck muscles with the addition of sodium lactate and soy protein isolate. J. Muscle Foods. 4:193-206.

Lawerence, T.E. M.E.Dikeman, M.C. Hunt, C.L. Kastner, D.E. Johnson. 2004. Effects of enhancing beef longissimus with phosphate plus salt, or calcium lactate plus non-phosphate water binders plus rosemary extract. Meat Sci. 67:129-137.

Lorezen, C.L., B.H. Weatherly, and J.W. Savell 1998. Determination of an aging index. A final report to the Texas Beef Council. Austin, from the Meat Science Section, Department of Animal Science, Texas A&M University, College Station.

Lorezen, C.L. T.R. Neely, R.K. Miller, J.D. Tatum, J.W. Wise, J.F. Taylor, M.J. Buyck, J.O. Reagan, and J.W. Savell. 1999. Beef Customer Satisfaction: Cooking method and degree of doneness effects on the top loin steak. J. Anim. Sci.77:637-644.

Loucks, L.J., E.E. Ray, B.W. Berry, E. A. Leighton, and D.G. Gray. 1984. Effects of mechanical tenderization and cooking treatments upon product attributes of pre- and post-rigor beef roasts. J. Anim. Sci. 58:626-630.

Mandigo, R.W. and D.G. Olsen. 1982. Effect of blade size for mechanically tenderizing beef rounds. J. Food Sci. 47:2095-2096.

McGee, M.R., K.L. Henry, J.C. Brooks, F.K. Ray, J.B. Morgan. 2003. Injection of sodium chloride, sodium tripolyphosphate, and sodium lactate improves Warner-Bratzler shear and sensory characteristics of pre-cooked inside round roasts. Meat Sci. 64:273-277.

McKenna, D.R., D.B. Griffin, H.K. Johnson, B.R. Covington, J.W. Savell. 2003. Retail yields from beef chuck and round subprimals from two grade groups when merchandised as single muscle cuts. J. Anim. Sci. 81:1482-1488.

McMillin, K.W. and A.P. Brock. 2005. Production practices and processing for value-added goat meat. J. Anim. Sci. 83:E57-68.

Miller, M.F., M.A. Carr, C.B. Ramsey, K.L. Crockett and L.C. Hoover. 2001. Consumer thresholds for establishing the value of beef tenderness. J. Anim.Sci. 79:3062-3068.

Miller, M.F., C.R. Kerth, J.W. Wise, J.L. Lansdell, J.E. Stowell, and C.B. Ramsey. 1997. Slaughter plant location, USDA quality grade, external fat thickness, and aging time effects on sensory characteristics of beef loin strip steak. J. Anim. Sci. 75:662-667.

Moeller, R.J. and S. Courington. 1998. Branded Beef Study. National Cattlemen's Beef Association, Englewood, CO.

Molina, M.E., D.D. Johnson, R.L. West, B.L. Gwartney. 2005. Enhancing palatability traits in beef chuck muscles. Meat Sci. 71:52-61.

Morgan, J. B., J. W. Savell, D. S., Hale, R. K. Miller, D. B. Griffin, H. R. Cross, and S.D. Shackelford. 1991. National Beef Tenderness Survey. J. Anim. Sci. 69:"3274-3283.

NCBA. 1998. Beef Industry Long Range Plan. National Cattlemen's Beef Assoc. Englewood, CO.

NBQA. 1995. Executive Summary: The National Beef Quality Audit. Colorado State University, Oklahoma State University and Texas A&M University.

NBQA. 2000. Executive Summary: The National Beef Quality Audit. Colorado State University, Oklahoma State University and Texas A&M University.

Neely, T.R., C.L. Lorenzen, R.K. Miller, J.D. Tatum, J.W. Wise, J.F. Taylor, M.J. Buyck, J.O. Reagan, and J.W. Savell. 1998. Beef customer satisfaction: Role of cut, USDA quality grade, and city on in-home consumer ratings. 76:1027-1033.

Nelson, J.L., H.G. Dolezal, F.K. Ray, J.B. Morgan. 2004. Characterization of certified angus beef steaks from the round, loin, and chuck. 82:1437-1442.

Nishimura, T., A. Liu, A. Hatori, and K. Takahashi. 1998. Changes in mechanical strength of intramuscular connective tissue during postmortem aging of beef. J. Anim. Sci. 76:528-532.

Parrish, F.C. Jr. 1977. Skeletal muscle tissue disruption. Proc. Recip. Meat Conf. 30:87-98.

Parrish, F.C., Jr., J.A. Boles, R.E. Rust, and D.G. Olson. 1991. Dry and wet aging effects on palatability attributes of beef loin and rib steaks from three quality grades. J. Food Sci. 56W-603.

Pearson, A.M. and T.A. Gillett. 1996 Processed Meats, 3rd Ed. Chapman and Hall, New York, New York.

Pietrasik, Z. and P.J. Shand. 2004. Effect of blade tenderization and tumbling time on the process characteristics and tenderness of injected cooked roast beef. Meat Sci. 66:871-879.

Pringle, T. D., S. E. Williams, and L. P. Johnson. 1998. Quality grade, portion size, needle tenderization and cookery method effects on cooking characteristics and palatability traits of portioned strip loin and top sirloin steaks. J. Foodservice Systems 10:73-88.

Rhee, M.S., T.L. Wheeler, S.D. Shackelford, and M. Koohmaraie. 2004. Variation in palatability and biochemical traits within and among eleven beef muscles. J. Anim. Sci. 80:534-550.

Romans, J.R., H.J. Tuma, and W.L. Tucker. 1965. Influence of carcass maturity and marbling on the physical and chemical characteristics of beef. Palatability, fiber diameter and proximate analysis. J. Anim. Sci. 42:681-685.

Savell, J.W. and S.D. Shackelford. 1992. Significance of tenderness to the meat industry. Proc. Recip. Meat Conf. 45:5-7.

Savell, J.W., R.E. Branson, H.R. Cross, D.M. Stiffler, J.W. Wise, D.B. Griffin and G.C. Smith. 1987. National consumer retail beef study: Palatability evaluations of beef loin steaks that differed in marbling. J. Food Sci. 52:517.

Savell, J. W., G. C. Smith, and Z. L. Carpenter. 1977. Blade tenderization of four muscles from three weight-grade groups of beef. J. Food Sci. 42:866-870.

Savell, J.W., F.K. McKeith, C.E. Murphy, G.C. Smith and Z.L. Carpenter. 1982. Singular and combined effects of electrical stimulation, post-mortem aging and blade tenderization on the palatability attributes of beef from young bulls. Meat Sci. 6:97.

Seideman, S.C., G.C. Smith, Z.L. Carpenter, and W.H. Marshall. 1977. Blade tenderization of beef psoas major and semitendinosus muscles. J. Food Sci. 42:1510-1512.

Shackelford, S.D., T.L. Wheeler and M. Koohmaraie. 1997. Repeatability of tenderness measurements in beef round muscles. J. Anim. Sci. 75:2411-2416.

Sheard, P.R., G.R. Nute, R.L. Richardson, A. Perry, and A.A. Taylor. 1999. Injection of water and polyphosphate into pork to improve juiciness and tenderness after cooking. Meat Sci. 51:371-376.

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

Sutton, D.S., M.S. Brewer, and F.K. McKeith, 1997. Effects of sodium lactate and sodium phosphate on the physical and sensory characteristics of pumped pork loins. J. Muscle Foods 8:111-120.

Stuby-Souva, M. A., J. W. Lamkey, and H. G. Dolezal. 1994. Aging response of beef muscles from different quality grades before and after freezing. Oklahoma Agricultural Experiment Station, Animal Science Research Report 70-77.

Lorenzen, C.L., B.H. Weatherly, and J.W. Savell. 1998. Determination of an aging index. A final report to the Texas Beef Council, Austin, from the Meat Science Section, Department of Animal Science, Texas A&M University, College Station.

Tatum, J.D., G.C. Smith, and Z.L. Carpenter. 1978. Blade tenderization of steer, cow and bull beef. J. Food Sci. 43:918.

Tatum, J.D., 1981. Is tenderness nutritionally controlled? Proc. Recip. Meat Conf. 34:65-68.

Tatum, J.D., K.E. Belk, M.H. George, and G.C. Smith. 1999. Identification of Quality Management Practices to Reduce the Incidence of Retail Beef Tenderness Problems: Development and Evaluation of a Prototype Quality System to Produce Tender Beef. J. Anim. Sci. 77:2112-2118.

Vote, D.J., W.J. Platter, J.D. Tatum, N.C. Speer, G.R. Schmidt, K.E. Belk, G.C. Smith, and N.C. Speer. 2000. Injection of beef strip loin with solutions containing sodium tripolyphosphate, sodium lactate, and sodium chloride to enhance palatability. J. Anim. Sci. 78:952-957.

Wheeler, T.L., J.W. Savell, H.R. Cross, D.K. Lunt, and S.B. Smith. 1990. Effect of postmortem treatments on the tenderness of meat from Hereford, Brahman, and Brahman-cross beef cattle. J. Anim. Sci. 68:3677-3686.

Wheeler, T.L., Cuniff, L.V., and Koch, R.M. 1994. Effect of marbling degree on beef palatability in *Bos Taurus* and *Bos Indicus* cattle. J. Anim. Sci. 72:3145.

Wheeler, T.L., S.D. Shackelford, and M. Koohmaraie. 1997. Standardizing the collection and interperation of Warner-Bratzler shear force and sensory tenderness data. Proc. Recip. Meat Conf. 50.

USDA. 2005. United States Department of Agriculture, National Statistics Service. Available http://www.usda.gov/nass/pubs/agr05/acro05.htm. Accessed September 21, 2005.

Appendix A

Table 14. Least square means and standard errors for Warner-Bratzler shear force values (kg) for subprimal steaks with a postmortem aging x grade interaction.

	Postmortem Aging, d			
Subprimal	7	10	14	21
Inside Round (n=104)				
US Choice	4.76[ab] ± 0.08	4.42[bc] ± 0.08	4.44[bc] ± 0.08	4.39[c] ± 0.08
US Select	4.71[ab] ± 0.06	4.42[c] ± 0.06	4.71[ab] ± 0.06	4.87[a] ± 0.06
Top Sirloin (n=50)				
US Choice	4.46[ab] ± 0.11	4.15[b] ± 0.12	4.88[a] ± 0.12	4.19[b] ± 0.12
US Select	4.60[ab] ± 0.11	4.43[ab] ± 0.14	4.62[ab] ± 0.11	4.19[b] ± 0.12
Clod (n=109)				
US Choice	4.74[ab] ± 0.07	4.51[b] ± 0.07	4.53[ab] ± 0.07	4.48[b] ± 0.07
US Select	4.67[ab] ± 0.07	4.83[a] ± 0.07	4.64[ab] ± 0.07	4.65[ab] ± 0.07

[a,b,c] Within subprimal Means without a common superscript differ ($P < 0.05$)

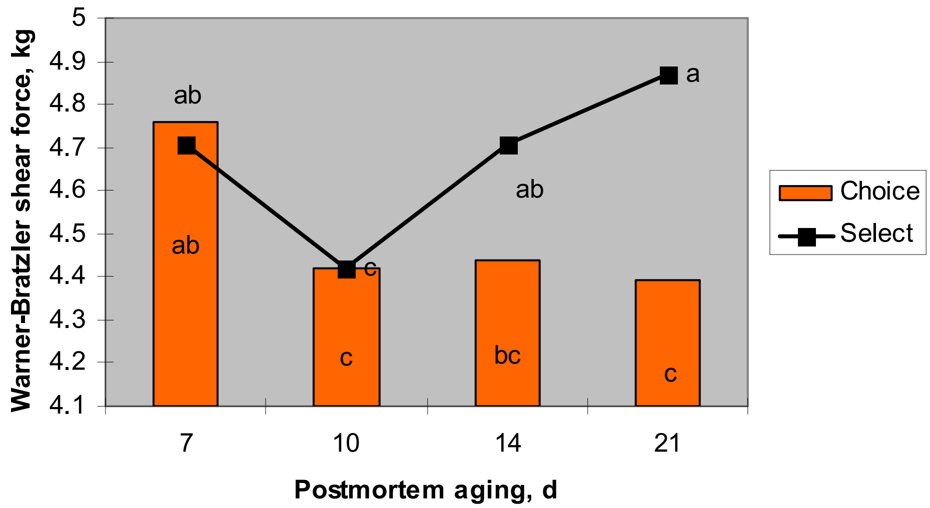
Table 15. Least square means and standard errors for Warner-Bratzler shear values (kg) for subprimal steaks with a tenderness category[1] x postmortem aging interaction.

	Postmortem aging, d			
Subprimal	7	10	14	21
Strip Loin (n=153)				
Tender	$3.81^{d} \pm 0.05$	$3.78^{d} \pm 0.05$	$3.71^{de} \pm 0.05$	$3.53^{e} \pm 0.05$
Tough	$5.41^{a} \pm 0.05$	$4.69^{b} \pm 0.05$	$4.40^{c} \pm 0.05$	$4.19^{c} \pm 0.05$
Top Sirloin (n=50)				
Tender	$3.96^{d} \pm 0.13$	$4.00^{d} \pm 0.16$	$4.81^{ab} \pm 0.13$	$4.07^{d} \pm 0.14$
Tough	$5.10^{a} \pm 0.08$	$4.58^{bc} \pm 0.09$	$4.68^{bc} \pm 0.09$	$4.30^{cd} \pm 0.10$
Knuckle (n=70)				
Tender	$4.07^{e} \pm 0.11$	$4.30^{cde} \pm 0.11$	$4.25^{de} \pm 0.11$	$4.17^{e} \pm 0.11$
Tough	$5.21^{a} \pm 0.07$	$4.82^{b} \pm 0.07$	$4.66^{bc} \pm 0.07$	$4.61^{bcd} \pm 0.07$
Inside Round (n=104)				
Tender	$4.14^{d} \pm 0.07$	$4.34^{cd} \pm 0.07$	$4.41^{cd} \pm 0.08$	$4.48^{bc} \pm 0.08$
Tough	$5.32^{a} \pm 0.07$	$4.51^{bc} \pm 0.07$	$4.74^{b} \pm 0.07$	$4.78^{b} \pm 0.07$
Eye of Round (n=113)				
Tender	$4.22^{d} \pm 0.33$	$4.69^{d} \pm 0.33$	$4.92^{cd} \pm 0.35$	$5.04^{cd} \pm 0.36$
Tough	$6.07^{a} \pm 0.06$	$5.92^{ab} \pm 0.05$	$5.86^{bc} \pm 0.05$	$5.63^{c} \pm 0.06$
Clod (109)				
Tender	$3.98^{c} \pm 0.08$	$4.28^{c} \pm 0.09$	$4.25^{c} \pm 0.09$	$4.12^{c} \pm 0.09$
Tough	$5.42^{a} \pm 0.05$	$5.06^{b} \pm 0.05$	$4.92^{b} \pm 0.05$	$5.00^{b} \pm 0.05$

[a,b,c,d,e] Within a subprimal Means without a common superscript differ ($P < 0.05$)

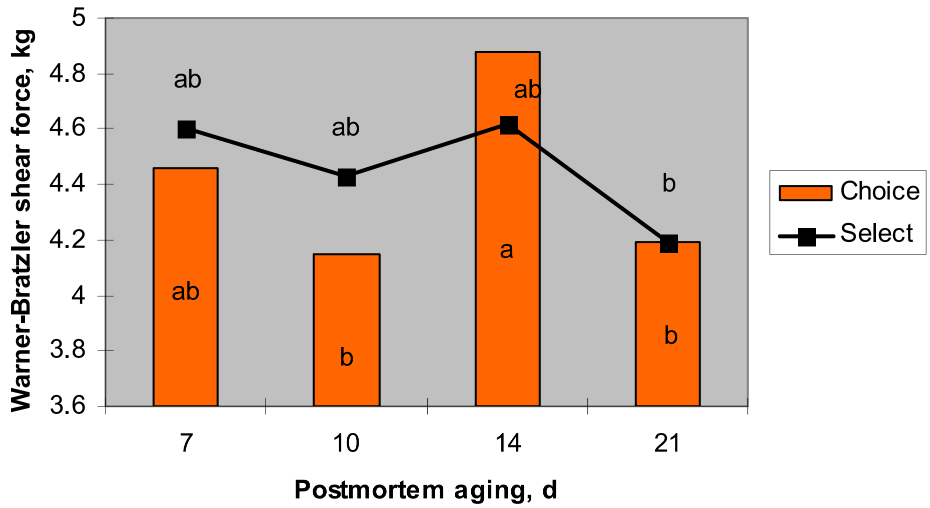
[1] Tough: Warner-Bratzler shear force value of ≥ 4.5 kg

Figure 29. Influence of postmortem aging and US quality grade on Warner-Bratzler shear force values of inside round steaks.



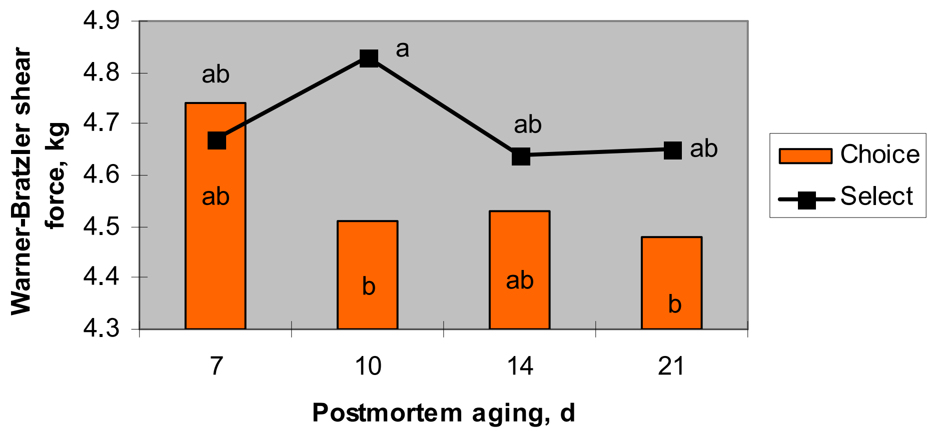
[a,b,c] Means without a common superscript differ ($P < 0.05$)

Figure 30. Influence of postmortem aging and US quality grade on Warner-Bratzler shear force values of top sirloin steaks.



[a,b,c] Means without a common superscript differ ($P < 0.05$)

Figure 31. Influence of postmortem aging and US quality grade on Warner-Bratzler shear force values of clod steaks.



a,b,c Means without a common superscript differ ($P < 0.05$)

VITA

Megan Leigh McMichael

Candidate for the Degree of

Master of Science

Thesis: INFLUENCE OF ENHANCEMENT AND BLADE TENDERIZATION ON BEEF SUBPRIMALS OF KNOWN CATEGORIES OF TENDERNESS

Major Field: Animal Science

Biographical:

Personal Data: Born in Louisville, Kentucky, on August 7, 1982, the daughter of Ken and Karen McMichael.

Education: Graduated from Scottsburg High School, Scottsburg, Indiana in May 2000; received a Bachelor of Science degree in Animal Science from Oklahoma State University, Stillwater, Oklahoma in August 2004. Completed the requirements for the Masters of Science degree with a major in Animal Science at Oklahoma State University in December 2005.

Experience: Employed by Oklahoma State University, Animal Science Department as graduate research and teaching assistant, May 2004 to present; employed by Oklahoma State University, Food and Agricultural Products Center as a meat lab student worker, August 2002 to May 2004; employed by United States Department of Agriculture, Meat Grading and Certification Branch, summer intern, May 2002 to August 2003.

Professional Memberships: American Meat Science Association

Name: Megan Leigh McMichael Date of Degree: December, 2005

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: INFLUENCE OF ENHANCEMENT AND BLADE TENDERIZATION ON BEEF SUBPRIMALS OF KNOWN CATEGORIES OF TENDERNESS

Pages in Study: 91 Candidate for the Degree of Master of Science

Major Field: Animal Science

Scope and Method of Study: Six paired subprimals (Strip loin, knuckle, clod, inside round, eye of round and top sirloin) from US Choice and Select carcasses were enhanced, blade tenderized or conventionally aged to potentially increase their tenderness values. Subprimal pairs were randomly assigned to blade tenderization, enhancement or postmortem aging. N=4, steaks were fabricated for postmortem aging of 7 d, 10 d, 14 d, and 21 d . N=2, steaks were fabricated for subprimals assigned to blade tenderization (two passes) or enhancement and were conventionally aged for 7 d and 14 d. Upon conclusion of each storage period, each steak was frozen (-20ºC) until WBSF analysis was conducted.

Findings and Conclusions: Subprimal pairs with a conventionally aged 7 d steak that exhibited a WBSF ≥ 4.50 kg were classified as “tough.” US Choice and Select enhanced strip loin steaks displayed a lower ($P < 0.05$) WBSF than blade tenderized or conventionally aged steaks. Enhanced “tough” strip loin, knuckle, and clod steaks possessed lower ($P < 0.05$) WBSF than blade tenderized or conventionally aged steaks regardless of postmortem aging. Blade tenderized and enhanced “tough” eye of round and top sirloin steaks displayed lower ($P < 0.05$) WBSF regardless of postmortem aging. Enhancement of “tender” clod steaks proved to be lower WBSF values ($P < 0.05$). Postmortem aging up to 14 d for “tough” strip loin and knuckles steaks proved to be effective ($P < 0.05$). US Choice knuckle steaks displayed a more desirable WBSF ($P < 0.05$) than US Select knuckle steaks. US Choice and Select “tough” blade tenderized and enhanced clod steaks possessed lower WBSF values ($P < 0.05$) as well as US Select “tender” enhanced clod steaks. US Choice and Select blade tenderized and enhanced eye of round steaks exhibited lower WBSF values ($P < 0.05$) however WBSF values would still be considered “tough”. It was concluded postmortem aging, enhancement, or blade tenderization or combinations of proved effective in increasing overall tenderness for only strip loins, knuckles, clods, eye of rounds and top sirloins.

ADVISER’S APPROVAL: Dr. J. Brad Morgan