THE INFLUENCE OF QUALITY GRADE, AGE, MECHANICAL TENDERIZATION, AND MARINATION ON BEEF BOTTOM SIRLOIN BUTT, TRI-TIP STEAKS

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NOMENCLATURE

°C	degree(s) Celsius
cm	centimeter
cm^2	squared centimeter
d	day(s)
g	gram(s)
h	hour(s)
IMPS	Institutional Meat Purchasing Specifications
kg	kilogram(s)
mm	millimeters per minute
mo	month(s)
NCBA	National Cattlemen's Beef Association
rpm	revolutions per minute
WBS	Warner-Bratzler shear
USDA	United States Department of Agriculture

CHAPTER I

INTRODUCTION

Beef is eaten because people like its taste (Savell et al., 1989). Forbes et al. (1974) concluded that consumers (81%) judge the quality of cooked beef steaks on the basis of tenderness. More recently, research has shown that consumers are willing to pay a premium for "guaranteed tender" beef products (Boleman et al., 1997). We also know that consumers can accurately assess differences among tenderness categories (Huffman et al., 1996 and Boleman et al., 1997).

Data collected over the last 25 years shows a staggering trend, in that cattle are becoming heavier, more muscular and carcasses have less marbling (NCBA, 2001) subsequently producing a leaner, yet less palatable, product. The beef industry fears that increasing leanness will contribute to decreases in palatability essentially, eliminating "waste" while sacrificing "taste" (Nelson, 1998).

A wide range of research has been conducted to identify factors that influence palatability, focusing on increasing tenderness and reducing variation in palatability. The National Beef Tenderness Survey (Morgan et al., 1991a) found that USDA quality grade failed to control the variation in trained panel tenderness ratings. As such, steps must be taken to address the palatability variation issue. The National Beef Tenderness Survey (Morgan et al., 1991a) provided data indicating a high percentage of retail cuts from the chuck and round were less than "slightly tender" when sampled by a trained panel. While improvements have been made in regard to the tenderness of the chuck, the round is still an area that needs improvement (Brooks et al., 2000).

Considerable work has been done on the effects of marination and mechanical tenderization on beef palatability (Davis et al., 1975; Bowling et al., 1976; Glover et al., 1977; Brooks et al., 1985; Oreskovich et al., 1992; and Scanga et al., 1999). In general, marination and mechanical tenderization work by disrupting connective tissue, and as a result, increasing tenderness. Considering the challenges faced by the beef industry relative to the consistency of beef palatability, it is postulated that mechanical tenderization coupled with marination can further reduce the variability associated with tenderness. The following research was conducted to 1) investigate the impact of USDA quality grade on bottom sirloin butt steaks as well as, 2) assess how great a contribution various postmortem improvement techniques (aging, mechanical tenderization and marination) have on reducing the variability of bottom sirloin steaks.

CHAPTER II

REVIEW OF LITERATURE

Factors affecting tenderness

The 1995 National Beef Quality Audit identified low overall palatability as a quality concern facing the beef industry (NCBA, 1995). Cooked beef palatability (tenderness, juiciness and flavor) is determined by structural and compositional differences of muscle components (sarcomeres, myofibrils, muscle fibers and muscle bundles), coupled with several animal and carcass factors (physiological age, marbling, fatness, biological type and ante- and postmortem management practices). Of the three palatability attributes, tenderness is the most variable, while juiciness and flavor can be largely determined by management practices and end-point degree of doneness (Smith et al., 1998).

Marbling. The preliminary U.S. standards for the Grades of dressed beef were formulated in 1916. Initially, the standards provided the basis to uniformly report the dressed beef markets according to grades. Revisions were made and those grade descriptions became the Official United States Standards for the Grades of Carcass Beef in 1926. These standards provided the basis for grading when the voluntary beef grading and stamping service began in 1927 (USDA, 1997). These grades were intended to section carcasses based on market value as a result of predicted cook meat palatability. Though numerous revisions have been made, the basic concept regarding the assessment of beef carcass quality has remained the same. Today, steer and heifer carcass quality grades range from USDA Prime (expected to be most palatable) to USDA Canner (expected to be least palatable). USDA beef carcass quality grades are determined using three factors: 1) physiological maturity of the carcass, 2) marbling degree within the *longissimus dorsi* at the $12^{th}/13^{th}$ rib interface, coupled with 3) meat firmness (USDA, 1997). Once maturity of a carcass has been determined, marbling becomes the primary factor when assigning the final quality grade. Overwhelming majorities, 95.1%, of steer/heifer carcasses qualify for the "A" (most youthful) maturity classification group (NCBA, 1995). As such, marbling remains the primary consideration in the assignment of the USDA quality grade in youthful beef carcasses (Tatum et al., 1982).

Numerous researchers have investigated the relationship between marbling and beef tenderness. Considerable research indicates a positive correlation between marbling and beef tenderness (McBee and Wiles, 1967; Jennings et al., 1978; Dolezal et al., 1982; Smith et al., 1984; May et al., 1992). McBee and Wiles (1967) found that *longissimus dorsi* tenderness, juiciness and flavor increased ($P < 0.05$) with additional degrees of marbling in a direct, linear relationship. Dolezal et al. (1982) found that as *longissimus dorsi* marbling degree increased, shear force values decreased ($P < 0.05$) and sensory panel ratings increased ($P < 0.05$). Similarly, Jennings et al. (1978) concluded that increases in *longissimus dorsi* marbling content were significantly ($P < 0.01$) associated with lower shear force values and higher panel tenderness ratings. Steaks from carcasses with Modest or higher degrees of marbling have been shown to have more desirable ($P < 0.05$) sensory ratings for all palatability attributes and lower ($P < 0.05$) shear force values than steaks with Slight-minus, Traces or Practically Devoid degrees of marbling (Dolezal et al., 1982). Jennings et al. (1978) also concluded that steaks possessing Modest or higher marbling scores had lower, more desirable shear values and more desirable sensory tenderness and juiciness values than steaks containing Slight or lower degrees of marbling. Despite a low degree of association between marbling and cooked beef palatability, marbling is relatively effective in identifying carcasses with "desirable" versus "undesirable" palatability attributes ("desirable" = mean panel rating of 4.50 or higher, "undesirable" = mean panel rating lower than 4.50) (Tatum et al., 1982). Tatum et al. (1982) showed that more than 92, 99 and 92% of steaks from carcasses with a Slight degree of marbling or higher received "desirable" sensory panel ratings for overall tenderness, flavor desirability and overall palatability, respectively.

Contrary to the findings above, some researchers have found a low association between marbling and cooked beef tenderness (Romans et al., 1965; Parrish et al., 1973; Crouse and Smith, 1978; Tatum et al., 1982). Parrish et al. (1973) found that degree of marbling (Slight, Modest and Moderately Abundant) had virtually no effect on tenderness, juiciness, flavor, overall acceptability and

Warner-Bratzler shear force values of cooked longissimus muscle. Romans et al. (1965) found there to be no significant ($P > 0.01$) differences in WBS values associated with longissimus muscle containing Slight and Moderate marbling levels. The lack of significant palatability differences, except for juiciness, between two marbling levels, which are noticeably separated on the graduated marbling scale, suggests that the use of marbling to predict palatability is overemphasized. Also, no tenderness differences due to marbling were detected by the trained taste panel. Romans et al. (1965) concluded as little as 5% of the variation in taste panel and shear force tenderness could be attributed to marbling level. In agreement, Tatum et al. (1982) found longissimus muscle marbling to account for approximately 5% of the variation in sensory panel ratings for overall tenderness.

The standards outlined by the USDA are a subjective measurement of predicted palatability. It stands to reason that a more objective measurement of expected palatability could be used. It has been postulated that chemical fat percentages could be used to better predict cooked beef palatability (McBee and Wiles, 1967; Campion and Crouse, 1975; Davis et al., 1979). McBee and Wiles (1967) found that percent ether extractable fat, on a moisture-free basis (MFB), increased with additional increments of marbling in *longissimus dorsi* steaks. Research conducted by Savell et al. (1986) supports the findings of McBee and Wiles (1967). Savell et al. (1986) developed a regression equation to predict the percentage ether extractable fat when the marbling score was known. The equation is as follows: Percentage ether extractable fat = (marbling score x

0.0127) - 0.8043 (the r-square for the equation is 0.7794). Differences in percent ether extract diminished among practically devoid, traces and slight degrees of marbling and an inverse relationship was found for percent moisture. This is supported by Davis et al. (1979) who showed percentages of intramuscular fat and moisture are inversely related. The most tender loin steaks had higher ($P < 0.05$) percentages of intramuscular fat and lower percentages of intramuscular moisture in USDA Choice and Commercial quality grades (Davis et al., 1979). The differences in intramuscular fat and moisture were not significant ($P > 0.05$) in the USDA Good (Select) grade. The lack of statistical significance found by Davis et al. (1979) among the USDA Good (Select) grade was not startling since the range in visible intramuscular fat (marbling) across the grade was very limited. Campion and Crouse (1975) suggested that 2.9% longissimus fat would assure a level of fat adequate for desirability acceptance. Savell and Cross (1988), in support of Campion and Crouse (1975), determined that rib and loin cuts must have a minimum of 3% fat on an uncooked basis (associated with minimum Slight marbling) for acceptable palatability (Appendix 1). Overwhelming evidence led to the conclusion that steaks with less than 3% animal fat (or the marbling levels associated with 3%- Practically Devoid and Traces) were drier, tougher and less flavorful (Savell and Cross, 1988). Armbruster et al. (1983) stated that since marbling score and actual longissimus intramuscular fat content contribute very little to sensory attributes, more reliable indicators need to be developed.

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Proteolysis. Variation in meat tenderness exists at harvest, is created during *post-mortem* storage or is a combination of both (Koohmaraie, 1996). Sometime after death, tenderization begins and continues for an unknown period of time. The tenderization phase does not occur equally in all species of animals. There is a large variation in both the rate and extent of post-mortem tenderization. For example, pork can benefit from as little as 5 d storage, while it is generally accepted that beef be stored for 10-14 d (Koohmaraie, 1996). Recent research (Koohmaraie, 1996) suggests that proteolysis of specific myofibrillar proteins are the cause of post-mortem tenderization. These proteins are involved in the inter- (desmin and vinculin) and intra- (titin and nebulin) myofibril linkages as well as the attachment of the muscle cells to the basal lamina (laminin and fibronectin). It is the degradation of these proteins that weakens the myofibrils, thus tenderizing. It can be said that μ-calpain is the mechanism responsible for tenderization of meat at refrigeration temperatures (Koohmaraie, 1996). Some doubt exists as to whether the calpain proteolytic system is the underlying mechanism of post-mortem proteolysis. oncerns are based on the following (Koohmaraie 1996): 1) μ-calpain is so rapidly inactivated it cannot account for tenderization beyond 24 to 48 h *post-mortem*; 2) how can μ-calpain be active when muscle contains twice as much calpastatin as μ-calpain activity?; and 3) if μ-calpain is involved in post-mortem proteolysis, why is m-calpain not degraded during post-mortem storage? First, μ-calpain activity is often quantified using the least sensitive methodology. Use of a more sensitive methodology indicates significant μ-calpain activity after extended storage at refrigeration temperatures (Koohmaraie et al., unpublished data). Second, most literature uses m-calpain to quantify calpastatin activity. It is important to note that it takes twice as much calpastatin to inhibit μ-calpain as is does to inhibit m-calpain. Thus, the actual ratio of calpastatin to μ-calpain is one-half of that mentioned in most research and the argument regarding excessive calpastatin activity is not as significant as it first appears (Koohmaraie, 1996).

Extensive research has been conducted on the use of post-mortem aging and its subsequent effect on tenderness (Smith et al., 1978; Mitchell et al., 1991; Eilers et al., 1996). Smith et al. (1978) found that a sensory panel rating for five muscles from the chuck (longissimus and triceps brachii), rib (longissumus dorsi) and round (semimembranosus and biceps femoris) for tenderness, flavor desirability and overall palatability was optimized at 11 d. Aging for more than 11 d (14, 21 or 28 d) did not result in continued improvement of sensory characteristics. Eilers et al. (1996) findings are consistent with that of Smith et al. (1978) in that, as the aging period was extended beyond 12 d, panel tenderness ratings continued to increase, but at a much slower rate. Eilers et al. (1996) concluded that strip loin steaks aged 12 d would ensure "acceptable" (3.2 - 3.9 kg) tenderness, but if the goal is to maximize the occurrence of "superior" (< 3.2 kg) tenderness aging up to 24 d was needed. Jennings et al. (1978) also found that either 10 or 20 d of vacuum package aging in combination with 5 d carcass aging may be adequate to produce acceptable tenderness in strip loin steaks from carcasses of minimal fat cover.

Physiological maturity. USDA classifies beef carcasses in one of five maturity groups. Maturity groups are separated into 5 classifications; A, B, C, D and E (NCBA, 1995) (Appendix 2). In 1995, 95.1% of cattle surveyed fell into the "A" maturity classification (NCBA, 1995). In accordance with the USDA standards (1997), visual evaluation of the size, shape and ossification of the bones and cartilages, in combination with the color and texture of fresh lean, is used to determine the maturity of a beef carcass. In the split chine bones, ossification changes occur at an earlier stage of maturity in the posterior region of the vertebral column (sacral vertebrae) and at increasingly later stages of maturity in the anterior region of the vertebral column (lumbar and thoracic vertebrae) (USDA, 1997). Ossification of the cartilaginous buttons of the thoracic vertebra is of primary importance. Size, as well as shape, of the ribs are important considerations when evaluating differences in beef carcass maturity (USDA, 1997). As a result of animal aging, meat tenderness decrease can be attributed to changes in the amount and/or structure of connective tissue within muscle. Conversely, carcass physiological indicators are not always consistent indicators of chronological age (Nelson, 1998). Romans et al. (1965) studied the *longissimus dorsi* muscle of A, B, C and D maturities and found there to be no differences ($P > 0.05$) in shear force. However, he did observe a trend for higher shear values in older maturity carcasses. Breidenstein et al. (1968) found that *longissimus dorsi* and *semimembranosus* tenderness between A and B maturities was not statistically significant ($P > 0.05$), but E maturity was significantly ($P < 0.01$) less tender than A or B maturities. Data analyzed by

Smith et al. (1982) suggests that USDA principles involved in assigning maturity levels are effective at segmenting carcasses into groups which produce steaks of differing flavor, tenderness and overall palatability. It was found that as the range of maturity of the test population increased from A to E, the ability of USDA overall maturity scores to account for observed variability increased for shear force requirements of loin, top round, bottom round and eye of round steaks. Moreover, Tuma et al. (1962) showed the greatest difference in tenderness can be observed between the 18- and 42- month-old animals. The association between marbling and tenderness of *longissimus dorsi* muscle varied with age. Slightly Abundant marbling, when compared to Slight marbling, did not enhance the tenderness of steaks from the 18- month-old animals. The more tender steaks from the 42- and 90-month-old animals were associated with the Slightly Abundant marbling level. From Tuma et al. (1962), the conclusion can be drawn that as physiological age increases, an increase in marbling is needed to compensate for the inherent decrease in tenderness due to changes in the amount and/or structure of connective tissue within muscle.

Subprimal or muscle type. Muscle is the major edible portion of an animal and is composed of three distinct types: skeletal, smooth and cardiac. Skeletal muscles are the most important of the three types because of quantity and economic value (Romans et al., 1994). There are more than 600 skeletal muscles in the animal body and they vary greatly in size, shape and function (Forrest et al., 1975). All muscles are mixtures of three types of muscle fibers:

white, red and intermediate (Bechtel, 1986). The proportions of fiber types vary between muscles and are dependent on muscle function. The majority of muscles in large animals contain a mixture of all three fiber types (Bechtel, 1986). Skeletal muscle is covered with and divided by connective tissue. Forrest et al. (1975) stated that collagen is the principle structural component of connective tissue. Collagen is the most abundant protein in the animal body and significantly influences meat tenderness (Forrest et al., 1975). Distribution and amount of collagen is not consistent among muscles and generally parallels their physical activity (Forrest et al., 1975). Collagen fibers form intermolecular cross linkages and become relatively insoluble and strong. Cross linkages are fewer and are more easily broken in youthful animals (Forrest et al., 1975). As the animal matures, the number of cross linkages increases and the easily broken linkages become stable (Forrest et al., 1975). Collagen is more soluble in young animals and, as the animal matures, becomes less soluble (Forrest et al., 1975). Differences in muscle fiber type and collagen amount throughout the carcass add to tenderness variability of muscles.

In research conducted by Ramsbottom and Strandine (1948), 50 muscles from US Good (Select) beef carcasses were cooked and shear force evaluation was performed. From that research, it was decided that beef muscles vary greatly in tenderness and the commercial practice of grouping muscles of similar tenderness should be extended so that the occurrence of both tender and tough muscles within a steak or roast would be eliminated. Work by Shackelford et al. (1995) agreed with previous work in that shear force values for the longissimus muscle are not a valid index of carcass tenderness. Data from the National Beef Tenderness Survey (Morgan et al., 1991a) reported that roasts tended to be more tender than did steaks from the same subprimal source. Approximately two to three times as many round and chuck steaks had shear force values in excess of 4.6 kg compared to their roast counterparts. It is speculated that this difference is due to variations in cooking method (braising versus roasting) and shorter cook times, as well as greater amounts of connective tissue in the thinner cuts. It has been shown that marbling accounts for more variation in palatability of loin steaks than in top round steaks. Smith et al. (1984) showed that carcasses with Moderately Abundant marbling produced loin steaks with higher palatability ratings in 60% of all comparisons compared to 37.1% in top round steaks. Wulf et al. (1996) reported differences in shear force due to collagen solubilization in round, sirloin and strip loin steaks. During heating, collagen solubilized in round and sirloin steaks and shear force was improved; however fiber shrinking offset the effect of collagen solubilzation and the meat began to toughen again. Because of low collagen content, strip loin steaks showed no shear force improvement as a result of heating. In most cases, subprimal cut has the largest effect on taste panel tenderness ratings.

Warner-Bratzler shear force

Since the invention of an apparatus by K.F. Warner, many studies have evaluated factors influencing shear force (Wheeler et al., 1996). Proper execution of a standardized protocol is essential for obtaining accurate and repeatable shear force measurement (Wheeler et al., 1997). Wheeler et al. (1996) verified that differences in protocol could result in illegitimate variation in Warner-Bratzler shear values. Shear force values differed in and among institutions due to protocol, execution of protocol and instrumentation variation. Until institutions use a standardized protocol, comparison of Warner-Bratzler shear values across institutions is not valid (Wheeler et al., 1997). Research has been conducted evaluating the relationship between shear force and trained sensory panel tenderness ratings (Shackelford et al., 1995). Minimal differences in mean Warner-Bratzler shear force were detectable among 10 muscles; however, mean sensory panel ratings for overall tenderness differed greatly. Consequently, muscles ranked on tenderness values are highly dependant on the method used to evaluate tenderness.

Procedures to enhance tenderness

Mechanical tenderization. Throughout the past thirty years, extensive research has been conducted on the benefits of using various forms of mechanical tenderization in order to improve/alter meat palatability traits. Mechanical tenderization is accomplished by passing subprimals or steaks through a bank of needles or through a rotary macerator (Romans et al., 1994). The bank of needles pass through the meat, effectively severing connective tissues and muscle fibers making meat more palatable (Romans et al., 1994).

Various claims have been made touting mechanical tenderization's ability to take low quality meat and make it eat like high quality meat. Advocates also claimed more rapid and uniform cooking, as well as more uniformity of tenderness by dissipating connective tissue or disrupting muscle fibers (Miller, 1975). Initially, mechanical tenderization was met with opposition from food service operators. They voiced concerns about higher cooking losses and loss of flavor and poor plate presentation (Miller, 1975). Many food service operators and purveyors believe the major benefits of using mechanical tenderization fall into three categories: 1) insurance of acceptable tenderness, 2) uniformity of tenderness in items containing two or more muscles of differing tenderness, and 3) upgrading of cuts/grades not previously used for steaks (Miller, 1975).

Countless researchers have studied the effect of mechanical tenderization on the palatability of beef (Davis et al., 1975; Bowling et al., 1976; Savell et al., 1977; Seideman et al., 1977; Loucks et al., 1984). Glover et al. (1977) found mechanical tenderization of round roasts to markedly ($P < 0.01$) improve Warner-Bratzler shear force values. Unfortunately, mechanically tenderized round roasts were found to be less juicy; likely a result of increased cook loss. In round and loin steaks, mechanical tenderization increased ($P < 0.01$) tenderness as measured by Warner-Bratzler shear values. However, Glover et al. (1977) found no improvement ($P > 0.05$) in treated chuck roasts. Results from Loucks et al. (1984) found mechanical tenderization improved Warner-Bratzler shear force values significantly ($P < 0.05$) for semimembranosus roasts from cold-boned carcasses when compared to hot-boned carcasses. Shear force data reported by Seideman et al. (1977) suggested that semitendinosus could be made as tender as psoas major by use of blade (mechanical) tenderization if the procedure is performed twice. Conversely, sensory panel scores do not support such a claim. Tatum et al. (1978) showed that while cow and bull longissumus muscle could be mechanically tenderized such that shear force values rivaled steer longissimus muscle, sensory panel ratings were insufficient for cow samples. Blade tenderization was found to increase sensory panel tenderness ratings of beef longissimus; however, overall palatability ratings were not affected (Savell et al., 1977). Bowling et al. (1976) reported that shear force data exaggerated the effect of blade tenderization on tenderness because the Warner-Bratzler shear blade can follow fracture lines created by the path of the tenderizer blades through the cooked sample during shearing. The shear machine cannot, as human subjects can, perceive organoleptic traits other than the resistance to shear. Sensory panel members can mentally compensate for (and average) mechanically tenderized areas with those areas within the sample that were not severed by the tenderizer blades (Bowling et al., 1976).

Marination. Webster's dictionary (Guralnik, 1982) defines a marinade as a spiced pickling solution, especially a mixture of oil, wine or vinegar and spices, in which meat, fish or salad is steeped, often before cooking. In order to counteract beef toughness problems, researchers have investigated curative actions that could be used to increase beef tenderness, reduce variability and add to consumer satisfaction of whole-muscle retail cuts (Scanga et al., 1999). As a general directive, marinades promote the swelling of collagen, which disrupts hydrogen bonds within the collagen fibril (Forrest et al., 1975). Work also indicates that weakening of intramuscular connective tissue may occur during marination (Lewis and Purslow, 1990). Intramuscular connective tissue influences meat texture indirectly by its shrinkage during cooking; which squeezes out fluid from the heated myofibrils (Lewis and Purslow; 1990).

Many studies have indicated that the concentration of acid present in the marinade affects pH and thus, tenderness. It has been determined that marinades act by altering ultimate pH (both low and high) and in turn alter the physical and/or chemical properties of meat. Oreskovich et al. (1992) found, through electron microscopy, a loss of the M-line at low pH and a loss of Z-line material at high pH.

Use of various ingredients to enhance meat tenderness has been well documented (Morgan et al., 1991b; Kerth et al., 1995; Scanga et al., 1999). The use of calcium chloride as a means to increase meat tenderness has been celebrated for over a decade. Scanga et al. (1999) reported trained panel detection of a bitter and metallic off-flavor in steaks marinated with calcium chloride; yet, the addition of a beef-flavoring agent appeared to mask the bitter and metallic off-flavor. Calcium chloride marination did not improve ($P > 0.05$) the tenderness of cooked steaks; however, it should be noted that the calcium chloride marinade was not absorbed into the steaks (Scanga et al., 1999). Morgan et al. (1991b) found cow subprimals injected with calcium chloride exhibited decreased Warner-Bratzler shear force values and improved sensory ratings by 40 to 50%. The difference in results from Morgan et al. (1991b) and Scanga et al. (1999) could be due to the technique used to apply the calcium chloride marinade; the former used injection, while the later used vacuum bag storage. Research conducted by Koohmaraie et al. (1990) found calcium chloride injected muscles at 1 d postmortem had shear force values similar to non-injected muscles at 14 d. Koohmaraie et al. (1990) daringly commented that elevation of calcium concentration eliminates the necessity for postmortem storage past 24 h to guarantee meat tenderness.

Proteolytic enzymes are known to improve tenderness of meat when properly used. This increase in tenderness is undeniably a result of protein breakdown (Kang and Rice, 1970). Brooks et al. (1985) found chicken muscle injected with crude papain and incubated at 35ºC did not ($P > 0.05$) increase collagen solubility compared to control muscle. However, incubation at 60ºC increased ($P < 0.05$) collagen solubility 210% compared to control. Heating collagen permits the double helix to unwind and denature into individual peptide chains, rendering collagen more susceptible to enzymes (Brooks et al., 1985). In a taste panel conducted by Gerelt et al. (2000), meat treated with papain received the highest scores for tenderness; unfortunately, those steaks also received a high score for bitterness. The untrained taste panel also gave high tenderness ratings to meat treated with *A. oryzae* when compared to non-treated meat. Gerelt et al. (2000) speculates the bitterness of papain treated meat is due to appearance of bitter peptides from proteolytic degradation of meat protein.

Electrical stimulation. Since the early 1950's, electrical stimulation has been recognized as a method of improving meat tenderness (Romans et al., 1994). Two types of electrical stimulation are recognized: high voltage and low voltage. High voltage (greater than 500 volts) is designed for use in large packing facilities with a continuous chain system (Romans et al., 1994). Low voltage stimulation uses the functioning nervous system of the animal, thus stimulation must occur within 15 minutes of stunning (Romans et al., 1994).

McKeith et al. (1981) studied the effect of electrical stimulation on the quality and palatability of beef. Electrical stimulation improved lean maturity score, improved marbling and decreased "heat-ring" incidence in the ribbed surface of longissimus muscle (McKeith et al., 1981). In concurrence with those findings, Crouse et al. (1983) found more youthful lean maturity scores for electrically stimulated beef carcasses when compared to non-electrically stimulated beef carcasses. McKeith et al. (1981) reported data that indicated that the use of 550 volts, rather than 150 volts, decreased ($P < 0.05$) shear force value and increased ($P < 0.05$) overall tenderness as well as ($P < 0.05$) overall palatability ratings for longissumus dorsi steaks. Stimulation for 2 minutes, rather than 1 minute, did not affect ($P > 0.05$) shear force values, overall tenderness or overall palatability of longissimus dorsi steaks. McKeith et al. (1981) concluded that stimulation at different stages of slaughter-dressing sequence did not induce differential responses in carcass characteristics nor cooked beef palatability. Additional data suggests stimulation of carcasses as individual sides is not required to gain an increase in quality and palatability (McKeith et al., 1981).

Stiffler et al. (1986) research findings support previous data (McKeith et al., 1981) in that electrically stimulated, when compared to control, beef carcasses were more youthful in their lean maturity scores and displayed improved tenderness. Bidner et al. (1985) found electrically stimulated carcasses produced steaks having lower Warner-Bratzler shear force values than steaks from non-electrically stimulated carcasses. Unfortunately, trained sensory panel scores did not support this finding, as electrical stimulation showed no significant effect on sensory panel traits.

In contrast to the aforementioned findings, several researchers (Calkins et al., 1980, Medeiros et al., 1988) found no improvement in carcass characteristics and palatability due to electrical stimulation. Calkins et al. (1980) boldly stated that any USDA grade-advantage associated with electrically stimulated carcass subsequent to 24 h chill is deceptive rather than actual. Data indicated that non-stimulated carcasses, which are chilled for 48 or 72 h, would grade as high or higher than carcasses that have been electrically stimulated (Calkins et al., 1980). Medeiros et al. (1988) supports the previous findings stating Warner-Bratzler shear force values for *longissimus dorsi* and *semimenbranosus* muscles from concentrate-fed steers were not decreased by electrical stimulation. The effects of electrical stimulation were not meaningful and mean differences were small; tenderness scores tended to be greater from electrically stimulated carcasses (Crouse et al., 1985). Electrical stimulation had no effect on quality grade or panel tenderness ratings (Crouse et al., 1983). Crouse et al. (1985)

suggests the lack of consistent findings in relation to the effects of electrical stimulation may be due to different methods of application.

Consumer demand and satisfaction

Consumer demand, as defined by Tomek and Robinson (1990), is the various quantities of a particular commodity that an individual consumer is willing and able to buy as the price of that commodity varies, with all other factors that affect demand held constant. According to the National Cattlemen's Beef Association (1999), beef demand is actually stabilizing for the first time in 20 years. Consumer spending on beef is up 4% from 1998 and, as a result, beef consumption is up. One explanation for this increase in consumption could be the influx of new beef products available to consumers. Over 30 new products were developed in 1999.

Extensive research has been conducted in order to determine consumer perceptions and expectations of beef at both retail and foodservice level (Forbes et al., 1974; Savell et al., 1987 and Savell et al., 1989). Savell et al. (1987) found regional (geographic) differences with respect to consumer reactions regarding differences in intramuscular fat in beef steaks. Consumer ratings suggested there was a greater chance for a steak with a low degree of marbling to be rated "low" in Philadelphia compared to San Francisco or Kansas City (Savell et al., 1987). Savell et al. (1989) asked customers in Philadelphia and San Francisco what factor was most important in their purchase of beef; "taste" was identified above other factors such as, "value for the money", "nutritional value" and "ease of preparation". When consumers were asked what concerns or dissatisfactions they had in regard to beef, "too expensive" was listed most frequently; "high fat content" followed a close second. When U.S. Choice and U.S. Select quality grades were made available, consumers in San Francisco showed a clear preference for U.S. Select, even when priced higher than U.S. Choice. Though buying activity did not increase when two U.S. quality grades of beef were available, approximately 40% of consumers purchased the new grade available in their market. Savell et al. (1989) found that retail cuts with excessive external fat were considered wasteful and projected a negative image on the perceptions of taste and healthfulness. Consumers observed no visual differences between U.S. Choice and U.S. Select beef when external fat trim was similar. Savell et al. (1989) concluded that retail cuts from U.S. Choice and U.S. Select carcasses were highly acceptable to consumers, but for differing reasons. U.S. Choice cuts were rated high in taste, but raised concerns about fatness. U.S. Select cuts were rated high in leanness, but concerns regarding taste and texture were voiced. Savell et al. (1989) stated that each grade should be marketed for its unique advantage in the marketplace. Results show, that as Warner-Bratzler shear values decrease, consumer tenderness ratings generally increase. This demonstrates the ability of the consumer panel to detect tenderness levels similar to the tenderness instrument (Huffman et al., 1996). When the question was asked, which sensory attribute: tenderness, juiciness, or flavor is most important in determining your satisfaction, 51% of consumers responded -

tenderness. Huffman et al. (1996) suggests consumers are willing to accept slightly tough meat if the juiciness and flavor are acceptable. These data imply that in the home environment, as family income increases, ratings for tenderness, juiciness, flavor and overall palatability decreases, which suggests that families with higher income levels have higher expectations for beef steaks than families with lower income levels (Huffman et al. 1996).

CHAPTER III

THE INFLUENCE OF QUALITY GRADE, AGE, MECHANICAL TENDERIZATION AND MARINATION ON BEEF BOTTOM SIRLOIN BUTT, TRI-TIP STEAKS

ABSTRACT

Steer and heifer beef carcasses (n = 150) of "A" maturity were randomly selected to compare tenderness values among USDA Choice (CH), Select (SE) and Standard (ST) bottom sirloin steaks (TRI-TIP), as well as assess the contribution of postmortem aging (7, 14, 21 or 28 d), mechanical tenderization (needle = NDLE, non-needled = NONDLE) and marination on Warner-Bratzler shear force values (WBS). Paired TRI-TIP muscles of each quality grade were assigned to two of the following treatment groups: 1) 7d, NDLE, 2) 7d, NONDLE, 3) 14 d, NDLE, 4) 14 d NONDLE, 5) 21 d, NDLE, 6) 21 d, NONDLE, 7) 28 d, NDLE and 8) 28 d, NONDLE. Four steaks were removed from the TRI-TIP and subsequently received a marination treatment (marinated = MAR, non-marinated

= NOMAR). A significant ($P < 0.05$) quality grade by marination by age interaction was observed for WBS. MAR significantly ($P < 0.05$) reduced shear force values for all quality grade by age combinations, with the exception of 7 d ST. WBS values were significantly ($P < 0.05$) lower for NDLE steaks when compared to NONDLE steaks. Percentage cook loss was affected by a significant ($P < 0.05$) age by marination interaction. MAR steaks aged 21 d (26.06%) and 28 d (26.46%) had significantly ($P < 0.05$) lower percent cook loss than 7 d (28.62%) and 14 d (27.31%) MAR steaks. NOMAR steaks aged 21 d (27.69%) and 28 d (28.60%) had significantly ($P < 0.05$) higher percent cook loss than 14 d (26.55%) NOMAR steaks. Percentage cook loss was affected by a significant ($P < 0.05$) quality grade by needle by marination interaction. Analysis was performed using NOMAR steaks to determine if a location effect. A significant ($P < 0.05$) location effect was observed for WBS and cook time and end temperature. The use of postmortem aging, mechanical tenderization and marination will insure the tenderness of beef bottom sirloin steaks.

(Key Words): Beef Quality Grade, Tenderness, Bottom Sirloin

INTRODUCTION

Low overall uniformity and consistency, and inadequate tenderness remain two of the top three "quality" challenges identified by producers, packers, purveyors, restaurateurs and retailers in the 2001 National Beef Quality Audit (NCBA, 2001). This, together with the fact that consumers are able to recognize differences in beef tenderness and are willing to pay a premium for "guaranteed tender" product (Boleman et al., 1997) created a serious challenge for the beef industry. The beef industry is meeting this challenge head-on by making the transition from commodity-based marketing to value-based marketing.

The ability to deliver a product that maximizes customer satisfaction, maintains customer loyalty and increases customer patronage is a complex issue facing the food service industry (Cox et al., 1997). The cooking process for steak requires a balance between enhancing or maintaining tenderness, ensuring food safety and delivering a steak compliant with the customers' preference for degree of doneness (Cox et al., 1997). While it is generally accepted that the optimum degree of doneness for steak is medium, this is not always the customers' preference. It is the attempt of the beef industry to enhance product such that beef items have the flexibility to meet the customers' degree of doneness preference while remaining tender, juicy and flavorful.

This research was conducted to 1) investigate the impact of USDA quality grade on bottom sirloin steaks as well as 2) assess the contribution of postmortem aging, mechanical tenderization and marination upon improving the inconsistency of bottom sirloin steaks.

MATERIALS AND METHODS

Sample collection (Figure 1). Steer and heifer carcasses (n = 150) of unknown origin were selected randomly at a commercial meat processing facility to fit previously determined USDA quality and yield grade specifications. Carcasses grading USDA Choice (CH), USDA Select (SE) and USDA Standard (ST) (n = 50 / grade) were selected. Four trained Oklahoma State University personnel collected carcass grade data information and the average score for each trait was recorded. After carcass data were collected, paired bottom sirloin butt, tri-tip, boneless or m. *tensor fasciae latae*, (IMPS 185c) (NAMP, 1990) were removed and shipped to a commercial processing facility located in Owasso, Oklahoma.

Mechanical tenderization. Subsequent to the aging period (7, 14, 21 or 28 d), all tri-tips were sorted into needle (NDLE) and non-needle (NONDLE) treatment groups. Tri-tips were then weighed and weights were recorded as raw weight. Mechanical tenderization was accomplished by using a Ross needle tenderizer (Midland, Virginia). After mechanical tenderization, tri-tips were weighed and weights were recorded as NDLE weight.

Marination. Approximately four, eight-ounce steaks were obtained from each tri-tip and sorted into one of two marination treatments. Steaks from location one and three received no marination (NOMAR), while steaks from location two and four were marinated (MAR) (Figure 2). Location of steak within each tri-tip was recorded. Steaks removed perpendicular to muscle fibers were designated as face steaks (FACE); all remaining steaks were recorded as other (OTHER). The active ingredient in the marinade consisted of a proprietary combination of various proteolytic enzymes and beef flavor. Steaks were marinated in batches using 2 Lyco vacuum tumblers (Model 401, Columbus, Wisconsin) at either 30 or 60 rpm. Targeted marinade pick up rate of 14% was achieved using two 6-minute cycles. Steaks were removed from the tumbler and weighed. Marinated (MAR) weights were recorded for each sample.

Mechanical Press. Prior to packaging, steaks were passed through a hydraulic steak press to create a uniform steak thickness and improve cooking time. The steaks were pressed to 0.9525 cm initially and gradually pressed to an end thickness of 0.6350 cm. Steaks were weighed and those pressed (PRESS) weights recorded.

Packaging. Steaks were packaged using a commercially available vacuum package machine. After packaging, steaks were boxed and stored in a blast freezer at -34 C for a minimum of 48 h and then transferred within the facility to a holding freezer and held at -18 C until analysis.

Warner-Bratzler shear force. Steaks were assigned randomly to a cooking order within treatment groups. One hundred and ten steaks were allowed to temper daily at 4 C for 24 h prior to cooking. Steaks were charbroiled on a 4-burner natural gas grill. Steaks were grilled to an internal temperature of 65 C. Temperatures were monitored using an Atkins, series 375 thermometer. Individual steak weights were recorded prior to and following cooking to determine cook loss percentages. Steaks were individually packaged in zip-lock bags, boxed and transported to Oklahoma State University for further analysis. After steaks were cooled to room temperature, a minimum of five cores (1.27 cm diameter) were removed parallel to the muscle fiber orientation. Cores were sheared using a Warner-Bratzler attachment on an Instron Universal Testing Machine (Model 4502, Instron, Canton, MS) moving at a crosshead speed of 200 mm/minute. The peak load (kg) of the cores was recorded by a Gateway personal computer (Model E-3000) using software provided by the Instron Corporation. The mean peak load of the cores was analyzed.

Statistical analysis. Data were analyzed using the mixed procedure of SAS, version 8.1 (Cary, NC). Design structure was a split-plot with quality grade serving as the whole plot and animal split into the sub-plot. Treatment structure was a 3 (grade) x 4 (age) x 2 (needle) x 2 (marination) factorial arrangement of treatments resulting in 48 possible combinations. Location affect was analyzed using a 3 (grade) x 4 (age) x 2 (needle) x 2 (marination) factorial arrangement of treatments. Location affect was measured by comparing FACE to OTHER, all of which were NOMAR, because too few FACE steaks were MAR. Means were separated using α at the 0.05 level.

RESULTS AND DISCUSSION

Carcass characteristics. Carcass data means are presented in Table 1. Carcasses were selected in order to represent the normal product mix found at the processing facility in Owasso, Oklahoma. As a result, USDA Choice carcasses with a Small degree of marbling were selected. Carcasses from Slight 00 to Slight 99 were selected to make up the USDA Select quality grade. Care was taken in the selection of USDA Standard carcasses in that quality defects, such as blood splash, dark cutters and calloused lean, were avoided. This carcass population represents the normal consist of beef carcasses harvested in a large commercial processing facility (NCBA, 2001)

Warner-Bratzler shear force. Least squares means for quality grade, age and marination combinations are presented in Figure 3. A significant ($P < 0.05$) quality grade by marination by age interaction was observed for Warner-Bratzler shear force (WBS). MAR significantly ($P < 0.05$) reduced shear force values for all quality grade by age combinations, with the exception of 7 d ST. After 14 or 21 d of post mortem aging, MAR CH, SE and ST WBS values were similar to each other. At 28 d, MAR SE had significantly ($P < 0.05$) lower WBS values than MAR CH. Within quality grades, among MAR steaks, differences ($P < 0.05$) in

WBS can be observed. For example, WBS values were significantly ($P < 0.05$) reduced in MAR ST steaks aged from 7 d to 14 d and again from 21 d to 28 d. Shear force values for MAR SE steaks were significantly ($P < 0.05$) lower at 28 d when compared to 7, 14 and 21 d counterparts. Throughout the aging period, shear force values for MAR CH steaks remained similar ($P > 0.05$) to each other. Across quality grades, within the non-marinated (NOMAR) treatment groups, steaks aged 7, 14 and 21 d remained similar ($P > 0.05$) in their inherent WBS values. However, at 28 d, NOMAR CH steaks were significantly more tender (3.28 kg) than NOMAR SE (3.42 kg) and NOMAR ST (3.53 kg) steaks. Within NOMAR ST, 21 d (3.52 kg) and 28 d (3.53 kg) WBS values were significantly ($P < 0.05$) lower when compared to NOMAR ST steak WBS values (3.91 kg) aged for only 7 d. Likewise, a similar trend was observed for NOMAR SE and CH steaks, in that longer aged products (i.e. 21 and 28 d) were more tender than their shorter-aged (i.e. 7 and 14 d) counterparts. Additional pair wise comparisons can be found in Appendix 2. Though a 3-way interaction is observed, it is obvious that marination had a pronounced effect on WBS values. However it is important to note that all presented means are still within the "very tender" tenderness classification (Morgan et al., 1991a).

Least squares means and standard errors for WBS treatment main effect of needling are presented in Figure 4. Shear force was significantly ($P < 0.05$) lower for NDLE steaks when compared to NONDLE steaks. Mechanical tenderization had a marked effect on WBS values. Tri-tips that were mechanically tenderized exhibited WBS values that were 7% more tender than their non-tenderized paired samples. Again, all presented means are within the "very tender" tenderness classification (Morgan et al., 1991a). These findings support those of Seideman et al. (1977), who found that blade tenderization of the psoas major and semitendinosus muscles decreased shear force values. As well, research reported by Savell et al. (1977) found blade tenderization to decrease shear force values.

Cook loss. Least squares means and standard errors for percent cook loss are presented in Table 2 and Table 3. Percentage cook loss was affected by a significant ($P < 0.05$) age by marination interaction (Table 2). MAR steaks aged for 21 d (26.06%) or 28 d (26.46%) had significantly ($P < 0.05$) lower percent cook loss than MAR steaks aged for 7 d (28.62%) or 14 d (27.31%). NOMAR steaks aged for 21 d (27.69%) or 28 d (28.60%) had significantly ($P < 0.05$) higher percent cook loss than NOMAR steaks aged for 14 d (26.55%). MAR steaks aged for 21 d (26.06%) or 28 d (26.46%) had significantly ($P < 0.05$) less cook loss than NOMAR steaks aged for 21 d (27.69%) or 28 d (28.60%), respectively. It appeared that MAR steaks displayed less cooking loss than NOMAR steaks. This seems reasonable in that MAR steaks contained approximately 14% addition liquid compared to NOMAR steaks. So, the added moisture associated with MAR influenced cooking loss. Lewis and Purslow (1990) found that absolute cooking loss was the same for marinated and non-marinated meat samples; concluding, the weight gained during marination was retained during cooking.

Percentage cook loss was affected by a significant (P < 0.05) quality grade by needle by marination interaction (Table 3). Percent cook loss was significantly (P < 0.05) higher for CH NOMAR NDLE (28.86%), when compared to CH MAR NONDLE (26.92%) and CH NOMAR NONDLE (26.45%). In the SE quality grade, percent cook loss was significantly (P < 0.05) lower for MAR NONDLE (24.76%) compared to MAR NDLE (28.13%), NOMAR NDLE (28.31%) and NOMAR NONDLE (26.70%). Within ST, no differences (P < 0.05) in percent cook loss are present. Steaks that were mechanically tenderized tended to have higher percent cook loss. This may be because of the physical puncture of the tri-tip muscle. Contrary to these findings, previous research (Tatum et al., 1978) found blade tenderization did not have an effect on cooking losses of *longissimus dorsi* steaks.

Cook time. Cook time was analyzed and no variables were found to be significant (P > 0.05).

End temperature. Least squares means and standard errors are presented for a significant (P < 0.05) quality grade by needle by marination interaction observed for end temperature (ETEMP) (Table 4). Within CH, NONDLE MAR steaks had a higher (P < 0.05) ETEMP compared to other CH steaks. Within SE, MAR steaks tended to have higher ETEMP, though not significant (P > 0.05). No differences (P > 0.05) were present within the ST quality grade. When comparing treatment across quality grade, no combinations were significant, except steaks in the NONDLE MAR treatment. Steaks from CH had significantly ($P < 0.05$) higher ETEMP compared to steaks from SE and ST.

Least squares means and standard errors are presented for a significant ($P < 0.05$) age by marination interaction present for ETEMP (Table 5). At 14 d or 21 d, MAR steaks were cooked to higher ($P < 0.05$) ETEMP when compared to NOMAR steaks. Within NOMAR treated steaks, steaks aged for 21 d had a significantly ($P < 0.05$) lower ETEMP compared to steaks aged for 7, 14 or 28 d.

Though differences to exist for the ETEMP variable, all presented means are within the "medium rare" to "medium" degree of doneness recommended by the American Meat Science Association (AMSA, 1995)

Location Effect

Warner-Bratzler shear force. A significant ($P < 0.05$) location by quality grade interaction was observed for shear force values. Least squares means and standard errors are presented in Table 6. No differences ($P > 0.05$) were observed for FACE location across CH, SE and ST quality grades. However, CH OTHER steaks (3.44 kg) was significantly ($P < 0.05$) more tender than SE (3.56 kg) and ST OTHER (3.75 kg) steaks. Within quality grade, no differences ($P > 0.05$) were observed for CH and SE steaks. However, ST FACE (3.49 kg) steaks had significantly lower shear force values than ST OTHER (3.75 kg) steaks.

A significant ($P < 0.05$) treatment main effect as a result of postmortem aging was present for NOMAR steaks when WBS values were analyzed (Figure

5). Shear force was ($P < 0.05$) decreased as postmortem age progressed from 7 d (3.71 kg) to 21 d (3.44 kg) and 28 d (3.41 kg).

A significant ($P < 0.05$) treatment main effect due to mechanical tenderization was observed for NOMAR steaks when WBS values were analyzed (Figure 6). Shear force was significantly ($P < 0.05$) lower in NDLE steaks (3.39 kg) compared to NONDLE steaks (3.66 kg). This finding is not surprising when you take into consideration how mechanical tenderization works. The increase in tenderness can be attributed to the fact that muscle fibers are disrupted and connective tissue is severed. This allows for a decrease in fiber and connective tissue shrink upon cooking.

Cook Loss. A significant ($P < 0.05$) quality grade by age by needle by location interaction was observed when NOMAR steaks were analyzed.

Cook Time. Least squares means and standard errors are presented for the significant ($P < 0.05$) needle by location by age interaction (Table 7). Mechanical tenderization (NDLE) significantly ($P < 0.05$) reduced cook time for 21 d FACE steaks. Cook time was significantly ($P < 0.05$) longer for 7 d NDLE FACE steaks compared to 14, 21 or 28 d NDLE FACE steaks. Also, cook time was significantly longer for 7 d NDLE OTHER steaks compared to 14, 21 or 28 d NDLE OTHER steaks. Non-needled FACE steaks had similar ($P > 0.05$) cook times across aging periods. Cook time for 7d NONDLE OTHER steaks was significantly ($P < 0.05$) longer compared to NONDLE OTHER 14, 21 or 28 d steaks. Though not statistically significant, FACE steaks tended to have longer cook times compared to OTHER steaks. In summary, it did not take OTHER steaks as long to reach the desired "medium" degree of doneness compared to FACE steaks. Data reported by Tatum et al (1978) found time required for biceps femoris and semimembranosus muscles to reach the desired internal temperature (75 ºC) was not influenced by blade tenderization. Bowling et al. (1976) reported blade tenderized lamb and goat cuts appeared to be more "done" after cooking and required reduced cooking time to reach the desired internal temperature. Jennings et al. (1978) reported that loin steaks aged for 20 d required significantly less time to cook to 70ºC than did steaks aged 10 d. Jennings et al (1978) offered the explanation that 20 d aged loin steaks underwent greater purge loss during storage and the faster cooking times of the 20 d steaks may be due to faster heat conduction via the channels in the muscle through which purge was lost.

End Temperature. A significant ($P < 0.05$) postmortem aging treatment main effect was present when data were analyzed for ETEMP (Figure 7). Steaks aged for 21 d were cooked to a significantly ($P < 0.05$) lower ETEMP compared to 7, 14 or 21 d. Though differences to exist for the ETEMP variable, all presented means are within the "medium rare" to "medium" degree of doneness recommended by the American Meat Science Association (AMSA, 1995)

Conclusion. This research supports the conclusion that the bottom sirloin, tri-tip muscle is inherently tender. All treatment combinations resulted in WBS values well within the "tender" tenderness classification (Morgan et al., 1991a). However, the use of postmortem aging, mechanical tenderization and marination will ensure maximum tenderness.

Figure 1. Experimental protocol

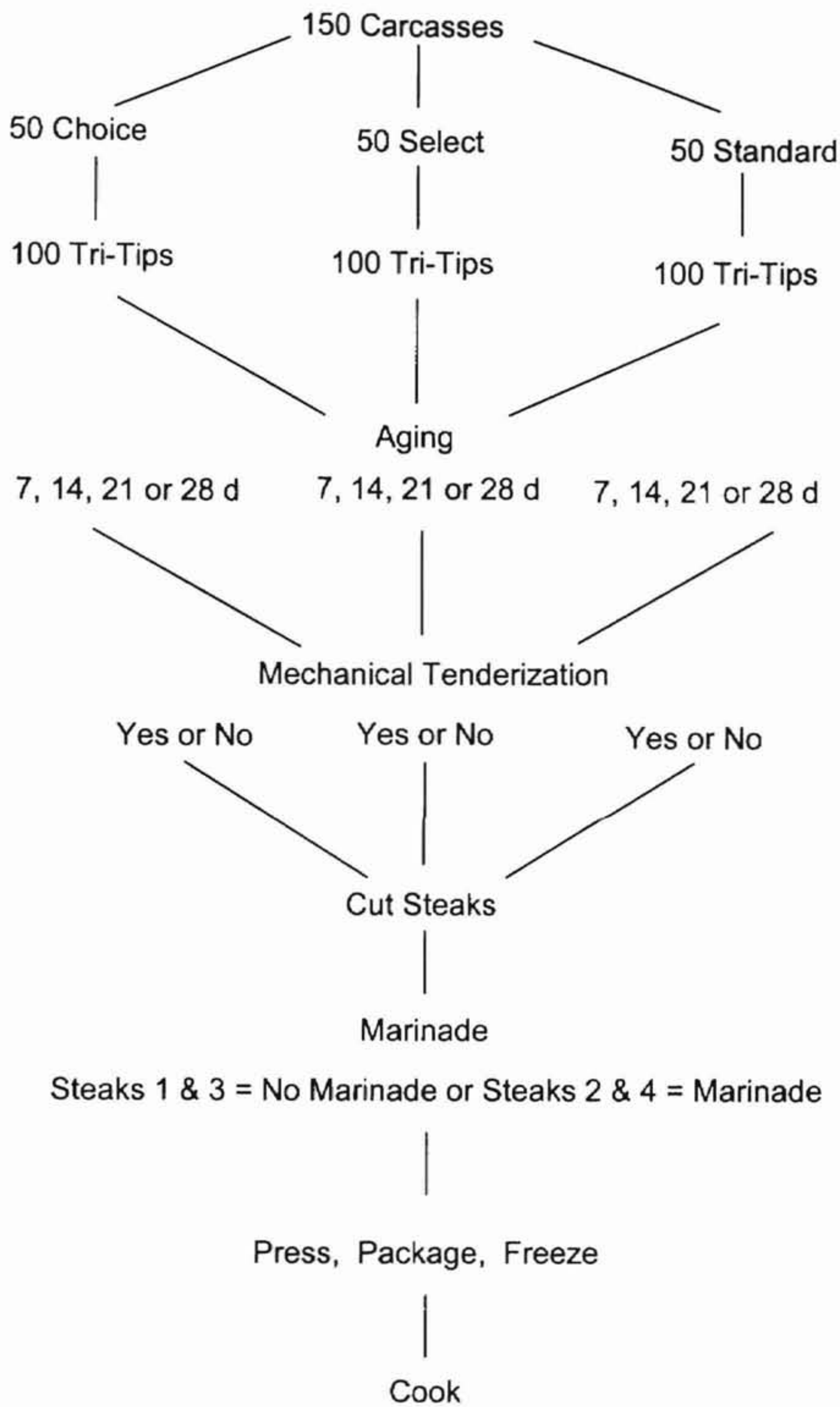


Figure 2: Schematic drawing of bottom sirloin butt, tri-tip showing steak location

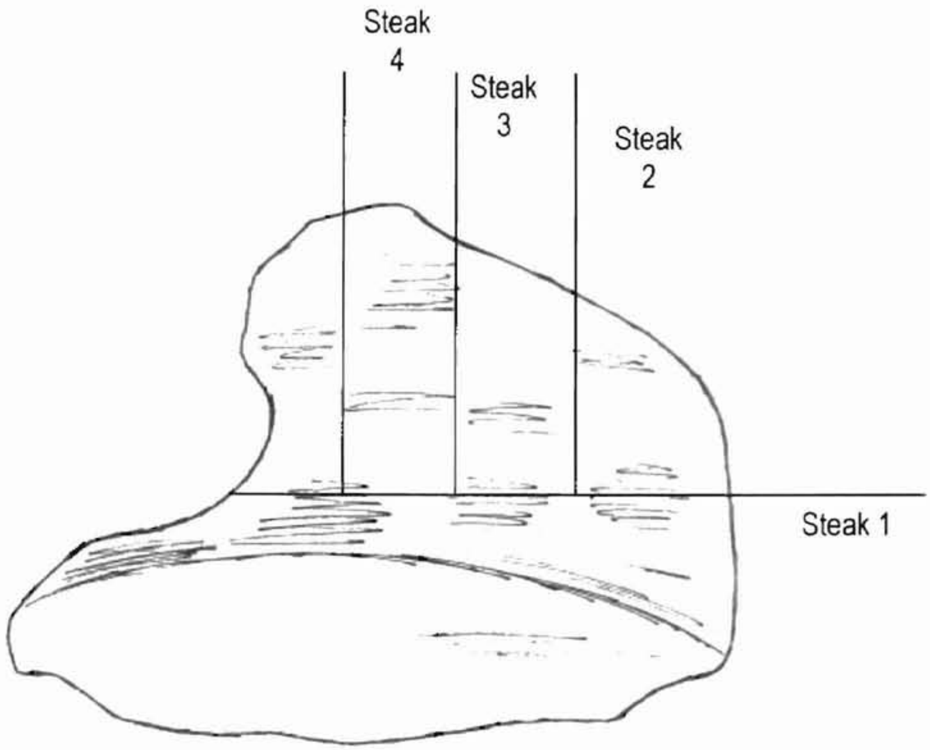


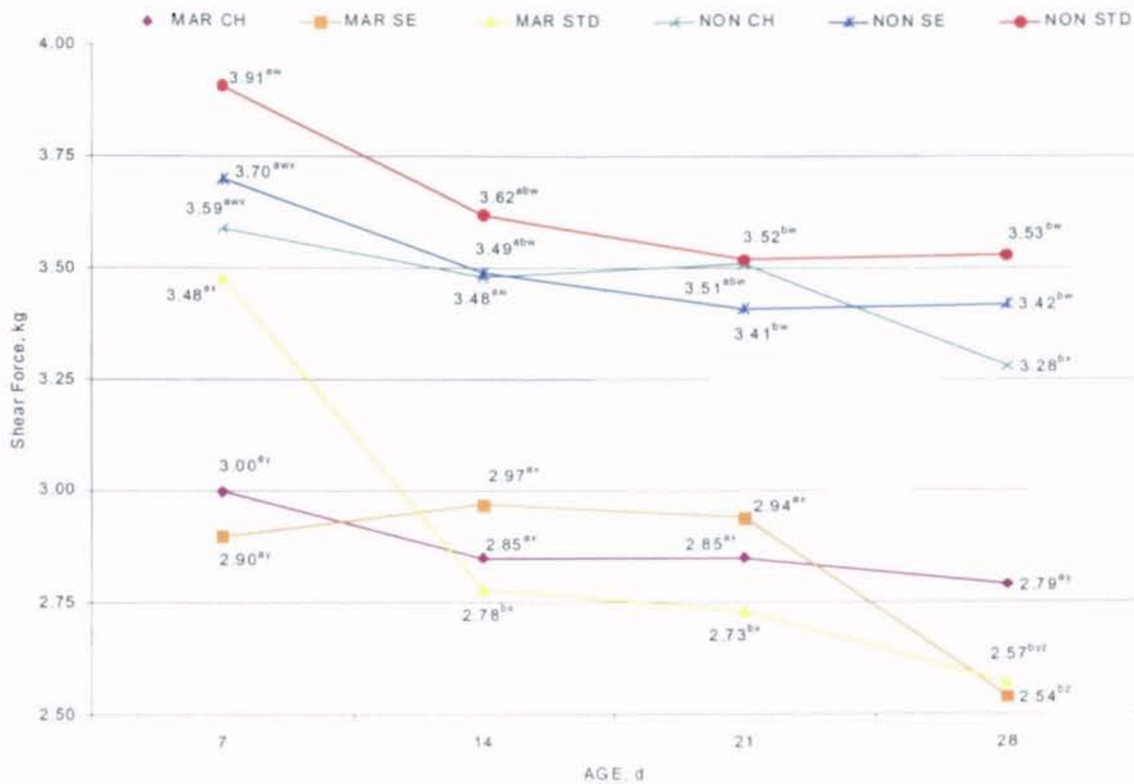
Table 1. Selected carcass characteristic means

Attribute	Quality Grade		
	Choice	Select	Standard
Marbling[a]	427	349	249
Skeletal Maturity[b]	152	148	168
Lean Maturity[b]	156	174	198
Hot Carcass Weight (kg)	362.4	349.2	300.7
Fat Thickness (cm)	1.2	1.0	0.8
Ribeye Area (cm^2)	85.1	81.9	76.7
Kidney, Pelvic & Heart Fat (%)	2.3	2.15	1.8

[a]Marbling score: 200-299 = "Traces", the amount required for U.S. Standard; 300-399 = "Slight", the amount required for U.S. Select; 400-499 = "Small" , the amount required for U.S. Low Choice (USDA, 1997).

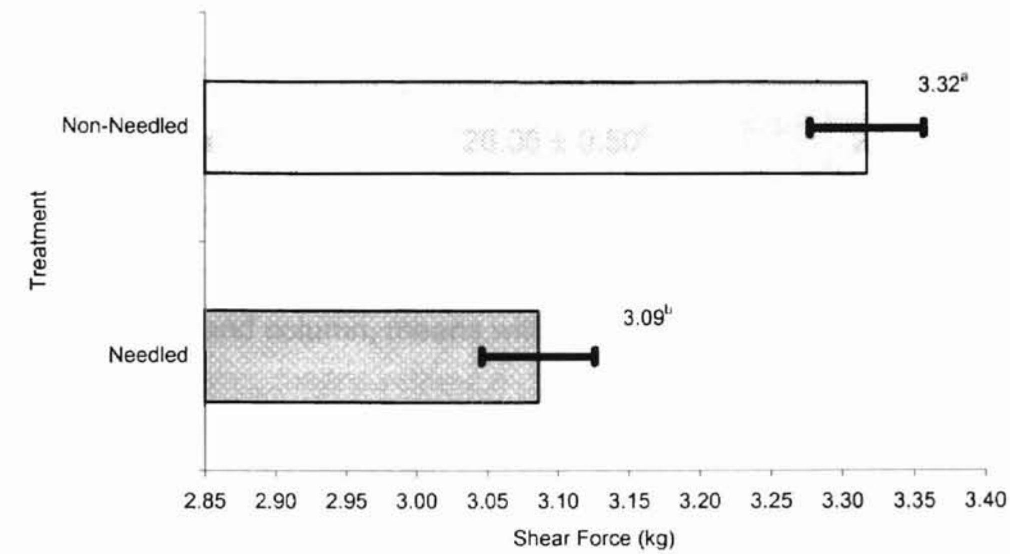
[b]Carcass maturity: 100-199 = approximately 9-30 months chronological age at time of slaughter (USDA, 1997).

Figure 3. Least squares means for Warner-Bratzler shear force of marinated/non-marinated, aged bottom sirloin butt, tri-tip steaks from various quality grades



^{ab}Within a grade, means without a common superscript differ (P< .05)
^{wxyz}Within age, means without a common superscript differ (P< .05)

Figure 4. Least squares means and standard error bars for shear force of needle/non-needled bottom sirloin butt, tri-tip steaks (P < 0.01)



[ab]Means without a common superscript differ (P < 0.01)

Table 2. Percentage cook loss presented by least squares means (± standard error) for age * marination interaction for bottom sirloin butt, tri-tip steaks

Age	Marination	
	Marinated	Non Marinated
7 d	28.62 ±0.68[a]	27.59 ± 0.64[ab]
14 d	27.31 ± 0.35[ab]	26.55 ± 0.33[b]
21 d	26.06 ± 0.50[c]	27.69 ± 0.48[a]
28 d	26.46 ± 0.39[bc]	28.60 ± 0.38[a]

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

Table 3. Percentage cook loss presented by least squares means (± standard error) for quality grade * needle * marination interaction for bottom sirloin butt, tri-tip steaks

Treatment		Quality Grade		
		Choice	Select	Standard
MAR	NDLE	27.73 ± 0.59^{abx}	28.13 ± 0.60^{abx}	27.51 ± 0.61^{ax}
MAR	NONDLE	26.92 ± 0.60^{bx}	24.76 ± 0.61^{cy}	27.62 ± 0.67^{ax}
NOMAR	NDLE	28.86 ± 0.56^{ax}	28.31 ± 0.57^{ax}	28.44 ± 0.60^{ax}
NOMAR	NONDLE	26.45 ± 0.57^{bx}	26.70 ± 0.59^{bx}	26.88 ± 0.62^{ax}

^{abc}Within a column, means without a common superscript differ ($P < 0.05$)
^{xy}Within a row, means without a common superscript differ ($P < 0.05$)

Table 4. End temperature presented by least squares means (± standard error) for quality grade * needle * marination interaction for bottom sirloin butt, tri-tip steaks

Treatment		Quality Grade		
		Choice	Select	Standard
NDLE	MAR	66.32 ± 0.31^{by}	66.88 ± 0.31^{ay}	66.99 ± 0.32^{ay}
NDLE	NOMAR	66.35 ± 0.29^{by}	66.07 ± 0.29^{by}	66.55 ± 0.31^{ay}
NONDLE	MAR	67.35 ± 0.31^{ay}	66.18 ± 0.32^{abz}	66.59 ± 0.35^{ayz}
NONDLE	NOMAR	65.91 ± 0.29^{by}	66.04 ± 0.31^{by}	66.29 ± 0.32^{ay}

^{ab}Within a column, means without a common superscript differ (P < 0.05).
^{yz}Within a row, means without a common superscript differ (P < 0.05).

Table 5. End temperature presented by least squares means (± standard error) for age * marination interaction for bottom sirloin butt, tri-tip steaks

	Age, d			
	7	14	21	28
Marinade	67.03 ± 0.35^{ay}	66.87 ± 0.18^{ay}	66.66 ± 0.26^{ay}	66.31 ± 0.20^{ay}
No Marinade	66.38 ± 0.33^{ay}	66.30 ± 0.17^{by}	65.44 ± 0.25^{bz}	66.68 ± 0.20^{ay}

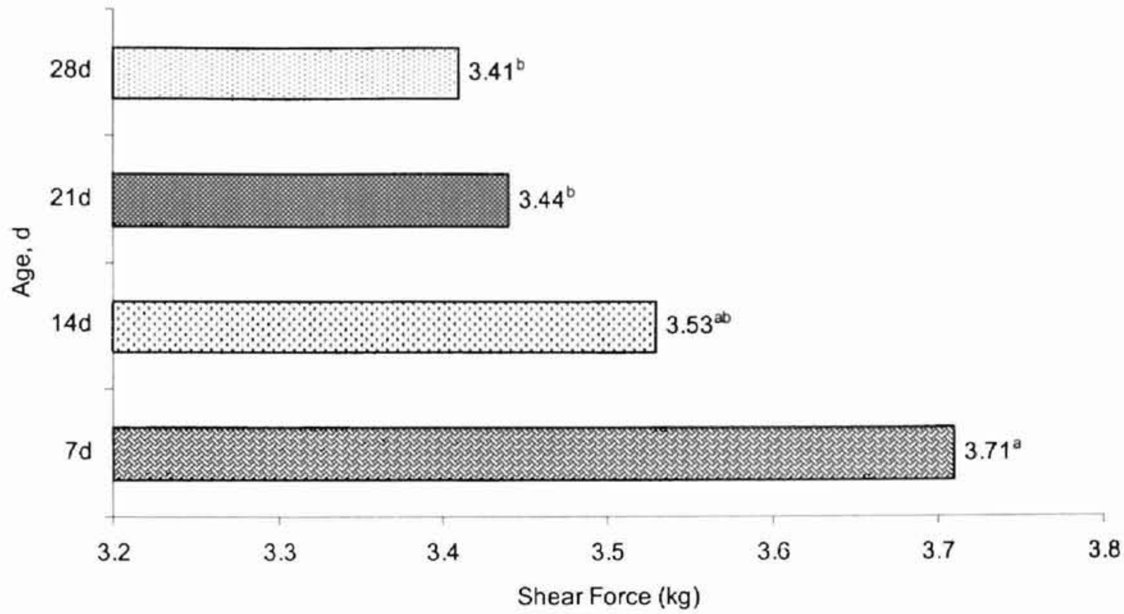
[ab]Within a column, means without a common superscript differ ($P < 0.05$).
[zy]Within a row, means without a common superscript differ ($P < 0.05$).

Table 6. Least squares means (± standard error) for Warner-Bratzler shear force by steak location across quality grade for bottom sirloin butt, tri-tip steaks

	Quality Grade		
	Choice	Select	Standard
Face Steak	3.46 ± 0.07[ax]	3.43 ± 0.08[ax]	3.49 ± 0.08[ax]
Other Steak	3.44 ± 0.07[bx]	3.56 ± 0.07[ax]	3.75 ± 0.07[ay]

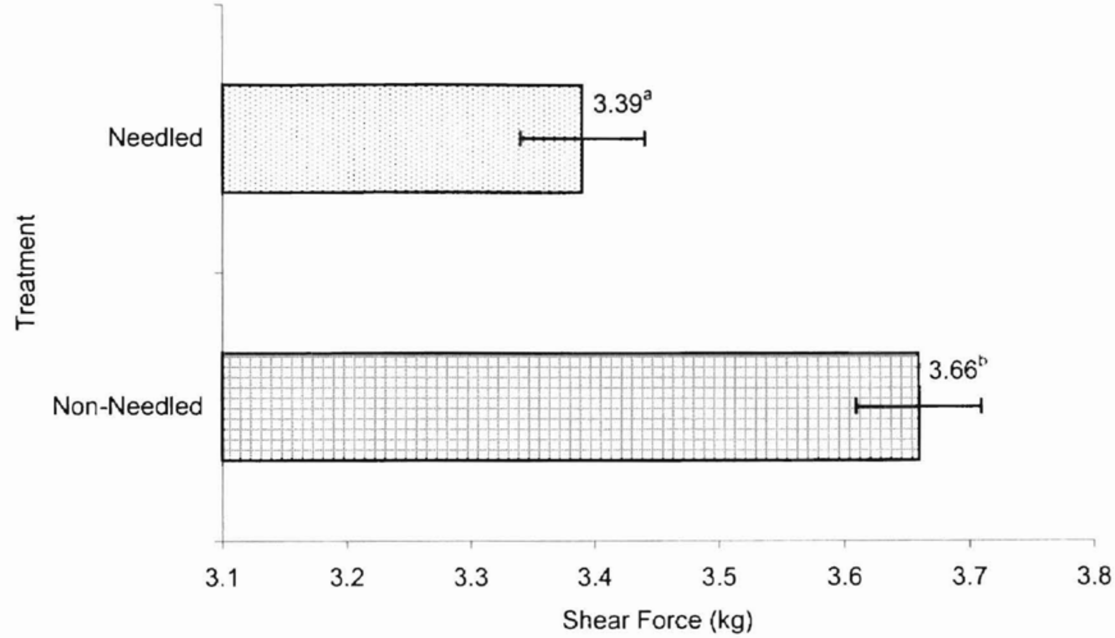
[ab]Within a row, means without a common superscript differ ($P < 0.05$)
[xy]Within a column, means without a common superscript differ ($P < 0.05$)

Figure 5. Least squares means for shear force of non-marinated bottom sirloin butt, tri-tip steaks distributed across aging periods (P < 0.05)



[ab]Means without a common superscript differ (P < 0.05)

Figure 6. Least squares means and standard error bars for shear force of needle/non-needled, non-marinated bottom sirloin butt, tri-tip steaks ($P < 0.01$)



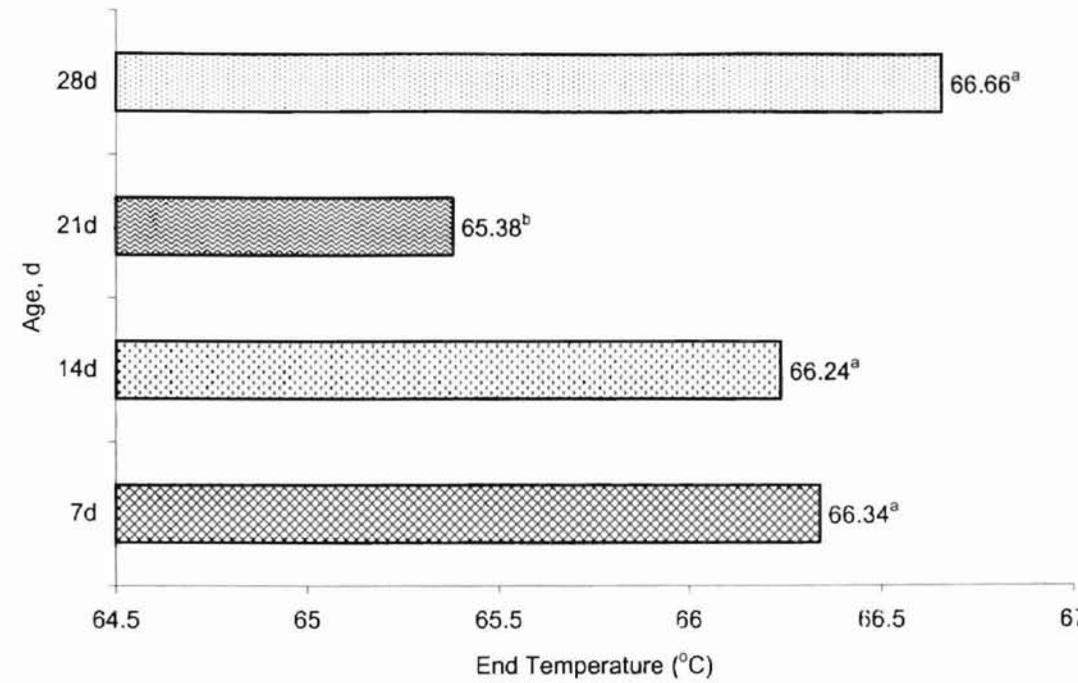
[ab]Means without a common superscript differ ($P < 0.01$)

Table 7. Least squares means (± standard error) for cook time (in minutes) stratified by location, age and needle treatment for bottom sirloin butt, tri-tip steaks

		Treatment	
Location	Age, d	Needled	Non Needled
Face Steak	7	13.84 ± 0.52^{ax}	12.92 ± 0.57^{ax}
Face Steak	14	11.35 ± 0.26^{bcx}	11.58 ± 0.26^{bx}
Face Steak	21	10.71 ± 0.37^{cdex}	12.47 ± 0.39^{aby}
Face Steak	28	11.11 ± 0.29^{cdx}	11.57 ± 0.32^{bx}
Other	7	12.20 ± 0.46^{abx}	12.22 ± 0.46^{abx}
Other	14	10.62 ± 0.23^{dex}	10.36 ± 0.23^{cx}
Other	21	10.19 ± 0.34^{ex}	9.96 ± 0.35^{cx}
Other	28	10.54 ± 0.26^{dex}	10.41 ± 0.28^{cx}

^{abcde}Within a column, means without a common superscript differ (P < 0.05)
^{xy}Within a row, means without a common superscript differ (P < 0.05)

Figure 7. Least squares means for end temperature of non-marinated bottom sirloin butt, tri-tip steaks distributed across aging periods (P < 0.05)



[ab]Means without a common superscript differ (P < 0.05)

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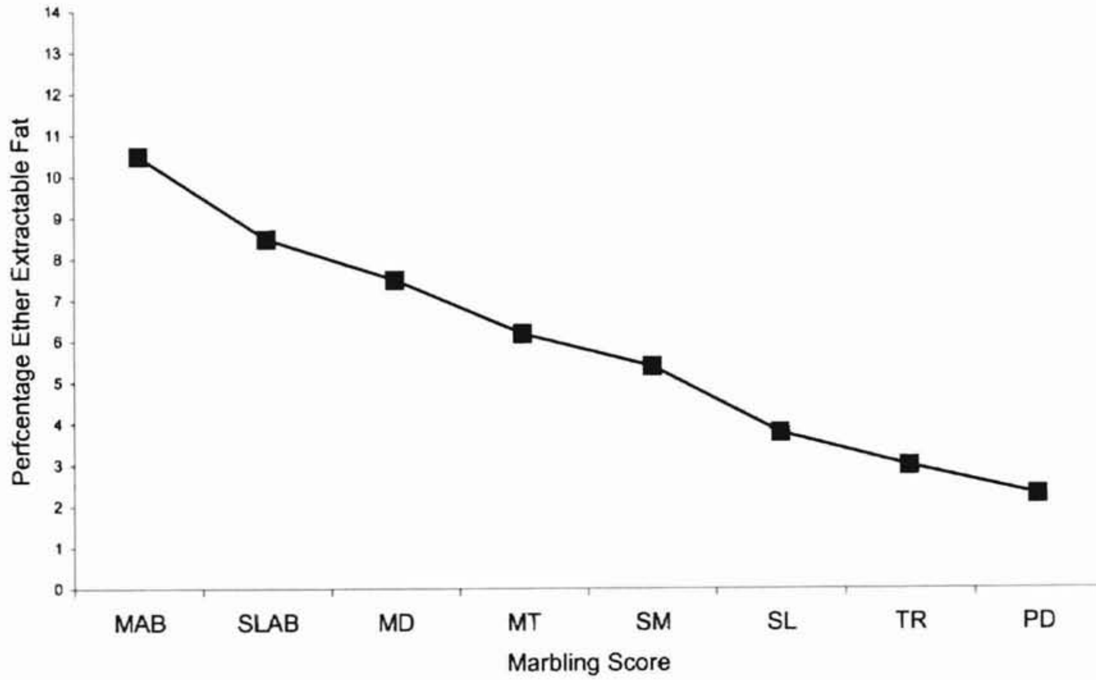
APPENDIX

Appendix 1. Marbling score and ether extractable fat relationship



Savell and Cross, 1988.

Appendix 2: Maturity classification table

	Physiological Maturity				
	A	B	C	D	E
Age, mo	9 - 30	30 - 42	42 - 72	72 - 96	> 96

Appendix 3. Warner Bratzler shear P-values for quality grade* by age by marination interaction

		MARINATED												NON-MARINATED											
		C 7	C 14	C 21	C 28	Se 7	Se14	Se 21	Se28	St 7	St 14	St 21	St 28	C 7	C 14	C 21	C 28	Se 7	Se14	Se 21	Se28	St 7	St 14	St 21	St 28
MARINATED	C 7	•	.2934	.3474	.1279	.6199	.8260	.6902	.0036	.0178	.1451	.1126	.0063	.0001	.0016	.0024	.0499	.0002	.0014	.0160	.0083	.0001	.0001	.0031	.0001
	C 14		•	.9995	.5814	.6768	.2450	.4750	.0073	.0001	.5298	.3743	.0148	.0001	.0024	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
	C 21			•	.6614	.7053	.3340	.5334	.0228	.0005	.6012	.4323	.0394	.0001	.0001	.0001	.0009	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
	C 28				•	.4431	.1094	.2642	.0378	.0001	.9274	.6531	.0664	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
	Se 7					•	.6922	.8738	.0091	.0046	.3963	.2939	.0326	.0003	.0002	.0004	.0195	.0001	.0001	.0030	.0003	.0001	.0001	.0005	.0001
	Se 14						•	.7749	.0001	.0023	.0792	.0741	.0005	.0001	.0001	.0001	.0061	.0001	.0001	.0002	.0001	.0001	.0001	.0001	.0001
	Se 21							•	.0028	.0027	.2199	.1681	.0062	.0001	.0001	.0001	.0096	.0001	.0001	.0001	.0002	.0001	.0001	.0001	.0001
	Se 28								•	.0001	.0397	.1898	.7929	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
	St 7									•	.0001	.0001	.0001	.5542	.9895	.8312	.2390	.2506	.9071	.7183	.7654	.0061	.3617	.7961	.7383
	St 14										•	.6764	.0506	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
	St 21											•	.2648	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
	St 28												•	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0085	.0001	.0001	.0001
NON MARINATED	C 7													•	.4321	.6337	.0198	.5464	.5167	.2736	.2820	.0911	.8271	.6912	.6760
	C 14														•	.7489	.0476	.1333	.8686	.5936	.6357	.0057	.1605	.7333	.6574
	C 21															•	.0651	.2551	.8808	.4959	.5027	.0208	.3824	.9494	.9200
	C 28																•	.0061	.0499	.3093	.2139	.0001	.0021	.0780	.0344
	Se 7																	•	.1615	.0791	.0453	.2722	.6046	.3011	.2613
	Se 14																		•	.4651	.5084	.0084	.2233	.8333	.7758
	Se 21																			•	.9160	.0039	.0950	.4612	.3832
	Se 28																				•	.0030	.0817	.4869	.3964
	St 7																					•	.0636	.0295	.0001
	St 14																						•	.4177	.3532
	St 21																							•	.9791
	St 28																								•

* C=Choice Quality Grade, Se = Select Quality Grade, St = Standard Quality Grade

VITA 2

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Candidate for the Degree of

Master of Science

Thesis: THE INFLUENCE OF QUALITY GRADE, AGE, MECHANICAL TENDERIZATION, AND MARINATION ON BEEF BOTTOM SIRLOIN BUTT, TRI-TIP STEAKS.

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