USDA MARBLING AND CARCASS PHYSIOLOGICAL MATURITY RELATED DIFFERENCES FOR BEEF TENDERNESS AND PALATABILITY CHARACTERISTICS

By

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NOMENCLATURE

AOAC	Association of Official Analytical Chemists
°C	degree (s) Celsius
cm	centimeter (s)
d	day (s)
g	gram (s)
h	hour (s)
kg	kilogram (s)
min	minute (s)
mL	milliliter (s)
mm	millimeter (s)
mM	millimolar
nm	nanometer (s)
N	normality
USDA	United States Department of Agriculture
WBS	Warner-Bratzler shear force
µg	microgram (s)
µM	micromolar

CHAPTER I

INTRODUCTION

Future success of the beef industry hinges on the ability to regain market share, and sustain demand from competing protein sources. Because of the 2000 National Beef Quality Audit (NBQA), aggregate concerns of several beef marketing segments (beef processors, purveyors, restaurateurs, and retailers) were made aware to the beef industry. The top three producer issues in the NBQA were low overall uniformity and consistency, inadequate tenderness, and low overall palatability (NCBA, 2001). One strategy the beef industry has utilized to address the concerns pertaining to the sustainability of beef demand and the issue of beef uniformity, consistency and palatability has been the emergence of branded beef programs. To combat inconsistencies, branded beef programs allow the beef industry to segment a very heterogeneous raw material into more homogenous groups based on strict carcass specifications to more accurately predict potential palatability differences. More paramount, however, branded beef programs allow separate divisions of the beef industry to supply targeted consumers with a product that meets their expectations.

Many researchers have documented the importance of tenderness on beef palatability. Smith et al. (1987), Savell et al. (1989), and Miller et al. (1995) determined tenderness to be the most quintessential palatability attribute of beef.

While tenderness has, and will continue to be, one of the focal points for future beef research, many questions still surround the variation in beef tenderness (Wheeler et al., 1994).

Marbling score has been used in the U.S. beef industry as the primary predictor of beef palatability among carcasses with similar maturity characteristics (USDA, 2001a). Intramuscular fat has been shown to have a small, positive relationship with beef palatability, along with a small inverse relationship with Warner-Bratzler shear force (WBS) (Wheeler et al., 1994). Interestingly, Boleman et al. (1997) revealed the willingness of consumers (78%) to purchase a product labeled "guaranteed tender" at a higher price. In certain branded beef programs, a high marbling specification (i.e., Modest or higher) is placed on beef carcasses to insure increased palatability and reduce the risk of an unfavorable eating experience. Currently, 54 branded beef programs exist (USDA, 2001b). Of those 54 programs, 22 strictly utilize carcasses with at least a Modest degree of marbling (USDA, 2001b). Within those 22 branded beef programs, six programs market carcasses with both "A" and "B" physiological maturity.

As cattle mature, total collagen increases and intramuscular collagen solubility decreases, resulting in tougher beef (Dikeman et al., 1971; Cross et al., 1973; Cross et al., 1984). Furthermore, as beef animals begin to mature physiologically, an increase in cartilage ossification and insoluble collagen is known to occur within the body. Further research is needed to determine the significance of differing increments of physiological maturation and marbling deposition on total collagen content, as well as collagen solubility, and their effects on *Warner-Bratzler* shear force values and sensory panel attributes.

In an effort to provide the consumer with a more uniform product, the USDA revised the standards for quality grades of carcass beef in 1997. The revision states that "B" maturity carcasses (overall) with a marbling score of Small and Slight cannot be graded USDA Choice or Select, but must grade USDA Standard (USDA, 2001a). Common belief has been that "B" maturity carcasses with these characteristics are both highly variable and often unacceptable in palatability. However, the jury is still out regarding potential palatability differences among carcasses of similar marbling score that differ in terms of physiological maturity (i.e., "A" and "B" maturity). In the present study, carcasses with similar marbling scores (Slight, Small, Modest, Moderate) were stratified by physiological maturity ("A" and "B") in order to determine if differences existed in WBS force, sensory panel tenderness, percent moisture and lipid content, and total collagen percent. Perhaps, these findings will answer the question: "Do carcasses with similar marbling and physiological maturity score differ significantly enough in palatability to warrant such sizeable discounts?"

CHAPTER 2

REVIEW OF LITERATURE

Contributing Factors in Beef Tenderness Variation

Webster's defines palatability as being "pleasant to the taste" (Webster's New Collegiate Dictionary, 824). Meat palatability is generally referred to as tenderness, juiciness and flavor of a cooked product. These three cooked meat characteristics are what consumers desire and what the beef industry is trying to supply on a consistent and uniform basis. Of these three palatability attributes, tenderness is the most influential of consumer preference (Savell et al., 1989). Miller et al. (1995) found that consumers preferred meat that offered increased tenderness and flavor. Although tenderness is the most influential organoleptic trait affecting consumer acceptance of beef, it remains unacceptably inconsistent (Brooks et al., 1999). Nelson et al. (1998) noted that variation in meat tenderness can be explained by examining multiple animal and/or carcass factors (marbling, physiological maturity, ante- and postmortem management practices and breed/genetic effects) and various compositional aspects of muscle structure (sarcomeres, myofibrils, muscle fibers and muscle bundles). The following review presents a detailed outline concerning tenderness variation resulting from multiple animal and carcass factors.

Marbling

Marbling: A Palatability Attribute. Interfascicular or intramuscular adipose tissue represents a unique fat depot. This tissue can be distinguished from other fat reservoirs by its location within perimysial connective tissue alongside myofibers. Postnatal growth of intramuscular fat involves substantial hypertrophy of the adipocytes and also appears to include a period of apparent hyperplasia of preadipocytes (Smith et al., 2000).

Intramuscular lipid (marbling) content of the *longissimus dorsi* muscle is a major determinant of carcass value and beef palatability. Smith and Carpenter (1974) noted that the perceived value of a fattened animal dates back to Biblical times. In the early 20th century, researchers seemed to further echo these findings. Hall (1910) postulated that an increase in tenderness is the direct result of decreased elasticity of connective tissue due to the deposition of fat therein. Soluble collagen will be discussed further, however deposition of intramuscular fat leads to increased tenderness by decreasing the rigidity of connective tissue due to accretion within (Nishimura et al., 2000). Henry and Morrison (1916) established fat animals deposit fat between the muscle bundles of muscle fibers, thus separating them, thereby increasing tenderness. Nelson et al. (1930) documented an 18 to 30% decrease in shear force values for samples from fat animals in relation to the force required to shear samples from thin animals.

These results led Lowe (1932) to believe that deposition of intramuscular fat tended to lessen the toughness of meat.

The perception of fattened animals at the beginning of the 20th century led the United States Department of Agriculture (USDA) to develop U.S. Standards for Grades of Carcass Beef. Grading, as it applies to beef, is a process of sorting a heterogeneous supply of beef carcasses into smaller segments (grades) each of which includes beef having a sufficiently narrow range of grade-determining factors such that individual carcasses in the same grade have a high degree of interchangeability (Smith et al., 1987). These grades for beef carcasses comprise a hierarchical quality grading system that is intended to segment carcasses into groups based upon potential palatability differences. Current quality grades for beef carcasses include U.S. Prime (most desirable) to U.S. Canner (least desirable). In order to sort carcasses, certified graders from the Meat Grading Branch of the Agricultural Marketing Service, USDA, assess sides of beef for physiological maturity indicators, marbling content of the *longissimus dorsi*, and firmness of lean at the 12/13th rib interface (USDA, 2001a). Once carcass maturation is established marbling becomes paramount for quality grade determination.

As indicated earlier, the "jury" is still out concerning the role marbling plays in the formulation of beef tenderness. Romans et al. (1965) documented that only 5% of the variation in beef tenderness is accounted for by differences in marbling, whereas Campion et al. (1975) determined that marbling explained 10% of the variation of cooked beef. Likewise, Armbruster et al. (1983) found that marbling explained 1% of the variation in tenderness after accounting for other sources of variation and only 1.2% when other sources of variation were ignored. Smith et al. (1984) noted that marbling accounted for increased panel scores and lower shear force ratings when a wide range of marbling scores were present. However, within a tighter range of marbling scores (i.e., Small to Moderately Abundant), marbling had little or no effect on percentage incidence of loin steaks with high or low panel ratings and shear force values (Smith et al., 1984). Wulf et al. (1996) stated that marbling defined little of the variation in steaks from Limousin steers. Conversely, McBee and Wiles (1967) found that shear force, sensory panel tenderness, juiciness and flavor improved as marbling increased. Dolezal et al. (1982a) found that steaks with a Modest or higher degree of marbling had increased overall palatability ratings in relation to steaks from carcasses with Slight degree of marbling.

Carpenter and Smith (1974) detailed several theories relating marbling and tenderness. The *bite theory* hypothesizes that within a certain bite-size portion of cooked meat, marbling reduces the overall mass per unit of volume, which in turn lowers bulk density. Bulk density is the amount, distribution, and chemical or physical state of intramuscular fat and moisture. The *strain theory* suggests that as intramuscular fat is being formed, a portion is deposited within the perimysium or endomysium thereby decreasing the strength of connective tissue fibers. Increased accumulation of marbling causes the actual rigidity of the connective tissue to be weakened causing increased tenderness. This proposed theory can be affirmed by a recent study done by Nishimura et al. (1999) which found the development of adipose tissue in *longissimus dorsi* muscle appears to disorganize the structure of the intramuscular connective tissue and contributes to the tenderization of highly marbled beef from Wagyu cattle. Increased tenderness is the result of connective tissue that is more heat susceptible; the direct result of structural changes causing more efficient collagen solubilization. The *lubrication theory* states that as heat is applied to meat, intramuscular fat dissolves. The cooked fat and meat juices combine and serve as lubrication during the chewing process. Pearson (1966) found sustained juiciness (the sensation of juiciness perceived during continued chewing) to be related to intramuscular fat content. The *Insurance theory* suggests that increased amounts of intramuscular fat allow different preparation opportunities to be utilized that could affect degree of doneness. Marbling would provide some insurance that meat cooked too extensively or too rapidly would still be relatively palatable.

In order to determine the amount of fat needed to satisfy consumers, an objective measurement of marbling is needed to replace the subjective estimation of intramuscular fat content. Many researchers utilize chemical fat measurements to accurately determine intramuscular fat levels. Savell et al. (1986) showed the relationship between USDA marbling score and ether extractable fat percentage were: Abundant (10.42%), Slightly Abundant (8.56%), Moderate (7.34%), Modest (5.97%), Small (4.99%), Slight (3.43%), Traces (2.48%), and Practically Devoid (1.77%). Savell and Cross (1988) documented that an intramuscular fat content of 3% (wet tissue basis) is needed for minimal acceptance of beef palatability in the United States.

Video Image Analysis, also termed VIA, is utilized by major beef processors to supply information to USDA personnel that will aid in the determination of USDA Quality and Yield grades. VIA allows processors to take an objective measure of the *longissimus dorsi*, allowing for the accurate measurement of fat thickness, ribeye area and marbling. Presently, ribeye area is the only information being utilized by USDA graders to more accurately determine Yield grades. Research is being conducted to determine if this technology is useful as a predictor of beef tenderness (Wulf et al., 1997). VIA technology utilizes CIE L*, a* and b* values to measure the luminance, redness and yellowness as related to muscle color, respectively. Wulf et al., (1997) determined the b* value was highly correlated with shear force value; more so than marbling.

Time-on-Feed. Traditionally, to increase marbling deposition, feedlot managers tend to increase the amount of time that animals are fed a high-concentrate finishing ration. Increased time-on-feed increases the probability that animals will produce carcasses with a more desirable Quality Grade due to increased marbling formation (Zinn et al., 1970; Tatum et al., 1980; May et al., 1992). However, documentation that marbling only accounts for a small percentage of the variation in beef tenderness is also evident (Armbruster et al., 1983, Smith et al., 1984). Ironically, carcass value today is largely determined by marbling degree and its relationship with quality grade.

The interaction between quality grade and palatability, as well as, marbling and carcass value has led researchers to hypothesize exactly how many days on feed are actually necessary for cattle to be acceptable in terms of palatability. Dolezal (1982b) suggested that feeding a high-grain ration for at least 90 d was necessary for acceptable palatability. May et al. (1992) and Van Koevering et al. (1995) suggest feeding animals for 84 and 119 d for palatability to be acceptable, respectively. Duckett et al. (1993) found that marbling levels doubled between 84 and 112 days on feed, but did not differ from day 0 to 84 or from day 112 to 196. Nash et al. (1999) utilized ultrasound technology to monitor changes in marbling deposition and USDA Quality Grade relative to days on feed. It was concluded that the percentage Choice increased 60% from day 84 to day 100 and 120, with little change occurring there after.

The most astounding problem with increased time-on-feed is the negative effect on yield grade caused by increased fat thickness. This has led to the possibility of USDA grades based fully, or in part, on backfat thickness (Dolezal et al., 1982a). Theoretically, a minimum fat thickness requirement not only insures that animals have been afforded the time on feed necessary to grade USDA Choice, but also aids in the prevention of cold shortening. Cold shortening is achieved when carcasses are chilled too rapidly, causing sarcomere length to decrease considerably. May et al. (1992) documented that subcutaneous fat also prevented a rapid decline in carcass temperature. While attempting to determine an objective method for the number of days that feedlot cattle should be fed a high concentrate finishing ration, Brethour (2000) found that ultrasound estimates of backfat and marbling made during the feeding period could be used to predict carcass merit at harvest. By evaluating backfat thickness in cattle that were on feed for an average of 166 d and 148 d, mathematical models were designed to predict the number of days cattle would need to be fed in order to reach 10 or 13 mm backfat. Ultrasound backfat measures could be used to predict days to reach a target carcass backfat level with an average error of 30 d or less when cattle averaged more than 3 mm backfat at evaluation. These results indicated that marbling deposition is slow early in the feeding period, (approximately 100 d or 0.01 marbling score units per d were required to move from low Select to low Choice) but improved at faster rates as initial marbling scores became higher. Projections obtained later in the feeding period exceeded 75% accuracy in distinguishing between USDA Choice and Select carcasses.

Breed Differences. Brahman and Brahman-crossbred cattle, in relation to other breeds, have been shown to have lower marbling scores. Sherbeck et al. (1995) showed that carcasses from Hereford steers had higher marbling scores in relation to carcasses of 25 or 50% Brahman decent. Hereford carcasses had an increased proportion of USDA Choice grade carcasses than carcasses from Brahman decent (44 versus 19 and 14%, respectively) and a smaller percentage of USDA Standard grade carcasses than Brahman-crossbred carcasses (0 versus 19 and 18%, respectively). Nevertheless, Wheeler et al. (1994) documented that carcasses originating from *Bos taurus* and *Bos indicus* steers experienced a small, positive relationship between marbling score and palatability.

It can be disputed how much appreciable difference between *Bos indicus* and *Bos taurus* breeds for marbling deposition actually exist. Nonetheless, sensory panel tenderness differences do exist between these two diverse biological types of cattle due to biochemical differences (i.e., increased calpastatin) in Zebu breeds (Koch et al., 1988). Proteolytic enzymes in postmortem muscle will be outlined later in review, however, Zebu breeds have increased calpastatin activity when compared to cattle of British decent (Wheeler et al., 1994).

Implants. Beef industry segmentation is a major problem surrounding the problems with consistency and uniformity. Time-on-feed and breed differences have already been discussed, however, management regimes which utilize different implant protocols are undoubtedly a "hot topic" when considering the potential impact implants have on carcass quality. Anabolic implants are used routinely during the feedlot phase in order to promote increased gain and feed efficiency with reckless disregard for beef quality (Morgan et al., 1997). Duckett's (1997) review of 36 research trials determined implants caused a mean reduction of 24% in marbling and a 14.5% reduction in the number of carcasses grading Choice. Roeber et al. (2000) revealed that different implant strategies resulted in increased hot carcass weights and larger *longissimus dorsi* area while decreasing marbling scores and consumer preference of steaks. Duckett et al. (1999) found a reduction in marbling score when comparing implanted cattle with non-implanted controls. Morgan et al. (1997), through forty-nine research trials involving implants, found that the negative effects of implants on marbling scores and percentage of carcasses grading USDA Choice was greatest if implant was administered late in the finishing period. Research also exists that portrays the fact that certain implant regimes differ in their effect on carcass quality. Gerken et al. (1995) found that use of single implants containing 140 mg trenbolone acetate or the combination of 24 mg 17-ß estradiol and 120 mg trenbolone acetate had little appreciable effect on marbling or beef tenderness in genetically identical steers. Within this same trial, carcasses from cattle implanted with a single estrogenic implant containing 20 mg estradiol benzoate and 200 mg progesterone had significantly reduced marbling scores and decreased tenderness of top sirloin steaks when compared to the previously mentioned implant treatments. These results, however, are somewhat abnormal due to the use of genetically identical animals that had an abnormally high propensity to produce intramuscular fat (Morgan, 2000).

A meat scientist made the following conclusion concerning implant usage in the beef industry:

> "The entire beef production system must become more customer oriented if it is to maintain its current market share. To accomplish this goal, implant strategies must balance the advantages in growth against reductions in meat palatability. Cooperation, initiative and investment from all involved parties is essential for solving problems associated with consumer acceptability of beef" (Morgan et al., 1997).

Physiological Maturity

Effect on Palatability. The USDA Quality Grades for beef carcasses of Prime, Choice, Select and Standard vs. Commercial, Utility, Cutter and Canner are dependent upon the evidence of differences in skeletal and lean maturity; primary emphasis is placed on the extent of skeletal maturation for the determination of overall physiological maturity (Gardner and Dolezal, 1997). Data depicting the negative effects of increased maturity on palatability provided the motive for the most recent revision to the Official United States Standards of Carcass Beef (USDA, 2001a). Under the new beef carcass grading system, carcasses with a combined lean and skeletal maturity score of "B," having either Small or Slight degrees of marbling will be excluded from the USDA Choice and Select grades and instead placed in the USDA Standard grade (Appendix B).

Five maturity classifications exist for beef carcasses: "A" (9-30 mo.), "B" (30-42 mo.), "C" (42-72 mo.), "D" (72-96 mo.) and "E" (over 96 mo.) (USDA, 2001a). These maturity groups are based upon the physiological indicators that a beef carcass possess, the most useful being characteristics of bone and cartilage. Carcass maturity is determined by evaluating the size, shape, and ossification of the vertebral column, as well as the color and texture of the cut and lean surface at the $12^{th}/13^{th}$ rib interface. Soft, porous chine bones and rib bones that are somewhat narrow and red characterize carcasses from very young animals ("A" maturity). Additionally, the sacral vertebrae show distinct separation and cartilage is present at the tips of the thoracic vertebrae. Moreover, the lean from young animals is smooth in texture and light red in color.

Carcasses from animals of advanced skeletal maturity ("E" maturity) have hard, white chine bones with the outlines of the cartilage on the end of the thoracic vertebrae showing increased ossification. The sacral vertebrae are completely fused; the rib bones are wide and flat, and the lean color is dark red and coarse in texture.

The effect physiological maturity has on palatability has been well documented. Gardner and Owens (2000), surveying data from 552 published research trials, documented that tenderness is inversely related to lean maturity, whereas greater skeletal maturity was associated with increased beef flavor. Zinn et al. (1970) noted that cattle with more than 180 days on feed experienced increased physiological maturity and subsequently, an adverse effect on tenderness. Likewise, Wulf et al. (1996) documented a negative correlation between animal age and taste panel tenderness. Conversely, Romans et al. (1965) found that steaks from "D" maturity carcasses had higher sensory panel ratings than did steaks from "A", "B" or "C" maturity carcasses. Tatum et al. (1980) found no statistical significance between "A" and "B" maturity carcasses for differences in flavor, tenderness and juiciness. However, "C" maturity carcasses had higher overall palatability ratings when compared to "A" and "B" maturity carcasses (Tatum et al., 1980). These results agree with historic work by McBee and Wiles (1967) and Breidenstein et al. (1968) who documented a low association between carcass maturity and palatability, within a narrow physiological maturity range.

Perceived palatability differences caused by increased physiological maturity are thought to be offset by increased marbling (USDA, 2001a). However, Smith et al. (1982) reported a low relationship between marbling and palatability variation for "C", "D", or "E" maturity carcasses. Tuma et al. (1962) indicated that increased marbling did not necessarily compensate for increased carcass maturity, but that tenderness differences due to marbling were more pronounced when chronological age, at the time of harvest, increased.

Chronological Age. It is generally accepted that all animals within a species or breed do not grow, develop, fatten or mature at the same chronological age. Numerous research articles have attempted to determine the significance of chronological age on physiological maturation. May et al. (1992) demonstrated, through an experiment consisting of 48 Angus X Hereford steers, that carcass maturity increased as days on feed increased. These findings are in agreement with previous studies (Moody et al., 1970; Tatum et al., 1980; Dolezal et al., 1982b).

Although the aforementioned research reveals that chronological age is associated with advanced skeletal maturity, research conducted by Shackelford et al. (1995) using 1 to 14 year old females found carcass maturity was only moderately related to chronological age. However, carcass maturity score became more advanced with increased chronological age at a much faster rate than originally indicated by the USDA. Results from this research trial prompted the proposal for a new chronological age group classification scheme that more accurately reflected the chronological age associated with each USDA carcass maturity class.

Total collagen levels (mg/g) increase with chronological age (Goll et al., 1963). Collagenous connective tissue contains 12.5% hydroxyproline (AOAC, 1990). Therefore, hydroxyproline is quantitatively determined as a measure of collagenous material in meat and meat products (AOAC, 1990). Total collagen levels are important to determine for meat products; total collagen is simply the amount of collagen that is present in muscle. Hill (1966) found that the amount of total intramuscular collagen increased with chronological age. Correspondingly, an increased sensation of toughness resulted from consumption of meat from older animals (Hill, 1966). Goll et al. (1963) found no significant difference for hydroxyproline content in animals ranging from veal calves to 10 y old Holstein cows. Furthermore, reported WBS values of cooked *biceps femoris* muscle from three 4 - 5 year old cows and two 10 year old cows indicated that tenderness decreased with animal age. This corresponds with the reported collagen values on a fresh-weight basis between the 4-5 and 10 year old cows (1.14% versus 1.83%, respectively). Cross et al. (1973), however, determined total concentrations of connective tissue components (elastin and collagen) were not closely related to muscle fiber tenderness or amounts of connective tissue, as assessed by a trained sensory panel.

At temperatures between 60 – 70 °C collagen solubilization begins and continues with increased temperature (McCrae and Paul, 1974).Additionally, Draudt et al. (1972) noted that within this range of temperatures, collagen shrinkage occurs causing the denaturation of the myofibrillar proteins resulting in increased tenderness of meat.

Gender. Research scientists and branded beef programs are placing increased emphasis on carcass maturity score since the most recent revision of the beef quality grading system. Gender differences (steer, heifer, bullock, cow and bull) have brought up certain issues from pregnancy and puberty to endogenous hormone levels which individually or collectively influence carcass maturity. What effect exactly these might have on the degree of physiological maturity has become a "top of mind" issue.

In an attempt to determine factors associated with tenderness and tenderness variation in virgin, ovariectomized, and single-calf heifers, Field et al. (1997) found "A" and "C" maturity carcasses to be similar for total collagen, panel tenderness ratings and WBS values. Within this particular study, three different slaughter age groups (31-, 33- and 35-month) resulted in 31 "A", 5 "B" and 16 "C" maturity carcasses, respectively. Field et al. (1997) attributed the high amount of "C" maturity carcasses to high levels of endogenous estrogen levels present in early maturing Angus x Gelbvieh females. It is clear that a difference of a few months in chronological age can influence carcass maturity scores (Field et al., 1997). Similarly, Ho et al. (1989) reported that bone of Finnsheep cross ewe lambs fused earlier than bone of ewe lambs from later sexually maturing breeds of sheep.

Consumers' desire for leaner meat products has resulted in research experiments to determine the effectiveness of feeding young bulls for highyielding carcasses. Field et al. (1971) reported elevated lean maturity scores for bulls versus steers. Likewise, increased WBS values were witnessed in beef from bulls as compared to steers (Field et al., 1971). Glimp et al. (1971) found that castrated Angus and Hereford calves had higher USDA Quality Grades than did intact males fed for the same period of time. Increased Quality Grades were the result of higher marbling score and lower physiological maturities (Glimp et al., 1971).

Implant Protocol. Implants have been shown to decrease carcass quality, namely marbling, in numerous review articles (Morgan et al., 1997; Duckett et al., 1999; Roeber et al., 2000). Research has also revealed little appreciable difference in marbling score between implanted animals and controls (Gerken et al., 1995). Anabolic implants administered to cattle cause increased feed efficiency and rate of gain. Nonetheless, implant regimes also cause differences (some more severe than others) in marbling deposition and physiological maturity, the two indicators of beef quality. The most documented effect implants have on meat quality has been their effect on marbling deposition. Most research proves that marbling deposition in implanted cattle is seldom suppressed enough to result in extreme differences in Quality Grade (i.e., Choice versus Select among cattle of the same physiological maturity). The effect implants have on physiological maturity can be characterized much the same way. Carcasses from implanted animals can experience both lower marbling scores and higher physiological maturity scores, causing carcasses to decline from USDA Choice to USDA Standard, because of recent revisions. As part of the OSU Implant Symposium, Morgan et al. (1997) ascertained that carcasses from cattle implanted with anabolic implants tended to have more advanced skeletal maturity than carcasses from non-implanted cattle. Also, skeletal maturity tends to be higher for carcasses from aggresively implanted cattle (i.e., estradiol and trenbolone acetate given in combination).

Estrogen inhibits cartilage proliferation, promotes mineralization, and speeds ossification of bone (Van Sickle, 1985). In a review summarizing management effects on physiological maturity, Gardner and Dolezal (1997) documented that the binding of estrogen receptors promotes mineralization and may result in increased bone densities and accelerated ossification of the cartilaginous buttons. Large doses of estrogen over a period of 17 – 26 d in the rat caused thinning of the epiphyseal plates and increased calcification, leading to an increase in skeletal age in female rats (Gardner and Pfeiffer, 1943).

Testosterone is the predominate androgen secreted by the testes. After birth, testosterone is involved in skeletal growth up to the time of puberty, when certain epiphyseal plates are closed (Silbermann, 1983). Results from rat studies have shown that normal rats, treated with testosterone, have decreased cartilage cell proliferation and increased metabolic activity of mature chondrocytes (Silbermann, 1983). These findings display how testosterone supplementation enhances the aging process of the epiphyseal growth plate (Silbermann, 1983). Lebovitz and Eisenbarth (1975) documented a retardation of skeletal growth in castrated animals. When testosterone is administered to castrated animals it accelerates skeletal growth (Silbermann, 1983). Fahmy et al. (1971) found an acceleration of the maturational process of young chondrocytes along with an increase in the size of matrical collagen fibers in testosterone-treated rats. These findings show that testosterone can result in premature mineralization of cartilage.

Proteolysis

Aging Effects on Muscle Structure. Thus far, this review of literature has focused extensively on the antemortem factors affecting beef tenderness variation. As outlined earlier, postmortem management of beef does play a particularly important role in helping to reduce the variation in beef tenderness at the consumer level (Koohmaraie, 1996). The following paragraphs will detail the effects of proteolysis on beef during postmortem refrigerated storage. Many different theories exist on the actual role certain enzymes have on muscle structure and ultimately their role in beef tenderization.

Postmortem refrigerated storage of beef improves tenderness. Increased tenderness in meat is caused by endogenous enzymatic activity in the form of the calpains (m- and μ-calpain) which occur naturally in the muscle. The calpain proteases are different in the amount of calcium required for activation; μ-calpain requires millimolar concentrations of calcium (200-300 μm) and m-calpain requires micromolar calcium concentrations (~10mM) for activation to occur. Calpastatin is an endogenous substrate that inhibits the calpain proteases. According to Koohmaraie (1992), when normal postmortem conditions are realized, m-calpain is very stable in the body due to insufficient calcium present for its' activation. Furthermore, a gradual decline in activity occurs with μ-calpain as calcium in the body is depleted and calpastatin loses activity very rapidly. Calpastatin is hydrolyzed by calpain proteases when greater quantities of protease are present in relation to inhibitor (Shannon and Goll, 1985). Prediction equations show 24-h calpastatin activity and 0-h μ-calpain activity account for 41% of the variation in WBS in beef aged 14 d (Shackelford et al., 1991). Likewise, research conducted by Johnson et al. (1990) and Calkins et al. (1988) found WBS values to be correlated with both calpastatin ($r = 0.41$) and μ-calpain activity ($r = -0.71$), respectively.

Calpain proteases were thought to downgrade myofibrillar structure by attacking only sarcomere boundaries or Z-lines. However, recent research has illustrated several different mechanisms detailing the role calpains play in meat tenderness. Taylor et al. (1995) found that Z-disk structure nearly went unchanged up to 16 d postmortem. These findings suggest the actual calpain mechanism could very well be different than what was documented; other mechanisms potentially occur in postmortem muscle that effect ultimate meat tenderness with regards to calpain activity. Taylor et al. (1995) theorized calpains increase postmortem muscle tenderization by weakening of the actin/myosin interaction, weakening of the thin filament (actin)/Z-disk connections and degradation of intermyofibrillar linkages.

The purpose for this particular research project is twofold. First, to explain the effect of minimal differences in marbling score across "A" and "B" skeletal maturity carcasses on WBS values, sensory panel tenderness and chemical measures of beef tenderness. Secondly, to evaluate branded beef programs that incorporate "B" maturity carcasses are significantly inferior in palatability when compared to other branded beef programs that utilize only "A" maturity carcasses.

CHAPTER 3

USDA MARBLING AND CARCASS PHYSIOLOGICAL MATURITY RELATED DIFFERENCES FOR BEEF TENDERNESS AND PALATABILITY CHARACTERISTICS

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ABSTRACT

Certified Angus Beef (CAB, Modest-Moderate marbling scores, "A" skeletal maturity), Sterling Silver A (SSA, Modest-Moderate marbling scores, "A" skeletal maturity), Sterling Silver B (SSB, Modest-Moderate marbling scores, "B" skeletal maturity), Low Choice containing High Small marbling A (HSMA, Small^{50}-Small^{99} marbling scores, "A" skeletal maturity), Low choice containing High Small marbling B (HSMB, Small^{50}-Small^{99} marbling scores, "B" skeletal maturity), Low Choice containing Low Small marbling A (LSMA, Small^{00}-Small^{49} marbling scores, "A" skeletal maturity), Low Choice containing Low Small marbling B (LSMB, Small^{00}-Small^{49} marbling scores, "B" skeletal maturity), High Select A (HSEA, Slight^{50}-Slight^{99} marbling scores, "A" skeletal maturity), High Select B (HSEB, Slight^{50}-Slight^{99} marbling scores, "B" skeletal maturity), Low Select A (LSEA, Slight^{00}-Slight^{49} marbling scores, "A" skeletal maturity) and Low Select B (LSEB, Slight^{00}-Slight^{49} marbling scores, "B" skeletal maturity) steer and heifer

carcasses (n=207) were selected for the determination of *Warner-Bratzler* shear (WBS) force and sensory panel values, as well as proximate analysis and chemical composition differences. A 10-11-12 rib *longissimus dorsi* section was obtained. Five steaks were fabricated from each meat rib section and assigned to WBS after 7, 14 or 21-d of postmortem storage (4°C), sensory panel evaluation and chemical analysis. After accounting for 20 or 30% cook loss, WBS values were lower and sensory panel attributes were more desirable for CAB, SSA, SSB and HSMA samples relative to other Quality Grade categories. No significant difference ($P > 0.05$) was found for WBS values or sensory panel tenderness, juiciness and overall acceptability between "A" and "B" maturity samples within the same Quality Grade category. Steaks with WBS values less than 3.9 kg was higher for CAB, SSA, SSB and HSMA relative to other Quality Grade categories. Marbling score accounted for 20.0%, 13.7% and 13.7% variation in WBS after 7, 14 and 21 d refrigerated storage, respectively. The percentage (%) lipid was higher for CAB, SSA and SSB relative to other Quality Grade categories. Percent hydroxyproline and total collagen values were similar among categories, except for SSA and SSB, which were significantly lower ($P < 0.05$) than other quality grade categories. Results from this research indicate that inclusion of "B" maturity carcasses in branded beef programs would not be detrimental to beef palatability.

INTRODUCTION

Beef industry leadership, in response to concerns related to uniformity and consistency of beef, developed various branded beef programs that more accurately stratify carcasses based on projected palatability differences. The development of such programs came at a time when research has shown that consumers are not only able to discern tenderness differences, but also are willing to pay a premium for "guaranteed tender" beef (Boleman et al., 1997). Additionally, branded beef programs enable industry segments to move away from traditional commodity-based marketing by adding value to a particular raw commodity.

Tenderness has been shown to be the most influential organoleptic trait affecting consumers perception of taste (Savell et al., 1989). Possible ante- and postmortem factors that affect meat tenderness includes multiple animal/carcass factors and structural/compositional differences regarding muscle structure. The premise of the USDA grading system is to not only separate carcasses based on USDA Quality and Yield Grades in order to exemplify differences in potential palatability, but to also facilitate marketing and sort carcasses into more consistent groups.

Intramuscular lipid, also termed marbling, is the most significant quality determinant of carcass value, once physiological maturity has been established. Ironically, research shows that marbling content explains little of the variation associated with beef tenderness (Armbruster et al., 1983). Even so, many researchers have documented small, linear relationships between marbling and

WBS values. Tenderness differences between carcasses with similar marbling scores have been proven insignificant (Smith et al., 1984). Likewise, physiological maturity has become a "hot topic" throughout the beef industry as a result of increased implementation of value-based marketing programs. Physiological maturation has been shown to be associated with increased flavor and decreased tenderness with regards to beef (Gardner and Owens, 2000).

The purpose for this particular research project is twofold: 1) to explain the effect of minimal differences in marbling score across "A" and "B" skeletal maturity carcasses on WBS values, sensory panel tenderness and chemical measures of beef tenderness, and 2) to determine if branded beef programs that incorporate "B" maturity carcasses are significantly inferior in palatability when compared to other branded beef programs which utilize only "A" maturity carcasses.

MATERIALS AND METHODS

Sample Collection. Carcasses (n = 207) from steers and heifers of unknown origin were selected randomly within a three month period at two separate commercial beef processing facilities in order to meet predetermined USDA Quality Grade criteria (i.e., marbling score and physiological maturity combinations). Carcasses verified as Certified Angus Beef® (n = 30) were compared to "A" and "B" skeletal maturity carcasses from Sterling Silver® (n = 60), Choice carcasses graded to contain Low and High Small marbling (Small 00-50 and Small 51-99) (n = 30), Select to contain Low and High Slight marbling

(Slight 00-50 and Slight 51-99) (n = 31), and No Roll (n = 57) to represent "B" physiological maturity carcasses within Choice and Select grading criteria (USDA, 2001a). Appendix A depicts branded beef program criteria utilized for selection and certification of Certified Angus Beef and Excel Corporation's Sterling Silver. Two highly trained personnel determined USDA beef carcass Quality and Yield Grade factors. After carcass data information was collected, a 10-11-12 rib section was individually identified and removed specific to carcass data collection, then vacuum packaged. Meat samples were transported to the Food and Agricultural Products Center at Oklahoma State University, where 5 steaks were obtained from each rib section. Three of the 2.54-cm steaks were randomly allotted to a postmortem aging treatment of either 7, 14, or 21 d (4°C). These steaks were used for Warner-Bratzler shear force (WBS) evaluation. The fourth 2.54-cm steak was aged for 14 d and designated for sensory panel analysis. A fifth steak, which varied in thickness/shape, was therefore used for proximate analysis and total collagen determination. The proximate analysis steak was trimmed of external fat and visible connective tissue, placed in a whirlpack bag, and stored at –28 °C.

Warner-Bratzler Shear Force. Steaks were randomly distributed across each cooking date so that all Quality Grade and aging times were represented. Each day, one hundred steaks were allowed to temper daily at 4 °C for 24 h prior to cooking. Steaks were broiled in an impingement oven (Lincoln Impinger, Model 1132-000-A, Lincoln Foodservice Products, Fort Wayne, IN.) at 180 °C to an internal temperature of 65 °C; temperature was monitored using a Digi-

Sense® type T thermocouple (Model 91100-20, Cole-Parmer Instrument Company, Vernon Hills, IL). After cooking, steaks were allowed to cool to room temperature. Initial and final weights were recorded for each steak, and used to calculate cook loss. A minimum of six cores (1.27 cm diameter) were removed parallel to muscle fiber orientation and sheared once, using a Warner-Bratzler head attached to an Instron Universal Testing Machine (Model 4502, Canton, MS). The Warner-Bratzler head moved at a crosshead speed of 200 mm/minute. Peak load (kg) of each core was recorded by an IBM PS2 (Model 55 SX) using software provided by the Instron Corporation. Mean peak load (kg) was analyzed for each sample.

Sensory Analysis. Twelve panel members were identified for use on two separate sensory panel. After training, panel members were divided equally. Steaks were assigned randomly to cooking order to allow all treatment groups to be represented equally during both sensory panels. Steaks were broiled as previously described for the WBS samples. Following the cooking process, steaks were placed in a foil pouch where they remained warm prior to sensory analysis. Two cubed sections (1.3 cm x 1.3 cm x cooked steak thickness) from each steak were served warm to panelists and the mean for each palatability attribute was recorded for each sample. Panelists evaluated steaks for tenderness (1=extremely tough, 8=extremely tender), juiciness (1=extremely dry, 8=extremely juicy), connective tissue (8=none, 1=abundant), flavor intensity (8=extremely intense, 1=extremely bland), beef fat flavor (3=very strong, 1=none detectable) and overall acceptability (7=extremely desirable, 1=extremely undesirable).

Proximate Analysis. Proximate analysis of *longissimus dorsi* samples was performed in duplicate according to a modified procedure outlined by AOAC (1980). In a refrigerated room, samples were placed in liquid nitrogen and frozen individually. After freezing, samples were pulverized in a Waring® Commercial Blender (Model 31BL46, Waring Products Division Dynamic Corporation of America, New Hartford, CT.). Glass thimbles were stuffed with cotton and placed in a drying oven for 2 h at 100°C to eliminate potential moisture from cotton. Two grams of each powdered sample was then placed in glass thimbles, dried at 100°C for 24 h, desiccated for 1 h, and re-weighed to determine percent moisture of each sample. Each sample was then placed in a soxhlet containing petroleum ether, and heated for 24 h to allow for lipid extraction. Samples were removed from soxhlet, air dried for 1 h and placed in a drying oven at 100°C for no more than 12 h. Each sample was then desiccated for 1 h and re-weighed to determine lipid content.

Total Collagen. Hydroxyproline assays to determine total collagen of *longissimus dorsi* samples were performed in duplicate according to a modified procedure of AOAC (1990). Four grams of each sample was placed in 125 mL Erlenmeyer flasks and an initial weight was obtained. Exactly 30 mL of 7N sulfuric acid was added to each flask. Samples were then placed in 105 °C drying oven for a minimum of 16 h for sample digestion to occur. The flasks were removed from oven and allowed to cool at room temperature. The liquid portion was filtered into 1000 mL Erlenmeyer flasks and diluted to volume with deionized water. Four mL of diluted filtrate, along with 16 mL deionized water, was pipetted into sampling jars and stored at -28°C to inhibit bacterial growth. A blank was prepared using two mL of deionized water and a standard curve constructed by using zero, two, four, six, eight, and ten g/mL hydroxyproline standard solutions. Two mL of each standard was pipetted into duplicate glass test tubes. Each tube received one mL of oxidant solution consisting of chloramine-T reagent in a buffer solution, vortexed and allowed to stand at room temperature for 20 min. Glass tubes then received one mL color reagent derived from 4-dimethylaminobenzaldehyde, perchloric acid, and 2-propanol. Tubes were vortexed and immediately placed in 60 °C water bath for approximately 15 min. Tubes were removed, cooled to room temperature, and sample fractions read at 558 nm using a Beckman DU 7500 spectrophotometer (Beckman Instruments, Inc., Houston, TX). Hydroxyproline (H) and total collagen content was computed using the following formulas:

$$H, g/100\ g = (h \times 2.5) / (m \times V)$$

h = hydroxyproline, µg/2 ml filtrate, read from calibration curve; m = weight of sample, g; and V = volume, ml, of filtrate taken for dilution.

$$\text{Total collagen} = \text{hydroxyproline content} \times 7.25$$

Statistical Analysis. Prior to data analysis, eleven brands were designated from original samples: Certified Angus Beef (CAB, Modest-Moderate marbling scores, "A" maturity), Sterling Silver A (SSA, Modest-Moderate marbling scores, "A" maturity), Sterling Silver B (SSB, Modest-Moderate marbling scores, "B" maturity), Low Choice containing Small marbling A (HSMA, $Small^{50}$-$Small^{99}$ marbling scores, "A" maturity), Low choice containg Small marbling B (HSMB, $Small^{50}$-$Small^{99}$ marbling scores, "B" maturity), Low Choice containg Small marbling A (LSMA, $Small^{00}$-$Small^{49}$ marbling scores, "A" maturity), Low Choice containing Small marbling B (LSMB, $Small^{00}$-$Small^{49}$ marbling scores, "B" maturity), High Select A (HSEA, $Slight^{50}$-$Slight^{99}$ marbling scores, "A" maturity), High Select B (HSEB, $Slight^{50}$-$Slight^{99}$ marbling scores, "B" maturity), Low Select A (LSEA, $Slight^{00}$-$Slight^{49}$ marbling scores, "A" maturity) and Low Select B (LSEB, $Slight^{00}$-$Slight^{49}$ marbling scores, "B" maturity). These eleven quality categories served as main effects for various analyses.

Analysis of data was performed using the Mixed procedure of SAS (Version 8.1, SAS Institute, Cary, NC.). Design structure for WBS was a completely randomized design with three repeated measures. Design structure for analysis of carcass and meat traits was a completely randomized design. Sensory panel evaluations were analyzed using a block design with multiple replications (dates) per block (panelist). Correlation analysis was performed to explain the effect of marbling score, lean maturity, skeletal maturity, pH, percent lipid, percent moisture, percent total collagen and objective color score (L^*, a^*, b^*) on WBS. Means were separated using least squares means and probabilities differences using α at the 0.05 level.

RESULTS AND DISCUSSION

Carcass and meat traits. Carcass traits for each quality grade group are presented in Table 1. By design, carcass skeletal maturity, lean maturity and marbling score differences between quality grade categories were significantly different ($P < 0.05$). "B" maturity quality grade categories (SSB, HSMB, LSMB, HSEB and LSEB, respectively) were statistically more advanced in skeletal maturity ($P < 0.05$) than their "A" maturity counterparts (CAB, SSA, HSMA, LSMA, HSEA and LSEA, respectively). Likewise, Quality Grade categories comprised of B maturity samples had darker lean color as compared to samples from more youthful carcasses.

Marbling score between quality grade categories differed among High Choice categories (CAB, SSA, SSB), High Small (HSMA and HSMB), Low Small (LSMA and LSMB), High Select (HSEA and HSEB) and Low Select (LSEA and LSEB) ($P < 0.05$). Furthermore, among carcasses with Modest – Moderate marbling scores, SSA had higher ($P < 0.05$) marbling scores than did CAB and SSB, respectively. No differences existed between quality grade categories for yield.

Proximate composition analysis. Chemical analyses and objective color measurements for meat samples, stratified by quality grade category, are represented in Table 2. Some variables listed had heterogeneity of variances among brands. Percentage lipid increased progressively with increased marbling score. Although not statistically significant, a trend was witnessed for "B" maturity carcasses within each specific quality grade category to have higher numeric values for percentage lipid than the "A" maturity samples. Percentage lipid was similar to trends observed for marbling score. HSMB, HSEB and LSEB had higher marbling score values as compared to HSMA, HSEA and LSEA, respectively. However, these trends do not account for percentage lipid differences between SSB and SSA or LSMB and LSMA.

Percentage moisture values were higher for carcasses with less initial marbling, specifically LSEA, LSEB, HSEA and HSEB when compared to Low Choice and Premium Choice Quality Grade categories. Numeric means from this trial for percentage moisture and lipid correspond to data published by Savell et al. (1986) with respect to percentage lipid and moisture for Modest, Small and Slight degrees of marbling.

Collagen determination. Hydroxyproline and total collagen content was lower ($P < 0.05$) for SSA carcasses compared to all other quality grade categories (Table 2). SSB had the next lowest hydroxyproline and total collagen percentages; SSB values were significantly lower ($P < 0.05$) than other Quality Grade categories except for LSMB. No difference was found for hydroxyproline or total collagen percentages among other Quality Grade categories. An accurate explanation for such low percentages of hydroxyproline and total collagen in SSA and SSB cannot be determined. Percentages reported are within the range of total collagen values as reported by Wheeler et al. (2000) and Boleman et al. (1996). Hydroxyproline percentage, however, was quite low as compared to results published by AOAC (1990). However, the cumulative findings are in partial agreement with Goll et al. (1963) (except SSA and SSB categories) who found no significant difference in collagen content among animals from a wide range of ages.

Objective lean color assessment. Results from Minolta colorimeter readings (Table 2) show that "A" maturity samples (excluding HSEA and HSEB) had higher L* values ($P < 0.05$) when compared to "B" maturity samples, within the same Quality Grade category. Carcasses with increased marbling score generated higher a* values as compared to carcasses with low degrees of marbling. SSA and SSB generated the highest a* values, but differed ($P < 0.05$) from each other. The same trend for L* values was witnessed for b* values with the exception of LSMA and LSMB; more youthful carcasses had significantly higher ($P < 0.05$) b* values than physiologically older, "B" maturity carcasses. Wulf et al. (1997) noted that b* values were the most highly correlated with shear force value and taste panel tenderness.

Warner-Bratzler shear force. Least squares means and standard error ranges summarizing WBS differences between quality grade categories are reported in Tables 3 and 4. Quality category comparisons were made utilizing 20% and 30% cook loss as a covariate due to a significant storage time effect on Quality Grade categories. Moreover, a cook loss covariate was used to account for differences resulting from marbling score, day-to-day variation in oven temperature and steak thickness. When WBS means were adjusted to reflect a 20% cooking loss, SSA was more tender ($P < 0.05$) compared to CAB, HSMB, LSMB and LSEA. WBS values indicate that as marbling level decreased (excluding HSMB), WBS increased. When compared to CAB samples, SSA had significantly lower WBS values. Additionally, SSB tended ($P = 0.07$) to have lower WBS values when compared to CAB carcasses. Table 4 reveals that after adjusting cook loss to 30%, SSA, SSB and HSMA had significantly lower WBS values when compared to LSMA and LSMB quality grade categories. CAB samples seemed to be the "benchmark for quality" as they had the lowest WBS (3.93 kg) values among quality grade categories. CAB WBS values, however, were similar for WBS to SSA, SSB and HSMA. Within each quality grade category, no significant differences for WBS were found for "A" versus "B" maturity samples. These results are not in agreement with Smith et al. (1982) who found significant differences ($P < 0.05$) in WBS value between "A" and "B" maturity top loin steaks. As Quality Grade decreased, WBS values were significantly less desirable for HSMB, LSMA, LSMB, HSEA, HSEB, LSEA and LSEB as compared to CAB samples. When comparing WBS values across Quality Grade categories from 20% to 30% cook loss, CAB, SSA, SSB and HSMA maintain more desirable WBS trends (below 4.5 kg) as compared to HSMB, LSMA, LSMB, HSEA, HSEB, LSEA and LSEB that became very high (above 4.5 kg) (Figure 1).

Analyzing the impact of increasing the amount of cooking loss, it was concluded that Premium Choice samples along with HSMA outperformed the lower Quality Grade categories. Several theories have been discussed pertaining to possible mechanisms in which marbling enhances beef tenderization. According to reported results from this study, the *insurance theory* from Smith and Carpenter (1974) can be validated. The increased marbling levels found in CAB, SSA, SSB and more youthful carcasses containing High Small amounts of marbling provide insurance against a potentially undesirable eating experience. These results certainly demonstrate that as cook loss increased, WBS values were maintained acceptable (below 4.5 kg) for CAB, SSA, SSB and HSMA categories.

Researchers have identified tenderness thresholds that represent a given level of confidence for a steak being rated at least "slightly tender" by trained panelist. Based upon sensory panel ratings and WBS values for steak samples, steaks having a WBS value less than 4.6 and 3.9 kg should have a 50 and 68% opportunity to be rated "slightly tender", respectively (Shackelford et al., 1991). Tables 5, 6 and 7 summarize the percentage distribution of steaks within each pre-determined tenderness threshold according to carcass quality grade category and postmortem storage time. After 7 d postmortem storage (Table 5), higher Quality Grade categories (CAB, SSA, SSB and HSMA) had an increased percentage of steaks with WBS values less than 3.9 kg. Select Quality Grade categories (HSEA, HSEB, LSEA and LSEB) had the highest percentage of steaks with WBS values greater than or equal to 4.5 kg after 7 d of refrigerated storage. Information in Table 6 overviews that after 14 d of refrigerated storage, the same trend was witnessed between high quality grades (CAB, SSA and SSB) and lower percentages of steaks with WBS values greater than or equal to 4.5 kg as compared to steaks from lower Quality Grade categories (HSMA, HSMB, LSMA, LSMB, HSEA, HSEB, LSEA and LSEB). Interestingly, the percentage steaks from CAB and Small Quality Grade categories (HSMA, HSMB, LSMA and

LSMB) with WBS values greater than or equal to 4.5 kg increased from d 7 to d 14. Likewise, SSA and SSB had higher combined percentages of steaks with WBS values of less than 3.9 kg and 3.9 kg to 4.5 kg when compared to CAB (80.0 and 83.3 versus 63.3%, respectively). After 21 d of aging, CAB, SSA, SSB and HSMA had higher percentages of steaks with WBS values of less than 3.9 kg than did all other Quality Grade categories. It appears the effect of decreased marbling score jeopardized the possibility for steaks to be categorized as "very tender", even after 21 d of postmortem aging.

Simple correlations coefficients stratified by aging periods between WBS and marbling score, lean maturity, skeletal maturity, pH, L*, a*, b*, lipid (%), moisture (%) and total collagen (%) are presented in Table 8. Across all aging periods, marbling score, L*, a* and b* values were the most highly correlated ($P < 0.01$) with WBS values. At d 7, marbling score was the most highly correlated ($P < 0.01$) with WBS compared to other variables, however, objective color evaluations (L*, a* and b*) were more highly correlated ($P < 0.01$) to beef tenderness after 14 and 21 d postmortem aging. After 14 d of refrigerated storage, Minolta colorimeter b* values were highly related ($P < 0.01$) to WBS, whereas, L* values were the most highly correlated with beef tenderness after 21 d postmortem aging. These results are in agreement with Wulf et al. (1997) who found that increased b* values were more highly correlated to beef tenderness, even more so than the degree of marbling.

Calculated coefficients of determination (R^2 x 100) revealed marbling score accounted for 20.0, 13.7 and 13.7% of the variation in WBS after 7, 14 and

21d of postmortem storage, respectively. This research is not in agreement with research that states marbling explains less than 10% of cooked beef tenderness variation (Campion et al., 1975 and Armbruster, 1983). Findings from this study indicate that marbling plays an important role in beef tenderness. Combined coefficients of determination for marbling, L^* (19.4, 11.7 and 16.0%), a^* (10.2, 13.0 and 12.3%) and b^* (16.8, 16.0 and 15.2%) values indicate these variables can account for 66.4%, 38.4% and 41.2% of the variation in WBS values after 7, 14 and 21 d postmortem storage, respectively.

Sensory panel evaluation. Least squares means and standard error ranges for sensory panel attributes stratified by Quality Grade category are presented in Table 9. SSA was rated more ($P < 0.05$) tender than all other quality grade categories. Similar panel ratings for tenderness were witnessed between CAB, SSB and HSMA quality grade categories. CAB and SSB had higher ($P < 0.05$) tenderness ratings as compared to cooked samples from HSMB, LSMA, LSMB, HSEA, HSEB, LSEA and LSEB quality categories. These results corroborate findings from May et al. (1992) who found that as marbling level increased, sensory panel ratings increased and WBS values decreased. Breidenstein et al. (1968), however, found that marbling level did not affect either shear force or sensory panel tenderness ratings for steaks from carcasses with Slight, Modest, Moderately Abundant or Abundant marbling scores. Likewise, Romans et al. (1965) suggested the effect of marbling on palatability may be overemphasized.

SSA and SSB received higher ($P < 0.05$) panel ratings for juiciness compared to all other quality grade categories. The findings from this research are in agreement with Boleman et al. (1997) who found that consumers, who scored steaks as tender, also found steaks to be juicy and flavorful.

SSA received significantly more desirable ($P < 0.05$) panel scores for connective tissue amount in relation to HSMB, LSMA, LSMB, HSEA, HSEB, LSEA and LSEA. Samples from SSA, SSB, CAB and HSMA carcasses recorded the highest numeric sensory panel ratings, indicative of low amounts of connective tissue. Values for connective tissue amount decrease across quality grade category; results that are similar to sensory panel tenderness ratings. Combined sensory and WBS results from this study reveal that panelists not only have the ability to associate increased marbling with increased tenderness, but also increased tenderness with less connective tissue amount. Further, the *strain theory* hypothesizes that the actual rigidity of connective tissue is compromised with increased marbling accumulation. CAB recorded the highest total collagen values, however, increased lipid percentage or even an increase in the percentage soluble collagen may have been responsible for "slightly desirable" sensory panel tenderness values to be experienced.

Flavor intensity ratings were higher ($P < 0.05$) for SSA and SSB when compared to CAB, HSMB, LSMA, LSMB, HSEA, HSEB, LSEA and LSEB. Gardner and Owens (2000) found greater skeletal maturity to be associated with increased flavor, and lean maturity to be inversely related to beef tenderness. However, findings from this research are not in full agreement. Flavor intensity ratings were lower for "B" maturity versus "A" maturity steaks from the same quality grade category with the exception of HSEA and HSEB.

SSA and SSB had higher beef fat flavor ratings when compared to HSEA, HSEB and LSEA. All other quality grade categories were similar ($P > 0.05$).

Quality grade effects on overall acceptability were similar to those noted for sensory panel tenderness findings. SSA was the highest rated Quality Grade category; SSA received higher ($P < 0.05$) overall acceptability ratings than CAB, HSMA, HSMB, LSMA, LSMB, HSEA, HSEB, LSEA and LSEB, while being similar to SSB. CAB samples were similar to HSMA and HSMB for overall acceptability, but had significantly ($P < 0.05$) higher overall acceptability ratings than LSMA, LSMB, HSEA, HSEB, LSEA and LSEB quality grade categories. All other quality grade categories were similar for overall acceptability. Findings from this sensory panel disagree with Smith et al. (1988) who showed that increased physiological maturity from "A" to "B" resulted in decreased sensory panel tenderness and overall palatability ratings.

Findings indicate that quality grade categories comprised from CAB, SSA and SSB carcasses, regardless of physiological maturity, offer increased palatability attributes such as tenderness, juiciness and flavor (Figure 2). Panelists were not able to discern the impact of physiological maturity on sensory differences between SSB and CAB for tenderness, juiciness, connective tissue amount or beef fat flavor. Overall acceptability for steaks from Quality Grade categories with increased marbling (i.e., Modest – Moderate) was higher than for steaks from the lower one-third Choice and Select carcass grades. This data is in agreement with findings from Savell and Cross (1983) who documented the need for 3.0% lipid to be present in meat for satisfactory palatability to be realized in the United States.

Implications

Beef industry leadership has been charged with the enormous task of improving the overall palatability, tenderness and consistency of beef products. Branded beef programs provide a means to deliver what each beef industry segment demands. The present study demonstrates that marbling level does have a significant impact on beef tenderness. Physiological skeletal maturity (i.e., "A" and "B" maturity) seems to have very little impact on WBS value or palatability traits as evaluated by WBS or a trained sensory panel. Steaks from carcasses qualifying for Premium Choice branded beef programs -- especially SSA -- displayed improved palatability ratings when cooked to a medium degree of doneness (65°C) compared to lower Quality Grade samples. Lean and skeletal maturity scores explained little of the variation associated with beef tenderness, whereas objective color scores provided a moderate correlation with beef tenderness. Marbling score, coupled with objective color values, can provide a way to predict beef tenderness for various market segments throughout the beef supply chain. Inclusion of B maturity carcasses into premium Choice quality branded beef programs appears to not be detrimental to overall beef palatability.

Table 1. Carcass traits stratified by quality grade category

	Quality grade categories[a]										
Trait	CAB	SSA	SSB	HSMA	HSMB	LSMA	LSMB	HSEA	HSEB	LSEA	LSEB
Number of Carcasses	30	30	30	15	15	16	12	14	15	16	14
Hot carcass weight, kg	378.5	374.6	363.0	345.5	360.4	361.9	354.2	361.0	352.3	335.8	335.7
Carcass maturity[b]											
Skeletal	158.3^{e}	151.7^{e}	249.3^{d}	156.0^{e}	251.3^{d}	151.9^{e}	248.3^{d}	162.9^{e}	245.3^{d}	150.0^{e}	250.0^{d}
Lean	147.3^{f}	149.3^{f}	185.3^{d}	154.0^{f}	172.7^{e}	151.3^{f}	182.5^{de}	154.3^{f}	184.0^{de}	153.1^{f}	183.6^{de}
Marbling score[c]	564.3^{e}	586.7^{d}	563.0^{e}	464.7^{f}	477.3^{f}	436.3^{g}	425.8^{g}	370.0^{h}	374.7^{h}	325.3^{i}	325.7^{i}
PYG	3.5	3.4	3.6	3.5	3.6	3.3	3.6	3.4	3.5	3.2	3.1
Ribeye area, cm^2	83.9	85.2	84.5	80.0	82.6	83.2	80.7	82.6	79.4	81.9	85.2
KPH, %	2.5	2.5	2.5	3.1	3.1	2.9	2.8	2.7	2.8	2.7	2.8

[a]Quality grade categories defined as Certified Angus Beef, Sterling Silver, A maturity; Sterling Silver, B maturity; High Small, A maturity; High Small, B maturity; Low Small, A maturity; Low Small, B maturity; High Select, A maturity; High Select, B maturity; Low Select, A maturity; Low Select, B maturity (CAB, SSA, SSB, HSMA, HSMB, LSMA, LSMB, HSEA, HSEB, LSEA, and LSEB, respectively).

[b]Carcass maturity scores: 100-199 = approximately 9 to 30 months chronological age at time of slaughter; 200-299 = 31 to 47 months chronological age at time of slaughter (USDA, 2001).

[c]Marbling score: Assuming "A" physiological maturity, 300-399 = "Slight", the amount required for U.S. Select; 400-499 = "Small", the amount required for U.S. Low Choice; 500-599 = "Modest", the amount required for U.S. Average Choice (USDA, 2001).

[defghi]Means within a row with different superscripts differ ($P < 0.05$).

Table 2. Chemical analyses and objective color measurements of meat samples stratified by quality grade category.

	Quality grade category[a]											
Traits[b]	CAB	SSA	SSB	HSMA	HSMB	LSMA	LSMB	HSEA	HSEB	LSEA	LSEB	SE[b]
Lipid, %	6.2^{d}	5.5^{e}	5.6^{de}	4.3^{fg}	4.8^{ef}	3.3^{hi}	3.8^{ghi}	3.0^{hi}	3.9^{gh}	2.9^{hi}	3.5^{ghi}	0.23 - 0.36
Moisture, %	71.1^{f}	72.4^{e}	71.3^{g}	71.6^{fg}	71.0^{g}	72.6^{de}	72.3^{ef}	72.9^{de}	72.7^{de}	73.1^{d}	72.7^{de}	0.15 - 0.48
Hydroxyproline, %	0.50^{d}	0.30^{f}	0.36^{e}	0.48^{d}	0.49^{d}	0.48^{d}	0.44^{de}	0.46^{d}	0.45^{d}	0.48^{d}	0.44^{d}	0.01 - 0.04
Total collagen, %	3.46^{d}	2.07^{f}	2.49^{e}	3.36^{d}	3.38^{d}	3.35^{d}	3.03^{de}	3.25^{d}	3.15^{d}	3.38^{d}	3.04^{d}	0.02 - 0.03
Objective color[c]												
L*	36.3^{d}	36.5^{d}	35.3^{e}	35.0^{e}	32.9^{h}	34.9^{ef}	32.8^{h}	33.6^{gh}	34.0^{fg}	34.9^{ef}	33.4^{gh}	0.51 - 1.41
a*	23.3^{f}	24.5^{d}	24.0^{e}	21.1^{i}	22.4^{g}	21.4^{hi}	21.5^{hi}	22.9^{fg}	21.6^{hi}	21.8^{h}	21.8^{hi}	0.17 - 0.93
b*	10.7^{e}	11.1^{d}	10.7^{e}	9.8^{f}	9.7^{f}	9.6^{f}	9.0^{g}	9.9^{f}	9.3^{g}	9.7^{f}	9.3^{g}	0.06 - 0.21

[a]Quality grade categories defined as Certified Angus Beef, Sterling Silver, A maturity; Sterling Silver, B maturity; High Small, A maturity; High Small, B maturity; Low Small, A maturity; Low Small, B maturity; High Select, A maturity; High Select, B maturity; Low Select, A maturity; Low Select, B maturity (CAB, SSA, SSB, HSMA, HSMB, LSMA, LSMB, HSEA, HSEB, LSEA, and LSEB, respectively).

[b]Traits represented as LS means along with ranges for standard error (SE).

[c]Objective color quantified as L* = white to black; a* = red to green; b* = yellow to blue.

[defghi]Means within row with different superscripts differ ($P < 0.05$).

Table 3. Results summarizing *Warner-Bratzler* shear (WBS) differences between quality grade categories compared with Certified Angus Beef after adjusting for a 20% cook loss[a]

	Quality grade categories[b]									
Trait	SSA	SSB	HSMA	HSMB	LSMA	LSMB	HSEA	HSEB	LSEA	LSEB
WBS, kg	3.75[e]	3.86[ef]	3.88[ef]	4.59[fg]	4.15[ef]	4.54[fg]	4.52[ef]	4.42[ef]	4.54[fg]	4.27[ef]
SE	0.20	0.18	0.31	0.33	0.34	0.33	0.36	0.33	0.32	0.32
Difference from CAB[c], kg	0.57	0.46	0.44	-0.27	0.17	- 0.22	-0.20	-0.10	-0.22	0.05
$P > \|t\|$[d]	0.03	0.07	0.22	0.49	0.67	0.56	0.62	0.81	0.55	0.88

[a]Cook loss = (initial steak weight – cooked steak weight) / initial steak weight.

[b]Quality grade categories defined as Sterling Silver, A maturity; Sterling Silver, B maturity; High Small, A maturity; High Small, B maturity; Low Small, A maturity; Low Small, B maturity; High Select, A maturity; High Select, B maturity; Low Select, A maturity; Low Select, B maturity (SSA, SSB, HSMA, HSMB, LSMA, LSMB, HSEA, HSEB, LSEA, and LSEB respectively).

[c]Difference between LS Means for CAB (Certified Angus Beef, 4.32 kg) and specific quality grade category (i.e., CAB – SSA = 4.32-3.75 = 0.57).

[d]Significance level for difference between CAB and specific quality grade category.

[efg]Means within a row with different superscripts differ ($P < 0.05$).
[efg]Means within row with different superscript are significantly different ($P < 0.05$).

Table 4. Results summarizing *Warner-Bratzler* shear (WBS) differences between quality grade categories compared with Certified Angus Beef after adjusting for a 30% cook loss[a]

	Quality grade categories[b]									
Trait	SSA	SSB	HSMA	HSMB	LSMA	LSMB	HSEA	HSEB	LSEA	LSEB
WBS, kg	4.36[e]	4.41[e]	4.55[ef]	5.52[fg]	6.20[g]	5.83[g]	5.21[efg]	5.79[g]	6.23[g]	6.08[g]
SE	0.33	0.34	0.36	0.41	0.44	0.47	0.50	0.47	0.47	0.42
Difference from CAB[c], kg	-0.43	-0.48	-0.62	-1.59	-2.27	-1.90	-1.28	-1.86	-2.30	-2.15
$P > \|t\|$[d]	0.32	0.28	0.17	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01

[a]Cook loss = (initial steak weight – cooked steak weight) / initial steak weight.

[b]Quality grade categories defined as Sterling Silver. A maturity; Sterling Silver, B maturity; High Small, A maturity; High Small, B maturity; Low Small, A maturity; Low Small, B maturity; High Select, A maturity; High Select, B maturity; Low Select, A maturity; Low Select, B maturity (SSA, SSB, HSMA, HSMB. LSMA, LSMB, HSEA, HSEB, LSEA, and LSEB respectively).

[c]Difference between LS Means for CAB (Certified Angus Beef, 4.32 kg) and specific quality grade category (i.e., CAB – SSA = 3.93-4.36 = -0.43).

[d]Significance level for difference between CAB and specific quality grade category.

[efg]Means within a row with different superscript differ ($P < 0.05$).

Table 5. Percentage distribution of steaks within tenderness thresholds stratified by quality grade category after 7 d postmortem aging

	Quality grade category[a]										
Tenderness Threshold	CAB	SSA	SSB	HSMA	HSMB	LSMA	LSMB	HSEA	HSEB	LSEA	LSEB
Less than 3.9 kg, %	40.0	50.0	50.0	40.0	20.0	18.8	25.0	7.1	13.3	12.5	14.3
3.9 to 4.49 kg, %	30.0	26.7	20.0	33.3	13.3	25.0	16.7	21.4	13.3	25.0	14.3
Greater than or equal to 4.5 kg, %	30.0	23.3	30.0	26.7	66.7	56.2	58.3	71.4	73.3	62.5	71.4

[a]Quality grade categories defined as Certified Angus Beef, Sterling Silver, A maturity; Sterling Silver, B maturity; High Small, A maturity; High Small, B maturity; Low Small, A maturity, Low Small, B maturity; High Select, A maturity; High Select, B maturity; Low Select, A maturity; Low Select, B maturity (CAB, SSA, SSB, HSMA, HSMB, LSMA, LSMB, HSEA, HSEB, LSEA, and LSEB, respectively).

Table 6. Percentage distribution of steaks within tenderness thresholds stratified by quality grade category after 14 d postmortem aging

	Quality grade category[a]										
Tenderness Threshold	CAB	SSA	SSB	HSMA	HSMB	LSMA	LSMB	HSEA	HSEB	LSEA	LSEB
Less than 3.9 kg, %	40.0	46.7	40.0	40.0	6.7	12.5	16.7	14.3	6.7	18.8	7.1
3.9 to 4.49 kg, %	23.3	33.3	43.3	20.0	20.0	25.0	16.7	28.6	40.0	18.8	28.6
Greater than or equal to 4.5 kg, %	36.7	20.0	16.7	40.0	73.3	62.5	66.7	57.1	53.3	62.5	64.3

[a]Quality grade categories defined as Certified Angus Beef, Sterling Silver, A maturity; Sterling Silver, B maturity; High Small, A maturity; High Small, B maturity; Low Small, A maturity, Low Small, B maturity; High Select, A maturity; High Select, B maturity; Low Select, A maturity; Low Select, B maturity (CAB, SSA, SSB, HSMA, HSMB, LSMA, LSMB, HSEA, HSEB, LSEA, and LSEB, respectively).

Table 7. Percentage distribution of steaks within tenderness thresholds stratified by quality grade category after 21 d postmortem aging

	Quality grade category[a]										
Tenderness Threshold	CAB	SSA	SSB	HSMA	HSMB	LSMA	LSMB	HSEA	HSEB	LSEA	LSEB
Less than 3.9 kg, %	53.3	66.7	53.3	46.7	20.0	31.3	50.0	21.4	20.0	18.8	14.3
3.9 to 4.49 kg, %	10.0	20.0	10.0	20.0	33.3	12.5	0.0	21.4	40.0	18.8	42.9
Greater than or equal to 4.5 kg, %	36.7	13.3	36.7	33.3	46.7	56.3	50.0	57.1	40.0	62.5	42.8

[a]Quality grade categories defined as Certified Angus Beef, Sterling Silver, A maturity; Sterling Silver, B maturity; High Small, A maturity; High Small, B maturity; Low Small, A maturity, Low Small, B maturity; High Select, A maturity; High Select, B maturity; Low Select, A maturity; Low Select, B maturity (CAB, SSA, SSB, HSMA, HSMB, LSMA, LSMB, HSEA, HSEB, LSEA, and LSEB, respectively).

Table 8. Pearson Correlation Coefficients (r) describing the relationship between WBS and certain carcass traits within aging periods.

	Aging period		
Comparisons[a]	7d	14d	21d
Marbling score	-0.45**	-0.37**	-0.37**
Lean maturity	0.12	0.07	0.07
Skeletal maturity	0.07	0.06	0.08
pH	-0.16*	-0.16*	-0.19**
L*	-0.44**	-0.34**	-0.40**
a*	-0.32**	-0.36**	-0.35**
b*	-0.41**	-0.40**	-0.39**
Lipid, %	-0.28**	-0.18**	-0.22**
Moisture, %	0.23*	0.15*	0.17*
TC, %	0.15*	0.13	0.16*

[a]TC = Total collagen

*$P < 0.05$

**$P < 0.01$

Table 9. Least squares means and pooled standard errors for palatability attributes stratified by quality grade category

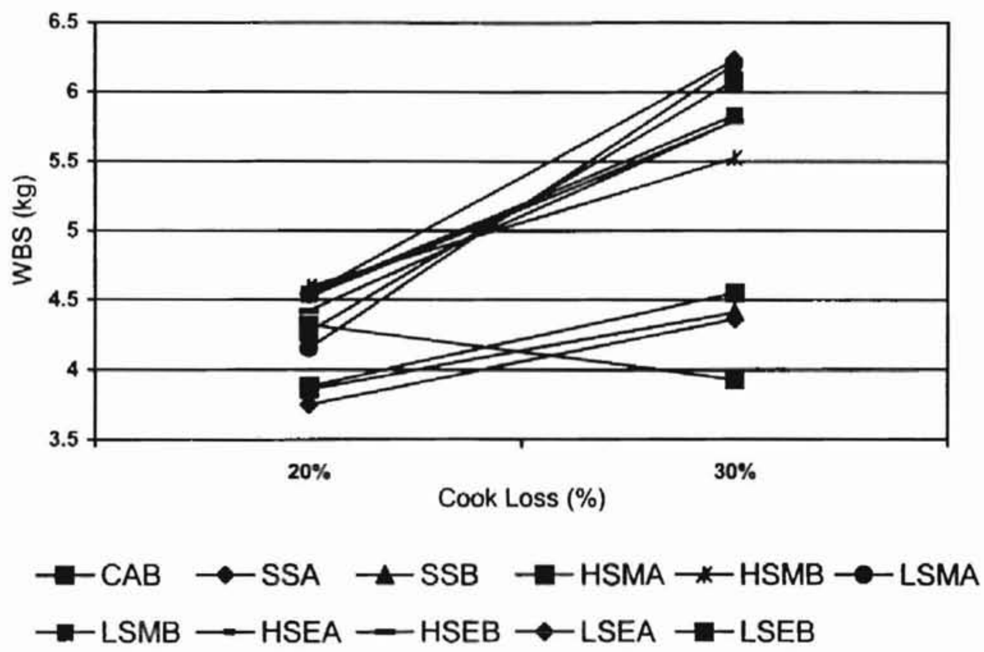
	Quality grade category[a]											
Trait[b]	CAB	SSA	SSB	HSMA	HSMB	LSMA	LSMB	HSEA	HSEB	LSEA	LSEB	SE
Tenderness	6.16^{d}	6.68^{c}	6.32^{cd}	6.14^{de}	5.43^{ef}	5.52^{ef}	5.43^{ef}	5.44^{ef}	5.43^{ef}	5.17^{f}	5.04^{f}	0.26
Juiciness	5.99^{d}	6.69^{c}	6.54^{c}	5.76^{d}	5.68^{d}	5.82^{d}	5.53^{d}	5.61^{d}	5.66^{d}	5.56^{d}	5.68^{d}	0.21
Connective tissue	6.26^{cde}	6.61^{c}	6.32^{cd}	6.33^{cde}	5.66^{f}	5.83^{ef}	5.78^{ef}	5.88^{def}	5.69^{f}	5.61^{f}	5.57^{f}	0.26
Flavor intensity	5.83^{e}	6.21^{c}	6.13^{cd}	5.90^{de}	5.72^{ef}	5.78^{ef}	5.50^{f}	5.63^{ef}	5.80^{ef}	5.63^{ef}	5.62^{ef}	0.16
Beef fat flavor	1.52^{cd}	1.58^{c}	1.58^{c}	1.53^{cd}	1.48^{cd}	1.47^{cd}	1.55^{cd}	1.44^{d}	1.45^{d}	1.43^{d}	1.46^{cd}	0.15
Overall Acceptability	5.59^{de}	6.13^{c}	5.82^{cd}	5.44^{def}	5.04^{efg}	5.01^{fg}	4.92^{fg}	4.87^{fg}	4.99^{fg}	4.63^{g}	4.51^{g}	0.22

[a]Quality grade categories defined as Certified Angus Beef, Sterling Silver, A maturity; Sterling Silver, B maturity; High Small, A maturity; High Small, B maturity; Low Small, A maturity, Low Small, B maturity; High Select, A maturity; High Select, B maturity; Low Select, A maturity; Low Select, B maturity (CAB, SSA, SSB, HSMA, HSMB, LSMA, LSMB, HSEA, HSEB, LSEA, and LSEB, respectively).

[b]Tenderness: 1=extremely tough, 8=extremely tender; Juiciness: 1=extremely dry, 8=extremely juicy; Connective tissue: 1=abundant, 8=none; Flavor intensity: 1=extremely bland, 8=extremely intense; Beef fat flavor: 1=none detectable, 3=very strong; Overall acceptability: 1=extremely undesirable, 7=extremely desirable

[cdefg]Means within a row with different superscripts differ ($P < 0.05$).

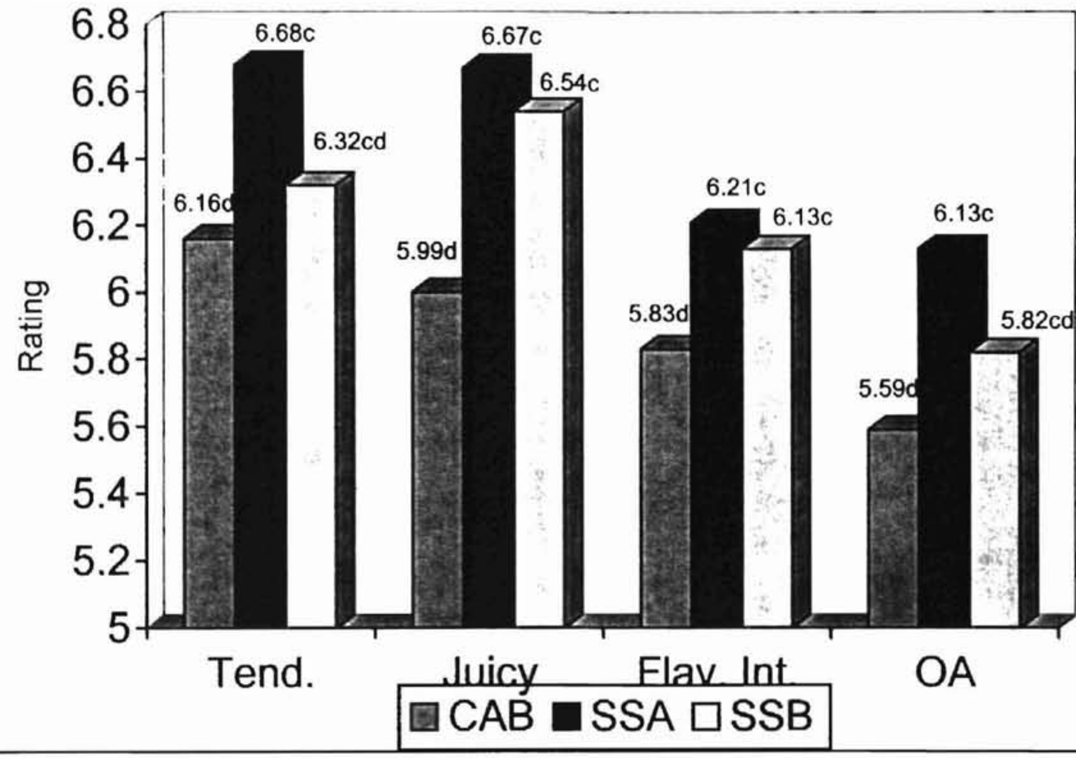
Figure 1. Warner-Bratzler shear (WBS) force (kg) trends for quality grade categories[a] adjusted for cook loss[b] (%)



[a]Quality grade categories defined as Sterling Silver, A maturity; Sterling Silver, B maturity; High Small, A maturity; High Small, B maturity; Low Small, A maturity, Low Small, B maturity; High Select, A maturity; High Select, B maturity; Low Select, A maturity; Low Select, B maturity (SSA, SSB, HSMA, HSMB, LSMA, LSMB, HSEA, HSEB, LSEA, and LSEB, respectively).

[b]Cook loss = (initial steak weight – cooked steak weight) / initial steak weight.

Figure 2. Palatability differences[a] between Certified Angus Beef[b] and Sterling Silver[b] branded beef programs



[a] Tenderness: 1=extremely tough, 8=extremely tender; Juiciness: 1=extremely dry, 8=extremely juicy; Flavor intensity: 1=extremely bland, 8=extremely intense; Overall acceptability: 1=extremely undesirable, 7=extremely desirable

[b] Quality grade categories defined as Certified Angus Beef (CAB), Sterling Silver, A maturity (SSA); Sterling Silver, B maturity (SSB).

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APPENDIX

APPENDIX A

COMPARISON OF CERTIFIED ANGUS BEEF AND STERLING SILVER BRANDED BEEF PROGRAM CRITERION

	Program	
Characteristic	Certified Angus Beef	Sterling Silver
GLA-phenotype	51% black	no req.
GLA-genotype	no specification	no specification
U.S. Prime	yes	yes
U.S. Choice	yes	yes
U.S. Select	no	no
Marbling requirements	Modest^{00} or higher	Modest^{00} or higher
Medium or fine marbling texture	yes	yes
Overall maturity[a]	"A" maturity	"A" or "B" maturity
Yield grade	3.9[b] or lower	no req.
Fat thickness (inches)	no specification	no specification
Ribeye (square inches)	no specification	no specification
Muscling[c]	yes	yes
Hot carcass weight (pounds)	no specification	no specification
No ribeye internal hemorrhages	yes	yes
Free of dark cutters	yes	yes
Hump height (inches)	2	2
Steer and heifer carcasses	yes	yes
Schedule number	G1	G2
Initial release date	1978	July, 1998
Effective date	May, 1994	May, 1999
USDA certified	yes	yes
USDA Process Verified	no	no

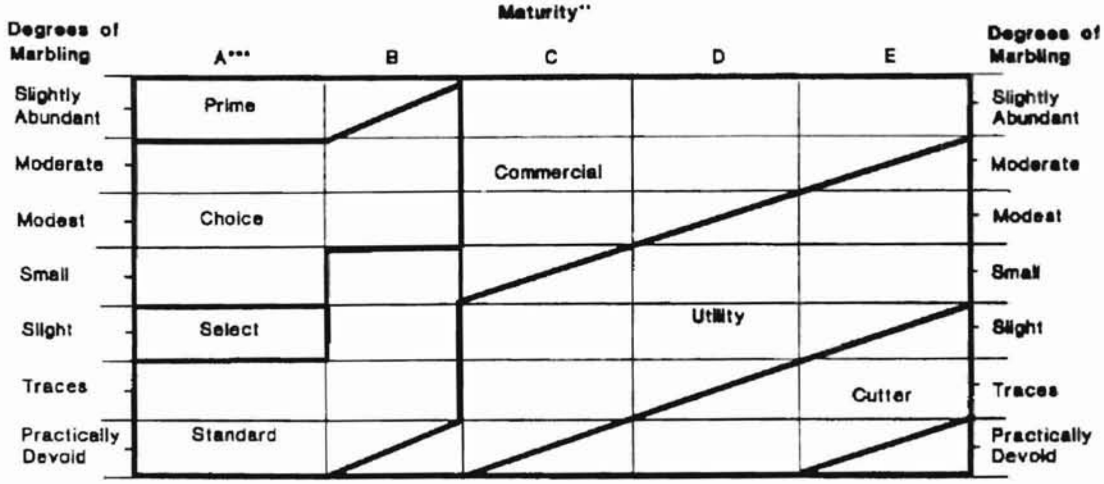
[a]Lean color, texture, firmness and overall skeletal characteristics, each must meet the requirements for the designated maturity, or younger

[b]Yield grade of 3.9 or lower, except carcasses evaluated after removal of KPH fat may not have a yield grade above 3.5

[c]Moderately thick or thicker muscling and tend to be moderately wide and thick in relation to their length

APPENDIX B

RELATIONSHIP OF USDA MARBLING, MATURITY AND CARCASS QUALITY GRADE*



* Assumes firmness of lean is comparably developed with the degree of marbling and that the carcass is not a "dark cutter"

** Marbling increases from left to right

*** "A" maturity portion of the figure is the only portion applicable to bullock carcasses

Adapted from USDA, 2001

VITA

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Candidate for the Degree of

Master of Science

Thesis: USDA MARBLING AND CARCASS PHYSIOLOGICAL MATURITY RELATED DIFFERENCES FOR BEEF TENDERNESS AND PALATABILITY CHARACTERISTICS

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