THESIS

EFFECTS OF USDA CARCASS MATURITY ON EATING QUALITY OF BEEF FROM FED STEERS AND HEIFERS THAT HAVE BEEN CLASSIFIED INTO MATURITY GROUPS USING DENTITION

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ABSTRACT

EFFECTS OF USDA CARCASS MATURITY ON EATING QUALITY OF BEEF FROM FED STEERS AND HEIFERS THAT HAVE BEEN CLASSIFIED INTO MATURITY GROUPS USING DENTITION

Objectives were to compare sensory properties of LM steaks from A maturity and B maturity or older carcasses that were produced by grain finished steers and heifers classified as less than and greater than 30 months of age at the time of slaughter by dentition. Carcasses were selected to represent 2 dentition groups, 2 maturity groups, and 3 marbling categories within each dentition x maturity group resulting in 12 dentition x maturity x marbling subclasses; each subclass consisting of 50 carcasses. Dental age groups consisted of carcasses classified as less than or 30 months of age (MOA) or 30 MOA or older by dentition. Maturity groups consisted of carcasses classified by USDA graders as either A^{00} to A^{99} overall (A) maturity or B^{00} to D^{99} overall (B-D) maturity; marbling categories consisted of carcasses with instrument marbling scores of Slight (SL), Small (SM), or Modest ^{00} to Moderate^{99} (MT-MD). Carcasses were selected in pairs so that each carcass selected to represent the B-D maturity group was paired with an A maturity carcass of the same sex and similar marbling score (± 50 marbling units.) Strip loin (LM) steaks were obtained from both sides of each carcass. After a 14-d aging period, 1 LM steak was evaluated for Warner–Bratzler shear force (WBSF) and slice shear force (SSF). The other LM steak was used for sensory analysis by a trained descriptive attribute panel. No differences ($P > 0.05$) were detected in WBSF, SSF, or sensory panel ratings for tenderness juiciness, or flavor between LM steaks from carcasses classified as A maturity vs. steaks of carcasses classified from B-D maturity.

Sex class influenced ($P < 0.05$) WBSF and sensory panel tenderness. As degree of marbling increased, sensory tenderness, juiciness, meaty/brothy flavor, and buttery/beef fat flavor increased ($P < 0.05$) while bloody/serumy flavor, WBSF and SSF decreased ($P < 0.05$). There was a significant interaction between dental age group and marbling category for SSF and panel tenderness ratings, where cattle classified as 30 MOA or older with a slight degree of marbling produced the toughest ($P < 0.05$) LM steaks. Within the SM and MT-MD marbling categories dental age had no effect. Results from this study suggest that USDA quality grades could be effective at determining eating quality differences to grain-finished cattle with a dental age less than 30 mo old at the time of slaughter if the A and B-D maturity groups were combined and quality grades were assigned only by marbling. In grain-finished cattle 30 mo or older at the time of slaughter the evidence was not sufficient to make conclusions.

Key words: beef, carcass, grading, dentition, maturity, quality.

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CHAPTER I

REVIEW OF LITERATURE

Overview US Beef Production Systems

Conventional cattle-production systems in the United States provide consumers with a supply of high-quality, grain-fed beef year-round. Grain-fed beef is preferred by mainstream U. S. beef markets domestically and internationally. Typically, heifer and steer calves are raised with the dams until between 5 to 8 months, of age at which point they are weaned (Tatum, 2011). Some calves immediately after weaning are placed in a feedlot to be grain-finished as calves ("Calf-fed"). Others are grown on a forage based diet until 12 to 18 months of age and then placed in feedlots as "yearlings" or "long-yearlings," respectively. Most beef cattle in the United States are harvested between 12 and 24 months of age. Typically calf-feds are harvested at 12 to 16 months of age, whereas yearlings or long-yearlings are harvested later between 16 and 24 months of age (Tatum, 2011). While pork and poultry industries are vertically integrated, the beef industry is fairly segmented into cow-calf producers, feeders/stockers, processors and retailers.

Development of United States Grading Standards for Beef

The United States Standards for Grades of Carcass Beef (USDA, 1997) are utilized to categorize carcass beef based on carcass characteristics and aid in the marketing of beef. Tentative Standards for the Grades of Beef were established in 1916. In 1925, public hearings allowing industry members to make suggestions to improve the grade standards were held in Portland, OR, Chicago, IL, and New York, NY. The suggestions put forth by the producers, processers, retailers, wholesalers and those in academic settings were used to revise and improve the standards. On June 3rd, 1926, the Secretary of Agriculture published The United States

Standards for the Grades of Carcass Beef. When voluntary grading and stamping began in May 1927, these standards provided the backbone for this service. Since 1926, the grade standards have been amended 12 times to reflect changes desired by the members of the industry. In 1997, the most recent amendment was made restricting the Select grade to A maturity carcasses only and raising the degree of marbling required for B maturity carcasses to grade Choice. The goal of this amendment was to increase the uniformity and consistency within the Choice and Select grades by requiring the B maturity carcasses to have at least a modest degree of marbling to grade U.S. Choice. Therefore, B maturity carcasses not meeting this marbling requirement would be graded U. S. Standard or no-roll and receive a price discount when marketed.

Grades of beef carcasses are set forth to determine two separate concerns: the predicted yield of closely trimmed, boneless retail cuts and the palatability of the lean (USDA, 1997). Official USDA Yield Grades (**YG**) and Quality Grades (**QG**) are applied to beef carcasses to reflect the indicated yield of closely trimmed, boneless retail cuts (YG) and the palatability of the lean (QG) respectively. Employees of the United States Department of Agriculture, commonly termed USDA graders, determine and apply both YG and QG standards to beef carcasses. Application of grade standards is a voluntary fee-for-use service paid for by the packer.

Numerical yield grades (1-5) are applicable to all classes of beef. YG 1 represents the highest percent of boneless closely trimmed retail cuts from the carcass and YG 5 represents the lowest percent of boneless closely trimmed retail cuts from the carcass, thus a lower numerical yield grade is more desirable. A yield grade of 1 refers to an expected yield of >52.3% closely trimmed, boneless retail cuts, whereas, yield grade 5 corresponds to an expected yield of <45.4% closely trimmed, boneless retail cuts (Tatum, 2007). Yield grade is determined by evaluating fat thickness over the ribeye, ribeye area, hot carcass weight, and percentage of kidney, pelvic and heart fat. Fat thickness is measured over the ribeye at a point three-fourths of the distance of the length of the ribeye from the chine bone side and then adjusted by USDA grader either up or down depending on differences in external fat in other areas of the carcass. To calculate a yield grade, the relationship between ribeye area and carcass weight is utilized. Ribeye area can be measured via instrument grading or with a plastic grid. Percentage of kidney, pelvic and heart fat is estimated as the percentage of carcass weight present in fat deposits around the kidney and heart and in the pelvic cavity. Carcasses typically have from 1 to 4% of the carcass weight present as kidney, pelvic and heart fat (Tatum, 2007).

Official QG is determined by the following criteria: sex classification, lean and skeletal maturity, marbling score, and lean firmness in the *Longissimus dorsi* (**LM**) at the 12^{th} -13^{th} rib interface. Quality grades are applied based upon classification 1) steer, heifer or cow beef and 2) bullock beef. Carcasses from steers and heifers are eligible for 8 quality grade designations: Prime, Choice, Select, Standard, Commercial, Utility, Cutter and Canner. With the exception of the Prime, grade carcasses from cow beef are eligible for the same grade distinctions as steers and heifers (USDA, 1997). The marbling score determination is based on the percentage of intramuscular fat (marbling) in the LM.

Physiological maturity of a beef carcass is determined by assessing the shape, size, and ossification of the rib bones and cartilages, as well as the color and texture of lean (USDA, 1997). Ossification of vertebral cartilage generally begins at the posterior section of the vertebral column and as the animal ages the ossification continues anteriorly. The amount of ossification in cartilaginous buttons of the thoracic vertebrae at the posterior end of the forequarter where the carcass is broken for grading is referenced when beef carcasses are presented for grading. Size and shape of the rib bones are also crucial indicators for determining differences in maturity. As a beef animal progressively ages, the color of the lean as well as the lean texture go through changes, the lean gradually becomes coarser in texture and darker red in color. Overall maturity is determined from both lean and skeletal maturity. If a difference exists between lean and skeletal maturity, more emphasis is placed on skeletal maturity so that the overall maturity cannot be more than one full maturity group different than the skeletal maturity.

Overall maturity consists of five groups: A, B, C, D, and E, where A maturity is the considered the youngest and E maturity is considered the oldest or most mature. A maturity carcasses have distinct separation of the sacral vertebrae, no presence of ossification in the lumbar and thoracic vertebrae, slightly flat rib bones, very red, soft chine bones, light grayish-red lean color and very fine textured lean. B maturity carcasses have the sacral vertebrae completely fused, and the lumbar vertebrae nearly completely fused, the thoracic vertebrae have some evidence of ossification, slightly soft and slightly red chine bones, the rib bones are slightly wide and slightly flat, and the LM is light red to slightly dark red in color with a fine lean texture. Carcasses with advanced maturity classified as C maturity have the sacral and lumbar vertebrae completely ossified, the thoracic vertebrae are partially ossified, with the outline of the cartilage still visible, the rib bones are moderately flat and wide, the chine bones are tinged with red and the LM is slightly dark red to moderately dark red in color and slightly coarse in texture. The most mature carcasses are classified as E maturity which is described as completely fused sacral vertebrae, completely ossified lumbar with the outline of the cartilage on the end of the thoracic vertebrae are barely visible, the chine bones are hard and white, the rib bones are wide and flat, LD lean color is very dark and coarse textured.

Within the current standards for determining quality grades, as the overall maturity increases the amount of marbling necessary to maintain the same quality grade increases. A maturity and the Choice grade within B maturity are the only two exceptions to this rule where the amount of marbling required does not increase with an increase in maturity (USDA, 1997). Carcasses classified as A maturity are eligible for the USDA Prime, USDA Choice, USDA Select, USDA Standard and USDA Utility quality grade categories. Carcasses classified as B maturity are eligible for the following quality grade categories: USDA Prime, USDA Choice, USDA Standard and USDA Utility. C maturity and older carcasses are eligible to be graded USDA Commercial, USDA Utility, USDA Cutter, and USDA Canner.

USDA quality grade is a prediction of expected eating quality. It is a used as a tool to market beef products to consumers. When consumers are making purchasing decisions, quality grade can help them select a product appropriate for the eating experience they are striving to achieve. However, one study determined that consumers may be confused by USDA quality grades. De Vuyst et al. (2014) completed a study to determine United States consumers' understanding of USDA quality grades of beef. In this study of over 1,000 consumers the sample population was designed to match the actual population of the United States in terms of demographics including gender, education, age and region in which participants resided. Only 14.4% of participants correctly ranked the USDA quality grades Prime, Choice, and Select in terms of leanness and while 57.1% of survey participants ranked Prime as the leanest, 55.6% of surveyed participants also ranked USDA Prime as the juiciest among Prime, Choice, and Select (DeVuyst et al., 2014). Furthermore, when asked to match a picture with expected price, over half (54.8% of the respondents matched the picture of the Prime steak with the lowest price (DeVuyst et al., 2014). This study indicated that consumers who consume more steak were more likely to provide correct answers and that they may have a better understanding of the application of USDA quality Grades. However, results of this study also indicated that most consumers do not understand USDA quality grades nomenclature and suggest the need for more education of consumers in a retail setting to assist them in gaining an understanding of the beef they are purchasing (DeVuyst et al., 2014).

Assessing Beef Tenderness

Warner-Bratzler shear force is one accepted method for determining tenderness in meat. The basic theory and original design was developed in 1928 by K.F. Warner. Originally the device was made of wood, and had a thin steel blade with a circular hole in the center where the round core was placed. The blade would slide through the wooden box and push the sample against the blade. In 1932 a graduate student at Kansas State University by the name of L. J. Bratzler made modifications to the original device. These modifications led to the device that is utilized currently. With Bratzler's contributions that method was named Warner-Bratzler shear force. Bratzler standardized the blade thickness at 0.04 inches thick and replaced the circular hole with a triangular shaped opening with rounded points. The wooden box was replaced with a steel apparatus that allowed the blade to pass through with 0.005 inches of clearance. The core diameter was standardized at 1.27 cm. The speed for the blade was also established at nine inches per minute (200 mm/min) (McKenna, 2014).

Development of slice shear force arose from the desire to develop a more rapid, direct method of determining tenderness testing. The time required to chill steaks for use in Warner-Bratzler shear force was too long to be used in a production setting. The actual development of slice shear force was formed from a failed attempt to develop an automated system to excise six Warner-Bratzler shear cores from a hot steak and the realization that it would be much easier to remove a single rectangular slice from a steak (Wheeler and Shackleford, 2009). The orientation of the slice removed from the steak needed to be parallel to the muscle fibers, so that when sheared, the blade would move perpendicular or across the muscle fibers. To match the orientation of the muscle fibers the slice needed to be removed at a 45° angle. The size of the slice was developed as 1-cm thick and 5-cm wide which should be obtained from the center of the steak (Wheeler and Shackleford, 2009). The slice is sheared perpendicular to the muscle fibers by a blunt blade at a speed of 500 mm/min.

Lorenzen et al. (2010) described a feasible method for combining both methods on the same steak. Correlations between WBSF and SSF were highly significant when shear force measurements obtained from the same steak, but depending on steak location within the top loin, the magnitude of the relationship between WBSF and SSF varied (Lorenzen et al., 2010). Furthermore, Lorenzen et al. (2010) determined the strongest relationship between the 2 measurements in steaks removed 2.54 cm from the 13^{th} rib when combining Warner-Bratzler and slice shear force measurements into one steak. Warner-Bratzler shear values cannot be compared among institutions. Wheeler et al. (1997) compared across institution implementation of Warner-Bratzler within and among institutions. Warner-Bratzler shear values differed ($P < 0.05$) both within and among institutions. Results from this study suggest that comparisons of Warner-Bratzler shear values among institutions are not valid. The study suggested that differences may have been caused by execution of protocol (despite training) and instrument variation due to improper calibration (Wheeler et al., 1997).

The American Society for Testing and Materials (ASTM) in designation F2925 established "Standard Specification for Tenderness Marketing Claims Associated with Meat Cuts Derived from Beef" in 2011 (ASTM, 2011). This standard was created to distinguish and add value to beef cuts in the marketplace This standard established a minimum tenderness threshold value (MTTV) for the two common methods of testing beef tenderness, slice shear force and

Warner-Bratzler shear force. The standard has established a “Certified Tender” claim as well as “Certified Very Tender.” To qualify for “Certified Tender,” beef cuts must meet MTTV of 4.4 kg for Warner-Bratzler shear force and 20.0 kg for slice shear force. To qualify for “Certified Very Tender” beef cuts must better than the MTTV for Warner Bratzler shear force by at least 0.5 kg and better than the MTTV for slice shear force by at least 4.6 kg. This marketing claim can be used by any party aiming to distinguish their product in the marketplace.

Chronological Age and Physiological Maturity

Many cow-calf producers keep accurate individual birth records for each year’s calf crop (Tatum, 2011). However, cattle are often transferred from producer to packer without documentation of actual animal ages (USDA, 2005). In these cases, carcass indicators of physiological maturity are utilized to assign USDA quality grades to try to reflect maturiy related differences. Smith and Judge (1991) showed that increased USDA physiological maturity associated with increased concentration of mature crosslinks and increased thermal stability of intramuscular collagen resulted in decreased beef tenderness (Smith et al., 1982; Smith et al., 1988; Hilton et al., 1998).

The relationship between chronological age and physiological maturity has not been well documented in previous studies. Approximate chronological ages corresponding to the physiological maturity groups are: A- 9 to 30 months, B- 30 to 42 months, C- 42-72 months, D- 72 to 96 months, and E- over 96 months (USDA, 1997). It is certain that as an animal ages, cartilage ossification occurs yielding characteristics of advanced skeletal maturity in carcasses from older animals. The UDSA Maturity Classifications (USDA, 1997) were established based on the expected skeletal maturity that an animal should exhibit over a range of chronological ages as it becomes older. The majority of grain finished steers and heifers under 30 months of age typically produce carcasses that are classified as A maturity; however, 3 to 14 % of these grain finished steers and heifers will produce carcasses will be classified as B maturity or older (Tatum, 2011).

Data originally published by O'Connor et al. (2007) were reanalyzed by Tatum (2011) in order to quantify the relationship between chronological age and USDA carcass maturity. In the study by O'Connor et al. (2007), 96.7% of the grain-finished cattle 12 to 24 months of age were classified as A maturity. When the animals age was increased to 18 months or older, the probability of producing a B maturity carcass increased as well to about 1 out of 100 (Tatum, 2011). For cattle that were 22 to 24 months old, the probability of producing a carcass that was either B or C maturity was 9.1 % and 3.1 %, respectively. These data suggest that chronological age is not the only factor that influences skeletal maturity.

Both endogenous and exogenous estrogens cause some carcasses to exhibit advanced skeletal maturity characteristics that are more advanced than the animal's chronological age would imply (Tatum, 2011). Estrogen is an activator of advanced skeletal ossification in females compared to male counterparts (Field et al., 1996). With just a natural level of estrogen, heifers will normally have increased cartilage ossification at a younger age. It has been well determined that increased estrogen promotes increased skeletal ossification (Grumbach and Auchus, 1999). Furthermore, Grumbach and Auchus (1999), reported that adolescent females of various mammalian species demonstrated more advanced skeletal maturity when compared to male contemporaries of the same age. Since heifers have an increased level of endogenous estrogen, there is an increased likelihood that carcasses produced by heifers will be classified as B maturity or older when compared to carcasses produced from steers of the same chronological age (Tatum, 2011). Furthermore, intact heifers had a higher skeletal maturity score than steers and ovariectomized heifers of the same age (Klindt and Crouse, 1990). Tatum (2011) reported skeletal maturity progressing at a much faster rate in heifers than steers when skeletal maturity data were analyzed comparing heifers (n = 3,095) and steers (n = 3,671) ranging from 16 to 27 months of age. This led to heifers with actual ages of 16 to 27 months being roughly 7 times more likely to produce a carcass that would be classified as B maturity and 11 times more likely to produce a carcass that would be classified as C maturity. This trend rapidly increased in heifers harvested at older than 20 months of age.

There is a profound increase in estrogen levels during pregnancy (Smith et al., 1973; Hoffman et al., 1976). When heifers are placed in the feedlot as yearlings or long yearlings is is not uncommon for some to be pregnant at the time of slaughter. From as low as 4 % to 17 % of feedlot heifers are pregnant at the time of slaughter (Laudert, 1988; Kreikemeier and Unruh, 1993; McKenna et al., 2002). Carcasses of pregnant heifers were determined to have more advanced skeletal maturity than carcasses produced by non-pregnant heifers (Kreikemeier and Unruh, 1993). Kreikemeier and Unruh (1993) reported the frequency of producing a B maturity or older carcass was 7.5 % in pregnant heifers harvested in the last trimester compared with 3.5 % in non-pregnant heifers. Waggoner et al. (1990) reported that heiferettes had more advanced skeletal maturity than non-calved heifers of the same age. Additionally, Field et al. (1996) found significant differences in skeletal maturity of spayed, virgin, or once-calved heifers ranging from 31 to 35 months of age. In this study (Field et al., 1996) only 5.6% of the ovariectomized heifers produced carcasses that were classified as B maturity or older, whereas the percentages were much higher for the other two treatment groups. In the same study, over one third (37.5%) of the virgin heifers produced a carcass that was classified as B maturity or older and over three-fourths (77.5%) of the once-calved heifers produced a carcass that was classified as B maturity or older

(Field et al., 1996). Numerous studies have confirmed that pregnancy increased skeletal maturity scores beyond the rate of chronological age (Bond et al., 1986; Waggoner et al., 1990; Field et al., 1996).

Skeletal maturity traits are impacted by the use of exogenous hormones. Estrogenic implants include active ingredients: estradiol 17-β, estradiol benzoate, or zeranol. Androgenic implants active ingredient is trenbolone acetate. An anabolic implant is one that contains an estrogen, androgen or a combination of an estrogen and an androgen. Tatum (2006) reported that over 97% of feedlot cattle receive some type of anabolic implant at least once during their lifetime. Increased exogenous estrogen similar to increased endogenous estrogen has been shown to increase skeletal maturity (Apple et al., 1991; Paisley et al., 1999; Roeber et al., 2000; Reiling and Johnson, 2003).

Overall and skeletal maturity of carcasses increased in Holstein steers implanted with estradiol compared to steers of the same chronological age implanted with trenbolone acetate (Apple et al., 1991). Moreover, Paisley et al. (1999) reported increased skeletal maturity in carcasses from steers implanted with estradiol. Many additional researchers have determined that implanting steers or heifers with an implant containing estradiol will lead to carcasses with more advanced skeletal maturity characteristics (Turner et al., 1981; Foutz et al., 1997; Paisley et al., 1999; Roeber et al., 2000; Reiling and Johnson, 2003). When cattle increase in age and are administered repetitive implants, over their lifetime, there seems to be an additive effect on increasing skeletal ossification (Platter et al., 2003; Scheffler et al., 2003). Turner et al. (1981) reported that the extent to which implanting increased skeletal maturity is determined by the dose of estrogen delivered by the specific implant. Furthermore, Scheffler et al. (2003) found that the number of estrogen-containing implants that the animal received before harvest also affected skeletal maturity. Platter et al. (2003) determined that administering estrogen-containing implants sequentially over an animal's lifetime promotes increased skeletal maturity. These data together suggest that exogenous estrogen may lead to increased skeletal maturity.

It is estimated that nearly 90% of the cattle harvested in the United States are under 20 months of age (O'Connor et al., 2007) which limits the impact of implants on skeletal maturity in the fed beef population. As animal age increases past 20 months, the successive use of implants causes a higher rate in skeletal maturity, and in turn, an increased number of carcasses being classified as B maturity or older. Tatum (2011) reported that implanted cattle ranging from 16 to 27 months of age, within sex class, were more than 3 times as likely to produce a carcass that would be classified as B-maturity and twice as likely to produce a carcass that would be classified as C-maturity or older than cattle that did not receive an implant. As cattle become older, and especially older than 21 months, implants have a larger impact on skeletal maturity (Tatum, 2011). In cattle harvested at 21 to 27 months of age, implanting greatly increased the risk of an animal producing a B-maturity carcass especially if the animal happened to be a heifer (Tatum, 2011).

Additional sources of exogenous estrogen are naturally produced by forage plants, and by fungi that live on forage plants and cereal grains. Estrogens produced by fungi are called mycoestrogens and are typically associated most with stored grain products, whereas estrogens produced by plants are called phytoestrogens. Several species of *Fusarium* produce a mycoestrogen zeralenone (Caldwell et al., 1970), which commercially is reduced into zeranol, a non-steroidal estrogen found in the product Ralgro. In one study zeranol was detected in untreated pasture fed cattle at a level comparable to cattle that were given a treatment of a zeranol-containing Ralgro implant (Erasmuson, et al., 1994). This suggests that some of the premature skeletal ossification in cattle may be explained if the cattle have been fed feeds that have been infected with *Fusarium* molds. Adams (1995) reported common forage legumes such as alfalfa and some clovers contain phytoestrogens that are able to bind to the estrogen receptor and mimic the effects of estradiol. Therefore, it is a possibility that these naturally occurring estrogens can bind to the estrogen receptor and act in a similar fashion to endogenous estrogen. Furthermore, they can limit the production of natural estrogen and over time reduce the total amount of estrogen and limit reproduction. Galey et al. (1993) found that, forage based diets containing phytoestrogens were associated with hyperestrogenism in female cattle and sheep. Additionally, it is certainly a possibility that ingestion of these naturally occurring estrogens could result in carcasses with advanced skeletal maturity characteristics. However, Tatum (2011) reported a review of literature indicating no published reports linking premature advanced skeletal maturity traits to the ingestion of naturally occcuring mycoestrogens or phytoestrogens.

Collagen Development and Impact on Meat Tenderness

Collagen formed from fibroblasts and myocytes provides structural support system for the cellular components of muscle (McCormick, 1994). Procollagen is formed through transcription and translation and later undergoes further modification into tropocollagen. A single collagen helix is formed from three alpha-strands of tropocollagen intertwining into a helical formation. The degree of covalent crosslinking significantly impacts the stability of collagen especially the thermal stability where an increased degree of covalent crosslinking leads to an increased solubility of collagen within muscle. Beef from young animals contains immature, intramuscular collagen, which has a higher proportion of reducible, heat-liable crosslinks. When properly cooked, the crosslinks gelatinize and the negative effect of collagen on meat tenderness will be reduced. With an increase in an animal’s age, non-reducible, heat stabile crosslinks form. A higher concentration of heat-stabile crosslinks contributes to increased toughness in meat that is produced from more mature animals compared to meat produced from younger animals (Goll et al., 1963; Zinn et al., 1970; Bailey 1985; MCcormick 1994, 1999; and Pruslow, 2005). The amount of soluble collagen decreases as an animal increases in physiological age (Cross et al., 1973) which explains the decrease in tenderness in beef from more mature animals. With advancing physiological maturity, there can be a significant decrease in overall eating quality.

Tenderness in meat is affected by many factors; however, the two most influential factors are 1) the nature and state of the contractile protein and 2) the content and properties of the connective tissue (Dutson, 1974). Animal age impacts crosslinking and content of connective tissue (MCclain, 1977). Regardless of age, the diet of an animal may have the greatest impact on crosslinking. Moody (1976) determined that cattle fed high energy diets for greater than 28 days before slaughter generally experience growth and protein turnover. Milward and Waterlow (1978) reported that in times of rapid growth, protein synthesis is increased and new collagen is formed. This new collagen will contain less heat-stable crosslinks, leading to an increase in tenderness of the meat (Hill, 1966) and an increase in the solubility of collagen (McClain, 1977). Many studies have shown that improved beef tenderness can be achieved in cattle fed a high energy diet for a short period of time prior to harvest (Zinn et al., 1970; Campion et al., 1975; Koch et al., 1976).

Studies of cattle of varying ages and on longer periods of feeding have been completed. Cows fed a high energy diet for at least 56 days before harvest had improved sensory tenderness scores, increased soluble collagen content, and a similar amounts of total collagen and similar Warner-Bratzler shear force values than did cattle not fed a high energy diet (Schnell et al., 1997). Miller et al. (1987), in a study comparing a low energy diet to a high energy diet in 10-year-old cows reported total collagen remained the same regardless of diet however, there was an increased percentage of soluble collagen, and improved Warner-Bratzler shear force values and sensory tenderness scores. Similarly, Cranwell et al. (1996) determined that carcasses from cows fed a high energy diet for 28 days compared to carcasses from cows not fed a high energy diet had similar total collagen and increased heat soluble collagen content. As newly synthesized collagen is produced in proportion to total lean synthesis, it is logical that total collagen should remain constant between age groups (Cranwell et al., 1996).

Similar research studies comparing low and high energy diets have been conducted to determine differences in more youthful carcasses. One such study by Fishell et al. (1985) reported that steers fed a high energy diet produced steaks with lower Warner-Bratzler values, improved sensory tenderness values, and increased amount of soluble collagen. In a study comparing palatability of steaks from steers fed with a low energy diet or a high energy diet, steers fed a low energy diet produced steaks that had increased Warner-Bratzler shear force values, decreased sensory tenderness, juiciness and flavor scores and decreased collagen solubility (Aberle et al., 1981). However, in a study conducted by Wu et al. (1981), intramuscular collagen content was similar for cattle fed a high energy diet and low energy diet. These studies do not support the grading concept that utilizing skeletal maturity characteristics to reflect differences in intramuscular collagen and associated differences in tenderness when grading grain-finished cattle.

Marbling and Meat Palatability

As degree of marbling is increased it is generally accepted that eating quality, defined as tenderness, flavor, and juiciness is increased. Emerson et al. (2013) reported decreased WBSF values as marbling increased from Traces (TR) to Moderately Abundant (MAB). Furthermore, Hiner (1956) and McBee and Wiles (1967) reported that flavor improved in a linear relationship with increased marbling. Smith et al. (1984) and Emerson et al (2013) reported an improved eating experience as overall sensory panel ratings increased. Furthermore, Acheson et al. (2014) reported increased tenderness, juiciness meaty/brothy flavor intensity and butteryy/beef fat flavor with an increased degree of marbling.

Dentition and Meat Tenderness

Carcasses are sorted based on dental age for the purpose of reducing risk of exposure to specified risk materials by determining which specified risk materials need to be removed. Carcasses are sorted into two groups: 1) from an animal classified as less than 30 months of age or 2) from an animal classified as greater than 30 months of age. An animal is considered to be 30 months of age or older with the eruption of the third permanent incisor. Carcasses from cattle that are determined to be 30 MOA or older are fabricated separately from carcasses from cattle that are determined to be less than 30 MOA in commercial fed beef plants. Typically the vertebral column on carcasses from cattle that are determined to be 30 MOA or older by dentition are stained purple or blue with ink and in some plants stamped with the symbol “30+” to easily identify them in the commercial beef plant and allow them to be separated for both grading and fabrication Identifying carcasses as less than 30 MOA or 30 MOA or older became mandatory in 2004, when specified risk materials from carcasses produced from cattle 30 MOA or older were prohibited from human consumption. Specified risk materials including the tonsils, and distal ileum of the small intestine of all cattle are considered inedible for human consumption, in addition, for cattle 30 MOA or older the brain, skull, eyes, trigeminal ganglia, spinal cord, vertebral column, and dorsal root ganglia must also be removed (FSIS, 2004). These specified risk materials could contain infective agents called prions that cause bovine spongiform encephalopathy (BSE). Classification of cattle as less than or greater than 30 months of age must be done by documentation of actual age or by dentition.

Therefore an additional objective method for estimating bovine age or maturity is by dental age (Graham and Price, 1982). Estimating an animal's age for beef grading systems in Australia and South Africa is completed utilizing dentition in place of skeletal ossification (Strydom, 2011). However, dentition is not currently used for grading of beef carcasses in the United States. Raines et al. (2008) reported that dental age is more closely related to chronological age than USDA physiological maturity. Strydom (2011) determined that differences in dentition may not be consistently related to the variation found in beef tenderness. Schönfeldt and Stydom (2011) compared 16 muscles from cattle representing three dental maturity groups: A- no permanent incisors, B- two, four or six permanent incisors, and C- eight permanent incisors to determine tenderness characteristics. While, in this study, increased dental maturity was related to decreased panel ratings for tenderness and reductions in collagen solubility in all 16 muscles, there was not always a statistical difference between adjacent maturity groups (A vs. B and B vs. C). Lawrence et al. (2001) studied the relationship of *Longissimus* tenderness and dental maturity in 200 commercially fed cattle with zero, two, four, six, or eight permanent incisors harvested in a large U.S. beef plant. This study determined that there was no relationship between dental age and sensory panel tenderness or Warner-Bratzler shear force (Lawrence et al., 2001). Shorthose and Harris (1990) reported an association of decreased beef tenderness with an increased number of permanent incisors (zero to seven). Conversely, Wythes and Shorthose (1991) saw no differences in tenderness (peak shear force) among cows with two, four, six, or eight permanent incisors or among steers with four, six or eight permanent incisors.

United States Grading Standards of Carcass Beef (USDA, 1997) are utilized to apply grades to carcass beef cattle and to explain the differences in tenderness as a result of increased chronological age. Several studies have established negative effects of increased physiological maturity when comparing youthful (A and B maturity) carcasses with carcasses that had more advanced skeletal maturity (D or E maturity) traits (Romans et al., 1965; Walter et al., 1965; Breidenstein et al., 1968; Berry et al., 1974). Many research studies have suggested that USDA A and B maturity classifications may not be completely justified based on tenderness differences (Tatum et al., 1980; Shackelford et al., 1995b; Hilton et al., 1998; Acheson et al., 2014). Tatum et al. (1980) reported no differences in overall tenderness, juiciness and flavor between steaks from A and B maturity carcasses from steers fed a high concentrate diet. Hilton et al. (1998), reported no differences in overall sensory tenderness, Warner-Bratzler shear force, amount of connective tissue or flavor between these two classifications between carcasses classified as A and B maturity. Furthermore, in agreement, Shackelford et al. (1995b) determined that there were no differences in overall tenderness or the amount of connective tissue in steaks from A or B maturity carcasses in cattle that were less than 35 months of age. Tatum (2011) reviewed studies (Romans et al., 1965; Walter et al., 1965; Breidenstein et al., 1968; Covington et al., 1970, Berry et al., 1974; Smith et al., 1982; Smith et al., 1988; Shackelford et al., 1995b; Hilton et al., 1998) that all compared *Longissimus* tenderness of A and B maturity carcasses. Seven of these studies were in agreement that no differences in beef tenderness were observed. However, there were two studies in contradiction, Smith et al. (1982; 1988) determined that steaks within equal marbling scores from A maturity carcasses had improved tenderness scores than steaks produced from B maturity carcasses. Using results of nine studies cited previously, Tatum (2011) calculated the weighted mean difference in tenderness of steaks from A- (n=680) vs B- (n= 503) maturity carcasses these results as only 0.12 kg.

Not all cattle with an actual age or dental age of less than 30 months of age produce an A maturity carcass. Tatum (20 011) cited an unpublished 2004 beef checkoff study which included more than 6,600 fed steers and heifers classified as less than 30 months of age by dentition. United States Department of Agriculture graders assigned maturity scores to these cattle which resulted in most being classified as A maturity (91.8%), 6.4% were classified as B- maturity and 1.8% were classified as C- or D-maturity. Results of the 2011 National Beef Quality Audit (Moore et al., 2012) reported 7.2% of the U.S. fed steer and heifer population produced carcasses that were classified as B maturity or older. Industry estimates indicate between 3.5 and 8% of cattle are classified B maturity or older (Acheson and Tatum, 2014).

Acheson et al. (2014) found no differences in WBSF, SSF, or sensory panel ratings for tenderness, juiciness, or flavor between beef LM steaks from carcasses classified as A maturity and LM steaks from carcasses classified as B maturity or older from cattle that were less than 30 months of age and grain-finished. These results suggests that all carcasses from cattle classified as less than 30 months of age could be considered A maturity for grading purposes irrespective of carcass maturity characteristics. With a discount of $20 to $55 per hundred weight on cattle classified as B maturity or older Acheson and Tatum (2014) estimated removing this discount would have a large economic impact on the beef industry.

CHAPTER II

INTRODUCTION

Although most cow-calf producers track individual birth records for calves this information is not always passed on when the cattle are transferred from feeders to packers (Tatum, 2011). To account for all age associated differences in beef quality, USDA graders examine indicators of physiological maturity and classify each carcass into 1 of 5 maturity groups designated A through E (USDA, 1997). Approximate ages corresponding to each maturity classification are: A = 9 to 30 mo, B = 30 to 42 mo, C = 42 to 72 mo, D = 72 to 96 mo and E = more than 96 mo. However, occasionally, cattle younger than 30 MOA, based on actual age or dentition, do not produce A maturity carcasses as they exhibit premature advanced skeletal ossification which causes them to be classified as B maturity or older (Tatum, 2011). Premature advanced skeletal maturity can be influenced by sex, use of implants and many other factors.

An additional method of determining animal age is to determine the animal's dental age (Graham and Price, 1982). Carcasses from all cattle harvested and processed in U.S. federally inspected beef plants are currently segregated into 2 age groups based on dentition. While dentition in the U.S. federally inspected plants is not used for application of USDA Quality Grades, it is primarily utilized in an ongoing effort to prevent human and animal exposure to beef tissues than may contain agent that causes bovine spongiform encephalopathy. Carcasses from cattle with less than 3 permanent incisors (PI) are classified as less than 30 mo of age (MOA). Conversely, carcasses from cattle with 3 or more PI are classified as 30 MOA or older. Carcasses from these 2 dental age groups are graded and fabricated separately within large commercial beef plants. If fed steers and heifers with fewer than 3 PI consistently produce beef that provides the same eating experience as beef from carcasses classified by USDA graders as A maturity, then all carcasses from cattle aged as less than 30 MOA based on dentition should be considered A maturity for grading purposes, regardless of their carcass maturity characteristics. This study was conducted to compare sensory properties of beef from A maturity and B maturity or older carcasses produced by grain-finished steers and heifers classified as less than and greater 30 MOA.

Studies that have examined the relationship between beef tenderness and physiological maturity, including a wide range of cattle and beef carcasses produced in the Unites States, suggest that with increases in USDA maturity progressively from A to E there is an association with greater beef toughness (Smith et al., 1982,; Smith et al., 1988; Hilton et al., 1998). Conversely, when comparisons among maturity groups are limited to include only carcasses produced by grain-finished steers and heifers not culled cattle or grass-fed cattle, research has failed to demonstrate a consistent relationship between beef tenderness and carcass physiological maturity (Miller et al., 1983; Field et al., 1997; Acheson, et al., 2014).

Moore et al. (2012) in the 2011 National Beef Quality Audit reported that 7.2 % of the U.S. fed steer and heifer population produced beef carcasses that were classified as B maturity or older. This study was conducted to compare sensory properties of beef from A maturity and B maturity of older carcasses produced by grain-finished steers and heifers classified as less than 30 MOA and greater than 30 MOA. Carcasses classified as B maturity or older currently receive price discounts when harvested (USDA, 2015). However, if beef from these carcasses, exhibiting more advanced physiological maturity, has sensory attributes, and tenderness measurements similar to those of beef produced by A maturity carcasses, then price discounts may not be justified. This study was conducted to compare sensory attributes of beef from A maturity and B maturity or older carcasses produced by grain-finished steers and heifers classified as less than 30 MOA

MATERIALS AND METHODS

Institutional Animal Care and Use Committee approval was not obtained because no live animals were utilized in conducting this study. The experimental sample consisted of chilled beef carcasses (*n* = 600) selected at 3 commercial fed-beef processing plants located in Colorado and Nebraska.

Carcass Selection

Carcass selection began 19 February 2014 and concluded 11 July 2014. Sampling for the experiment included cattle that were classified as either less than 30 months of age (MOA) or 30 MOA or older based on dentition. Carcasses were selected to represent 2 dental age groups, 2 maturity groups, and 3 marbling categories within each dental age x maturity subclass. Dental age groups included carcasses of cattle classified as less than 30 months by dentition and carcasses produced by cattle classified as 30 MOA or older by dentition. Maturity groups included carcasses with an overall maturity score of A^{00} to A^{99} (**A**) and carcasses with an overall maturity score of B^{00} to D^{99} (**B-D**). Marbling categories consisted of Slight (**SL**), Small (**SM**), and Modest ^{00} to Moderate^{99} (**MT-MD**).

During each day of collection, carcasses were pre-selected based on preliminary assessment of carcass maturity characteristics and official marbling score which was determined using on-line, USDA-approved instrument grading system (E+V Technology, Oranienburg, Germany) then pre-selected carcasses were transferred to stationary rails. United States Department of Agriculture-Agriculture Marketing Service graders assessed each pre-selected carcass to determine the skeletal, lean, and overall maturity scores. Final selection of carcasses for inclusion to the study was determined by the overall maturity scores combined with instrument-based marbling score as recorded by Colorado State University (**CSU**) personnel Colorado State University personnel collected additional data on carcasses that fit selection criteria. Each carcass selected to represent the B-D maturity groups was paired with an A-maturity carcass of the same sex and similar marbling score (± 50 marbling units) within dentition classification. When possible, pairs were selected from the same slaughter lot.

Colorado State University personnel recorded the following information for each selected carcass: HCW, preliminary yield grade at the 12th rib, fat thickness, estimated KPH fat percentage, stamped yield grade, sex classification (heifer or steer), presence or absence of an "A stamp" and cattle type (Zebu or Non-Zebu). Yield grade was calculated by gathering and utilizing instrument measurements of LM area from the data archives at each plant combined with data collected by CSU personnel. Of the carcasses selected in the study, 406 (68%) were produced by heifers, whereas, 194 (32%) were produced by steers. Sex, cattle type, carcass weight and yield grade were allowed to differ randomly in this experiment. If quality defects and dressing defects (i.e., dark cutter, blood splash, excessive trimming, fat pulls, etc.) were present on a carcass, the carcass was not included in the experimental sample.

Longissimus Sampling and Postmortem Aging

Upon the completion of carcass data collection, LM samples (4 cm thick) were removed from the left and right sides of each carcass at the 13th rib region to be used for shear force measurements and sensory panel evaluation. Objective color measurements comprised of L*, a*, and b* values were attained in triplicate 20 m after the sample was excised from the 13th rib region (Hunter Lab Miniscan, Model 45/O-S, Hunter Associates Laboratory Inc., Reston, VA). Objective color measurements were measured on the posterior surface of the sample in a 2° C cooler environment. Objective color measurements from each side were averaged to obtain a single L* (0=black; 100=white), a* (negative number=green; positive number=red), and b* (negative number=blue; positive number=yellow) value for each carcass. The spectrophotometer (6-mm aperture, D-65 light source) was calibrated using black and white tile before use on each sampling day and when prompted by the spectrophotometer. Following color observation, samples were packaged individually and transported in ice-filled coolers to the Colorado State University Meat Laboratory and aged at 0 to 2°C until the 14th d postmortem. On the 14th d postmortem, individually vacuum-packaged LM samples were frozen and stored at -20°C. All frozen LM sample sections were fabricated using a band saw (Model 400, AEW-Thrune, AEW Engineering Co. Ltd., Norwich, UK) to produce 1 steak (2.5 cm thick) per sample section. At the time of fabrication the LM steak from the left side of the carcass was designated for sensory evaluation and the LM steak from the right side of the carcass was designated for shear force measurements.

Shear Force Measurements

Steaks from the right side of the carcass designated for shear force measurements were randomly assigned to 5 cooking days (block) with 120 steaks per block. Block defined as day included LM steaks equally representing the 2 dental age classes, 2 maturity groups and 3 marbling categories. Shear force measurements for samples in each block were completed on 5 different days with all steaks in a block being measured for shear force on the same day.

Frozen steaks designated for slice shear force (SSF) and Warner Bratzler shear force (WBSF) were tempered for 48 to 60 hours at 0 to 2°C to ensure raw internal temperatures were between 0 to 4°C prior to cooking. Raw internal temperature was measured and recorded using a calibrated, type K thermocouple thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation, Middlefield, CT) placed in the geometric center of each steak. Uncooked weight in grams was measured using a calibrated scale and recorded (Digital Scale Titan-Compact, model SK-1000WP, A&D Company, Limited; Tokyo, Japan). Steaks were cooked in a combi-oven dry-heat setting of 204°C with a fan speed of high and 0% relative humidity (Model SCC WE 61 E; Rational, Landsberg am Lech, Germany) to attain a peak internal temperature of 71°C. Peak internal temperature was measured and recorded using a calibrated, type K thermocouple thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation, Middlefield, CT) placed in the geometric center of each steak. Cooked weight in grams was measured using a calibrated scale and recorded on a datasheet (Digital Scale Titan-Compact, model SK-1000WP, A&D Company, Limited; Tokyo, Japan).

Warner-Bratzler Shear Force and SSF measurements were obtained from the same steak using procedures described by Lorenzen et al. (2010). A single 1-cm thick, 5-cm long slice was removed from the lateral end of the steak and parallel to the muscle fibers for slice shear force. Each slice was sheared perpendicular to the muscle fiber direction within 10 min of recording peak internal temperature using a universal testing machine (Instron Corp., Canton, MA.) equipped with a blunt-end blade (cross head speed 500 mm/min, load capacity: 100 kg). Remaining portions of each individual cooked steak was reserved and equilibrated to room temperature (22°C) before 3 to 8 cores (1.2 cm in diameter) were excised from each steak parallel to the muscle fiber direction. Each core was sheared once perpendicular to the muscle fiber direction utilizing a universal testing machine (Instron Corp., Canton, MA.) equipped with a Warner-Bratzler blade (cross head speed 200 mm/min, load cell capacity 100kg). Maximum shear force value of each core was recorded and the resulting values were averaged to obtain one single WBSF value for each steak.

Sensory Analysis

Steaks designated for sensory analysis were randomly assigned to 50 complete blocks, where block is also defined as session, with 12 samples stratified and randomly assigned to each block. Each block consisted of one steak representing each dental age x maturity group x marbling subclass. Twelve samples (1 complete block) were evaluated in each panel session and panelists participated in no more than 2 sessions per d with a period of 5 h between sessions.

Panelists were trained, selected and tested to assess their abilities to distinguish differences between tenderness, juiciness, and flavor according to procedures outlined by Miller and Prusa (2010), and Adhikari et al. (2011). The lexicon used for sensory training and analysis (AMSA, 1995; Adhikari and Miller, 2010; Adhkari et al., 2011) included tenderness, juiciness, and the following flavor descriptors: meaty/brothy (basic flavor and aroma of grilled or roasted beef), butteryy/ beef fat flavor (flavor and aroma associated with cooked fat from grain-finished beef; frequently described as a butteryy flavor) (Acheson et al. 2014), bloody/ sermuy/ metallic (flavor and aroma associated with blood in beef cooked to a rare degree of doneness), livery/ organy (flavor and aroma associated with cooked beef liver or kidney), grassy/ fishy (flavor and aroma of beef produced by grass finished or short-fed cattle; frequently described as green or hay like), and gamey (flavor and aroma associated with meat from game.)

Identical tempering and cooking procedures as described for shear force evaluations were used for sensory evaluations. Upon completion of cooking, steaks were cut into 1.3 cm x 1.3 cm x 1.3 cm cubes, placed in a glass bowl, and covered in aluminum foil. Steaks were held in a warming oven at 70°C for no longer than 30 min prior to being served to a 9-member trained descriptive attribute panel. Each panelist was seated in a private booth, equipped with a red light bulb. Furthermore, each panelist was supplied unsalted saltines, unsweetened apple juice, and distilled water for palate cleansing between each sample. Panelists received 2 cubes from each sample and had the opportunity to receive additional cubes from the same sample, if needed, to determine differences in sensory attributes. Sensory attributes for each sample was quantified using 15 cm unstructured line scales anchored at both ends with descriptive terms. For each attribute, 0 cm denoted a very low intensity or presence of that attribute; whereas, 15 cm denoted a very high intensity or presence for that specific attribute. Sensory analysis was conducted for 25 d with a routine retraining session at the midpoint. Individual panelists' scores for descriptive attributes were averaged to obtain one value for each descriptive attribute per sample. These averages were utilized in analyses.

Statistical Methods

All analyses used statistical procedures of SAS (SAS Inst. Inc, Cary NC. Data for carcass characteristics such as marbling score, fat thickness at the 12^{th} rib, HCW, REA and calculated YG, L*, a*, and b*, were analyzed (PROC MIXED) to compare carcasses for each sex classification, dental age group, maturity group and marbling category. Sensory panel ratings and LM shear force measures were analyzed using the MIXED procedure. The final reduced model included the random effect of block. The fixed effects for the reduced model included plant, dental age group, maturity group, marbling category, sex, dentition x marbling and dentition x maturity. The peak internal temperature of the steak as it was removed from the oven was used as a covariate. Denominator degrees of freedom were calculated using the Satterthwaite approximation. All comparisons were tested using a comparison-wise significance level of $\alpha = 0.05$. In all analyses conducted using MIXED and GLIMMIX, adjusted least squares means were compared using the PDIFF option of LSMEANS when F-tests were significant ($P < 0.05$).

Analyses conducted to determine probabilities of LM steaks meeting ASTM standard specifications for shear force (ASTM, 2011), with the response variable coded as 1 and 0, were performed using PROC GLIMMIX. The statistical model used for these analyses included fixed effects of dentition group, maturity group, marbling category, and maturity group × marbling category, random effect of block. Peak temperature of the steak after it was removed from the oven was used as a covariate.

RESULTS AND DISCUSSION

Characteristics of Experimental Sample

The experimental design of and number of carcasses selected for the study is presented in Table 1. The proportion of heifers and steers for each maturity level within the less than 30 MOA and 30 MOA or older group did not differ because sampling criteria requirements designated that the B-D maturity carcasses be paired with A maturity carcasses of the same sex and similar marbling score. Carcasses from heifers and steers had similar marbling scores although within the MT-MD marbling category steers had a slightly higher mean marbling score than did heifer carcasses (Table 2). This difference, although statistically significant is of questionable practical importance as there was less than 20 units difference.

Characterization of data for USDA quality grade and LM color scores for dentition classification, maturity group, sex class, and marbling category are presented in Table 2. Criteria for sample selection required all selected A maturity carcasses to be within 50 marbling degrees of paired B-D maturity carcasses within each dentition classification (less than 30 MOA and 30 MOA or older). As a result, marbling score did not differ ($P > 0.05$) between maturity groups or dentition classification. Skeletal and overall maturity scores were greater ($P < 0.05$) for cattle designated as 30 MOA or older; conversely, lean maturity scores were greater ($P < 0.05$) for cattle designated as less than 30 MOA. Skeletal, lean, and overall maturity scores were greater ($P < 0.05$) for B-D maturity carcasses than in selected A maturity carcasses. Lean maturity scores in the MT-MD marbling category were less ($P < 0.05$) than lean maturity scores in the Small and Slight marbling categories indicating a more youthful color associated with a higher marbling category. Distribution of overall carcass maturity scores for B maturity or older carcasses within each dental age group is presented in Figure 1. Overall maturity scores in the A maturity group ranged from A^{30} to A^{99} and the B-D maturity group ranged from B^{00} to D^{60}. Within the less than 30 MOA dentition group, overall maturity scores ranged from A^{30} to A^{99} within A maturity carcasses and from B^{00} to D^{00} within B-D maturity carcasses. However, 30 MOA or older dentition group overall maturity scores ranged from A^{30} to A^{99} within the A maturity carcasses and from B^{00} to D^{60} within the B-D maturity carcasses. Heifer's overall maturity tended to be greater than overall maturity for steers ($P = 0.0574$). Additionally, carcasses from cattle that were classified as 30 MOA or older had a greater ($P < 0.05$) overall maturity score than carcasses from cattle that were classified as less than 30 MOA. Furthermore, there were no differences in overall maturity score between marbling groups ($P > 0.05$).

Least squares means showing the effects of dentition classification, maturity group, sex class, and marbling level on objective LM color measurements are presented in Table 2. Carcasses in the B-D maturity group produced LM steaks with lower ($P < 0.05$) b* values, and similar ($P > 0.05$) a* values compared with LM steaks from carcasses in the A maturity group meaning that steaks from A maturity carcasses and B maturity carcasses were similar in redness. Furthermore, a* values differed ($P < 0.05$) for dentition classification; LM steaks from carcasses classified as 30 MOA or older had greater ($P < 0.05$) a* (redder-colored lean) values than LM steaks from carcasses classified as less than 30 MOA. Conversely, no differences ($P > 0.05$)

were detected in b* values among LM steaks from each dentition classification. As an animal advances in age it is generally accepted that the muscle tissue becomes darker red in color. A darker lean tissue color was associated with advanced skeletal maturity in previous studies by Tuma et al. (1963), Romans et al. (1965), and Breidenstein et al. (1968). There was a significant interaction between sex class and marbling group for L* color measurement. Steer carcasses with a SM level of marbling had lower ($P < 0.05$) L* color values in LM steaks (darker-red colored lean) than from carcasses from other sex x marbling subclasses. However, a* and b* values were similar ($P > 0.05$) for LM steaks from steers and heifers.

Effects of Dentition Classification, Maturity Group, Marbling Level, and Sex class on Sensory Attributes and Shear Force Measurements

Results showing the effects of dental age group, maturity group, marbling category and sex class on sensory tenderness and shear force measurements are presented in Table 3. For decades researchers have attempted to determine the effect of physiological maturity on sensory panel attributes of beef samples from grain-finished steers and heifers with inconsistent results (Miller et al., 1983; Field et al., 1997). Acheson et al., (2014) reported that maturity group (A vs. B-C) had no effect ($P > 0.05$) on shear force measurements or sensory tenderness in LM steaks from cattle less than 30 MOA. Likewise, in the current study maturity group (A vs. B-D) had no effect on shear force measurements or sensory tenderness (Table 3). This is in agreement with several other studies in which researchers have reported that sensory panel tenderness of LM steaks from A or B maturity carcasses did not differ (Romans et al., 1965; Covington et al., 1970; Norris et al., 1971 Field et al., 1997; Hilton et al., 1998; Acheson et al., 2014). Other studies have reported no differences in sensory panel tenderness between A maturity and C maturity carcasses (Cross et al., 1973; Regan et al., 1976; Field et al., 1997). Conversely, two studies (Smith et al., 1982 and 1988) reported steaks from A maturity and B maturity carcasses differed in sensory panel tenderness and WBSF.

Many previous studies (Tatum et al., 1980; Aberle et al., 1981; Miller et al., 1987; Schnell et al., 1997) have reported an improvement in sensory panel tenderness and Warner-Bratzler shear force values when cattle are finished on grain irrespective of age of the animal. Protein turn-over in grain-finished steers and heifers occurs at a rapid rate limiting the formation of heat-stable collage crosslinks that lead to decreased tenderness in beef. Waggoner et al., (1990), Apple et al., (1991), and Field et al., (1996) observed endogenous and exogenous hormone levels with premature skeletal ossification which caused carcasses to appear more mature than the true chronological age. Shackelford et al. (1995a) determined that grain finished Heiferettes (mean age = 35.9 months; mean skeletal maturity score = B^{78}) had similar overall tenderness ratings as yearling heifers (mean age = 22.2 months; mean skeletal maturity = A^{80}). These studies collectively reported an improvement in tenderness when animals are grain finished.

Few studies have attempted to determine differences in tenderness related to dental classification of cattle. There have been inconsistent results in the limited number of studies completed. Lawrence et al. (2001) determined that there was no relationship between dental age and sensory panel tenderness or Warner-Bratzler shear force in a study with commercially fed cattle with zero, two, four, six, or eight permanent incisors. Wythes and Shorthose (1991) also saw no differences in tenderness (peak shear force) among cows with two, four, six, or eight permanent incisors or among steers with four, six or eight permanent incisors. On the other hand, Shorthose and Harris (1990) reported an association of decreased beef tenderness as the number of permanent incisors increased from zero to seven.

In the current study, there was a significant interaction between dental classification and marbling group for SSF and sensory tenderness. Among both dentition classifications, marbling level had an (*P* <0.05) effect on sensory tenderness for the MT-MD group compared to the SM and SL marbling categories. Carcasses classified as less than 30 MOA with a SL level of marbling had greater (*P* < 0.05) sensory tenderness scores and lower SSF values compared to LM steaks from carcasses classified as 30 MOA or older with the same marbling level. Carcasses classified as 30 MOA or older with a SL level of marbling produced LM steaks with the highest (*P* < 0.05) SSF value and the lowest (*P* < 0.05) sensory tenderness value; and in addition, WBSF tended to be greater (*P* = 0.0774) suggesting that these steaks were the toughest. Sensory panelists were unable to detect differences (*P* > 0.05) in tenderness between LM steaks produced by carcasses with a MT-MD level of marbling classified as less than 30 MOA or greater than 30 MOA. Furthermore, trained panelists were unable to detect differences (*P* > 0.05) among carcasses classified as less than 30 MOA or 30 MOA or older by dentition within the SM marbling category.

While the interaction of dentition x marbling group was not significant for tenderness differences measured by WBSF, marbling category influenced (*P* < 0.05) WBSF values. Acheson et al. (2014) reported increased marbling was associated with reduced ((P < 0.01) values for WBSF and SSF in fed steers and heifers less than 30 MOA. In the current study carcasses with a SL level of marbling produced LM steaks with greater (*P* < 0.05) WBSF values than LM steaks from carcasses with a SM or MT-MD level of marbling irrespective of dentition classification or maturity group. This suggests that LM steaks from carcasses with a lower degree of marbling were tougher than LM steaks from carcasses with a higher degree of marbling. This finding is also in agreement with Emerson et al. (2013) who reported that WBSF values decreased with increased degree of marbling from TR to MAB. In the current study an increased level of marbling from SL to SM resulted in decreased ($P < 0.05$) WBSF and SSF values, but an additional increase in marbling from SM to MT-MD did not ($P > 0.05$) result in decreased WBSF or SSF values (SL > CH = MT-MD). Emerson et al. (2013) also reported that SSF values decreased with increased marbling from TR to SM, but additional increases in degree of marbling above SM did not reduce SSF values further.

The American Society for Testing and Materials (ASTM) specifications classify beef with WBSF values less than 4.4 kg and SSF values less than 20 kg as "Certified Tender" for beef marketing claims (ASTM International, 2011). A greater ($P < 0.05$) percentage of LM steaks from steers met the criteria for WBSF than heifers (Table 5); however, there were no differences ($P > 0.05$) in percentage of steaks meeting certified tender specifications between steers and heifers for SSF measurements. A greater ($P < 0.05$) percentage of LM steaks from carcasses that were classified as less than 30 MOA met the SSF certified tender specification than LM steaks from carcasses classified as 30 MOA or older. A greater percentage of LM steaks from carcasses that were classified as less than 30 MOA tended ($P = 0.0996$) to meet WBSF certified tender specification. Furthermore, as marbling increased from SL to SM or MT-MD a greater ($P < 0.05$) percentage of LM steaks met specifications for WBSF and SSF. However, there was no significant difference between percentage of steaks meeting the specification for WBSF and SSF from carcasses with a SM level and a MT-MD level of marbling.

Research studies have shown that when comparing only A and B maturity carcasses, sensory juiciness and flavor values are not affected by maturity (Smith et al., 1982; Hilton et al., 1998). When comparing A maturity to C maturity carcasses flavor intensity has been shown to decrease and off-flavor intensity has been reported to increase (Smith et al., 1982; Hilton et al., 1998). Least squares means for sensory attributes are presented in Table 4. Juiciness and sensory flavor attributes were affected ($P < 0.05$) by dentition group, sex class, and marbling category. Carcasses classified as 30 MOA or older produced LM steaks with increased ($P < 0.05$) juiciness, as well as more intense livery/organy, and grassy flavors. However, livery/organy, grassy, and gamey flavors were detected at levels below 1 cm on a 15 cm line scale. Likewise, Emerson et al. (2013) reported livery/organy and grassy flavors were detected at levels below 1 cm on a 15 cm line scale in grain-finished cattle. Marbling category had an effect ($P < 0.05$) on sensory juiciness, meaty/brothy flavor intensity, buttery/beef fat flavor intensity, bloody/sreumy flavor intensity, livery/organy flavor intensity, grassy flavor intensity, but did not have an effect ($P > 0.05$) on gamey flavor intensity (Table 4). There were no differences ($P > 0.05$) in gamey flavor intensity between marbling categories. As marbling category increased from SL to MT-MD, LM steaks had increased ($P < 0.0001$) juiciness, meaty/ brothy flavor intensity, buttery/ beef fat flavor intensity. However, bloody/serumy flavor intensity decreased ($P < 0.0001$) as marbling increased. Carcasses within the SL marbling category had the highest ($P < 0.05$) average panel ratings for livery/organy flavor intensity while there were no differences ($P > 0.05$) between SM and MT-MD for livery/organy flavor intensity. Previous studies have reported similar relationships between beef sensory attributes and marbling categories in LM steaks (McBee and Wiles. 1967; Smith et al., 1984; Emerson et al., 2013; Acheson et al., 2014). Researchers have stated that flavor increases directly in a linear relationship with additional degrees of marbling (Hiner et al., 1956; McBee and Wiles, 1967). Smith et al. (1984) and Emerson et al. (2013) suggested that as the degree of marbling increases, overall sensory panel ratings increase, ultimately providing a steak with a better eating experience.

Sex class affected ($P < 0.05$) Warner Bratzler Shear Force, sensory tenderness, juiciness, buttery/beef fat flavor and grassy flavor. Steer carcasses produced more tender LM steaks as indicated by lower ($P < 0.05$) WBSF values and increased ($P < 0.05$) sensory tenderness ratings compared to heifer carcasses. Steer carcasses produced LM steaks with increased ($P < 0.05$) juiciness and buttery/beef fat flavor intensity; and decreased ($P < 0.05$) intensity of grassy flavor compared to LM steaks from heifer carcasses.

Discussion

As an animal increases in chronological age, ossification of cartilage will occur and lean tissue becomes darker in color and coarser in texture. A USDA Quality Grade is assigned by assessing and utilizing a combination of sex classification, lean and skeletal maturity, marbling score, and firmness of the *Longissimus dorsi* as described by the Official Standards for Grades of Beef Carcasses (USDA, 1997). The animal will be classified into a USDA maturity classification ranging from A through E reflecting physiological maturity. Skeletal maturity traits such as, size, shape, and ossification of bones and cartilage, and color and texture of the lean are utilized as an indicator of the animal's chronological age to sort carcasses into a corresponding maturity group approximately related to actual age where: A = 9 to 30 mo, B = 30 to 42 mo, C = 42 to 72 mo, D = 72 to 96 mo, and E = older than 96 mo.

Furthermore, to compensate for tenderness and overall palatability differences that may occur with increased age, the current quality grade standards require increased marbling scores for cattle that classify as older than A maturity. With the justification of creating a more uniform beef supply to the consumer, B maturity carcasses are not eligible for the Select grade and B maturity carcasses without at least a Modest^{00} degree of marbling are graded US Standard. With these restrictions, the price received for these cattle is greatly reduced due to discounts (USDA, 2015). Some previous research has indicated that as an animal increases in age, overall tenderness decreases (Smith et al., 1982 and 1988; Hilton et al., 1998). B-maturity carcasses with SM or SL degree of marbling are graded standard based on research conducted by Smith et al. (1982 and 1988). Beef produced from carcasses within A maturity was determined to be less variable in overall palatability from a study conducted by Smith et al. (1982). Additionally, Smith et al. (1988) reported that within the A maturity group, differences is flavor, juiciness, tenderness, overall palatability, and WBSF did not exist; however, within the B maturity group, differences in tenderness and overall palatability did exist.

Moore et al. (2012) reported that most (92.8%) of the beef carcasses produced by fed steers and heifers in the United States are classified as A maturity. However, even when the animal is under 30 MOA, a small percentage will produce B maturity carcasses or older (Moore et al., 2012). Results of the current study combined with previous tenderness research in grain-finished cattle indicate that when cattle classified as less than 30 MOA by dentition are grain-finished, sensory characteristics do not differ regardless of skeletal and overall maturity. The current price discount B maturity cattle classified as less than 30 months of age receive is not justified. A change in the quality grade standards to remove apply quality grades based solely on marbling in cattle classified as less than 30 MOA, would this remove the unjustified price discounts, but also by eliminating the increased marbling requirements would allow for an increased supply of carcasses that qualify for the Choice and Select quality grades. Furthermore, by not calling maturity factors on cattle classified as less than 30 MOA by dentition may decrease the reliance on human graders to determine skeletal, lean and overall maturity and increase the utilization of instrument grading to determine quality grade.

However, when comparing cattle that are less than 30 MOA to cattle that are 30 MOA or older, differences do exist in SSF tenderness, sensory juiciness, carcass characteristics and off-flavors. Carcasses from cattle classified as 30 MOA or older had a higher intensity of liver/organy and grassy flavors. Sensory panel ratings for tenderness determined that carcasses classified as greater than 30 months of age with a SL degree of marbling produced the toughest LM steaks. Degree of marbling along with dentition for SSF tenderness measurements showed that carcasses with a low degree of marbling from both cattle less than and 30 MOA or older produce tougher steaks than from carcasses with a higher degree of marbling.

From the data presented in this study, price discounts for B maturity carcasses produced from grain-finished cattle classified as less than 30 MOA by dentition are not justified. Changes to current grading practice may need to be implemented reflecting findings of the current study and those of Acheson et al. (2014). The results from this study and similar study by Acheson et al., (2014) support considering all cattle classified as less than 30 MOA, by documentation of actual age or by dentition, as A maturity for the purposes of grading. However, findings from this study do not provide sufficient evidence to make changes to grade standards for cattle classified as 30 MOA or older.

Table 1. Number of carcasses selected for the experiment

	Dental age < 30 mo		Dental age ≥ 30 mo	
Marbling category	A maturity	B-D maturity	A maturity	B-D maturity
Slight	50	50	50	50
Small	50	50	50	50
MT-MD	50	50	50	50

[1] < 30 MOA = carcasses classified as less than 30 months of age by dentition.
[2] ≥ 30 MOA = carcasses classified as 30 months of age or older of age by dentition.
[3] A= carcasses exhibiting A^{00} to A^{99} overall maturity characteristics.
[4] B-D = carcasses exhibiting B^{00} to D^{99} overall maturity characteristics.
[5] MT-MD = carcasses with Modest ^{00} to Moderate ^{99} marbling scores

Table 2. USDA quality grade traits and objective LM color measurements for beef carcasses selected to represent 2 dentition designations, 2 maturity groups and 3 marbling categories

		USDA quality grade trait[1]				LM color measurement[2]		
Effect	*N*	Marbling score	Skeletal maturity score	Lean maturity score	Overall Maturity Score	L*	a*	b*
Dentition (DENT)		*P* = 0.1258	*P* < 0.0001	*P* = 0.0260	*P* = 0.0011	*P* = 0.2323	*P* = 0.0003	*P* = 0.3655
<30[3]	300	455	248	151	218	37.6	11.7	11.8
≥ 30[4]	300	459	264	148	228	37.2	12.3	11.9
SEM[5]		2.1	2.9	0.9	2.2	0.2	0.1	0.1
Maturity (MAT)		*P* = 0.6319	*P* <0.0001	*P* < 0.0001	*P* < 0.0001	*P* < 0.0001	*P* = 0.0927	*P* = 0.0006
A[6]	300	456	177	146	165	39.3	12.1	12.0
B-D[7]	300	458	335	153	280	35.5	11.9	11.7
SEM		2.1	2.9	0.9	2.2	0.2	0.1	0.1
Marbling (MARB)		*P* < 0.0001	*P* = 0.5490	*P* < 0.0001	*P* = 0.6914	*P* = 0.0929	*P* = 0.8170	*P* = 0.4679
Slight	200	361[c]	255	151[b]	222	37.9	12.0	11.9
Small	200	448b	254	152[b]	221	37.0	12.0	11.8
Modest+[8]	200	563[a]	255	146[a]	224	37.2	12.1	11.9
SEM		2.8	3.6	1.0	2.7	0.4	0.1	0.1
Sex		*P* = 0.3834	*P* = 0.0312	*P* = 0.0867	*P* = 0.0574	*P* = 0.0376	*P* = 0.5873	*P* = 0.8739
Heifer	404	456	261	151	226	37.7	12.0	11.9
Steer	196	458	251	148	219	37.0	12.0	11.8
SEM		2.5	3.6	1.0	2.6	0.3	0.1	0.1
Sex X MARB		*P* = 0.0390				*P* = 0.0193		
Heifer/Slight	134	360[d]				37.7[a]		
Heifer/Small	126	451[c]				38.0[a]		
Heifer/Modest+	146	556[b]				37.4[a]		
Steer/Slight	66	362[d]				38.0[a]		
Steer/Small	74	444[c]				36.0[b]		
Steer/Modest+	54	569[a]				37.0[a]		
SEM		4.8				0.6		

[1] Marbling scores were measured using USDA-approved grading instruments (Slight = 300, Small = 400 to 499, Modest = 500 to 599); carcass maturity characteristics (USDA, 1997) were evaluated and scored by official USDA graders (A = 100 to 199, B = 200 to 299).

[2] L*: 0 = black, 100 = white; a*: negative number = green, positive number = red; b*: negative number = blue, positive number = yellow.

[3] < 30 MOA = carcasses classified as less than 30 months of age by dentition.

[4] ≥ 30 MOA = carcasses classified 30 months of age or older by dentition.

[5] SEM = pooled standard error.

[6] A= carcasses exhibiting A^{00} to A^{99} overall maturity characteristics.

[7] B-D = carcasses exhibiting B^{00} to D^{99} overall maturity characteristics.

[8] Modest+ = carcasses with Modest ^{00} to Moderate ^{99} marbling scores.

[a-d] Means in the same column within an effect that do not share a common superscript letter differ (*P* < 0.05).

Table 3. Least squares means comparing Warner-Bratzler shear force (WBSF) measurements, slice shear force (SSF) measurements and sensory tenderness of LM steaks from beef carcasses selected to represent 2 dentition designations, 2 maturity groups and 3 marbling categories

		LM shear force measurement, kg		LM sensory attribute[1]
Effect	*N*	WBSF	SSF	Tenderness
Dentition (DENT)		*P* = 0.0991	*P* = 0.0381	*P* = 0.1050
<30[2]	300	3.88	18.30	9.40
≥ 30[3]	300	4.04	19.54	9.19
SEM		0.1	0.6	0.1
Maturity (MAT)		*P* = 0.7027	*P* = 0.7501	*P* = 0.2529
A[4]	300	3.95	18.45	9.36
B-D[5]	300	3.97	18.99	9.24
SEM		0.1	0.5	0.1
Marbling (MARB)		*P* < 0.0001	*P* < 0.0001	*P* < 0.0001
Slight	200	4.29[b]	20.48[b]	8.65[c]
Small	200	3.88[a]	18.23[a]	9.40[b]
Modest+[6]	200	3.72[a]	18.05[a]	9.84[a]
SEM		0.1	0.6	0.1
Sex		*P* = 0.0350	*P* = 0.1012	*P* = 0.0002
Heifer	404	4.05	19.34	9.08
Steer	196	3.88	18.50	9.51
SEM		0.1	0.6	0.1
DENT X MARB		*P* = 0.0774	*P* = 0.0286	*P* = 0.0132
< 30 Slight	100	4.09	19.27[b]	8.97[c]
< 30 Small	100	3.88	18.46[bc]	9.37[b]
< 30 Modest+	100	3.68	17.17[c]	9.87[a]
≥ 30 Slight	100	4.49	21.69[a]	8.32[d]
≥ 30 Small	100	3.88	17.99[bc]	9.43[b]
≥ 30 Modest+	100	3.76	18.94[bc]	9.82[a]
SEM		0.1	0.8	0.2

[1] Scored using a 15-cm unstructured line scales: 0= extremely tough, extremely dry, no presence of flavor, or minimum level of performance; 15= extremely tender, extremely juicy, strong presence of flavor, or maximum level of performance.

[2] < 30 MOA = carcasses classified as less than 30 months of age by dentition.

[3] ≥ 30 MOA = carcasses classified as 30 months of age or older by dentition.

[4] SEM = pooled standard error.

[5] A= carcasses exhibiting A^{00} to A^{99} overall maturity characteristics.

[6] B-D = carcasses exhibiting B^{00} to D^{99} overall maturity characteristics.

[7]. Modest+ = carcasses with Modest ^{00} to Moderate ^{99} marbling scores.

[a-d] Means in the same column within an effect that do not share a common superscript letter differ (*P* < 0.05).

Table 4. Least Squares means comparing sensory attributes of LM steaks from beef carcasses selected to represent 2 dentition designations, 2 maturity groups, and 3 marbling categories

		LM sensory attribute[1]						
Effect	*N*	Juiciness	Meaty/ brothy flavor	Butteryy/ beef fat flavor	Bloody/ serumy flavor	Livery/ organy flavor	Grassy flavor	Gamey flavor
Dentition (DENT)		$P = 0.0120$	$P = 0.2682$	$P = 0.0603$	$P = 0.1180$	$P = 0.0375$	$P = 0.0057$	$P = 0.1412$
<30[2]	300	8.66	8.94	6.30	1.84	0.22	0.06	0.05
≥ 30[3]	300	8.94	9.02	6.51	1.96	0.30	0.17	0.07
SEM[4]		0.094	0.077	0.093	0.080	0.039	0.039	0.016
Maturity (MAT)		$P = 0.7192$	$P = 0.3328$	$P = 0.3355$	$P = 0.2710$	$P = 0.2484$	$P = 0.9931$	$P = 0.2135$
A[4]	300	8.78	8.95	6.37	1.93	0.28	0.11	0.05
B-D[5]	300	8.82	9.01	6.45	1.87	0.25	0.11	0.07
SEM		0.074	0.069	0.073	0.070	0.034	0.034	0.014
Marbling (MARB)		$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$	$P = 0.0033$	$P = 0.0067$	$P = 0.0888$
Slight	200	8.50[c]	8.73[c]	5.72[c]	2.11[c]	0.34[b]	0.17[b]	0.08
Small	200	8.80[b]	9.00[b]	6.41[b]	1.96[b]	0.23[a]	0.11[ab]	0.05
Modest+[6]	200	9.10[a]	9.22[a]	7.10[a]	1.63[a]	0.22[a]	0.05[a]	0.05
SEM		0.093	0.077	0.092	0.080	0.039	0.039	0.016
Sex		$P = 0.0060$	$P = 0.0811$	$P = 0.0046$	$P = 0.6287$	$P = 0.0776$	$P = 0.0118$	$P = 0.2220$
Heifer	404	8.67	8.93	6.27	1.89	0.29	0.15	0.07
Steer	196	8.93	9.04	6.56	1.92	0.23	0.07	0.05
SEM		0.084	0.073	0.083	0.075	0.036	0.036	0.015

[1] Scored using a 15-cm unstructured line scales: 0= extremely tough, extremely dry, no presence of flavor, or minimum level of performance; 15= extremely tender, extremely juicy, strong presence of flavor, or maximum level of performance.

[2] < 30 MOA = carcasses classified as less than 30 months of age by dentition.

[3] ≥ 30 MOA = carcasses classified as 30 months of age or older by dentition.

[4] SEM = pooled standard error.

[5] A= carcasses exhibiting A^{00} to A^{99} overall maturity characteristics.

[6] B-D = carcasses exhibiting B^{00} to D^{99} overall maturity characteristics

[7]. Modest+ = carcasses with Modest ^{00} to Moderate ^{99} marbling scores

[a-c] Means in the same column within an effect that do not share a common superscript letter differ ($P < 0.05$).

Table 5. Least squares means comparing Warner-Bratzler shear force (WBSF) and slice shear force (SSF) measurements of steaks from carcasses representing 2 dentition classifications, 2 maturity groups, and 3 marbling categories for steaks meeting ASTM specifications for "Certified Tender1"

		Steaks meeting ASTM specifications for "Certified Tender," %	
Effect	*N*	WBSF specification	SSF specification
Dentition (DENT)		$P = 0.0996$	$P = 0.0140$
<30[2]	300	76.83	72.26
≥ 30[3]	300	68.99	59.72
SEM		0.4	0.4
Maturity (MAT)		$P = 0.2918$	$P = 0.6148$
A[4]	300	71.10	67.25
B-D[5]	300	74.99	65.29
SEM		0.4	0.4
Marbling (MARB)		$P < 0.0001$	$P = 0.0046$
Slight	200	54.93[b]	56.56[b]
Small	200	78.28[a]	69.59[a]
Modest+[6]	200	82.02[a]	71.18[a]
SEM		0.4	0.4
Sex		$P = 0.0451$	$P = 0.1921$
Heifer	404	68.74	63.41
Steer	196	77.04	69.03
SEM		0.4	0.4

[1] Minimum tenderness threshold values (MTTV) required for classification as "Certified Tender": WBSF= 4.4 kg, SSF= 20kg (ASTM International, 2011).

[2] < 30 MOA = carcasses classified as less than 30 months of age by dentition.

[3] ≥ 30 MOA = carcasses classified as 30 months of age or older by dentition.

[4] SEM = pooled standard error.

[5] A= carcasses exhibiting A^{00} to A^{99} overall maturity characteristics.

[6] B-D = carcasses exhibiting B^{00} to D^{99} overall maturity characteristics.

[7]. Modest+ = carcasses with Modest ^{00} to Moderate ^{99} marbling scores.

[a-c] Means in the same column within an effect that do not share a common superscript letter differ ($P < 0.05$).

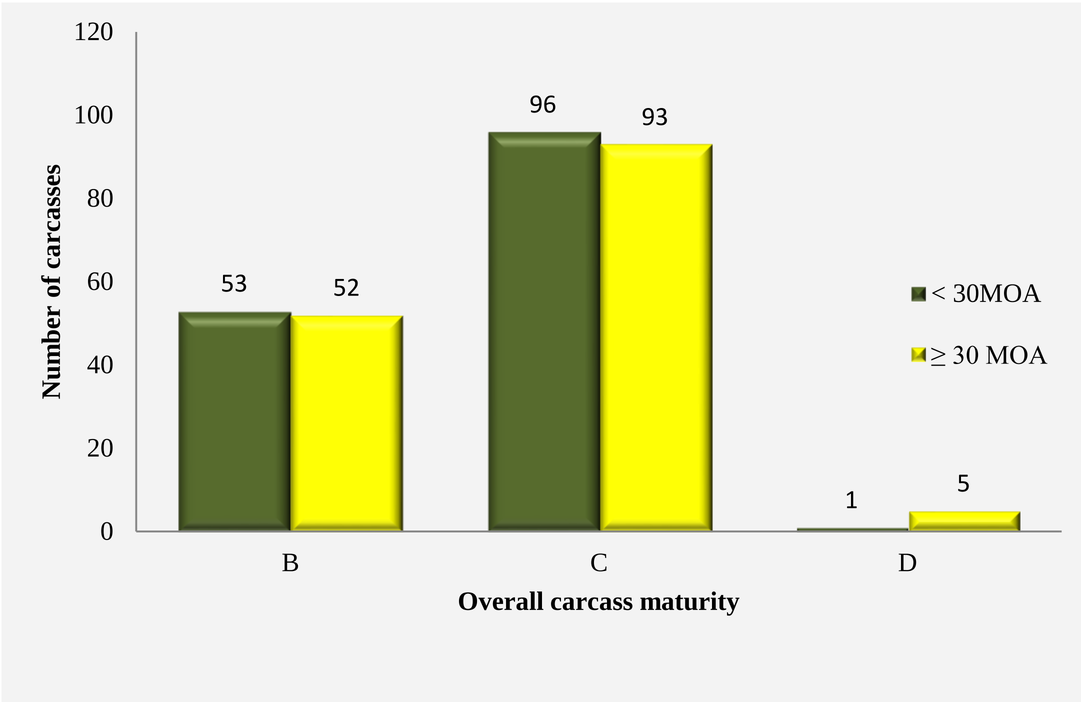

Figure 1. Distribution of overall carcass maturity scores for B maturity or older carcasses within each dental age group

REFERENCES

Aberle, E. D., E. S. Reeves, M. D. Judge, R. E. Hunsley, and T.W. Perry. 1981. Palatability and muscle characteristics of cattle with controlled weight gain: time on a high energy diet. J. Anim. Sci. 52: 757-763.

Acheson, R. J. and J. D. Tatum. 2014. Beef Carcass Maturity and Palatability Research. http://www.meatscience.org/Page.aspx?ID=9344. (Accessed December 22, 2014.)

Acheson, R.J., Woerner D. R. and J.D. Tatum. 2014 Effects of USDA carcass maturity on sensory attributes of beef produced be grain-finished steers and heifers classified as less than 30 months old using dentition. J. Anim. Sci. 92:1792-1799.

Adhikari, K., E. Chambers, IV, R. Miller, L Vasquez-Araujo, N. Bhumiratana, and C. Phillip. 2011. Development of a lexicon for beef flavor in intact muscle. J. Sensory Studies 26:413-420.

Adhikari, K., and R. Miller. 2010. Beef flavor lexicon: A reciprocation session. http://www.meatscience.org/page.aspx?id=6116. (Accessed June 15, 2014.)

American Meat Science Association (AMSA). 1995. Research Guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat. National Livestock and Meat Board, Chicago, IL.

Anderson, P., and J. Gleghorn. 2007. Non-genetic factors that affect quality grade of fed cattle. Proc. Beef Improvement Fed. 39th. Annu. Res. Symp. Annu. Mtg., Fort Collins, CO. *http://beefimprovement.org/content/uploads/2013/07/BIF-Proceedings5.pdf*. (Accessed 26 December 2014.)

Apple, J. K., M. E. Dikeman, D. D. Simms, and G. Kuhl. 1991. Effects of synthetic hormone implants, singularly or in combinations on performance, carcass traits and longissimus muscle palatability of Holstein steers. J. Anim. Sci. 69: 4437-4448.

ASTM. 2011. Standard specification for tenderness marketing claims associated with meat cuts derived from beef. http://www.astm.org/Standards/F2925.htm. (Accesses 5 December 2014.)

Bailey, A. J. 1985. The role of collagen in the development of muscle and its relationship to eating quality. J. Anim. Sci. 60:1580-1587.

Berry, B.W., G. C. Smith, and Z. L. Carpenter. 1974. Beef carcass maturity indicators and palatability attributes. J. Anim. Sci. 38:507-514.

Bond, J., B. W. Berry, H. R. Cross. D. A. Dinius, R. R. Oltjen. 1986. Growth and carcass traits of open beef heifers versus beef heifers that have calved. Nut. Rep. Int. 34: 1.

Breidenstein, B. B., C.C. Cooper, R. G. Casssens, G. Evans, and R. W. Bray. 1968 Influence of marbling and maturity on the palatability of beef muscle. I. chemical and organoleptic considerations. J. Anim. Sci. 27: 1532-1541.

Caldwell, R. W., J. Tuite, M. Stob, and R. Baldwin. 1970. Zearalenone production by Fusarium species. Appl. Mircobiol. 20:31-34.

Campion, D., J. Crouse, and M. Dikeman. 1975. Predictive value of USDA beef quality grade factors for cooked meat palatability. J. Food Sci. 40: 1225-1228.

Covington, R.C., H. J. Tuma, D. L. Grant, and A. D. Dayton. 1970. Various chemical and histological characteristics of beef muscle as related to tenderness. J. Anim. Sci. 30:191-196.

Cranwell, C.D., J. A, Unruh, J. R. Brethour, and D. D. Simms. 1996. Influence of steroid implants and concentrate feeding on carcass and longissimus muscle sensory and collagen characteristics of cull beef cows. J. Anim. Sci. 74: 1777-1783.

Cross, H. R., Z. L. Carpenter and G.C. Smith. 1973. Effects of intramuscular collagen and elastin on bovine muscle tenderness. J. Food Sci. 38: 998-1003.

Duston, T.R. 1974. Connective Tissue. Proc. Meat Ind. Res. Conf.: 1.

DeVuyst, E.A., J. L. Lusk, and M. A. DeVuyst. 2014. The USDA quality grades may mislead consumers. J. Anim. Sci. 92:3142-3148.

Emerson, M. R., D.R. Woerner, K.E. Belk, and J.D. Tatum. 2013. Effectiveness of USDA instrument-based marbling measurements for categorizing beef carcasses according to differences in longissimus muscle sensory attributes. J. Anim. Sci. 91:1024-1034.

Erasmuson, A. F., B. G. Scahill and D. M. West. 1994. Natural zeranol (α-zearalanol) in the urine of pasture-fed animals. J. Agric. Food Chem. 42:2721-2725.

Field R., R. McCormick, V. Blasubramanian, D. Sanson, J. Wise, D. Hixon, M. Riley, and W. Russell. 1996. Growth, carcass and tenderness characteristics of virgin, spayed and single-calf heifers. J. Anim. Sci. 74: 2178-2186.

Field R., R. McCormick, V. Blasubramanian, D. Sanson, J. Wise, D. Hixon, M. Riley, and W. Russell. 1997. Tenderness variation among loin steaks from A and C maturity carcasses of heifers similar in chronological age. J. Anim. Sci. 75:693-699.

Fishell, V. K., E. D. Arbele. M. D. Judge, and T. W. Perry. 1985. Palatability and muscle properties of beef as influenced by pre-slaughter growth rate. J. Anim. Sci. 61:151-157.

Foutz, C. P., H. G. Dolezal, T. L. Gardner, D. R. Gill, J. L. Hensley, and J. B. Morgan. 1997. Anabolic implant effects on steer performance, carcass traits, subprimal yields and longissimus muscle properties. J. Anim. Sci. 75:1256-1265.

Galey, F. D., L. E. Mendez, W. E. Whitehead, D. M. Holstege, K. H. Plumlee, and B. Johnson. 1993. Estrogenic activity in forages; Diagnostic use of the classical mouse uterine bioassay. J. Vet. Diag. Invest. 5:603-608.

Goll, D. E., R. Bray, and W. Hoekstra. 1963. Age-associated changes in muscle composition. the isolation and properties of a collagen tesidue from bovine muscle. J. Food Sci. 28: 503-509.

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

Grumbach, M. M., and R. J. Auchus. 1999. Estrogen: Consequences and implications of human mutations in synthesis and action. J. Clin. Endocrinol. Metab. 84:4677-4694.

Hill, F. 1966. The Solubility of Intramuscular Collagen in Meat Animals of Various Ages. J. Food Sci. 31:161-166.

Hilton, G. G., J. D. Tatum, S. E. Williams, K. E. Belk, F. L. Williams, J. W. Wise, and G. C. Smith. 1998. An evaluation of current and alternative systems for quality grading carcasses of mature slaughter cows. J. Anim. Sci. 76: 2094-2103.

Hiner, R. L. 1956. Visual evidence of beef quality as associated with eating desirability. Proc. Recip. Meat Conf. 9:20.

Hoffman, B., W. C. Wagner and T. Gimenez. 1976. Free and Conjugated Steroids in Maternal and Fetal Plasma in the Cow Neat Term. Biol. Reprod. 15: 126-133.

Klindt, J. and J. D. Crouse. 1990. Effect of ovariectomy and ovariectomy with ovarian autotransplantation on feedlot performance and carcass characteristics of heifers. J. Anim. Sci. 68: 3481-3487.

Koch, R. M., M. E. Dikeman, D. M. Allen, M. May, J. D. Crouse and D. R. Campion. 1976. Characterization of biological types of cattle III. Carcass composition, quality and palatability. J. Anim. Sci. 43:48-62.

Kreikmeier, K. K., and J. A. Unruh. 1993. Carcass triats and the occurance of dark cutters in pregnant and nonpregnant feedlot heifers. J. Anim. Sci. 71:1699-1703.

Lawrence, T. E., J. D. Whitley, T. H. Montgomery, L. J. Perino, and M. E. Dikeman. 2001. Influence of dental carcass maturity classification on carcass traits and tenderness of longissimus from commercially fed cattle. J. Anim. Sci. 79:2092-2096.

Laudert, S. B. 1988. Incidence of pregnancy in feedlot heifers at slaughter. http://krex.k-state.edu/dspace/bitstream/handle/2097/6554/cattle88pg112-114.pdf.;jsessionid=65A6E0F6CB87894BC26E9100A5D6E69B?sequence=1 (Accessed 26 December 2014.)

Lorenzen, C. L., C. R. Calkins, M. D. Green, R. K. Miller, J. B. Morgan, and B. E. Wasser. 2010 Efficacy of performing Warner-Bratzler and slice shear force on the same beef steak following rapid cooking. Meat Sci. 85:792-794.

McBee, J. L., and J. A. Wiles. 1967. Influence of marbling and carcass grade on the physical and chemical characteristics of beef. J. Anim. Sci. 26:701-704.

McClain, P. 1977. Chemistry of collagen crosslinking: relationship to aging and nutrition. Adv. Exp. Med. Biol. 86.

McCormick. R.J. 1994. The flexibility of the collagen compartment of muscle. Meat Sci. 36:79-91.

McCormick, R. J. 1999. Extracellular modifications to muscle collagen: Implications for meat quality. Poultry Sci. 78: 785-791.

McKenna, D. Warner-Bratzler Shear Force Measurement. College Station, TX. http://animalscience.tamu.edu/wp-content/uploads/sites/14/2012/04/ASWeb072-warnerbratzler.pdf. (Accessed 21 December 2014.)

McKenna, D. R., D. L. Robert, P. K. Bates, T. B. Schmidt, D. S. Hale, D. B. Griffin, J. C. Brooks, J. B. Morgan, T. H. Montgomery, K. E. Belk, and G. C. Smith. 2002. National Beef Quality Audit- 2000: survey of targeted cattle and characteristics related to quality, quantity, and value of fed steers and heifers. J. Anim. Sci. 80: 1212-1222.

Miller, M. F., H. R. Cross, J. D. Crouse, and T. G. Jenkins. 1987. Effect of feed energy intake on collagen characteristics and muscle quality of mature cows. Meat. Sci. 21:287-294.

Miller R., J. Tatum, H, Cross, R. Bowling, and R Clayton. 1983. Effects of Carcass maturity on collagen solubility and palatability of beef from grain-finished steers. J. Food Sci. 48:484-486.

Miller, R., and K. Prusa. 2010. Sensory evaluation of pork. http:// www.extension.org /pages/27315/sensory-evaluation-of-pork. (Accessed 15 June 2014.)

Millward, D., and J. Waterlow. 1978. Effect of nutrition on protein turn-over in skeletal muscle. In: Fed. Proc. p 2283.

Moody, W. 1976. Quantitative and qualitative differences in beef from various energy regimes. In: Proc. Recip. Meat Conf. p 128.

Moore, M. C., G.D. Gray, D. S. Hale, C. R. Kerth, D. B. Griffin, J. W. Savell, C.R. Raines, K. E. Belk, D. R. Woerner, J. D. Tatum, J. L. Igo, D. L. VanOverbeke, G. G. Mafi, T. E. Lawrence, R. J. Delmore, L. M. Christensen, S. D. Shackelford, D.A. King, T. L. Wheeler, L. R. Meadows, and M. E. O'Connor. 2012. National Beef Quality Audit-2011: In-plant survey of targeted carcass characteristics related to the quality, quantity, value and marketing of fed steers and heifers. J. Anim. Sci. 90: 5143-5151.

O'Connor, M. E. J. R. Ransom, and M. Feil. 2007. USDA physiological maturity validation study: Validating the relationship between chronological age and physiological maturity in the U. S. fed-beef population. http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELDEV3097778. (Accessed 18 October 2014.)

Paisley, S. I., G. W. Horn, C. J. Ackerman, B. A. Gardner, and D. S. Secrist. 1999. Effects of implants on daily gain of steers wintered on dormant native tallgrass prairie, subsequent performance, and carcass characteristics. J. Anim. Sci. 77: 291-299.

Platter, W. J., J. D. Tatum, K. E. Belk, J. A. Scanga, and G. C. Smith. 2003. Effects of repetitive use of hormonal implants on beef carcass quality, tenderness, and consumer ratings of beef palatability. J. Anim. Sci. 81: 984-996.

Pruslow, P. P. 2005. Intramuscular connective tissue and its role in meat quality. Meat Sci. 70:435-447.

Reiling, B. A., and D. D. Johnson. 2003. Effects of implant regiments (trenbolone acetate-estradiol administered alone or in combination with zeranol) and vitamin D3 on fresh beef color and quality. J. Anim. Sci. 81: 135-195.

Roeber, D. L., R. C. Cannell, K. E. Belk, R. K. Miller, J. D. Tatum, and G. C. Smith. 2000. Implant strategies during feeding: impact on carcass grades and consumer acceptability. J. Anim. Sci. 78: 1867-1874.

Romans, J. R., H. J. Tuma, and W. L. Tucker. 1965. Influence of carcass maturity and marbling on the physical and chemical characteristics of beef. II. Muscle pigments and color. J. Anim. Sci. 24:686-690.

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

Schnell, T. D., K. E. Belk, J. D. Tatum, R. K. Miller, and G.C. Smith. 1997. Performance, carcass, and palatability traits for cull cows fed high-energy concentrate diets for 0, 14, 28, 42, or56 days. J. Anim. Sci. 75: 1195-1202.

Shackelford, S. D., M. Koohmaraie, and T. L. Wheeler. 1995a. Effects of slaughter age on meat tenderness and USDA carcass maturity scores of beef females. J. Anim. Sci. 73:3304-3309.

Shackelford, S. D., T. L. Wheeler, and M. Koohmaraie. 1995b. Relationship between shear force and trained sensory panel tenderness ratings of 10 major muscles from Bos indicus and Bos Taurus cattle. J Anim. Sci. 73: 3333-3340.

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

Smith, G., B.W. Berry, J.W. Savell, and H.R. Cross. 1988. USDA maturity indices and palatability of beef rib steaks. J. Food Qual. 11:1-13.

Schönfeldt, H. C., P. E. Strydom. 2011. Effect of age and cut on tenderness of South African beef. Meat Sci. 87: 206-218.

Smith G.C., H. R. Cross, Z. L. Carpenter, C. E. Murphey, J. W. Savell, H. C. Abraham. G.W. Davis. 1982. Relationship of USDA maturity groups to palatability of cooked beef. J. Food Sci. 47.

Smith, S. H., and M. D. Judge. 1991. Relationship between pyridioline concentration and thermal stability of bovine intramuscular collagen. J. Anim. Sci. 69: 1989-1993.

Smith, V. G., L. A. Edgerton, H. D. Hafs, and E. M. Convey. 1973. Bovine Serum Estrogens, Progestins and Glucocorticoids during Late Pregnancy, Parturition and Early Lactation. J. Anim. Sci. 36. 391-396.

Tatum, J. D., G.C. Smith, B.W. Berry, C. E. Murphey, F. L. Williams, and Z. L. Carpenter. 1980. Carcass characteristics, time on feed and cooked beef palatability attributes. J. Anim. Sci. 50: 833-840.

Tatum, J. D. 2006. Pre-harvest cattle management practices for enhancing beef tenderness. Centennial, CO. http://www.beefresearch.org/cmdocs/beefresearch/pe_executive _summaries/pre_harvest_cattle_management.pdf. (Accessed 20 December 2014.)

Tatum J. D. 2011. Animal age, physiological maturity, and associate effects on beef tenderness. Centennial, CO. http://www.beefresearch.org/cmdocs/beefresearch/pe_white_%20 papers/animal_age.pdf. (Accessed 21 Jan. 2014.)

Tatum J. D. 2007. Beef grading. http://www.beefresearch.org/cmdocs/beefresearch/pe_fact _sheets/beef_grading.pdf. (Accessed 15 November 2014.)

Tuma, H. J. R. L. Henrickson, G. V. Odell, and D. F. Stephens. 1963. Variation in the physical and chemical characteristics of the longissimus dorsi muscle from animals differing in age. J. Anim. Sci. 22: 354-357.

Turner, H. A., R. L. Phillips, M. Vavra, D. C. Young. 1981. The Efficacy of an Estradiol-Silicone Rubber Removable Implant in Suckling, Growing and Finishing Steers. J. Anim. Sci. 52: 939-944.

USDA. 2015. National weekly direct slaughter cattle. USDA Market News Service, St. Joseph MO. http://www.ams.usda.gov/mnreports/lm_ct155.txt. (Accessed Janruary 5, 2015).

USDA. 2005. Final Report to the Government of Japan on the USDA Maturity Study: Determining the relationship between chronological age and physiological age in the U.S. fed beef population. http://www.avc-beef.org/AgingCattle-Griffin/USDA-AMS-BeefPhysiologicMaturity.pdf. (Accessed January 5, 2015)

USDA. 1997. United States Standards for Grades of Carcass Beef. United States Department of Agriculture, Agricultural Marketing Service, Washington, DC.

Waggoner, A. W., A. E. Dikeman, J. R. Brethour, and K. E. Kemp. 1990. Performance, carcass cartilage calcium, sensory and collagen traits of longissimus muscles of open versus 30 month old heifers that produced one calf. J. Anim. Sci. 68: 2380-2386.

Walter, M. J., D. E. Goll, E. A. Kline, L. P. Anderson, and A. F. Carlin. 1965. Effect of marbling and maturity on beef muscle characteristics. Food Technol. 19:841-848.

Wu, J. J., C. L. Kastner, M. C. Hunt, D.H. Kropf and D. M. Allen. 1981. Nutritional effects on beef collagen characteristics and palatability. J. Anim. Sci. 53:1256-1261.

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

Zinn, D. W., C. T. Gaskins, G. L. Gann, and H. B. Hedrick. 1970. Beef Muscle Tenderness as Influenced by Days on Feed, Sex, Maturity, and Anatomical Location. J. Anim. Sci. 31:307-309.

APPENDIX

Appendix A. Least squares means comparing characteristics of steer and heifer carcasses selected to represent 2 dentition distinctions, 2 maturity groups and 3 marbling categories

Effect	*N*	Marbling score[1]	Fat thickness, cm	LM area, cm^2	HCW, kg	Yield grade	KPH, %
Dentition group		*P* = 0.1258	*P* < 0.0001	*P* = 0.3334	*P* = 0.3860	*P* = 0.0058	*P* < 0.0001
<30[3]	300	455	0.58	13.39	865	3.3	1.8
≥ 30[4]	300	459	0.48	13.26	857	3.1	1.7
SEM		2.1	0.01	0.1	6.3	0.1	0.02
Maturity group		*P* = 0.6319	*P* = 0.0194	*P* = 0.0747	*P* = 0.0447	*P* = 0.4985	*P* = 0.6814
A[5]	300	456	0.52	13.20	852	3.2	1.8
B-D[6]	300	458	0.55	13.44	869	3.2	1.8
SEM		2.1	0.01	0.1	6.3	0.1	0.02
Marbling category		*P* < 0.0001	*P* < 0.0001	*P* = 0.0843	*P* = 0.0005	*P* < 0.0001	*P* = 0.0037
Slight	200	361[c]	0.44[b]	13.52	837[b]	2.8[b]	1.71[b]
Small	200	448[b]	0.56[a]	13.29	871[a]	3.3[a]	1.83[a]
Modest+[7]	200	563[a]	0.59[a]	13.16	875[a]	3.5[a]	1.75[b]
SEM		2.9	0.01	0.1	7.7	0.1	0.03
Sex		*P* = 0.3834	*P* = 0.0017	*P* = 0.7785	*P* < 0.0001	*P* = 0.6268	*P* = 0.0261
Heifer	404	456	0.56	13.34	839	3.2	1.8
Steer	196	458	0.51	13.30	883	3.2	1.7
SEM		2.5	0.01	0.1176	7.6	0.1	0.03
DENT X MARB				*P* = 0.0015			
< 30 Slight	100			13.92[a]			
< 30 Small	100			13.15[b]			
< 30 Modest+	100			13.10[b]			
≥ 30 Slight	100			13.12[b]			
≥ 30 Small	100			13.44[b]			
≥ 30 Modest+	100			13.22[b]			
SEM				0.2			
DENT X MAT				*P* = 0.0325			
< 30 A	200			13.41[a]			
<30 B-D	200			13.36[ab]			
≥ 30 A	200			13.00[b]			
≥ 30 B-D	200			13.52[a]			
SEM				0.1			
Sex X MARB		*P* = 0.0390					
Heifer/Slight		360[d]					
Heifer/Small		451[c]					
Heifer/Modest+		556[b]					
Steer/Slight		362[d]					
Steer/Small		444[c]					
Steer/Modest+		569[a]					
SEM		4.8					

[1] Slight = 300 to 399, Small = 400 to 499, Modest = 500 to 599 (USDA, 1997).
[2] LM areas were measured using USDA-approved, grading instruments by accessing plant data archives.
[3] < 30 MOA = carcasses classified as less than 30 months of age by dentition.
[4] ≥ 30 MOA = carcasses classified as 30 months of age or older by dentition.
[5] A= carcasses exhibiting A^{00} to A^{99} overall maturity characteristics.
[6] B-D = carcasses exhibiting B^{00} to D^{99} overall maturity characteristics.
[7] Modest+ = carcasses with Modest ^{00} to Moderate ^{99} marbling scores.
[8] SEM = pooled standard error.
[a-c] Means in the same column within an effect that do not share a common superscript letter differ (P < 0.05).

Appendix B. Correlations among camera marbling score, dentition, overall maturity, panel ratings for beef sensory attributes and LM shear force measurements

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Marbling Score		0.03	0.03	-0.15	-0.05	0.01	-0.02	0.27	0.29	0.52	-0.27	-0.08	-0.12	-0.02	0.34	-0.23	-0.12
2. Overall Maturity	0.03		0.98	0.23	-0.34	-0.02	-0.10	-0.01	0.06	0.04	-0.05	-0.04	0.03	0.09	-0.06	0.03	0.03
3. Skeletal Maturity	0.03	0.98		0.19	-0.34	-0.01	-0.09	-0.03	0.06	0.02	-0.05	-0.04	0.03	0.08	-0.07	0.03	0.03
4. Lean Maturity	-0.15	0.23	0.19		-0.08	-0.03	-0.03	-0.05	-0.01	-0.12	0.12	0.09	0.08	0.08	-0.13	0.06	0.12
5. L*	-0.05	-0.34	-0.34	-0.08		0.20	0.46	-0.03	-0.03	-0.05	-0.01	0.06	0.01	-0.01	-0.04	0.04	0.09
6. a*	0.01	-0.02	-0.01	-0.03	0.20		0.77	0.02	0.05	0.01	-0.01	-0.01	-0.00	-0.05	-0.04	0.08	0.15
7. b*	-0.02	-0.10	-0.09	-0.03	0.46	0.77		-0.02	0.02	-0.04	0.00	0.02	-0.03	0.00	-0.05	0.07	0.12
8. Juiciness	0.27	-0.01	-0.03	-0.05	-0.03	0.02	-0.02		0.24	0.63	0.09	-0.08	-0.18	-0.10	0.50	-0.15	-0.09
9. Meaty/ brothy flavor	0.29	0.06	0.06	-0.01	-0.03	0.05	0.02	0.24		0.45	-0.21	-0.22	-0.21	-0.16	0.30	-0.09	-0.10
10. Butteryy/ beef fat flavor	0.52	0.04	0.02	-0.12	-0.05	0.01	-0.04	0.63	0.45		-0.27	-0.23	-0.28	-0.18	0.51	-0.23	-0.16
11. Bloody/ serumy flavor	-0.27	-0.05	-0.05	0.12	-0.01	-0.01	0.00	0.09	-0.21	-0.27		0.25	0.19	0.10	-0.08	0.08	0.02
12. Livery/ organy favor	-0.08	-0.04	-0.04	0.09	0.06	-0.01	0.02	-0.08	-0.22	-0.23	0.25		0.45	0.43	-0.10	0.03	0.02
13. Grassy flavor	-0.12	0.03	0.03	0.08	0.01	-0.00	-0.03	-0.18	-0.21	-0.28	0.19	0.45		0.32	-0.16	0.08	0.07
14. Gamey flavor	-0.02	0.09	0.08	0.08	-0.01	-0.05	0.00	-0.10	-0.16	-0.18	0.10	0.43	0.32		-0.14	-0.00	0.05
15. Tenderness	0.34	-0.06	-0.07	-0.13	-0.04	-0.04	-0.05	0.50	0.30	0.51	-0.08	-0.10	-0.16	-0.14		-0.52	-0.54
16. WBSF[2]	-0.23	0.03	0.03	0.06	0.04	0.08	0.07	-0.15	-0.09	-0.23	0.08	0.03	0.08	-0.00	-0.52		0.59
17. SSF[3]	-0.12	0.03	0.03	0.12	0.09	0.15	0.12	-0.09	-0.10	-0.16	0.02	0.02	0.07	0.05	-0.54	0.59	

[1] Coefficients > 0.10 ($P < 0.01$)

[2] Warner-Bratzler Shear Force

[3] Slice Shear Force

Appendix C. Sample ballot used for sensory panels

Tenderness	Extremely Tough	Extremely Tender
Juiciness	Extremely Dry	Extremely Juicy
Beefy/Brothy	No Presence	Very Strong Presence
Butteryy/Beef	No Presence	Very Strong Presence
Bloody/Serum	No Presence	Very Strong Presence
Livery/Organy	No Presence	Very Strong Presence
Grassy/Fishy	No Presence	Very Strong Presence
Gamey	No Presence	Very Strong Presence