THESIS

RELATIONSHIPS BETWEEN USDA CAMERA-BASED QUALITY GRADES AND BEEF SENSORY ATTRIBUTES

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ABSTRACT

RELATIONSHIPS BETWEEN USDA CAMERA-BASED QUALITY GRADES AND BEEF SENSORY ATTRIBUTES

This study quantified relationships of recently adopted camera-based USDA beef quality grades to LM sensory attributes and shear force. Heifer and steer carcasses (n = 718, all A-maturity) were selected at beef processing plants in CO, KS, NE, and TX, using marbling scores determined by on-line camera grading systems, to represent 7 marbling degrees: Traces (TR), Slight (SL), Small (SM), Modest (MT), Moderate (MD), Slightly Abundant (SA), and Moderately Abundant (MA). Strip loin steaks were obtained from both sides of each carcass and aged for 14 d. One steak was used to obtain Warner-Bratzler shear force (WBSF) and slice shear force (SSF) measurements; the other steak was evaluated by a trained sensory panel for juiciness, tenderness, detectable levels of several flavors (meaty/brothy, buttery/beef fat, bloody/serumy, livery/organy, and grassy), and overall sensory experience (negative vs. positive). Camera marbling score explained 45, 40, 32, 71, and 61% of the variation in panel ratings for juiciness, tenderness, meaty/brothy flavor intensity, buttery/beef fat flavor intensity, and overall sensory experience, respectively.

Increased degree of marbling resulted in steaks having greater ($P < 0.001$) juiciness, tenderness, meaty/brothy flavor intensity, and buttery/beef fat flavor intensity. The likelihood of a steak delivering a positive sensory experience also became greater ($P < 0.001$) as degree of marbling increased (MA = SA > MD = MT > SM > SL > TR). Nearly all (98 to 99%) of the steaks with MA and SA marbling, and most (between 80 and 90%) of the steaks with MD and MT marbling received positive ratings for overall sensory experience compared with 62% of the SM steaks, 29% of the SL steaks and 15% of the TR steaks. Steaks produced by steers had lower ($P < 0.05$) WBSF and SSF values and were generally rated as more tender by sensory panelists than steaks produced by heifers, but the effect of sex on panel tenderness was significant only within the TR category. Comparison of 2 methods for determining camera-based quality grades (i.e., use of original camera grade lines, based on marbling assessments of USDA grading experts vs. use of adopted camera grade lines, based on marbling assessments of field graders) showed that both methods of grade placement effectively stratified carcasses into grades that differed ($P < 0.05$) with respect to steak juiciness, tenderness, and flavor, with little discernible difference between methods.

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CHAPTER I

INTRODUCTION

For more than 8 decades, beef carcasses (and resulting primal and sub-primal beef cuts) have been sorted into marketing categories that differ with respect to expected eating quality using USDA beef quality grades. Although the US Standards for Grades of Carcass Beef have been revised or amended 12 times since their adoption in 1926, the basic elements of the original beef quality grades (i.e., assessments of physiological maturity and amount of marbling) remain in use today (USDA, 1997). The most significant and controversial change in the Standards occurred in 1975, when marbling-maturity relationships were redefined, reducing minimum marbling requirements for the Prime, Choice, and Standard grades by as much as one full marbling score within the A and B maturity groups. Shortly after the 1975 revision, USDA-AMS commissioned a study to document the relationships of maturity and marbling to beef palatability traits. That study, which was completed in 1980 (Smith et al., 1980), represents the most recent comprehensive scientific evaluation of the beef quality grade standards.

Much has changed in the beef industry since 1980. Cattle feeding and management practices have been modified – more by-product feeds are being utilized, growth enhancement programs have become more aggressive, and today's cattle are harvested at younger average ages. In addition, the genetic make-up of the US fed cattle population and the grade-mix within the fed beef supply gradually have changed. Beef carcass grading procedures also have evolved. Camera-assisted quality grading recently was approved for use by USDA-AMS and has now been implemented in several US beef plants, providing for greater objectivity and consistency of grade application, together with more precise definition of marbling intersects between grades.

For purposes of approving the use of instrument grading systems for official marbling assessment, USDA developed a rigorous 2-phase testing protocol that required instruments to accurately predict “gold standard” marbling scores (estimated to the nearest 10 marbling units) at commercial production speeds. The “gold standard” for marbling used by USDA to certify and calibrate grading instruments was a “mean expert panel marbling score” calculated on an individual carcass basis using the independent marbling assessments of a 5-member panel of USDA-AMS grading experts. More than 4,000 beef carcasses representing the full range in marbling were used to establish the relationship between instrument-predicted marbling and “gold standard” marbling. Following the 2006 approval of 2 instrument grading systems (VGB2000, E+V Technology, Oranienburg, Germany and Computer Vision System, Research Management Systems, Inc., Fort Collins, CO), further testing in commercial beef plants revealed disparity between grades assigned using the instruments and grades assigned by USDA field graders. Instrument grades were considerably lower than grades assigned by field graders and the disparity in grading was large enough to prevent adoption of instrument-based quality grading by commercial beef processors. After several months of data collection and analysis (involving a sample of over 400,000 carcasses), USDA officials eventually aligned instrument-based quality grades with those assigned by

USDA field graders to facilitate a seamless transition into technology augmented grading (O'Connor, 2009). This adjustment of instrument-based quality grades resulted in the following marbling intersects between quality grades, expressed in "gold standard" marbling units: Standard/Select = Traces^{83}, Select/Choice = Slight^{81}, Choice/Prime = Moderate ^{38} (O'Connor, 2009). The calibration of grading instruments to match marbling assessments by field graders, rather than the "gold standard" for marbling, while necessary to encourage industry adoption of instrument-based quality grading, has been viewed as a reduction in beef quality standards by some critics.

The new, objectively determined marbling standards theoretically should remain unchanged (within limits of instrument precision) from plant-to-plant, region-to-region, and year-to-year. Considering the changes that have occurred since the last evaluation of the beef quality grading system and due to the development of instrument-based objective marbling standards for beef quality grading, the need for a re-evaluation of the USDA quality grades for carcasses comprising the U.S. fed beef supply to determine relationships between recently implemented camera-based USDA quality grades and palatability attributes (tenderness, flavor, and juiciness) of fed steer and heifer beef, is apparent.

CHAPTER II

REVIEW OF LITERATURE

Development of USDA Beef Grading Standards

The Official United States Standards for Grades of Carcass Beef (USDA, 1997) were most recently reprinted with amendments effective January 31, 1997. Since their inception in 1916, United States beef grading standards have been utilized to better serve the industry using the most accurate representations of the current beef market and practices. Standards for grades of beef were first published in mimeograph form in 1923. After minor adjustments, the standards were published as a department bulletin, "Market classes, and Grades of Dressed Beef", in 1924. In 1925, public hearings were conducted in Portland, OR, Chicago, IL, and New York, NY, in order to allow various sectors of the industry to provide their professional insight on the standards. Few suggestions were made, but all were taken into careful consideration as potential improvements to the standing document. After approved revisions were made, the standards were declared the Official United States Standards for the Grades of Carcass Beef by the Secretary of Agriculture on June 3, 1926. When voluntary grading services began in 1927, this document provided the guidelines by which the service operated. The standards were initially used to establish selection aids and specification guides for government purchases of beef products. This included beef purchased for the military and other commercial transactions.

Standards for grades of beef continued to evolve as necessary amendments have been made 12 times to better satisfy the needs of the industry. Revisions to the standards in 1939 and 1941 provided a specific set of standards for steer, heifer, and cow carcasses as well as a separate set for carcasses of bull and stag beef, separating beef into standards based on similar quality characteristics. The 1939 and 1941 revisions also established USDA Prime, Choice, Good, Commercial, Utility, Cutter, and Canner as official grade designations for all beef. Use of fat color for grade determination was eliminated in 1949.

Additional amendments were added to the standards in 1950. The 1950 amendments were made to better clarify the grade interpretations so that carcasses could be better segregated into existing quality grades, making grade use better facilitated. In 1956, USDA Commercial was separated into two separate quality grades, adding Standard to the grades for young carcasses previously designated as Commercial, and retaining Commercial for older carcasses.

For the grades USDA Prime, Choice, Good, and Standard were amended to receive less emphasis on maturity for their determination in 1965. Additional amendments were also made in 1965 to clarify conformation requirements, establish a requirement of cattle being ribbed before quality grade assignment, and the addition of cutability grades to the standards. In 1973, the term “Yield Grade” was coined to replace cutability grades. Also included in the 1973 revisions, a segregation of carcasses designated “bull” was made. Due to their superior eating characteristics when compared to more mature bulls, young bulls received a separate distinction as bullocks. Quality grades for young bull carcasses more closely resembled the grades of steer, heifer, and cow beef; however bullock grades only included five quality grades, Prime, Choice, Good, Standard, and Utility. The term “bull” was retained for carcasses of mature bulls, but quality grades for “bulls” were eliminated making them eligible for yield grading only.

In 1975, less emphasis was placed on maturity for carcasses from cattle in the youngest maturity group, referenced at that time. Additionally, the use of conformation when assigning quality to all beef carcasses was eliminated. Changes made to the Good grade, also made grade selection more restrictive and directed toward a leaner carcass and allowed for an increased measure of value that more readily differentiated those cattle grading Good from those in the Choice grade.

Changes made in 1980 specified conditions concerning the removal of yield grade stamps from the carcass or cuts and carcass grading eligibility. The edits deemed carcasses with fat tampered or damaged at the ribeye ineligible for yield grading. Also, the changes restricted carcass grading services to only include establishments where cattle were slaughtered or where cattle were initially chilled. The minimum allowed time from ribbing to the assignment of grades also was set at 10 minutes. These changes were meant to increase accuracy as well as uniformity in the assignment of beef grades.

In 1987, the Good grade underwent a name change to Select for all steer, heifer, cow, and bullock beef. This was followed by a change that allowed for USDA graders to assign yield and quality grades independently of one another or together on a given carcass in 1989. The most recent amendments occurred in 1997 when the Select grade was limited to A maturity carcasses only and Choice required a minimum marbling score of modest for B maturity carcasses in order to increase uniformity and consistency within Choice and Select quality grades. With these changes, B-maturity cattle with a marbling score of slight or small now grade Standard.

Current USDA Beef Grading Standards

The United State Department of Agriculture (USDA) established *United States Standards for Grades of Carcass Beef* (USDA, 1997) with the purpose of separating beef carcasses into categories based on differences in quality and composition in order to aid in the marketing of beef. Official Quality Grades and Yield Grades are two separate assignments designed to predict eating quality and estimate beef carcass cutability, respectively (USDA, 1997). Grades are determined or accepted by an employee of the USDA, independently of producers and packers as part of a voluntary, service paid for by the packer.

Yield Grading. USDA Yield Grades are calculated for all classes of beef in order to estimate the carcass yield of closely trimmed, boneless retail cuts derived from the major wholesale cuts. Beef yield grades range numerically from 1.0 to 5.9, by tenth, with lower numerical yield grades representing carcasses with a higher percent of boneless, closely trimmed retail cuts. Four factors, external fat thickness over the ribeye, ribeye area, hot carcass weight, and percentage of kidney, pelvic, and heart fat (KPH) are evaluated and used to determine beef carcass yield grades. These factors are utilized in the following equation to calculate beef yield grades: Yield Grade = 2.5 + (2.5 x adjusted fat thickness, inches) + (0.20 x percent kidney, pelvic, and heart fat) + (0.0038 x hot carcass weight, pounds) - (0.32 x ribeye area, square inches). Fat thickness is a single measurement, at a point opposite the ribeye, three-fourths the length of the ribeye from the chined side. The measurement may then be adjusted to more accurately predict overall carcass fatness with adjustments made for less or additional fat located on other regions of the carcass. Carcass muscularity is predicted using the relationship between ribeye area and hot carcass weight. The adjustment for KPH is based on a subjective estimate of the percentage of carcass weight present as fat located in and around the kidneys, pelvic cavity, and heart. Although the USDA Yield Grade equation provides a basis for yield grading carcasses, yield grades are most commonly assigned based on a grader's previous training and without calculating the yield grade of each carcass.

Quality Grading. Beef quality grades are utilized to assign beef carcasses to groups that differ with respect to expected eating quality. Graders employ indicators of physiological maturity as well as marbling in order to assign quality grades. Due to maturity's direct effect on tenderness, five maturity groups, A through E, with A being the youngest and E being the oldest, were developed to better predict eating experience. Physiological maturity is determined by skeletal ossification as well as lean color. Visual evaluation of the amount, distribution, and texture of intramuscular fat located in the cut surface at the 12^{th} rib intersection provide the means for determining marbling scores ranging from the highest amount, Abundant, to the lowest amount, Practically Devoid. A combination of one of the ten marbling scores and maturity compose the final quality grade. For beef there are eight USDA Quality Grades: USDA Prime, Choice, Select, Standard, Commercial, Utility, Cutter, and Canner. Generally, USDA Prime represents carcasses of the most desirable or palatable grade and USDA Canner, the lowest. Prime, Choice, Select, and Standard most commonly represent younger cattle while Commercial, Utility, Cutter, and Canner groups are comprised of carcasses classified as “C” maturity or older.

Beef Carcass Instrument Quality Grading

A 1978 GAO investigative report to the U.S. Congress, concluded that USDA’s highly subjective beef grading system lacked accuracy and consistency and that these issues would persist until objective grading instruments could be developed (GAO, 1978). Advancements made by way of Video Image Analysis (VIA) are now being implemented to aid in the assignment of USDA beef grades. VIA technologies were approved for official measurement of beef carcass LM area by the USDA in 2003 as well as the assignment of USDA Yield grades by the USDA in 2005 (National Cattlemen’s Beef Association 2007). Nevertheless, U.S. beef quality grades continued to be based on subjective assessments of marbling until 2006 when 2 camera-based grading systems, designed to objectively quantify marbling, were approved for use in determining official USDA quality grades (Woerner and Belk, 2008). By utilizing instruments to aid in the grading of beef carcasses, the USDA aimed to increase accuracy as well as uniformity of grade application within the industry (USDA, 2009).

Prior to USDA approval of VIA instruments to augment the assignment of USDA Quality grades, Moore et al. (2010) conducted a 3-phase study to utilize output data from a VIA-Computer Vision System (VIA-CVS; Research Management Systems Inc., Fort Collins, CO) in developing a standardized method of evaluating VIA marbling score output for accuracy, precision, and repeatability. It was reported that the current CVS VIA system was capable of operating with great accuracy (>89%), precision, and repeatability (>99.5%) (Moore et al., 2010). In order to gain final USDA approval, grading instruments were required to meet Prime I performance standards for prediction of marbling assessments of a 5-member USDA expert grading panel when operated at stationary as well as commercial production speeds (USDA, 2006).

However, instrument grading was not implemented immediately because post-approval testing revealed considerable disparity between grades assigned by instruments and grades assigned by USDA field graders. Instruments underestimated marbling scores assigned by field graders and the resulting differences in grade placement were great enough to prevent industry adoption of camera-assisted quality grading. After extensive evaluation, involving grade comparisons among more than 400,000 carcasses, USDA officials eventually aligned camera-based quality grades with grades assigned by USDA field graders (O'Connor, 2009), leading to a more wide spread adoption of instrument-assisted quality grading by beef processors.

This adjustment of instrument-based quality grades resulted in the following marbling intersects between quality grades, expressed in "gold standard" marbling units: Standard/Select = Traces^{83}, Select/Choice = Slight^{81}, Choice/Prime = Moderate ^{38} (O'Connor, 2009).

Fat Deposition

As an animal reaches market weight, given a normal plane of nutrition, it accumulates fat as part of normal growth. In early research involving lambs and swine respectively, Hammond (1932) and McMeekan (1940) discovered that tissue growth and development occurred first in the animal's skeleton (bone growth),then in muscle tissues, and lastly in fat tissues. Several years later, Berg and Butterfield (1968) made very similar conclusions for the sequence of tissue growth and development in cattle. Adipose tissue or fat is deposited in order of visceral, intermuscular, subcutaneous, and intramuscular (Andrews, 1958). Intramuscular fat, , also commonly referred to as marbling in meat, is deposited between the muscle bundles near the blood vessels within perimysial connective tissue network (Aberle et al., 2001). Although much is known about the locations and order in which fat is accumulated, much less is known about the actual biological processes involved in fat deposition. According to Gerrard and Grant (2003) adipogenesis begins with the formation of precursor cells (adipoblasts) located in the mesoderm of a developing embryo. In the earliest stages of adipose tissue development, adipoblasts are formed mesenchymal cells associated with connective tissures. As the connective tissue develops, it undergoes increased vascularization, building an extensive capillary network necessary for increased blood flow, which is essential for the storage of energy in the body. Adipoblasts then begin to gather into lobes which, in turn, proliferate into new cells. Replication is ceased in response to various signals and some adipoblasts differentiate into preadipocytes which contain small lipid droplets that eventually colese into one larger lipid globule. After maturation, the adipocyte becomes the predominant cell type of adipose tissue. In the presence of adequate energy for fat deposition, lipids continue to deposit in the adipocytes enlarging the cell by way of hypertrophy. As an animal ages, adipose cell hypertrophy results in an increase in cell diameter as well as cell volume as lipid is accumulated (Gerrard and Grant, 2003). In addition to hypertrophic growth, some research suggests that adipose tissue enlargement may also occur by way of hyperplasia or an increase in cell number. Growth of adipose tissue has also been shown to be attributed to additional cells recruited from surrounding connective tissue (Signh et al. 2007). Preadipocytes can fill with adequate lipid to be considered large enough to count as an adipocyte or actual differentiation and proliferation of new adipocytes stimulated by growth can occur (Hood, 1982). In support of growth via hyperplasia, it has also been shown, in cell culture models, that mature adipocytes already containing considerable lipid deposition are still able to proliferate (Fernyhough et al., 2005). Smaller sized adipocytes, in the presence of an existing population of mature adipocytes, provide evidence that the smaller cells were in fact recruited, contributing to hyperplasia of the cell, as the mean diameter of the mature adipocytes increased. Repeated phases of such recruitment are often evident in obese animals (Gerrard and Grant, 2003).

Marbling Relationships

Meat quality includes flavor, juiciness, tenderness, appearance or color (Bray, 1966; Kauffman et al., 1959), and texture (Weir, 1960). Studies conducted over the past several decades to quantify marbling's contribution to differences in eating quality of beef generally have established low to moderate, positive relationships between marbling and cooked beef tenderness, juiciness, and flavor (Briskey and Bray, 1964; Jeremiah et al., 1970; Smith et al., 2008). In a study involving LM steaks from youthful (A-maturity) carcasses with marbling scores ranging from Practically Devoid (PD) to Abundant (AB), Campion et al. (1975) reported that marbling accounted for no more than 10% of the variation in any of the organoleptic properties of beef and suggested that intramuscular fat content may be relatively unimportant in steaks produced by young cattle. In contrast, much stronger, positive relationships between marbling and beef palatability characteristics were reported by Smith et al. (1984), who found that, among LM steaks from A-maturity carcasses, differences in marbling (ranging from PD to MA) explained

24, 27, 30, and 34% of the variation in sensory panel ratings for juiciness, tenderness, flavor, and overall palatability, respectively.

Flavor. The sensations of odor, taste, texture, temperature, and pH combine to equate flavor (Lawrie, 1966). Beef flavor is one that is very complex with a wide variety of influences as well as descriptive terms. Previous beef flavor studies have focused on beef flavor as a single collective measurement of these complex profiles. Smith et al., (1984) indicated that steaks derived from A-maturity cattle, with higher marbling scores had more desirable mean flavor ratings 31.7% of the time when compared to A-maturity steaks with lower marbling scores. Hiner (1956) and McBee and Wiles (1967) also stated that flavor increased in a direct, linear relationship with additional degrees of marbling. It is suggested that diet plays a large role in the development of beef flavor and can undergo changes of flavor precursors as a direct result of feed type. When compared with cattle produced corn diets, cattle fed grass diets differ in concentrations of many flavor precursors. The differences in flavor found between cattle slaughtered directly off of pasture and those finished on high energy, corn diets differs in the greatest magnitude when compared to studies evaluating other feed regimens (Melton, 1990). Differences noted by Melton (1990), however, showed confounding results from a variety of studies reseraching which feeding practices result in more desirable beef flavor. It can simply be concluded that the flavors are different, thus adding to the argument of the complexity and subjectivity of beef flavor.

Carrie Oliver (2007), founder of The Artisan Beef Institute, includes flavor profiles such as flat, cheese notes, caramelized, buttered popcorn, tangy, nutty, seaweed, grass, iron, blood, and barnyard, among others, as complex descriptors potentially found in beef. Oliver encourages the use of such descriptors to classify sensory and savory notes of beef much like a taster evaluates wine. A flavor lexicon is an applied set or list of sensory terms that describe a given product for use in descriptive analysis. Lexicons should be discriminating and target key descriptive terms that differentiate yet represent the broad representative sample (Drake and Civille, 2002). Panels trained using beef lexicons or similar flavor descriptors, are employed in beef flavor research as a tool to decrease variability in the understanding of descriptive terms and their differences to increase the usefulness of the measurements that might otherwise be considered subjective. One of the more standard beef lexicons used today is that developed by Adhikari and Miller (2010) which focus on major beef flavor and aroma notes of beef, brown/roasted, bloody/serumy, fat-like, metallic, liver-like, and Green or hay-like as well as how each note may be simulated or recreated. Most current beef lexicons stemmed from research conducted by Johnsen and Civille (1986) which listed descriptive terms characterized by aromatic notes perceived by olfactory nerve responses, taste bud perceptions, and chemical feelings detected by the trigeminal nerve in the oral cavity.

Flavor descriptors for beef also commonly include meaty, brothy, buttery, fat, bloody, metallic, serumy, liver or organy, and grassy. Definitions of these flavors and related aromas can be found in The Dictionary of Flavors (Rovira, 1999). Meaty and brothy are commonly used together to describe a flavor derived from meat or the juices of meat often associated with savory characteristics. Non-ezymatic or Maillard browning accomplished by the formation of brown type compounds by sugars acting on amino acids and proteins also likely play a role in the intensity of meaty and brothy flavor attributes. Buttery and fat descriptors may also be used in unison to characterize attributes related to flavor and/or mouthfeel of the product of simple and complex fatty acid chains. Bloody, metallic, and serumy can be used as descriptive terms focused on differentiating samples of differing level of iron-like or raw/rare meat flavors. Liver and organy represent flavors reminiscent of offal or flavors associated with the organs of the body. Grassy reminds one of green grass or hay-like qualities that may or may not develop into more autumnal flavors. Grassy may also be recreated by the use of coumarin (Rovira, 1999). Bloody, metallic, serumy, liver or organy, and grassy may all also be characterized as off flavors or odors. Off odor and flavors present a profile that may often be seen as incongruous or objectionable to taste (Rovira, 1999).

Juiciness. It has been documented that differences in pH, water-holding capacity, fatness, and firmness were directly related to the juiciness of cooked meat products (Lawrie, 1966). Specifically, variability in fat, moisture, and water-holding capacity can all be associated with observed differences in the juiciness of beef. Juiciness can be defined as the combined effects of initial fluid release and sustained juiciness (Weir, 1960). Initial fluid release is described as the impression of wetness occurring due to the rapid release of juices associated with the first few chews of a meat sample while sustained juiciness can be characterized as the perception of juiciness with continued chewing produced by stimulation and release of saliva by fat (Bratzler, 1971). Juiciness and tenderness are closely related and often noted that the more tender the meat, the more readily juices are emitted and the more juicy the meat is perceived.

Tenderness. Bratzler (1971) and Smith (1972) both concluded that tenderness is the single most important attribute in distinguishing beef palatability and acceptability. Although tenderness appears to be sought after above all other quality attributes by the consumer, the term is also the most difficult to define (Lawrie, 1966). Cover and Hostetler (1960) define the term using three basic principles: (a) amount and firmness of connective tissue, (b) Crumbliness of actual muscle fibers, and (c) the softness of the bite to your teeth, tongue, and cheek. Weir (1960), cites a slightly modified set of three key concepts to highlight tenderness: (a) the initial ease of penetration of the sample by the teeth, (b) how easily the meat is fragmented, and (c) the amount of particle left after chewing. Bratzler (1971) further explained Weir's concepts by narrowing the definition down to reflect muscle fiber resistance perpendicular to its axis and the amount of collagen or connective tissue present in the meat, more accurately describing tenderness.

Once tenderness is defined, according to Smith et al. (1973) the effects of the contractile state of actomyosin , the integrity of the z-line, amounts of connective tissue, the state of collagen, and the amount, state, and dispersion of intramuscular fat and moisture all play a role in distinguishing differences among muscles or meat samples.

Although previous research suggests that degree of marbling is associated with the likelihood that a steak will be tender (Smith et al., 1984; Platter et al., 2003), little is known about the exact role intramuscular fat deposition plays in cooked meat tenderness. A minimum of four well known theories exist pertaining to the effect of marbling on meat tenderness.

The bite theory suggests that given the fact that fat is less dense and less resistant to shear force than coagulated protein, the increase of marbling in a given meat sample decreases bulk density (Smith et al., 1973). It is also suggested that intramuscular fat acts to dilute connective tissue (Lawrie, 1966) and muscle fibers (Jeremiah et al., 1970), decreasing the force needed to sever fewer fibers.

The strain theory suggests that connective tissue width, thickness, and thus strength maybe effectively decreased by the deposition of intramuscular fat within the perimysial connective tissue network, therefore effecting the connective tissue walls on either side of the given depot. Intramuscular fat may also loosen the structure of connective tissue fibers enough to aid in heat penetration and thus solubility of the connective tissue (Carpenter, 1962).

Tenderness and juiciness are associated with each other to a very high degree. The lubrication theory highlights that meat samples that readily release fat and maintain juiciness throughout the chewing process have a perceived tenderness. Carpenter (1962) suggested that the lubricating properties of fat confound the sensation of tenderness. Therefore, by way of directly contributing to juiciness, marbling indirectly contributes to tenderness as the intramuscular fat is solubilized and becomes part of the juices produced by the meat (Jeremiah et al., 1970).

This theory suggests that meat exhibiting higher levels of marbling are able to withstand the use of more severe cooking methods while still maintaining a higher eating quality integrity (Briskey and Kauffman, 1971). Marbling provides an insurance that with increasing incidence would protect the palatability of meat from adverse cooking situations such as rapid cooking, the wrong cookery method, or advanced degrees of doneness.   It is known that fat does not conduct heat as readily as lean tissue sources. Thus, it is likely that highly marbled meat is more capable of withstanding higher temperatures without overcooking than meat containing less intramuscular fat.

Objectively Measuring Tenderness.

Warner-Bratzler shear force (WBSF) and slice shear force (SSF) are the two forms of shear force analysis most commonly used as laboratory measurement of tenderness. With the use of these techniques, scientists are able to report individual muscle differences. It has been previously reported that individual muscles vary greatly in tenderness. A study of 50 muscles indicated a range in WBSF values from 3.22 to 7.39 kg (Ramsbottom and Strandine 1948) while a 20 muscle study with cuts from the chuck, rib, loin, and round observed a 2.2 to 5.0 kg range in tenderness measurements (Smith et al., 1978).

In order to perform WBSF, steaks must be allowed to equilibrate to room or refrigerated temperature for approximately 2 to 24 hours (Crouse and Koohmaraie, 1990; Wheeler et al., 1994). A Warner-Bratzler shear machine or a testing machine equipped with a Warner-Bratzler attachment must be used. A 60 degree angle, vee shaped (quarter-round 2.363-mm-diameter circle, cutting blade with a thickness of 1.016mm beveled half-round) slides through a 1.245 mm thick space on the apparatus for the actual measurement. Samples or cores (1.27 cm) are then obtained from the steak. Each sample is sheared once, at the center perpendicular to the fibers with a crosshead speed of 200mm/min (Shackelford et al., 1997).

*S*ingular, SSF samples (1 cm thick, 5 cm long) are collected from the lateral end of a Logissimus steak using a double bladed knife, spaced 1 cm apart directly after peak internal temperature is reached. The sample is cut at a 45 degree angle, approximately parallel to muscle fiber orientation (Shackelford et al., 1999). Peak slice shear force (kg) is determined using a flat, blunt-ended blade (1.016 mm thick, beveled half-round) on an

Instron Testing Machine (Instron, Corp., Canton, MA) running with a crosshead speed of 500 mm/min (Shackelford et al., 1999).

CHAPTER III

RELATIONSHIPS BETWEEN USDA CAMERA-BASED QUALITY GRADES AND BEEF SENSORY ATTRIBUTES

Materials and Methods

Carcass Selection

Beef carcasses (N = 718) were selected for the study at 4 commercial beef plants dispersed geographically among the major cattle feeding and beef packing states (CO, KS, NE, TX) using VGB2000, E+V Technology (Oranienburg, Germany). The study design specified that the experimental sample consist of carcasses selected from commercial beef processing plants in which USDA-approved camera grading systems had been installed and actually were being used to assist graders with on-line assignment of official USDA beef carcass quality grades. Carcass selection was conducted in these 4 plants, beginning 12-June and concluding 19-Aug, 2010.

To reduce known effects of animal age and physiological maturity on sensory properties of beef, the experimental sample was restricted to include only A-maturity carcasses. Results of the 2005 National Beef Quality Audit determined that more than 97% of carcasses in US fed beef plants (i.e., those carcasses that are routinely graded by USDA in US commerce) were classified as A-maturity (Garcia et al., 2008). Prior to selection, overall maturity scores for individual carcasses were determined by USDA field graders in each plant. Carcasses classified by graders as A-maturity then were evaluated for marbling using on-line, USDA-approved camera grading systems installed in each of the 4 plants. Camera marbling scores were obtained for both sides of each carcass and the greater of the 2 marbling scores ("high side") was used to assign each carcass to one of 7 marbling degrees: Traces (TR), Slight (SL), Small (SM), Modest (MT), Moderate (MD), Slightly Abundant (SA), and ≥ Moderately Abundant (MA). This approach was consistent with normal application of official USDA quality grades for beef carcasses. When beef carcasses are graded, the USDA grader evaluates marbling on both sides of each carcass and assigns a single quality grade to the entire carcass using the greater of the 2 marbling scores. An effort was made to select carcasses representing the entire range of marbling scores within each marbling degree (Table 1). It is noteworthy that only 58 carcasses (8% of the experimental sample) would have been assigned to a different marbling degree had classification been based on the side with lesser marbling and all of these carcasses were within the MD, SA, or MA marbling groups. All carcasses with TR, SL, SM, and MT marbling would have been assigned to the same respective marbling degree regardless of which side was used for classification.

Cattle type, carcass weight, and yield grade were allowed to vary randomly in the experimental sample, because USDA quality grades are applied without consideration of these factors. Very few dairy steers were processed in the 4 commercial beef plants during the sampling period, so the sample consisted primarily of beef-type steer and heifer carcasses. Only 7 carcasses (1% of the sample) were identified as dairy type based on carcass-phenotype and, of the beef-type carcasses, only 6 carcasses exhibited obvious indicators of *Bos indicus* breed influence. Sex classification (steer or heifer) was not strictly controlled in the selection process; however, the research team did attempt to obtain adequate representation of carcasses produced by steers and heifers within each marbling category. Bullock carcasses and carcasses with quality or dressing defects (i.e., blood splash, LM calluses, dark cutters, fat pulls, excessive trimming, etc.) were excluded from the experimental sample.

The original sampling plan targeted selection of 100 carcasses representing each of the 7 degrees of marbling. As sampling progressed, however, the research team found it difficult to identify carcasses to represent the MA degree of marbling, especially in KS, TX, and CO. When it became apparent that 100 carcasses with MA marbling could not be identified within the sampling time frame established by cooperating plants, the decision was made to select additional carcasses representing the upper 50% of the SA marbling category in order to ensure adequate representation of the US Prime grade in the experimental sample. Final numbers of carcasses selected to represent each of the 7 marbling degrees at each of the 4 plant locations are presented in Table 1.

Carcass Data Collection

On each sampling date, carcasses selected for the experiment were transferred to stationary rails in the sales cooler of each plant for further data collection. Each carcass was scored for skeletal, lean, and overall maturity by a USDA grader and Colorado State University (CSU) personnel recorded the following information for each carcass: hot carcass weight (HCW), fat thickness, LM area, hump height, and presence or absence of an "A stamp" which is used as a specification in several USDA Certified beef programs to identify carcasses produced by cattle with predominantly black hair coat color. In addition, LM lean color (L*, a*, b*) was measured (Hunter Lab Miniscan, Model 45/O-S, Hunter Associates Laboratory, Inc., Reston, VA) at the 12^{th}-13^{th} rib interface on the right side of each carcass. Data files containing camera measurements of LM area, fat thickness, and calculated yield grade for both sides of each selected carcass were retrieved from archives maintained by Cargill Meat Solutions. For each trait, camera measurements obtained from both sides of each carcass were averaged to obtain a single mean value for each carcass.

LM Sampling and Postmortem Aging

When carcass data collection was complete, LM samples, 4-cm in thickness, were removed from the 13th rib (loin) region of both sides of each carcass to be used for shear force measurement and sensory evaluation. In addition, a thin slice of the LM was removed from the right side of each carcass, immediately posterior to the 13th rib sample, for pH determination. Samples were packaged in barrier bags, packed in ice-filled coolers, and transported to the Colorado State University Meat Laboratory. Upon arrival at the Meat Laboratory, samples for pH determination were vacuum packaged and placed in frozen storage (-20°C). Vacuum packaged LM sections obtained for shear force measurement and sensory evaluation were aged at 2°C until the 14th day postmortem.

After completion of the 14-d aging period, LM sections were frozen and stored at -20°C. Frozen LM sections from the left and right sides of each carcass then were fabricated in a refrigerated (4°C) fabrication room using a band saw (Model 400, AEW-Thurne, AEW Engineering Co. Ltd., Norwich, UK) yielding 2 steaks (2.5 cm thick) per carcass. The LM steak from the left side of each carcass was designated for sensory evaluation and the steak from the right side of each carcass was used for shear force measurements. Both LM steaks from each carcass were vacuum packaged individually and returned to frozen storage (-20°C). The remaining portion of each LM section also was stored (-20°C) for later analysis to determine LM fat and moisture content.

Shear Force Measurement

Steaks to be measured for shear force were stratified by marbling degree and randomly allocated to 7 blocks with 100 to 104 steaks per block. Blocks included similar proportions of steaks representing the 7 degrees of marbling. Steaks comprising an entire block were measured for shear force on the same day and blocks were measured on 7 different days.

One-half of the LM steaks designated for shear force measurements in each marbling degree were randomly chosen and used to obtain measurements of Warner-Bratzler shear force (WBSF) and slice shear force (SSF), with both measurements being obtained from the same steak following procedures described by Lorenzen et al. (2010). Frozen LM steaks were tempered for 36 to 48 h at 2ºC and, then cooked using a convection conveyor oven (Model 1832-EL XTL OVENS, BOFC, Inc., Wichita, KS) to attain a peak internal temperature of 71ºC. Within five minutes of recording final cooked temperature, measured using Type K Thermocouple Thermometer (AccuTuff 340, model 34040, Cooper-Atkins Corporation, Middlefield, CT), a 1-cm-thick, 5-cm-long slice was removed from each steak parallel to the muscle fibers and sheared perpendicular to the muscle fibers using a universal testing machine (Instron Corp., Canton, MA) equipped with a flat, blunt-end blade resulting in a single SSF measurement for each steak. Measurement of SSF utilized the lateral portion (approximately 1/3) of the LM steak. The remaining portion of each steak was allowed to equilibrate to room temperature (22°C) and 4 to 6 cores (1.2 cm in diameter) were removed from each steak portion parallel to the muscle fiber orientation. Each core was sheared once perpendicular to the muscle fiber orientation using a universal testing machine (Instron Corp., Canton, MA) fitted with a Warner-Bratzler shear head. Peak shear force measurements were recorded for individual cores and averaged to obtain a single WBSF value for each steak.

The remaining steaks designated for shear force measurements in each marbling degree were only measured for WBSF. Frozen LM steaks were thawed and cooked using procedures identical to those described in the previous paragraph. Cooked steaks then were allowed to equilibrate to room temperature (22°C) and 6 to 10 cores (1.2 cm in diameter) were removed from each steak parallel to the muscle fiber orientation. Each core was sheared once perpendicular to the muscle fiber orientation using a universal testing machine (Instron Corp., Canton, MA) fitted with a Warner-Bratzler shear head. Peak shear force measurements were recorded for individual cores and averaged to obtain a single WBSF value for each steak.

Descriptive Sensory Analysis

Descriptive sensory analysis was used to characterize sensory attributes of a cooked LM sample from each carcass. Sensory analysis procedures were approved prior to the experiment by the Institutional Review Board of the Colorado State University Research Integrity & Compliance Review Office, which oversees research involving human subjects. The lexicon of descriptive attributes used for sensory analysis in this study (developed using guidelines provided by AMSA (1995) and Adhikari and Miller, 2010) included tenderness, juiciness, and the following flavor descriptors: meaty/brothy (basic flavor and aroma of grilled or roasted beef; simulated by the flavor of beef broth), buttery/beef fat (flavor and aroma associated with cooked fat from grain-finished beef; often described as a buttery flavor), bloody/serumy (flavor and aroma associated with blood in beef cooked to a rare degree of doneness; sometimes described as a metallic taste), livery/organy (flavor and aroma associated with cooked beef liver or kidney), and grassy (flavor and aroma of beef produced by grass-finished or short-fed cattle; often described as green or hay-like).

Following recruitment and familiarization with the lexicon of descriptive attributes for beef, prospective panelists were screened for sensory acuity using a series of tests designed to determine their abilities to distinguish and rate differences in meat tenderness, juiciness, aroma, and flavor. Selected panelists were trained using procedures similar to those outlined by Miller and Prusa (2010) and Adhikari and Miller (2010).

Steaks designated for sensory analysis were stratified by marbling degree and randomly allocated to 34 complete blocks (20 or 21 steaks per block) and 1 partial block (consisting of 11 steaks). Blocks consisted of similar proportions of steaks representing the 7 degrees of marbling. Samples comprising each block were evaluated for sensory attributes on the same day in 2 sessions (10 or 11 samples per session), with 2.5 to 3 h between sessions.

Frozen LM steaks used for each panel session were tempered for 36 to 48 h at 2°C and then cooked on electric grills (model GGR64, Salton, Inc., Mt. Prospect, IL) to a peak internal temperature of 71°C. A Type K thermocouple (Omega Engineering Inc., Stamford, CT) was placed in the geometric center of each steak and internal temperature was monitored during cooking using a microprocessor thermometer (model HH21, Omega Engineering Inc., Stamford, CT). After cooking, steaks were cut into sections (1.3 cm × 1.3 cm × cooked steak thickness), and the resulting sections from each steak were placed in a ceramic bowl, wrapped in aluminum foil, and held in a warming oven at

70°C for a maximum of 30 min before being served to an 8 to 10-member trained descriptive attribute panel. Each panelist received 2 sections from each steak.

During testing, panelists were seated in individual cubicles within a clean sensory panel room. Samples were served under red incandescent light to mask color variation among samples and panelists were supplied with unsalted, saltine crackers, distilled water, and unsweetened apple juice, which were used for palate cleansing prior to testing each sample.

Panelists quantified descriptive sensory attributes of each sample using 15-cm unstructured line scales anchored at both ends with descriptive terms. For juiciness and tenderness, 0 denoted extremely dry and extremely tough, respectively, and 15 denoted extremely juicy and extremely tender, respectively. For tenderness, the mid-point of the line (7.5 cm) was considered a neutral response (i.e., neither tough nor tender). For all flavor descriptors, 0 indicated "no presence," whereas 15 indicated "very strong presence." Panelists also assigned each sample a composite rating to quantify the overall sensory experience using a 15-cm unstructured line scale anchored on the ends with a minus (0 = minimal overall level of performance with respect to juiciness, tenderness, and flavor) and a plus (15 = maximal overall level of performance with respect to juiciness, tenderness, and flavor). The mid-point of the line (7.5 cm) was considered a neutral response (neither negative nor positive).

Sensory testing was conducted for 18 d and, then, suspended for a period of 7 d to accommodate a 5-d re-training session. Testing resumed following the weeklong suspension and was completed in 17 d.

LM pH Measurements

Samples collected for pH determination were diluted 10:1 (wt/vol) with double-distilled deionized water and homogenized (Model 225318 VirTisShear, The VirTis Co. Inc, Gardiner, NY). The pH of the homogenate formed from each sample was determined using a pH meter fitted with a glass electrode (Ultra Basic – 5, Denver Istrument, Arvada, CO).

Determination of LM Intramuscular Fat and Moisture Content

An LM sample from each carcass was sent to a commercial laboratory (Food Safety Net Services, San Antonio, TX) for analysis. In most cases, LM samples represented the carcass side with the greater camera marbling score; however, in the event that the sample collected from the high-marbling carcass side was of insufficient size, a sample of LM from the opposite carcass side was substituted. Fat (and moisture) content of each LM sample was determined using methods outlined in the AOCS Official Procedure Am 5-04 for rapid determination of oil/fat utilizing high-temperature solvent (petroleum ether) extraction (AOCS, 2005).

Statistical Methods

All analyses utilized statistical procedures of SAS (SAS Inst. Inc., Cary, NC). Exploratory data analyses, using the FREQ and CORR procedures, were conducted to characterize the experimental sample and quantify linear relationships among camera marbling score, panel ratings for beef sensory attributes, and LM shear force measurements. In addition, data for carcass yield grade traits were analyzed (PROC GLM) to further characterize and compare carcasses selected to represent each marbling degree. The least squares model used for this analysis included the fixed effects of marbling degree (TR, SL, SM, MT, MD, SA, MA) and sex (Heifer, Steer).

Panel ratings for beef sensory attributes and LM shear force measurements were analyzed using REML-based, mixed model procedures (PROC MIXED). The statistical model used for these analyses included the random effect of block and fixed effects of marbling degree, sex, and marbling degree × sex. Denominator degrees of freedom were calculated using the Kenward-Roger approximation.

Analyses conducted to determine probabilities of steaks meeting or exceeding threshold specifications for tenderness, overall sensory experience, and shear force (with response variables coded as 1 and 0) were conducted using PROC GLIMMIX. None of the statistical models would converge when block was included as a random effect. Consequently, these analyses were conducted using models that included the fixed effects of marbling degree, sex, and marbling degree × sex, with binomial distribution and the logit link function specified as options.

Mixed model procedures (MIXED and GLIMMIX), identical to those described above, were used to test effects of "Angus" phenotype (black vs. non-black) on sensory attributes and shear force. The only modification to statistical models used for these analyses was inclusion of color (black vs. non-black) as a fixed effect.

To test effects of grade placement approach (original grade lines vs. adopted grade lines) on sensory attributes and shear force, the data were analyzed using a mixed effects model for repeated measures (PROC MIXED). The statistical model included block as a random effect together with fixed effects of camera-based quality grade and grade placement approach partitioned within camera-based quality grade. The repeated statement of the model designated grade placement approach partitioned within camera-based quality grade as the repeated measure and carcass ID was specified as the subject.

A similar repeated measures mixed effects model was used with PROC GLIMMIX to test effects of grade placement approach on probabilities of steaks meeting or exceeding threshold specifications for tenderness, overall sensory experience, and shear force; however, for these analyses, the random effect of block was excluded from the model. In the random statement of each GLIMMIIX model, grade placement approach partitioned within camera-based quality grade was specified as a repeated measure and carcass ID was specified as the subject.

All comparisons were tested using a comparison-wise significance level of $\alpha = 0.05$. In analyses conducted using GLM, MIXED, and GLMMIX, means were compared, using the PDIFF option, when F-tests were significant ($P < 0.05$).

Results and Discussion

Experimental Sample Characteristics

Data characterizing distributions of camera marbling scores among carcasses selected to represent each marbling degree are presented in Table 1. Camera marbling scores within the SL, SM, MT, MD, and SA categories were approximately normally distributed with mean values near the center of each respective marbling degree and minimum and maximum values that spanned almost the entire range of marbling within each degree (Table 1). Subclasses consisting of carcasses selected to have the greatest (MA) and least (TR) amounts of marbling had skewed distributions of camera marbling scores. Most (84%) of the carcasses chosen to represent MA had marbling scores less than 870 (MA^{70}), whereas most (82%) of the carcasses selected to represent TR had marbling scores of 270 (TR^{70}) or greater (Table 1).

Camera marbling score was closely correlated with percentages of crude fat (r = 0.85) and moisture (r = -0.82) in the LM. Strong, positive correlations between camera-based marbling scores and percentage of fat in the LM (extracted using ether) also were reported by Moore et al. (2010) and Dow et al. (2011). Mean values (± SEM) for fat percentages corresponding to each degree of marbling in the current study (TR = 2.19 ± 0.23, SL = 3.32 ± 0.22), SM = 5.31 ± 0.23, MT = 6.95 ± 0.24, MD = 8.61 ± 0.24, SA = 10.77 ± 0.20, MA = 13.69 ± 0.31) were slightly greater than previously reported values (Savell et al., 1986; Moore et al., 2010; Dow et al., 2011).

Sampling resulted in similar proportions of steer and heifer carcasses within the TR, SL, SM, and MT degrees of marbling. However, due to the superior marbling ability of heifers compared with steers (Anderson and Gleghorn, 2007), the MD, SA, and MA categories necessarily included more heifer carcasses than steer carcasses.

Approximately 70% of all carcasses selected for the study were identified with an A stamp, indicating that they had been produced by cattle that were predominantly (51% or greater) black in color. It is noteworthy that the frequency of carcasses identified with an “A” stamp increased steadily as marbling level increased. More than 80% of selected carcasses with MD or greater marbling were produced by predominantly black cattle.

The sample mean for LM pH was 5.46 (SD = 0.104) and most (76.5%) of the LM pH values ranged from 5.4 to 5.5, which is considered a normal range for final LM pH (Immonen and Puolanne, 2000). Approximately 9% of carcasses selected for the study had LM pH values less than 5.4 and only 1.4% had values for LM pH of 5.8 or greater.

There were no meaningful differences in LM pH among marbling degrees (data not presented).

Data presented in Table 2 compare yield grade traits of carcasses selected to represent each degree of marbling. Least squares means shown in Table 2 were computed using a least squares model that included fixed effects of marbling degree and sex. Correspondingly, data in Table 2 may be interpreted as comparisons of carcasses differing in level of marbling, produced by animals of the same sex. Among carcasses selected for the study, increased marbling level generally was associated with increased 12th rib fat thickness, decreased LM area, and greater numerical (less desirable) camera-based yield grades. Mean carcass weights were similar for all marbling degrees except TR. Carcasses selected to represent TR were lighter ($P < 0.05$) in weight than carcasses representing the other 6 marbling degrees (Table 2).

Correlations among Marbling, Beef Sensory Attributes, and Shear Force

Pearson correlation coefficients quantifying linear relationships among camera marbling score, panel ratings for various beef sensory attributes, and LM shear force measurements are presented in Table 3. Camera marbling score was most closely correlated with sensory panel ratings for intensity of buttery/beef fat flavor (r = 0.84). Moderately strong, positive correlations also were observed between camera marbling score and panel ratings for juiciness (r = 0.67), tenderness (r = 0.63), and meaty/brothy flavor intensity (r = 0.57). Slightly weaker, negative relationships (Table 3) were observed between camera marbling score and panel ratings for flavors characterized as bloody/serumy (r = -0.48), livery/organy (r = -0.30), and grassy (r = -0.36). Panel ratings for overall sensory experience were very closely correlated with ratings for tenderness (r

= 0.90), buttery/beef fat flavor (r = 0.87), and juiciness (r = 0.84). Correspondingly, ratings for overall sensory experience also exhibited a strong, positive relationship (r = 0.78) to camera marbling score (Table 3).

Measurements of LM shear force (WBSF and SSF) were moderately correlated with one another and with camera marbling score (Table 3). In addition, both LM shear force measurements (WBSF and SSF) were moderately correlated with sensory panel ratings for tenderness and overall sensory experience (Table 3).

Studies conducted over the past several decades to quantify marbling's contribution to differences in eating quality of beef generally have established low to moderate, positive relationships between marbling and cooked beef tenderness, juiciness, and flavor (Briskey and Bray, 1962; Jeremiah et al., 1970; Smith et al., 2008). In a study involving LM steaks from youthful (A-maturity) carcasses with marbling scores ranging from Practically Devoid (PD) to Abundant (AB), Campion et al. (1975) reported that marbling accounted for no more than 10% of the variation in any of the organoleptic properties of beef and suggested that intramuscular fat content may be relatively unimportant in steaks produced by young cattle. In contrast, much stronger, positive relationships between marbling and beef palatability characteristics were reported by Smith et al. (1984), who found that, among LM steaks from A-maturity carcasses, differences in marbling (ranging from PD to MA) explained 24, 27, 30, and 34% of the variation in sensory panel ratings for juiciness, tenderness, flavor, and overall palatability, respectively. In the current study, camera-based marbling assessments explained 45, 40, 32, and 71% of the variation in panel ratings for juiciness, tenderness, meaty/brothy flavor intensity, and buttery/beef fat flavor intensity, respectively and 61%

of the variation in ratings for overall sensory experience (Table 3). The increased precision of instrument-based vs. subjective marbling assessment likely contributed to the greater magnitude of correlations between marbling and beef sensory attributes observed in the current study compared with those reported previously.

Effects of Marbling Degree and Sex

For the purpose of assigning quality grades, camera-based marbling scores are rounded to the nearest 10 units and categorized into full degrees of marbling (e.g., TR = 200 to 295; SL = 300 to 395, SM = 400 to 495, etc.). Correspondingly, categorical analyses were conducted to examine the effects of marbling degree and sex classification on beef sensory attributes and LM shear force measurements.

Results from least squares analyses showing the effects of marbling degree, sex, and marbling degree × sex on juiciness, tenderness, meaty/brothy flavor, buttery/beef fat flavor, and overall sensory experience are summarized in Table 4 and Table 5. Increased degree of marbling resulted in steaks having greater ($P < 0.001$) juiciness (MA > SA> MD > MT > SM > SL = TR), meaty/brothy flavor intensity (MA = SA > MD = MT > SM > SL > TR), and buttery/beef fat flavor intensity (MA > SA > MD > MT > SM > SL > TR). Steak tenderness also increased ($P < 0.001$) as marbling degree increased; however, the effect of marbling on tenderness was influenced by sex (Table 4). As shown in Table 4, steaks from steer carcasses with TR, SL, SM, and MT marbling were comparable ($P > 0.05$) in tenderness to steaks from heifer carcasses with 1 degree more marbling (i.e., SL, SM, MT, and MD, respectively). Although sensory panelists generally found steaks produced by steers to be more ($P < 0.05$) tender than steaks from heifers, the difference in panel tenderness ratings for steers vs. heifers was large enough for statistical significance only within the TR category (Table 4). Detectable differences in tenderness among marbling degree × sex subclasses were reflected in panelists' ratings for overall sensory experience (Table 5).

Relationships between marbling degree and beef sensory attributes summarized in Table 4 are similar to those reported previously by McBee and Wiles (1967) and Smith et al. (1984). However, the current study identified statistically significant differences in sensory attributes between adjacent marbling degrees that were not detected in either of the other studies (McBee and Wiles, 1967; Smith et al., 1984), resulting in more effective stratification of carcasses according to differences in steak juiciness, tenderness, and flavor.

Least squares means summarizing the effects of marbling degree, sex, and marbling degree × sex on additional flavor attributes and LM shear force measurements are presented in Table 6 and Table 7. Intensity of bloody/serumy flavor was greatest ($P < 0.05$) among steaks with TR and SL marbling, gradually decreasing ($P < 0.05$) as marbling degree increased (Table 6). Grassy flavor, which is most prevalent in beef from grass-finished or short-fed cattle, was detected at extremely low levels (mean values < 1 cm on a 15 cm scale, Table 6) in the experimental sample, which consisted of carcasses produced by grain-finished cattle. Nevertheless, grassy flavor intensity was influenced ($P < 0.001$) by marbling degree, decreasing ($P < 0.05$) gradually as marbling degree increased from TR to MA (Table 6). Livery/organy flavor, when detected, also occurred at extremely low levels of intensity (mean values < 1 cm on a 15 cm scale) and was least ($P < 0.05$) detectable among steaks with MD, SA, or MA marbling (Table 6).

Shear force measurements differed (*P* < 0.05) among marbling degrees and between sexes (Table 8). Values for LM WBSF decreased (*P* < 0.001) almost linearly as degree of marbling increased (TR > SL > SM > MT > SA > MA, Table 8). Values for LM SSF also decreased (*P* < 0.05) as degree of marbling increased from TR to SM; however, additional increases in degree of marbling (from MT through MA) did not (*P* > 0.05) result in further reduction of LM SSF. Smith et al. (1984) also found that LM shear force (WBSF in their study) was unaffected as degree of marbling increased from MT to MA.

Heifers had greater values for WBSF and SSF than did steers, indicating that steaks from heifers were slightly tougher. Moreover, the marbling degree × sex interaction was not significant (*P* > 0.05) for either measure of shear force suggesting that the shear force difference between heifers and steers was consistent across marbling levels. Other studies have found a difference in tenderness of steaks produced by heifers and steers (Jeremiah et al., 1991; Wulf et al., 1996; Choat et al., 2006). Collectively, results of these and a few additional studies suggest that product tenderness often favors steers, even though heifers typically produce carcasses with greater degrees of marbling (Tatum et al., 2007).

Previous research suggests that degree of marbling is associated with the likelihood that a steak will be juicy, tender, and flavorful (Smith et al., 1984; Platter et al., 2003). Therefore, frequency analyses were conducted to determine effects of marbling degree and sex on the probability of a steak meeting or exceeding pre-determined threshold values for tenderness, overall sensory experience, and LM shear force (Table 6). In these analyses, the marbling degree × sex interaction was not significant for any of the dependent variables tested. Therefore, only main effect means were presented in Table 8.

The likelihood of a steak delivering a positive overall sensory experience became much greater (P <0.001) as degree of marbling increased (MA = SA > MD = MT > SM > SL > TR; Table 9). Nearly all (98 to 99%) of the steaks with MA and SA marbling, and most (between 80 and 90%) of the steaks with MD and MT marbling received positive ratings for overall sensory experience (Table 9). In contrast, only 29% of the SL steaks and 15% of the TR steaks received positive overall sensory experience ratings (Table 9). Based on sensory panel ratings and SSF values, steaks with SM marbling were just as likely to be tender as were steaks with MT or MD; however, due to lower ratings for juiciness and flavor (Table 4), SM steaks were less likely (P < 0.05) to deliver a positive sensory experience.

Proposed standard WBSF and SSF specifications for tenderness marketing claims, developed by the ASTM International Committee F10.60 on Livestock, Meat and Poultry Marketing Claims, were used to classify steaks as “tender” (WBSF ≤ 4.4 kg ; SSF ≤ 20 kg) and “very tender” (WBSF ≤ 3.9 kg ; SSF ≤ 15.3 kg). Of the LM steaks tested in this study, approximately 88% were classified as “tender” and 77% were classified as “very tender” based on WBSF specifications. Similarly, 86% and 61% of steaks were classified as “tender” and “very tender” based on SSF specifications. For comparison, sensory panelists rated 78% of all steaks tested in the study as tender (i.e., sensory tenderness rating ≥ 7.5). Collectively, data summarized in Table 9 indicate that the probability of a steak being tender increased as degree of marbling increased; however, few statistical differences in mean probabilities were detected among steaks with SM or greater marbling (Table 9).

Based on sensory tenderness ratings and SSF, heifers were less ($P < 0.05$) likely to produce tender steaks than were steers. However, steaks from steers and heifers had similar ($P > 0.05$) odds of delivering a positive sensory experience (Table 9).

USDA Quality Grade Comparisons

In the USDA beef grading system, carcass maturity and degree of marbling are the 2 primary determinants of carcass quality grade. Among carcasses classified as A-maturity, those with AB, MA, or SA are graded Prime (PR); those with MD, MT, or SM are graded Choice (CH); those with SL are graded Select (SE); and those with TR or PD are graded Standard (ST). In addition, most commercial beef packers segregate carcasses comprising the upper 2/3 of the Choice grade (i.e., those with MD and MT marbling) for use in various "premium Choice" marketing programs.

When camera-based quality grades (originally based on marbling assessments of USDA grading experts) were re-aligned to match marbling assessments of USDA field graders, the marbling lines dividing each grade category were adjusted as follows: the line dividing ST and SE was reduced by 12 marbling units; the line dividing SE and low Choice (CH-) was reduced by 14 marbling units; the line dividing CH- and average Choice (CH^{o}) was reduced by 28 marbling units; and the line between high Choice (CH+) and PR was reduced by 57 marbling units (O'Connor, 2009). An objective of the current study was to quantify the impact of these modifications in grade placement on steak juiciness, tenderness, and flavor.

Quality grades were determined for carcasses comprising the experimental sample using both grade placement approaches (i.e., original grade lines, based on marbling assessments of the expert panel and adopted grade lines, based on marbling assessments of field graders).

Sensory attributes of LM steaks from carcasses graded using original and adopted grade lines are compared in Table 10. Both methods of grade placement effectively stratified carcasses into grades that differed ($P < 0.05$) with respect to steak juiciness, tenderness, and flavor. Using both grade placement methods, grades were ranked identically for juiciness: PR > CHº/CH+ > CH- > SE = ST; tenderness: PR > CHº/CH+ > CH- > SE > ST; meaty/brothy flavor intensity: PR > CHº/CH+ > CH- > SE > ST; buttery/beef fat flavor intensity: PR > CHº/CH+ > CH- > SE > ST; and overall sensory experience: PR > CHº/CH+ > CH- > SE > ST (Table 10). Smith et al. (1987) reported very similar grade rankings for LM steak juiciness: PR > CH > SE = ST; tenderness: PR > CH > SE > ST; flavor: PR > CH > SE > ST; and overall palatability: PR > CH > SE > ST.

Modification of grade lines dividing CH- from CHº and CH+ from PR had a minor, yet statistically significant impact on sensory ratings for buttery/beef fat flavor intensity (Table 10). Steaks from carcasses graded CHº, CH+, or PR using original grade lines received higher ($P < 0.05$) panel ratings for buttery/beef fat flavor than did steaks from carcasses placed in the same grades using adopted grade lines (Table 10). Additionally, steaks from carcasses placed in the upper 2/3 of CH using original grade lines received slightly higher ($P < 0.05$) overall sensory experience ratings compared with upper 2/3 CH steaks whose grades were based on adopted grade lines. These differences, though statistically significant, were small in magnitude (< 0.5 cm on a 15 cm scale) and of questionable practical importance. The mean probability of a positive overall sensory experience was the same for steaks within each grade regardless of which approach was used to assign camera-based quality grades (Table 10).

Data summarizing the impact of quality grade and grade placement method on LM shear force are presented in Table 8. Within-grade comparisons (Table 10) indicated that modification of camera grade lines had no effect ($P > 0.05$) on LM WBSF or SSF.

Comparison LM Steaks from Black and Non-Black Cattle

Currently, there are 47 different USDA Certified Beef Programs with an "Angus" phenotype (GLA schedule) requirement, which specifies that, to be eligible for the program, cattle must be predominantly (≥ 51%) solid black and not of dairy background (USDA, 2011). During processing, before complete hide removal, cattle deemed eligible for these programs, based on phenotype, are identified with an ink-stamp of the letter "A" placed on the round of the carcass. During sampling for this study, the research team, noted whether or not carcasses selected for the experiment had been identified with an A stamp. Data presented in Table 11 summarize results of an analysis conducted to determine the effect of the "Angus" phenotype requirement on steak juiciness, tenderness, and flavor.

Least squares means presented in Table 11 were calculated using a model that included the effects of sex, camera-based quality grade, and sex × camera-based quality grade, as well as the effect of color (black vs. non-black). Correspondingly, these means may be interpreted as comparisons between black and non-black cattle of the same sex with the same camera-based carcass quality grade. Shear force measurements and sensory panel ratings for tenderness, meaty/brothy flavor intensity, and bloody/serumy flavor intensity were not (P > 0.05) affected by color. However, black cattle produced LM steaks that received greater panel ratings for juiciness (*P* = 0.001), buttery/beef fat flavor intensity (*P* = 0.005), and overall sensory experience (*P* = 0.044) compared with non-black cattle. These findings provide some tangible evidence supporting the use of a phenotypic breed specification to augment quality grading in “Angus” beef programs.

Use of Additional Carcass Measurements to Enhance Prediction of Sensory Performance.

Previous research has identified additional carcass measurements, such as LM pH, LM color, and hump height, which may be used to improve the accuracy and precision of predicting beef palatability attributes (Wulf et al., 1997; Wulf and Page, 2000; Vote et al., 2003). In the current study, measurements of hump, height LM pH, and LM color (L*, a*, b*) exhibited low to moderate correlations with LM sensory attributes and shear force measurements (Table 12). Results of stepwise multiple logistic regression analysis, conducted to examine the value of these measurements, used in combination with marbling, for predicting the likelihood of a positive sensory experience are summarized in Table 13.

Camera marbling score was the single best predictor of the likelihood of a positive eating experience (R^2 = 0.56). The only other variables to enter the regression model were LM pH, LM L*, and LM a*. Together these measurements explained an additional 3.4% of variation in the odds of a steak providing a positive overall sensory experience. The regression model summarized in Table 13 correctly classified 84.7% of the 718 LM steaks evaluated in the study. Camera marbling score, used as a single predictor, correctly classified 83.6% of the steaks in the experimental sample, with respect to their likelihood of delivering a positive sensory experience.

Table 1. Sample of A-maturity beef carcasses (N = 718) selected for the study

Camera marbling degree[1]	Plant location				Row total	Camera marbling score[1]			
	Colorado	Kansas	Nebraska	Texas		Mean	SD	Minimum	Maximum
	Number of carcasses selected								
Traces (TR)	36	25	5	35	101	284	15.5	220	299
Slight (SL)	30	26	20	36	112	357	26.1	304	399
Small (SM)	26	25	26	25	102	450	28.8	400	499
Modest (MT)	20	25	26	25	96	556	24.4	509	598
Moderate (MD)	25	25	24	28	102	650	27.3	601	699
Slightly Abundant (SA)	31	26	62	23	142	752	28.8	700	799
≥ Moderately Abundant (MA)	2	2	56	3	63	837	34.5	800	931

[1] Based on the carcass side with the greater camera marbling score (CMS). Marbling scores were encoded as follows: TR = 200 to 299, SL = 300 to 399, SM = 400 to 499, MT = 500 to 599, MD = 600 to 699, SA = 700 to 799, MA = 800 to 899, Abundant (AB) = 900 to 999.

Table 2. Least squares means[1] comparing yield grade traits of carcasses selected to represent the 7 marbling categories

Item	Marbling degree[2]							Residual SD[3]
	TR	SL	SM	MT	MD	SA	≥ MA	
Number of carcasses	101	112	102	96	102	142	63	
HCW, kg	315[b]	362[a]	367[a]	366[a]	363[a]	371[a]	372[a]	39.15
Camera fat thickness, cm	0.70[e]	1.10[d]	1.30[c]	1.54[b]	1.66[ab]	1.66[ab]	1.74[a]	0.45
Adjusted preliminary YG	2.9[e]	3.3[d]	3.5[c]	3.7[b]	3.8[ab]	3.9[a]	3.9[a]	0.46
Camera LM area, cm^2	86.8[ab]	89.2[a]	84.5[b]	80.3[c]	79.2[c]	77.7[c]	73.8[d]	10.07
Camera yield grade	1.9[f]	2.6[e]	3.1[d]	3.5[c]	3.7[bc]	3.9[b]	4.1[a]	0.76

[1] Estimates were calculated using a least squares model that included the fixed effects of marbling degree and sex.

[2] TR = Traces, SL = Slight, SM = Small, MT = Modest, MD = Moderate, SA = Slightly Abundant, MA = Moderately Abundant (USDA, 1997).

[3] Standard errors of least squares means may be calculated as $1/\sqrt{n} \times$ residual SD for a trait, where n = number of carcasses in that particular marbling degree.

[,b,c,d,e,f] Means in the same column within an effect that do not share a common superscript letter differ ($P < 0.05$)

Table 3. Correlations[1] among camera marbling score, panel ratings for beef sensory attributes, and LM shear force measurements

	1	2	3	4	5	6	7	8	9	10	11
1. Camera marbling score		0.67	0.63	0.57	0.84	-0.48	-0.30	-0.36	0.78	-0.48	-0.45
2. Juiciness	0.67		0.75	0.43	0.79	-0.26	-0.30	-0.31	0.84	-0.42	-0.36
3. Tenderness	0.63	0.75		0.47	0.72	-0.31	-0.32	-0.29	0.90	-0.54	-0.65
4. Meaty/Brothy	0.57	0.43	0.47		0.60	-0.62	-0.22	-0.32	0.63	-0.37	-0.40
5. Buttery/Beef fat	0.84	0.79	0.72	0.60		-0.50	-0.33	-0.37	0.87	-0.47	-0.46
6. Bloody/Serumy	-0.48	-0.26	-0.31	-0.62	-0.50		0.23	0.23	-0.31	0.23	0.27
7. Livery/Organy	-0.30	-0.30	-0.32	-0.22	-0.33	0.23		0.27	-0.42	0.19	0.22
8. Grassy	-0.36	-0.31	-0.29	-0.32	-0.37	0.23	0.27		-0.29	0.18	0.16
9. Sensory experience	0.78	0.84	0.90	0.63	0.87	-0.31	-0.42	-0.29		-0.53	-0.59
10. WBSF	-0.48	-0.42	-0.54	-0.37	-0.47	0.23	0.19	0.18	-0.53		0.48
11. SSF	-0.45	-0.36	-0.65	-0.40	-0.46	0.27	0.22	0.16	-0.59	0.48	

[1] Coefficients ≥ 0.10 differ from 0 ($P < 0.01$).

Table 4. Least squares means showing effects of marbling degree and sex on sensory panel ratings for juiciness, tenderness, meaty/brothy flavor, buttery/beef fat flavor and overall sensory experience

		Sensory panel rating[1]				
Effect	N	Juiciness	Tenderness	Meaty/brothy flavor	Buttery/beef fat flavor	Sensory experience
Marbling degree		*P* < 0.001	*P* < 0.001	*P* < 0.001	*P* < 0.001	*P* < 0.001
TR	101	7.41[f]	6.99	6.99[e]	1.59[g]	5.90
SL	112	7.52[f]	7.66	7.40[d]	2.06[f]	6.74
SM	102	8.49[e]	8.64	7.89[c]	2.92[e]	7.77
MT	96	9.01[d]	9.49	8.47[b]	3.95[d]	8.75
MD	102	9.54[c]	9.74	8.66[b]	4.85[c]	9.38
SA	142	10.41[b]	10.70	9.16[a]	6.28[b]	10.52
MA	63	10.94[a]	11.24	9.43[a]	7.53[a]	11.23
Sex		*P* = 0.708	*P* = 0.004	*P* = 0.302	*P* = 0.932	*P* = 0.040
Heifer (H)	390	9.07	9.02	8.32	4.17	8.50
Steer (S)	328	9.03	9.40	8.23	4.17	8.73
Residual SD[2]		1.35	1.72	1.09	1.22	1.42

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

[2] Standard errors of least squares means may be calculated as $1/\sqrt{n} \times$ residual SD for a trait, where n = number of carcasses in that particular subclass.

[a,b,c,d,e,f,g,h] 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 showing effects of marbling degree × sex on sensory panel ratings for juiciness, tenderness, meaty/brothy flavor, buttery/beef fat flavor and overall sensory experience

		Sensory panel rating[1]				
Effect	N	Juiciness	Tenderness	Meaty/brothy flavor	Buttery/beef fat flavor	Sensory experience
Marbling degree × Sex		*P* = 0.054	*P* = 0.012	*P* = 0.501	*P* = 0.764	*P* = 0.040
TR-H	51		6.27^{h}			5.40^{h}
TR-S	50		7.72^{fg}			6.41^{g}
SL-H	54		7.43^{g}			6.63^{g}
SL-S	58		7.89^{fg}			6.85^{g}
SM-H	47		8.35^{ef}			7.70^{f}
SM-S	55		8.94^{de}			7.84^{f}
MT-H	46		9.23^{cd}			8.51^{e}
MT-S	50		9.74^{bc}			9.00^{de}
MD-H	64		9.89^{b}			9.57^{c}
MD-S	38		9.58^{bcd}			9.20^{cd}
SA-H	86		10.70^{a}			10.47^{b}
SA-S	56		10.70^{a}			10.56^{b}
MA-H	42		11.23^{a}			11.21^{a}
MA-S	21		11.25^{a}			11.25^{a}
Residual SD[2]		1.35	1.72	1.09	1.22	1.42

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

[2] Standard errors of least squares means may be calculated as $1/\sqrt{n}$ × residual SD for a trait, where n = number of carcasses in that particular subclass.

[a,b,c,d,e,f,g,h] Means in the same column within an effect that do not share a common superscript letter differ ($P < 0.05$).

Table 6. Least squares means showing effects of marbling degree and sex on bloody/serumy flavor, livery/organy flavor, grassy flavor, Warner-Bratzler shear force, and slice shear force

		Sensory panel rating[1]			Shear force measurement, kg	
Effect	N	Bloody/serumy flavor	Livery/organy flavor	Grassy flavor	Warner-Bratzler	Slice
Marbling degree		$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$
TR	101	3.25[a]	0.75	0.86[a]	4.12[a]	19.68[a]
SL	112	3.29[a]	0.65	0.63[b]	3.82[b]	17.94[b]
SM	102	2.95[b]	0.60	0.47[c]	3.55[c]	15.17[c]
MT	96	2.52[c]	0.54	0.39[cd]	3.31[d]	14.23[cd]
MD	102	2.32[c]	0.27	0.35[cd]	3.17[de]	14.66[cd]
SA	142	1.92[d]	0.32	0.28[de]	2.97[e]	13.25[d]
MA	63	1.50[e]	0.27	0.14[e]	2.68[f]	12.75[d]
Sex		$P = 0.596$	$P = 0.111$	$P = 0.866$	$P = 0.015$	$P = 0.012$
Heifer (H)	390	2.56	0.52	0.44	3.45	15.98
Steer (S)	328	2.52	0.45	0.45	3.30	14.79
Residual SD		0.93	0.55	0.52	0.80	4.24

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

[2] Standard errors of least squares means may be calculated as $1/\sqrt{n} \times$ residual SD for a trait, where n = number of carcasses in that particular subclass.

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

Table 7. Least squares means showing effects of marbling degree × sex on bloody/serumy flavor, livery/organy flavor, grassy flavor, Warner-Bratzler shear force, and slice shear force

		Sensory panel rating[1]			Shear force measurement, kg	
Effect	N	Bloody/serumy flavor	Livery/organy flavor	Grassy flavor	Warner-Bratzler	Slice
Marbling degree × Sex		P = 0.281	P = 0.042	P = 0.532	P = 0.308	P = 0.368
TR-H	51		0.83^{a}			
TR-S	50		0.67^{ab}			
SL-H	54		0.73^{ab}			
SL-S	58		0.57^{bcd}			
SM-H	47		0.59^{bc}			
SM-S	55		0.60^{b}			
MT-H	46		0.72^{ab}			
MT-S	50		0.37^{de}			
MD-H	64		0.28^{e}			
MD-S	38		0.27^{e}			
SA-H	86		0.25^{e}			
SA-S	56		0.38^{cd}			
MA-H	42		0.24^{e}			
MA-S	21		0.30^{de}			
Residual SD		0.93	0.55	0.52	0.80	4.24

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

[2] Standard errors of least squares means may be calculated as $1/\sqrt{n}$ × residual SD for a trait, where n = number of carcasses in that particular subclass.

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

Table 8. Effects of marbling degree and sex on the probability (mean ± SEM) of a steak meeting or exceeding pre-determined specifications for tenderness, sensory experience, and LM shear force

		Sensory panel rating ≥ 7.5[1]		Warner-Bratzler shear force[2]		Slice shear force[2]	
Effect	N	Sensory Experience	Tenderness	≤ 4.4 kg (tender)	≤ 3.9 kg (very tender)	≤ 20 kg (tender)	≤ 15.3 kg (very tender)
Marbling degree		*P* < 0.001	*P* < 0.001	*P* < 0.001	*P* < 0.001	*P* < 0.001	*P* < 0.001
TR	101	0.15 ± 0.04[e]	0.39 ± 0.05[e]	0.63 ± 0.05[c]	0.47 ± 0.05[e]	0.61 ± 0.07[c]	0.26 ± 0.06[b]
SL	112	0.29 ± 0.04[d]	0.56 ± 0.05[d]	0.80 ± 0.04[b]	0.61 ± 0.05[d]	0.70 ± 0.06[b]	0.41 ± 0.07[b]
SM	102	0.62 ± 0.05[c]	0.79 ± 0.04[c]	0.84 ± 0.04[b]	0.73 ± 0.04[c]	0.91 ± 0.04[a]	0.63 ± 0.07[a]
MT	96	0.82 ± 0.04[b]	0.89 ± 0.03[bc]	0.95 ± 0.02[a]	0.87 ± 0.03[b]	0.94 ± 0.04[a]	0.70 ± 0.07[a]
MD	102	0.88 ± 0.03[b]	0.88 ± 0.03[bc]	0.97 ± 0.02[a]	0.89 ± 0.03[b]	0.93 ± 0.04[a]	0.68 ± 0.07[a]
SA	142	0.99 ± 0.01[a]	0.99 ± 0.01[a]	0.98 ± 0.01[a]	0.92 ± 0.02[ab]	1.00 ± 0.00[a]	0.80 ± 0.05[a]
MA	63	0.98 ± 0.02[a]	0.97 ± 0.02[ab]	1.00 ± 0.00[a]	0.98 ± 0.02[a]	0.95 ± 0.04[a]	0.82 ± 0.07[a]
Sex		*P* = 0.594	*P* = 0.009	*P* = 0.096	*P* = 0.339	*P* = 0.034	*P* = 0.556
Heifer (H)	390	0.79 ± 0.04	0.85 ± 0.03	0.98 ± 1.07	0.83 ± 0.03	0.98 ± 1.58	0.61 ± 0.04
Steer (S)	328	0.81 ± 0.04	0.91 ± 0.02	0.99 ± 0.71	0.86 ± 0.03	0.99 ± 0.78	0.64 ± 0.04

[1] Sensory attributes were scored using a 15-cm unstructured rating scale: 0 = extremely tough or minimal level of performance, 15 = extremely tender or maximal level of performance, and 7.5 = neutral response. Steaks with tenderness ratings ≥ 7.5 were classified as "tender" and steaks with overall sensory experience ratings ≥ 7.5 delivered a "positive" sensory experience.

[2] Threshold values for shear force correspond to proposed standard specifications for tenderness marketing claims developed by ASTM International Committee F10.60 on Livestock, Meat and Poultry Marketing Claims.

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

Table 9. Comparison of sensory attributes[1] of LM steaks representing USDA camera-based quality grades determined using original grade lines vs. grade lines eventually adopted for official grading purposes

	Quality Grade Category				
Basis for grade placement	Standard	Select	Low Choice	Upper 2/3 Choice	Prime
			—— Juiciness ——		
Original grade lines (expert panel)	7.42 ± 0.15^{d}	7.55 ± 0.14^{d}	8.63 ± 0.14^{c}	9.59 ± 0.11^{b}	10.70 ± 0.12^{a}
Adopted grade lines (field graders)	7.41 ± 0.15^{d}	7.52 ± 0.14^{d}	8.51 ± 0.15^{c}	9.34 ± 0.11^{b}	10.58 ± 0.11^{a}
			—— Tenderness ——		
Original grade lines (expert panel)	7.01 ± 0.17^{e}	7.67 ± 0.16^{d}	8.87 ± 0.16^{c}	9.90 ± 0.12^{b}	10.95 ± 0.14^{a}
Adopted grade lines (field graders)	6.99 ± 0.17^{e}	7.67 ± 0.17^{d}	8.66 ± 0.17^{c}	9.64 ± 0.12^{b}	10.86 ± 0.12^{a}
			—— Meaty/brothy flavor ——		
Original grade lines (expert panel)	7.01 ± 0.13^{e}	7.39 ± 0.12^{d}	8.01 ± 0.13^{c}	8.73 ± 0.10^{b}	9.23 ± 0.12^{a}
Adopted grade lines (field graders)	6.99 ± 0.13^{e}	7.40 ± 0.13^{d}	7.88 ± 0.13^{c}	8.58 ± 0.11^{b}	9.21 ± 0.11^{a}
			—— Buttery/beef fat flavor ——		
Original grade lines (expert panel)	1.62 ± 0.14^{g}	2.05 ± 0.14^{f}	3.14 ± 0.14^{e}	4.83 ± 0.11^{c}	6.93 ± 0.13^{a}
Adopted grade lines (field graders)	1.60 ± 0.15^{g}	2.06 ± 0.14^{f}	2.93 ± 0.15^{e}	4.43 ± 0.12^{d}	6.66 ± 0.11^{b}
			—— Overall sensory experience ——		
Original grade lines (expert panel)	5.94 ± 0.15^{f}	6.73 ± 0.14^{e}	8.00 ± 0.14^{d}	9.44 ± 0.10^{b}	10.87 ± 0.12^{a}
Adopted grade lines (field graders)	5.83 ± 0.15^{f}	6.75 ± 0.15^{e}	7.78 ± 0.15^{d}	9.11 ± 0.11^{c}	10.73 ± 0.11^{a}
			—— Probability of "tender" sensory panel rating——		
Original grade lines (expert panel)	0.39 ± 0.05^{e}	0.58 ± 0.05^{d}	0.82 ± 0.04^{bc}	0.90 ± 0.02^{b}	0.99 ± 0.01^{a}
Adopted grade lines (field graders)	0.40 ± 0.05^{e}	0.56 ± 0.05^{d}	0.79 ± 0.04^{c}	0.88 ± 0.02^{bc}	0.99 ± 0.01^{a}
			—— Probability of a "positive" overall sensory experience ——		
Original grade lines (expert panel)	0.15 ± 0.04^{e}	0.29 ± 0.04^{d}	0.67 ± 0.04^{c}	0.89 ± 0.02^{b}	0.99 ± 0.01^{a}
Adopted grade lines (field graders)	0.15 ± 0.04^{e}	0.29 ± 0.04^{d}	0.62 ± 0.05^{c}	0.85 ± 0.03^{b}	0.99 ± 0.01^{a}

[1] Scored using 15-cm unstructured line scales: 0 = extremely dry, extremely tough, no presence of flavor, or minimal level of performance, 15 = extremely juicy, extremely tender, strong presence of flavor, or maximal level of performance. Steaks with tenderness ratings ≥ 7.5 were classified as "tender" and steaks with overall sensory experience ratings ≥ 7.5 delivered a "positive" sensory experience.

[a,b,c,d,e,f,g] For each trait, means that do not share a common superscript letter differ ($P < 0.05$).

Table 10. Comparison of shear force values for LM steaks representing USDA camera-based quality grades determined using original grade lines vs. grade lines eventually adopted for official grading purposes

	Quality Grade Category				
Basis for grade placement	Standard	Select	Low Choice	Upper 2/3 Choice	Prime
		—— Warner-Bratzler shear force, kg ——			
Original grade lines (expert panel)	4.11 ± 0.08[a]	3.87 ± 0.08[b]	3.40 ± 0.08[cd]	3.17 ± 0.06[e]	2.84 ± 0.07[f]
Adopted grade lines (field graders)	4.13 ± 0.08[a]	3.81 ± 0.08[b]	3.53 ± 0.08[c]	3.22 ± 0.06[de]	2.88 ± 0.06[f]
		—— Slice shear force, kg ——			
Original grade lines (expert panel)	19.77 ± 0.60[a]	18.00 ± 0.54[b]	14.67 ± 0.57[cd]	13.92 ± 0.40[cde]	13.41 ± 0.49[de]
Adopted grade lines (field graders)	19.83 ± 0.60[a]	17.95 ± 0.57[b]	15.10 ± 0.59[c]	14.36 ± 0.43[cde]	13.23 ± 0.42[e]
		—— Probability of WBSF ≤ 4.4 kg (tender)[1] ——			
Original grade lines (expert panel)	0.63 ± 0.05[c]	0.80 ± 0.04[b]	0.88 ± 0.03[b]	0.97 ± 0.01[a]	0.98 ± 0.01[a]
Adopted grade lines (field graders)	0.62 ± 0.05[c]	0.80 ± 0.04[b]	0.84 ± 0.04[b]	0.96 ± 0.01[a]	0.99 ± 0.01[a]
		—— Probability of SSF ≤ 20 kg (tender)[1] ——			
Original grade lines (expert panel)	0.61 ± 0.07[b]	0.69 ± 0.06[b]	0.93 ± 0.03[a]	0.95 ± 0.02[a]	0.97 ± 0.02[a]
Adopted grade lines (field graders)	0.60 ± 0.07[b]	0.70 ± 0.06[b]	0.90 ± 0.04[a]	0.93 ± 0.03[a]	0.98 ± 0.01[a]
		—— Probability of WBSF ≤ 3.9 kg (very tender)[1] ——			
Original grade lines (expert panel)	0.46 ± 0.05[d]	0.61 ± 0.05[c]	0.78 ± 0.04[b]	0.89 ± 0.02[a]	0.94 ± 0.02[a]
Adopted grade lines (field graders)	0.47 ± 0.05[d]	0.61 ± 0.05[c]	0.74 ± 0.04[b]	0.88 ± 0.02[a]	0.94 ± 0.02[a]
		—— Probability of SSF ≤ 15.3 kg (very tender)[1] ——			
Original grade lines (expert panel)	0.25 ± 0.06[e]	0.45 ± 0.07[cd]	0.64 ± 0.06[b]	0.71 ± 0.04[ab]	0.80 ± 0.05[a]
Adopted grade lines (field graders)	0.26 ± 0.06[e]	0.41 ± 0.06[de]	0.63 ± 0.07[bc]	0.69 ± 0.05[ab]	0.80 ± 0.04[a]

[1] Threshold values for shear force correspond to proposed standard specifications for tenderness marketing claims developed by ASTM International Committee F10.60 on Livestock, Meat and Poultry Marketing Claims.

[a,b,c,d,e] For each trait, means that do not share a common superscript letter differ ($P < 0.05$).

Table 11. Comparison[1] of sensory attributes[2] and shear force measurements of LM steaks produced by black and non-black cattle

	Predominant color[3]		
Trait	Black	Non-black	*P* > F
N	505	213	
Juiciness	8.80 ± 0.08	8.40 ± 0.11	0.001
Tenderness	8.82 ± 0.08	8.64 ± 0.12	0.221
Meaty/brothy flavor	8.04 ± 0.09	7.95 ± 0.10	0.342
Buttery/beef fat flavor	3.64 ± 0.09	3.32 ± 0.11	0.005
Bloody/serumy flavor	2.75 ± 0.10	2.72 ± 0.11	0.656
Sensory experience	8.14 ± 0.07	7.88 ± 0.10	0.044
Warner-Bratzler shear force, kg	3.50 ± 0.04	3.56 ± 0.06	0.428
Slice shear force, kg	15.74 ± 0.30	16.66 ± 0.43	0.086

[1] Least squares means (± SEM) calculated using a least squares model that included random effects of block and fixed effects of sex, camera-based quality grade, sex × camera-based quality grade, and color (black, non-black).

[2] Scored using 15-cm unstructured line scales: 0 = extremely dry, extremely tough, no presence of flavor, or minimal level of performance, 15 = extremely juicy, extremely tender, strong presence of flavor, or maximal level of performance.

[3] Determined by presence or absence of an A stamp on the carcass.

Table 12. Pearson correlation coefficients[1] describing associations among carcass measurements, LM sensory attributes, and LM shear force

Trait	Hump height, cm	LM lean color measurement			LM pH
		L*	a*	b*	
Juiciness	-0.17	-0.08	0.36	0.25	-0.18
Tenderness	-0.13	-0.02	0.35	0.27	-0.20
Meaty/brothy flavor	-0.16	-0.09	0.40	0.16	-0.11
Butter/beef fat flavor	-0.21	-0.09	0.34	0.23	-0.17
Bloody/serumy flavor	0.13	0.17	-0.18	-0.06	0.01
Sensory experience	-0.18	-0.06	0.40	-.29	-0.20
LM WBSF	0.05	0.04	-0.20	-0.14	0.12
LM SSF	0.02	-0.08	-0.22	-0.14	0.18

[1] Coefficients ≥ 0.10 differ from 0 ($P < 0.01$).

Table 13. Stepwise multiple logistic regression analysis using camera marbling score, LM pH, and LM color measurements as predictors of the likelihood of a positive sensory experience[1]

Step	Predictor	β	SE β	Wald's χ^2	Df	*P*	Model R^2
0	Intercept	9.0698	6.7914	1.78	1	0.182	NA
1	Camera marbling score	0.0111	0.0009	157.10	1	< 0.001	0.555
2	LM pH	-3.6868	1.1443	10.38	1	0.001	0.575
3	LM L*	0.1117	0.0398	8.64	1	0.003	0.580
4	LM a*	0.1723	0.0614	7.88	1	0.005	0.589

[1] Ratings for overall sensory experience ≥ 7.5 were coded as 1; ratings < 7.5 were coded as 0.

CHAPTER IV

LITERATUTE CITED

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APPENDIX

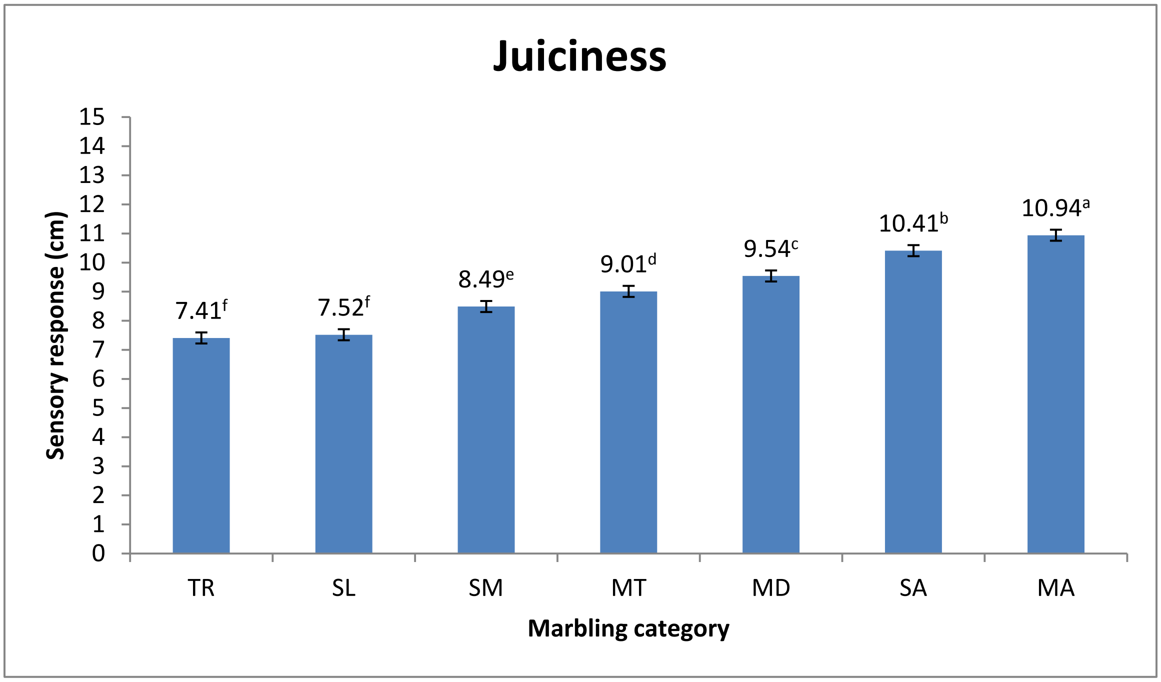

Figure 1. Least squares means ± standard errors for the effect of marbling degree on sensory panel ratings for juiciness ($P < 0.001$). Scored using 15-cm unstructured line scales: 0 = extremely dry and 15 = extremely juicy. Bars that do not share a common superscript letter differ ($P < 0.05$).

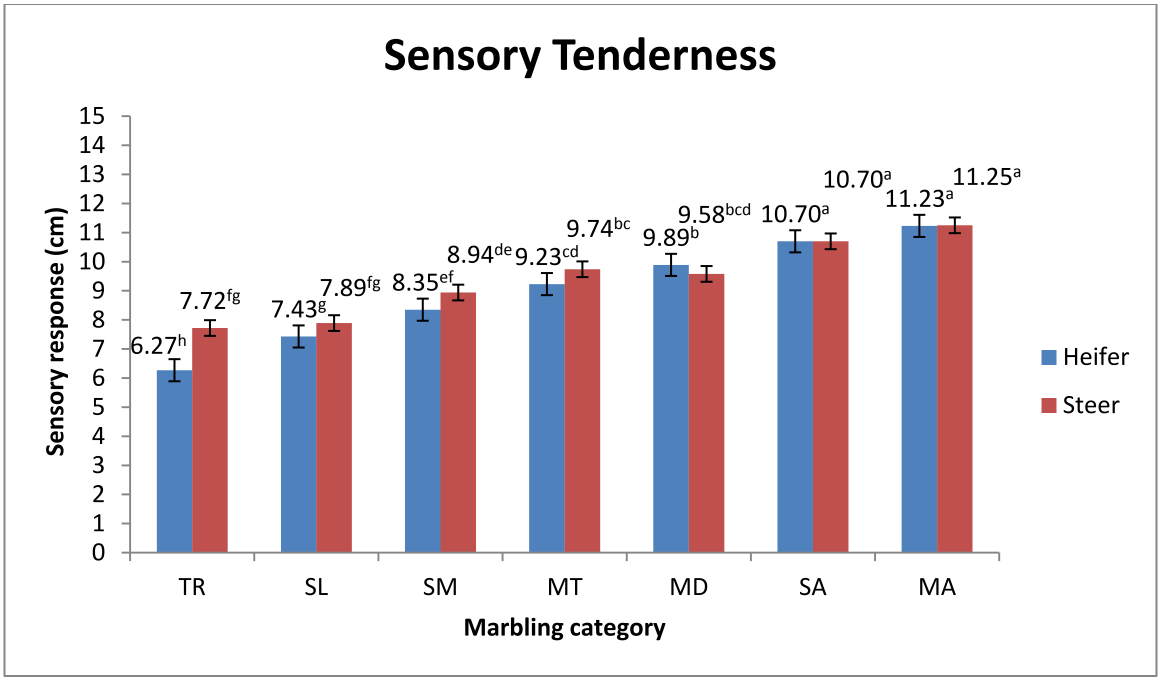

Figure 2. Least squares means ± standard errors for the interaction of marbling degree x sex on sensory panel ratings for tenderness (P = 0.012). Scored using 15-cm unstructured line scales: 0 = extremely tough and 15 = extremely tender. Bars that do not share a common superscript letter differ (P < 0.05).

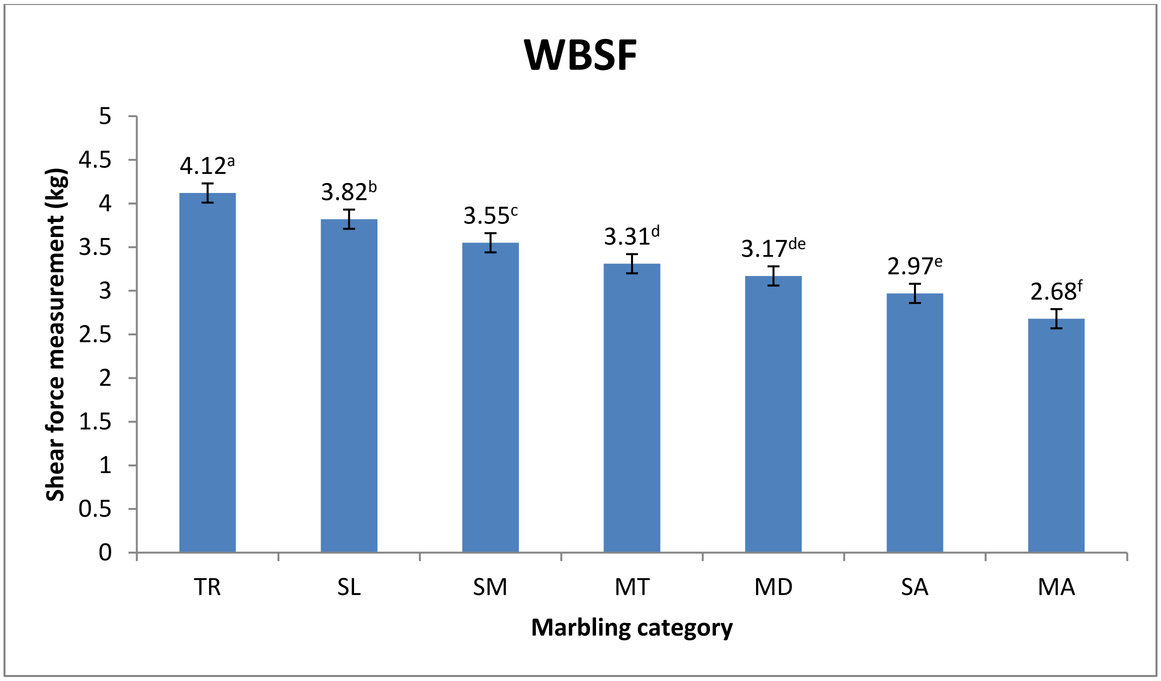

Figure 3. Least squares means ± standard errors for the effect of marbling degree on Warner-Bratzler shear force ($P < 0.001$). Bars that do not share a common superscript letter differ ($P < 0.05$).

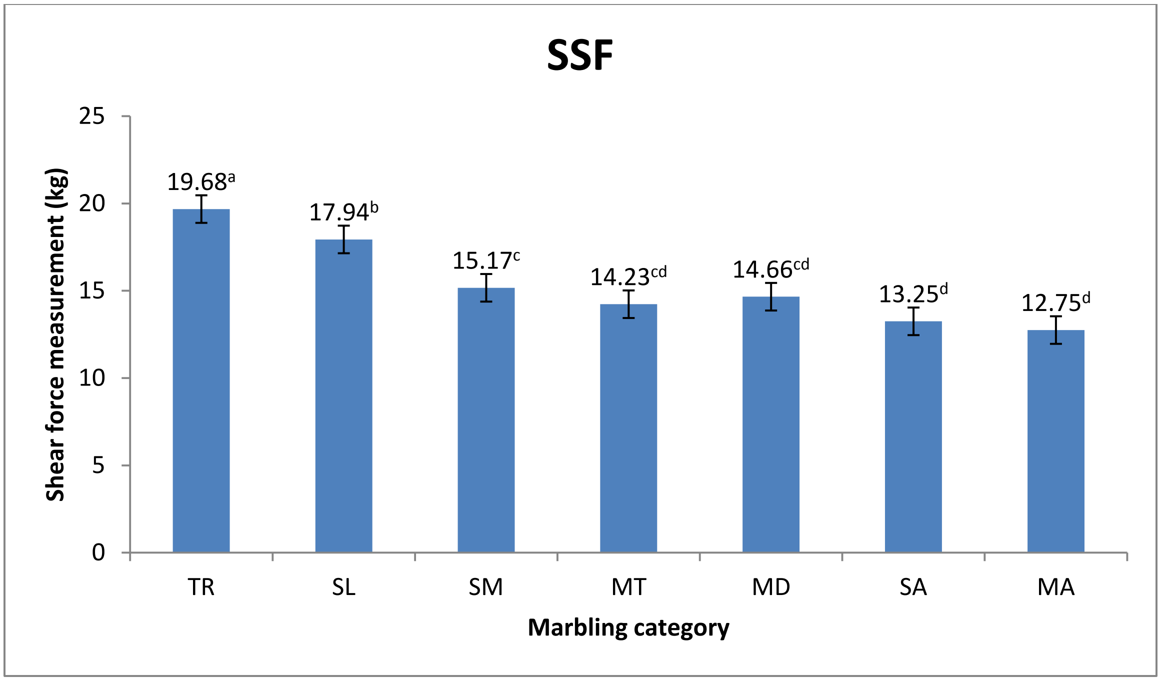

Figure 4. Least squares means ± standard errors for the effect of marbling degree on slice shear force (*P* < 0.001). Bars that do not share a common superscript letter differ (*P* < 0.05).

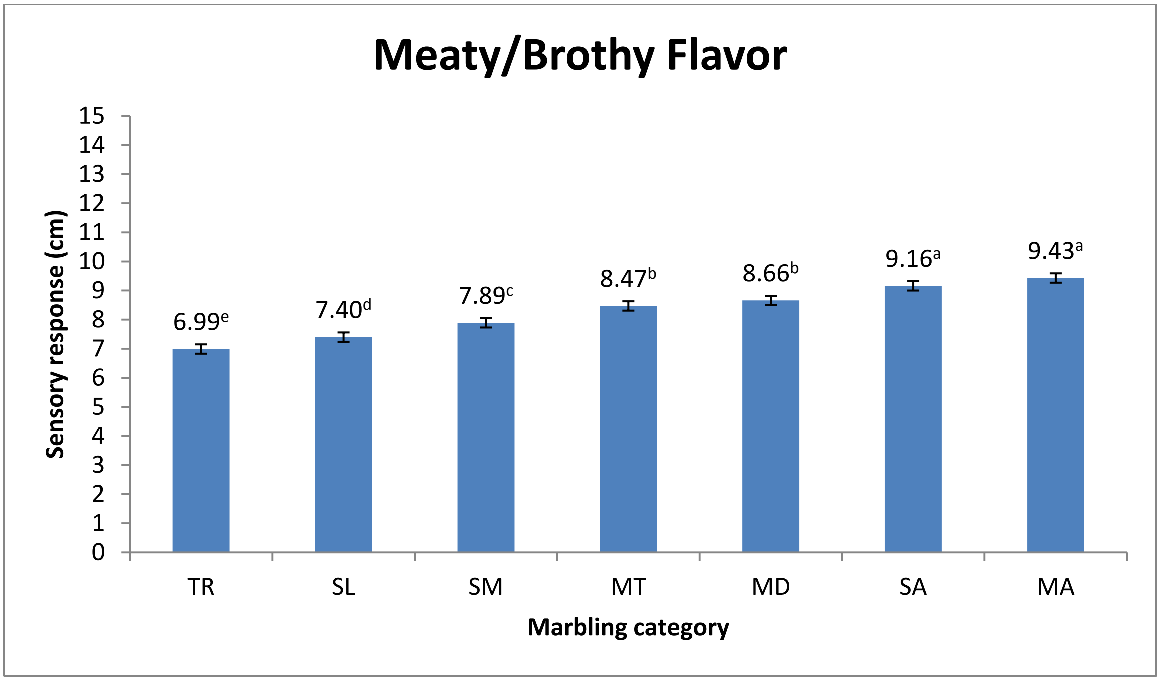

Figure 5. Least squares means ± standard errors for the effect of marbling degree on sensory panel ratings for meaty/brothy flavor (P < 0.001). Scored using 15-cm unstructured line scales: 0 = no presence of flavor or minimal level of performance and 15 = strong presence of flavor or maximal level of performance. Bars that do not share a common superscript letter differ (P < 0.05).

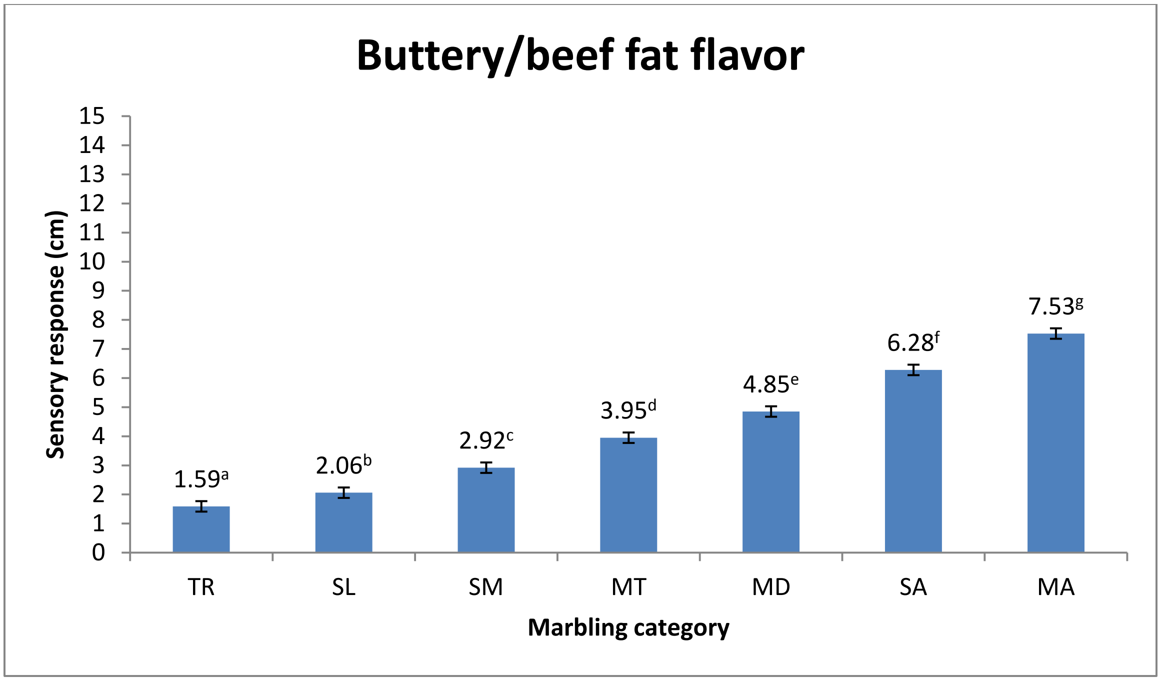

Figure 6. Least squares means ± standard errors for the effect of marbling degree on sensory panel ratings for buttery/beef fat flavor ($P < 0.001$). Scored using 15-cm unstructured line scales: 0 = no presence of flavor or minimal level of performance and 15 = strong presence of flavor or maximal level of performance. Bars that do not share a common superscript letter differ ($P < 0.05$).

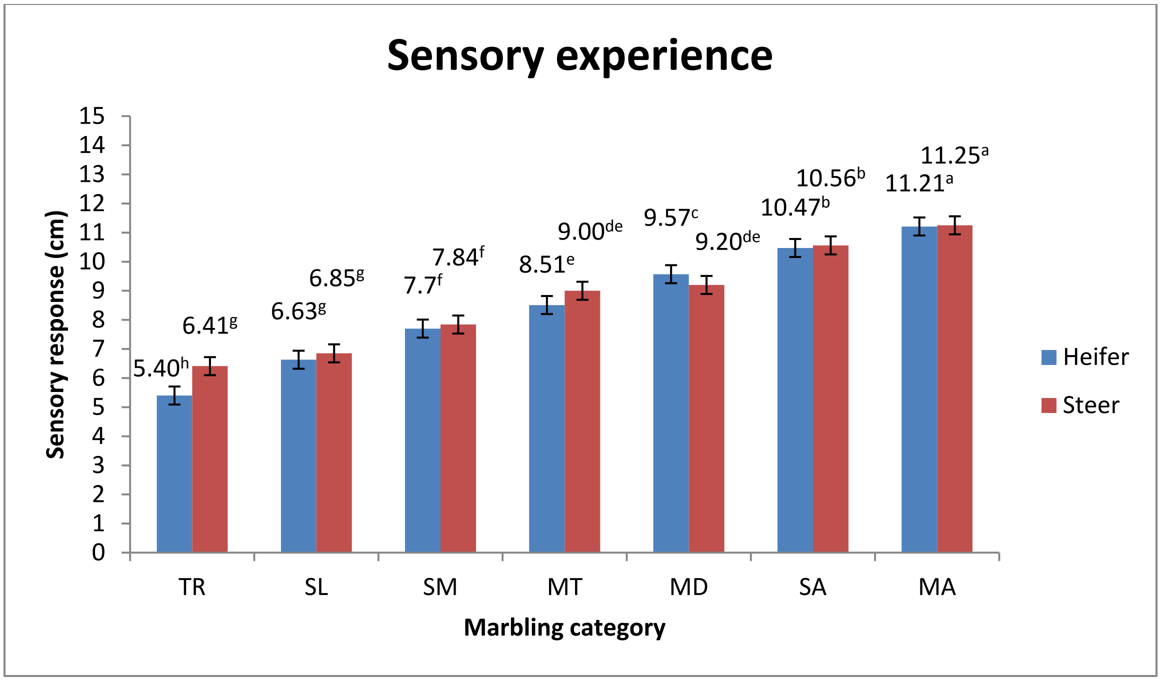

Figure 7. Least squares means ± standard errors for the interaction of marbling degree x sex on sensory panel ratings for overall sensory experience (*P* = 0.040). Scored using 15-cm unstructured line scales: 0 = minimal level of performance and 15 = maximal level of performance. Bars that do not share a common superscript letter differ (*P* < 0.05).

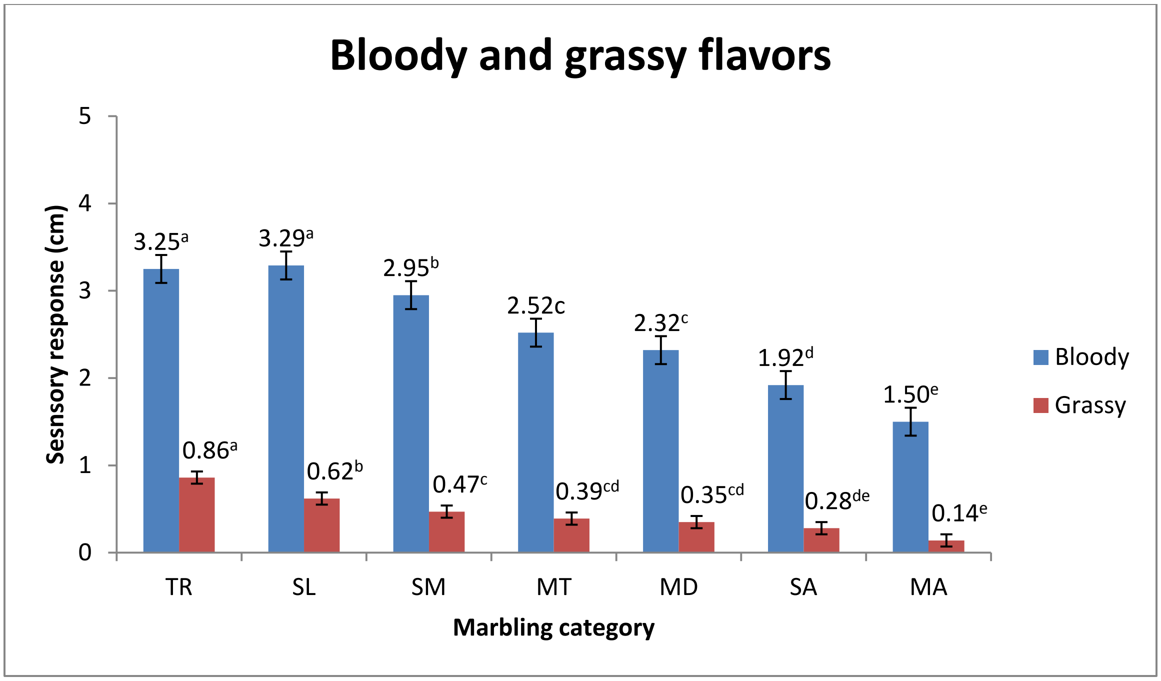

Figure 8. Least squares means ± standard errors for the effect of marbling degree on sensory panel ratings for bloody/serumy and grassy flavor ($P < 0.001$). Scored using 15-cm unstructured line scales: 0 = no presence of flavor or minimal level of performance and 15 = strong presence of flavor or maximal level of performance. Bars of the same color that do not share a common superscript letter differ ($P < 0.05$).

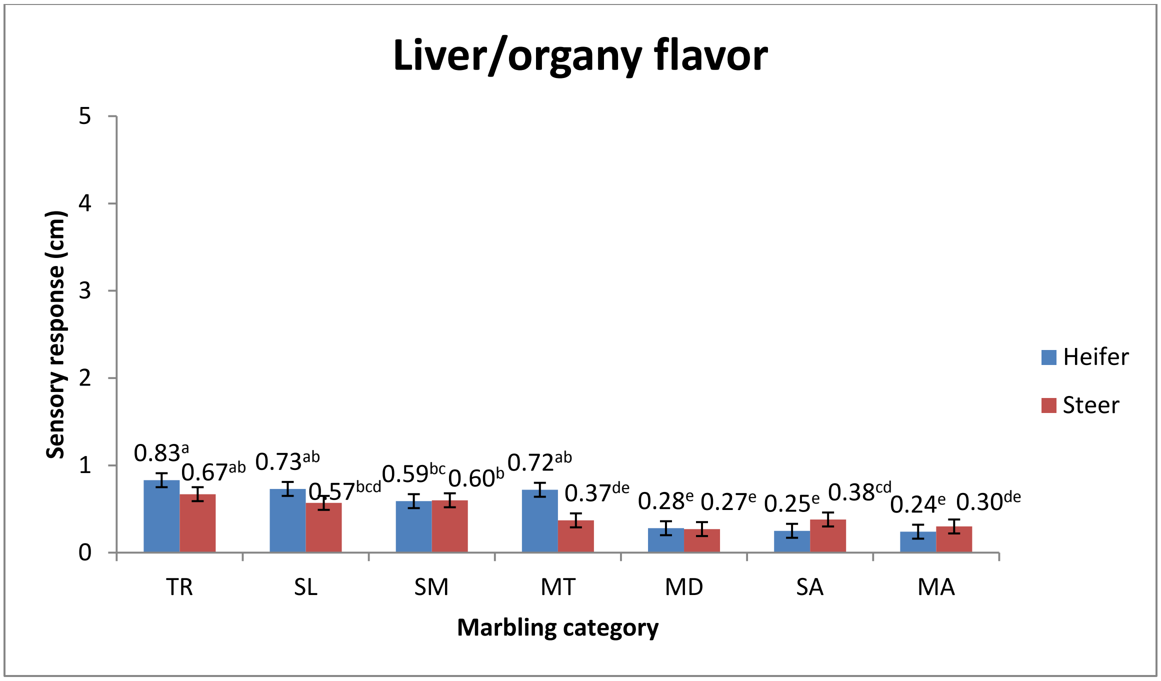

Figure 9. Least squares means ± standard errors for the interaction of marbling degree x sex on sensory panel ratings for liver/organy flavor (P = 0.042). Scored using 15-cm unstructured line scales: 0 = no presence of flavor or minimal level of performance and 15 = strong presence of flavor or maximal level of performance. Bars that do not share a common superscript letter differ (P < 0.05).

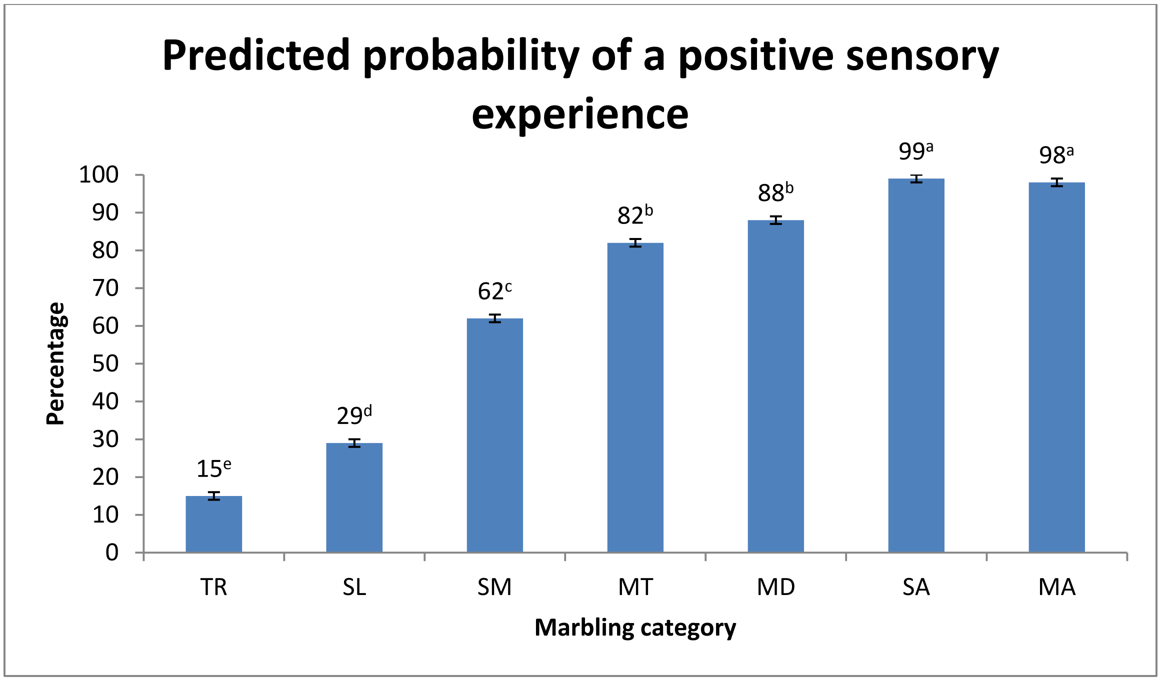

Figure 10. . Effects of marbling degree on the probability of a steak meeting or exceeding pre-determined specifications for sensory experience ($P < 0.001$). Sensory attributes were scored using a 15-cm unstructured rating scale: 0 = minimal level of performance and 15 = maximal level of performance, and 7.5 = neutral response. Steaks with overall sensory experience ratings ≥ 7.5 delivered a “positive” sensory experience. Bars that do not share a common superscript letter differ ($P < 0.05$).

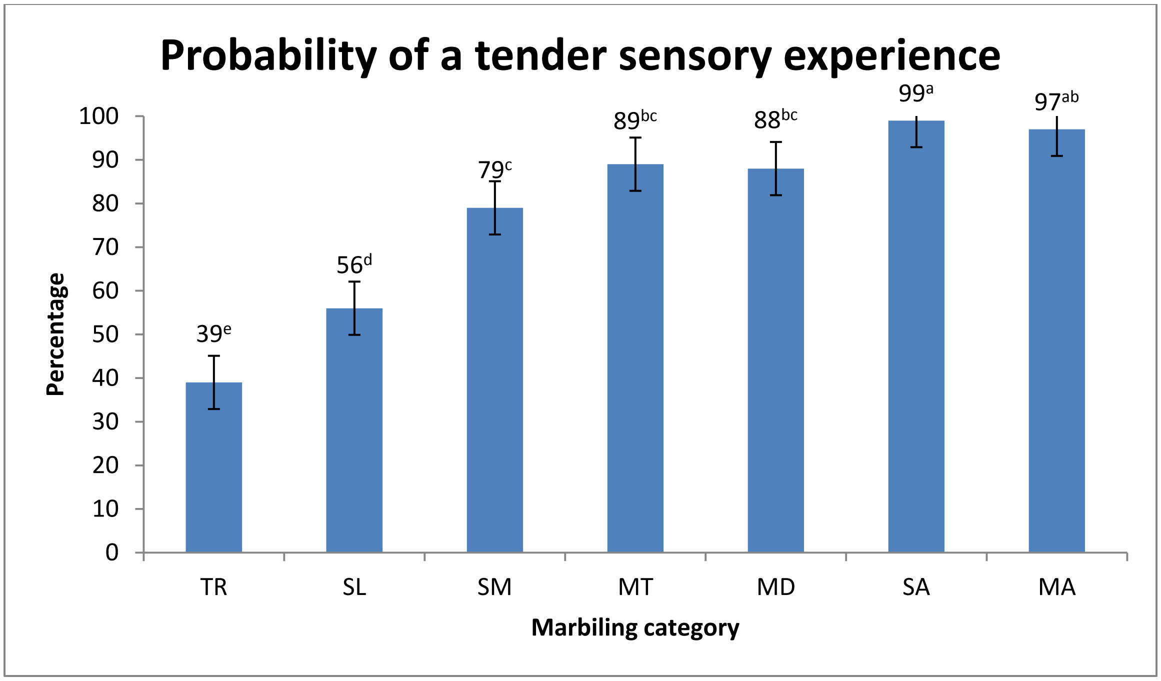

Figure 11. . Effects of marbling degree on the probability of a steak meeting or exceeding pre-determined specifications for sensory tenderness ($P < 0.001$). Sensory attributes were scored using a 15-cm unstructured rating scale: 0 = extremely tough and 15 = extremely tender and 7.5 = neutral response. Steaks with tenderness ratings ≥ 7.5 were classified as "tender". Bars that do not share a common superscript letter differ ($P < 0.05$).

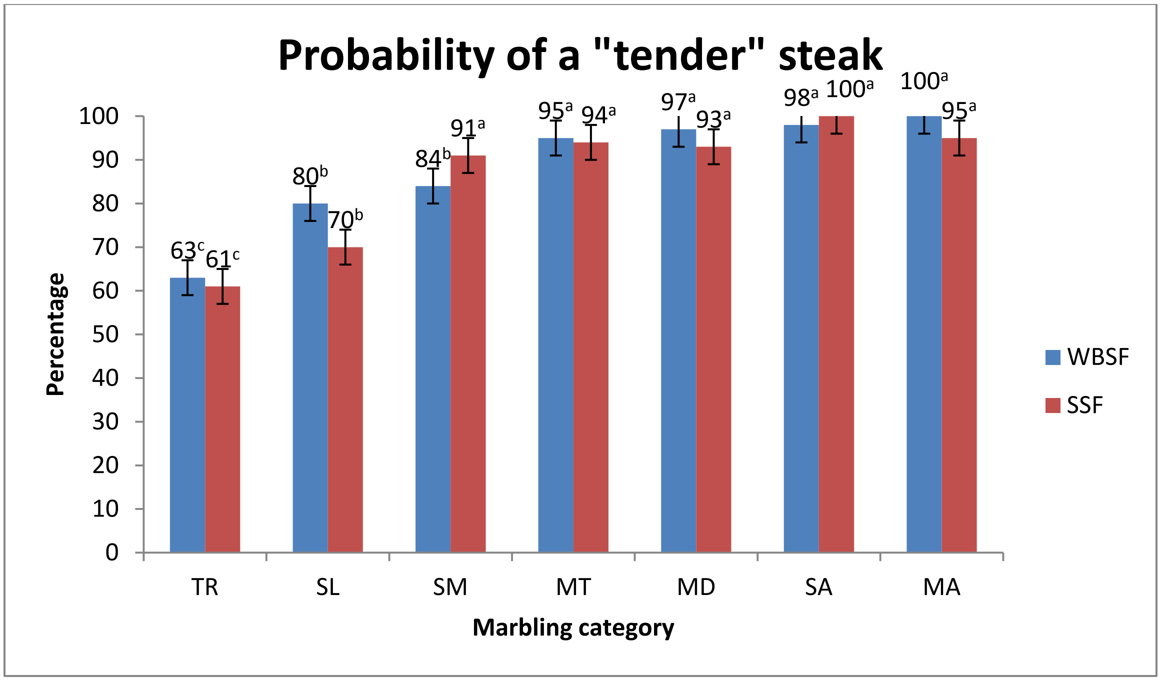

Figure 12. . Effects of marbling degree on the probability of a steak meeting or exceeding pre-determined specifications tenderness ($P < 0.001$). Threshold values for shear force correspond to proposed standard specifications for tenderness marketing claims developed by ASTM International Committee F10.60 on Livestock, Meat and Poultry Marketing Claims (WBSF ≤ 4.4 kg and SSF ≤ 20 kg). Bars of the same color that do not share a common superscript letter differ ($P < 0.05$).

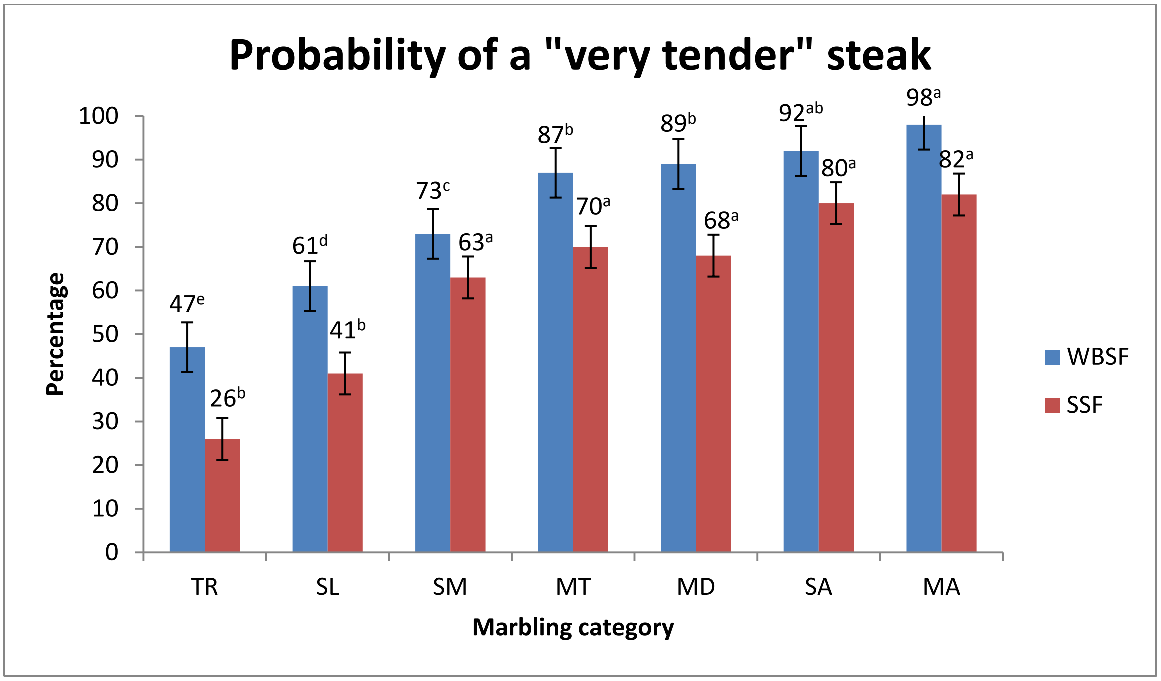

Figure 13. . Effects of marbling degree on the probability of a steak meeting or exceeding pre-determined specifications tenderness ($P < 0.001$). Threshold values for shear force correspond to proposed standard specifications for tenderness marketing claims developed by ASTM International Committee F10.60 on Livestock, Meat and Poultry Marketing Claims (WBSF ≤ 3.9 kg and SSF ≤ 15.3kg). Bars of the same color that do not share a common superscript letter differ ($P < 0.05$).

Least squares means showing effects of marbling degree and sex on carcass characteristics for lean L*, a*, b*, pH, IMF, and moisture.

		Sensory panel rating[1]					
Effect	N	Lean L*	Lean a*	Lean b*	pH	IMF	Moisture
Marbling degree		*P* = 0.007	*P* < 0.001	*P* < 0.001	*P* = 0.003	*P* < 0.001	*P* < 0.001
TR	101	37.90^{bc}	9.72^{c}	11.21^{d}	5.49^{a}	2.19^{g}	5.90
SL	112	38.43^{ab}	10.12^{bc}	11.66^{cd}	5.47^{ab}	3.32^{f}	6.74
SM	102	39.07^{a}	10.63^{b}	11.89^{bc}	5.45^{bc}	5.34^{e}	7.77
MT	96	38.24^{ab}	11.35^{a}	12.27^{ab}	5.46^{bc}	6.95^{d}	8.75
MD	102	38.15^{abc}	11.60^{a}	12.67^{a}	5.44^{bc}	8.65^{c}	9.38
SA	142	37.66^{bc}	11.81^{a}	12.42^{a}	5.44^{c}	10.84^{b}	10.52
MA	63	37.14^{c}	11.99^{a}	12.44^{ab}	5.43^{c}	13.81^{a}	11.23
Sex		*P* = 0.675	*P* = 0.079	*P* = 0.258	*P* = 0.479	*P* = 0.011	*P* = 0.040
Heifer (H)	390	38.03	11.18	12.12	5.46	7.52	8.50
Steer (S)	328	38.14	10.89	11.96	5.45	7.07	8.73
Residual SD[2]		0.02	0.13	0.07	0.03	0.72	1.42

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

[2] Standard errors of least squares means may be calculated as $1/\sqrt{n} \times$ residual SD for a trait, where n = number of carcasses in that particular subclass.

[a,b,c,d,e,f,g] Means in the same column within an effect that do not share a common superscript letter differ (*P* < 0.05).

	Extremely Dry	Extremely Juicy
Juiciness		
	Extremely Tough	Extremely Tender
Tenderness		
	No Presence	Very Strong Presence
Meaty/Brothy		
	No Presence	Very Strong Presence
Buttery		
	No Presence	Very Strong Presence
Metallic/Bloody/Serumy		
	No Presence	Very Strong Presence
Liver/Organy		
	No Presence	Very Strong Presence
Grassy		
	Negative (-)	Positive (+)
Overall Sensory Experience		

Comments: ____