DISSERTATION

USE OF VIDEO IMAGE ANALYSES TO IDENTIFY CARCASS CHARACTERISTICS AND SENSORY QUALITY OF BEEF PRODUCTS GENERATED FROM MATURE COW CARCASSES

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY DALE RAY WOERNER ENTITLED USE OF VIDEO IMAGE ANALYSIS TO IDENTIFY CARCASS CHARACTERISTICS AND SENSORY QUALITY OF BEEF PRODUCTS GENERATED FROM MATURE COW CARCASSES BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

USE OF VIDEO IMAGE ANALYSES TO IDENTIFY CARCASS CHARACTERISTICS AND SENSORY QUALITY OF BEEF PRODUCTS GENERATED FROM MATURE COW CARCASSES

A single study (sponsored by the beef check-off) was conducted to investigate the ability of video image analysis technology to identify carcass characteristics and sensory attributes of products generated from mature cow carcasses. Market cows representing three pre-harvest management strategies were used to evaluate the ability of video image analysis (VIA) to identify the impacts of pre-harvest management (MGMT) on carcass muscle and beef sensory characteristics. Cow MGMT groups were as follows: 1) Non-fed cows (n = 104) (NON-FED; beef-type cows entering the slaughter facility as culls from sale barns and/or ranching operations); 2) Fed cows (n = 108) (FED; beef-type cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period); 3) Dairy cows (n = 113) (DAIRY; cows entering the slaughter facility directly from dairies as culls). FED market cows were fatter, heavier, and more muscular than either NON-FED or DAIRY cows. DAIRY cows were slightly fatter (in the carcass), heavier, and less muscular (alive, muscle score) than were NON-FED beef cows. FED beef cows had the most desirable ; lean color scores, the most tender LM steaks, and had whiter colored fat than NON-FED beef cows. DAIRY cows were the most youthful (lowest SKELMAT and dentition scores) at the time of harvest and produced carcasses that had similar marbling and fat color scores to those of FED beef cow carcasses. NON-FED beef cows produced the lowest marbling scores, the toughest LM steaks, and the most yellow colored fat. Correspondingly, fat from NON-FED beef cows had the highest concentrations of vitamin A and β-carotene in the fat. NON-FED cows had the greatest probability of producing beef with undesirable flavor attributes but no meaningful differences were found among MGMT groups in fatty acid composition. Cow LM representing all MGMT groups responded to postmortem muscle-aging ($P < 0.001$) whereas the PM did not ($P = 0.075$). A MGMT × postmortem muscle aging time interaction existed for the INFRA ($P < 0.042$). A significant interaction of MGMT × evaluation method (USDA grader vs. VIA instrument) existed for marbling score, LMA, and 12th rib fat thickness. Compared to USDA grader determined values, VIA instrument scores were higher for marbling score and lower for LMA. A prediction model developed from VIA instrument outputs demonstrated the ability to characterize the MGMT of cow with less than 13% error. The findings of this research warrant the continued development VIA instruments to identify cow carcass characteristics and sensory quality.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

OBJECTIVE OF DISSERTATION

The objective of this dissertation was to evaluate the ability of video image analysis technology to identify carcass characteristics and sensory attributes of products generated from mature cow carcasses. A single study (sponsored by the beef check-off) was conducted to investigate these effects. The specific objectives were as follows:

1) Evaluate the ability of Video Instrument Assessment (VIA; cold camera $12^{th}/13^{th}$ rib interface assessment) technology to evaluate carcass characteristics and to identify the impacts of pre-harvest market cow management practices on cow carcass quality.

2) Identify the influence of pre-harvest market cow management, live animal characteristics, and carcass characteristics on subsequent sensory quality of product from individual carcasses existing in the market cow sector of the beef industry.

3) Evaluate the effects of postmortem aging on the tenderness of three individual muscle cuts from individual mature-cow carcasses representing the range of variability currently existing in the market cow sector of the beef industry.

CHAPTER II

REVIEW OF LITERATURE

Instrument Assessment of Beef

In the eighty year history of grading beef in the U.S., subjective human judgment has been the primary tool in determining carcass yield and quality grades and consequently carcass value. Objective means of evaluating the attributes of beef, including carcass yield and quality grades as well as other beef characteristics such as cutability, tenderness, and appearance, increase the functionality of a value-based marketing system. Improving the consistency and accuracy of evaluations to improve conformity and consistency of beef products with the use of instrumentation ultimately contributes to increased producer and consumer satisfaction with beef and enhances communication with all segments of the beef industry. The 30 year progression of advancement in the area of instrument assessment of beef yield and quality characteristics is illustrated in Figure 2.1.

Instrument Assessment of Beef Tenderness

USDA marbling scores combined with physiological maturity (USDA quality grades) has historically served as an the primary indication of beef palatability. The decision to include marbling as a primary value-determining characteristic in beef carcass assessment was based on the premise that marbling is associated with eating quality (McBee and Wiles, 1967; Jennings et al., 1978; Tatum et al., 1980; Dolezal et al., 1982).

Smith et al. (1987) illustrated how marbling effectively sorts carcasses on the basis of expected eating quality when the sample population spans the entire range of possible quality grades experienced in the U.S. beef supply. However, over 75% of U.S. beef carcasses today grade USDA Select or low Choice (Slight and Small degrees of marbling) (NCBA, 2005). Within this narrow range of marbling scores, marbling does not do an adequate job of sorting beef carcasses into palatability groups reflecting differences in value at the consumption level (Smith et al., 1995; Wulf et al., 1997). As a result, in recent years, some researchers have shifted their focus to the instrument assessment of beef tenderness (NCBA, 2002; NCBA, 2005). Therefore, new technologies with the ability to more precisely assess beef carcasses for tenderness would be useful, particularly for branded beef programs that make "guaranteed tender" claims.

Warner-Bratzler shear force (WBSF) has been widely accepted and adopted as the standard for objective measurement of beef tenderness. However, the WBSF method was intended to be used as a laboratory research tool and not to assess beef tenderness in a non-invasive manner at commercial production speeds. To fit the needs of today's beef industry, an ideal system to assess beef tenderness would involve an objective, non-invasive, tamper-proof, accurate, rapid, and robust technology. Therefore, recently conducted research pertaining to instrument assessment of beef tenderness has been aimed at minimally invasive techniques targeted to explain differences in WBSF and could be potentially integrated into a beef carcass assessment system at commercial speeds. With rapid advances in imaging technology and technologies utilized in the medical field, a great deal of promise is evident for future research in this area.

Slice Shear Force (SSF) as an Objective Method for Assessing Beef Tenderness

The slice shear force (SSF) method was developed by scientists at the Roman L. Hruska U.S. Meat Animal Research Center (MARC) as a system for measuring beef *longissimus* muscle tenderness under commercial processing conditions using a simplified method of shear force determination (Shackelford et al., 1997). The same scientists have found WBSF measured at the traditional time of beef carcass grading (1 to 2 days postmortem) was an accurate predictor of beef *longissimus* steaks at 14 days postmortem (Shackelford et al., 1997). Based on these findings, MARC scientists designed SSF to serve as a more rapid objective measurement (compared to WBSF methods) to quantify and classify beef carcass tenderness immediately following carcass ribbing. By classifying carcass tenderness at the time of carcass grading, SSF was predicted to facilitate the use of tenderness classification in a value-based marketing system and result in clearer economic signals in the beef production chain (Shackelford et al., 1997).

In determining the SSF value of beef *longissimus* muscle steaks, a single steak must be obtained from the carcass and cooked following protocols identical to those utilized for WBSF determination. As described by Shackelford et al. (1999b), immediately after cooking (while the steak is still hot), a single 1-cm thick, 5-cm long slice is removed from each steak parallel to the muscle fibers. Each slice is then sheared perpendicular to the muscle fibers using an electronic testing machine equipped with a flat, blunt-end blade using a crosshead speed of 500 mm/min. In contrast, WBSF protocols can involve an extended cooling period (often in excess of 24 hours) following cooking and require multiple cores (also taken parallel to the muscle fiber) to be obtained from each steak which are individually sheared at a slower crosshead speed (200 mm/min). As a result, SSF can be determined in a matter of minutes, whereas WBSF protocols often require 24 hours before tenderness is quantified.

Research performed by Shackelford et al. (1999a and 1999b) has shown SSF to be a highly repeatable method to assess beef *longissimus* tenderness and is even more repeatable than WBSF measures by the same group of scientists. *Longissimus* tenderness determined using SSF 3 days postmortem has been shown to be highly correlated with WBSF and trained sensory panel tenderness rating at 14 days postmortem (Shackelford et al, 1999a). Additionally, SSF exhibited the ability to effectively classify tenderness (tender, intermediate and tough) determined by WBSF and trained sensory panel with a high level of accuracy. In fact, SSF has also been shown to be more highly correlated with trained sensory panel tenderness ratings than is WBSF. Furthermore, when compared to indirect, non-invasive methods/technologies primarily utilizing lean color to predict beef tenderness, SSF is more capable of classifying beef tenderness (Wheeler et al., 2002). Therefore, SSF methods could be utilized to assess consumer tenderness experience in *longissimus* muscle steaks at a very early point in the production chain.

Despite the fact that SSF has been shown to be technically less difficult, more rapid, more repeatable, and more accurate than WBSF (Shackelford et al., 1999a; Shackelford et al, 1999b), it has not been utilized in a commercial production setting to assess the tenderness of beef carcasses at the time of grading. The mechanically invasive nature of the SSF technique and the monetary loss associated with removing a single steak from each carcass has left researchers searching for more indirect, non-invasive technologies to assess beef tenderness in a real-time commercial setting. Nonetheless, the positive attributes of SSF have attracted the attention of researchers and, along with

WBSF, is routinely utilized to assess beef tenderness in academic and industry research. In fact, many individual companies currently utilize SSF in an offline, laboratory setting to verify branded beef and tenderness claims.

Use of Objective Color Measurement to Assess Beef Tenderness

Due to the limited success of tenderness probes and industry opposition to invasive systems, researchers have also investigated the use of color as a palatability predictor. Hodgson *et al.* (1992) and Hilton *et al.* (1997) found that subjective lean and fat color scores for mature cow carcasses were related to subsequent cooked beef palatability. With the concept that lean color explains physiological and postmortem factors known to influence beef palatability, Wulf et al. (1997) used a portable colorimeter to evaluate the ability of objective color measurements obtained from the lean of the exposed 12th rib interface (ribeye) to segregate beef carcasses into tenderness groups. Wulf et al. (1997) found that Commission Internationale de I'Eclairage (CIE) L*, a*, and b* values, measured on the exposed *longissimus* muscle of beef carcasses, were highly related to beef carcass palatability. Specifically, b* measurements, colorimeter readings valued on a continuum from blue to yellow, were highly correlated to muscle pH and were useful in predicting cooked beef tenderness. Additionally, when compared to marbling scores, objective color scores were more highly related to WBSF and sensory panel tenderness ratings and showed a greater ability to effectively segregate carcasses into tenderness groups (Wulf et al., 1997).

To emulate a scenario under which a quality grading system would be employed, Wulf and Page (2000) evaluated the effectiveness of objective muscle color, muscle pH, and hump height (maximal protrusion of the rhomboideus muscle; to serve as an indication of *Bos indicus* influence in cattle) to segregate palatable and unpalatable beef from a sample population that was representative of the U.S. cattle population in terms of breed type (including native, Brahman, and dairy carcasses). Additionally, Wulf and Page (2000) evaluated these factors' ability to augment the current USDA quality grading standards to improve their effectiveness at distinguishing palatable from unpalatable beef. The carcasses utilized in this study were all selected within the USDA marbling scores of Slight^{00} and Small^{99} (USDA Select and low Choice quality grades), because substantial unexplained palatability variation exists within these two marbling levels. Also, carcasses were selected to represent a wide range in b* values (as a result, a wide range of L* values also existed). To represent overall carcass palatability, Wulf and Page (2000) created an index which was the additive measure of *longissimus*, *gluteus medius*, and *semimembranosus* WBSF values and sensory panel attributes.

Wulf and Page (2000) found that L* and b* values effectively segregated beef that was especially low in palatability and specifically low in tenderness and flavor desirability, whereas muscle pH was useful at distinguishing carcasses that have especially tender *longissimus* steaks. As L* and b* values increased, palatability increased, and when muscle pH was below 5.45, *longissimus* steaks were more tender. It was also determined that a hump height specification of not more than 8.9 cm was effective at sorting out palatability problems associated with *Bos indicus* carcasses (Wulf and Page, 2000). When used in combination, marbling score, hump height, and L* were able to explain 36% of the variation in the carcass palatability index (Wulf and Page, 2000). Despite the fact that b* value and muscle pH were able to explain variation in overall palatability, these variables were not included in the two systems proposed by Wulf and Page (2000) to augment the quality grading system. Measures of b* were variable depending upon bloom time (amount of time the *longissimus* muscle was exposed to air prior to assessment), and L* values were able to replace b* with only a small sacrifice in accuracy of palatability prediction (Wulf and Page, 2000). Muscle pH was not considered due to the level of difficulty associated with accurately determining pH at commercial chain speeds as well as the associated risk of breaking glass pH probes off in beef carcasses.

Wulf and Page (2000) proposed two systems to augment the current USDA quality grading standards to improve their effectiveness at distinguishing carcasses likely to produce palatable versus unpalatable loin steaks (Table 2.1). The grading systems proposed by Wulf and Page (2000) increased the consistency of palatability by reducing the variation within carcasses of Choice versus Select grades. Variation in palatability among groups of carcasses/steaks within groups of steaks from carcasses in the Choice grade was reduced by 29% and 39%, while variation within groups of steaks from carcasses in the Select grade was reduced by 37% and 12% by applying proposed systems 1 and 2, respectively. In addition to reducing variation within carcasses of the same quality grade, the proposed systems were able to reduce the incidence of unpalatable carcasses from each grade, as they were applied using current USDA standards. For cattle grading USDA Choice under the current standards, the incidence of carcasses producing unpalatable steaks was reduced from 14% to 4% and 1% using proposed systems 1 and 2, respectively. Also, for cattle grading USDA Select under the current standards, the incidence of carcasses producing unpalatable steaks was reduced from 36% under the current USDA standards to 7% and 29% for proposed systems 1 and 2, respectively (Figure 2.2; Wulf and Page, 2000).

In summary, the use of objective color measurements in combination with other carcass characteristics effectively explains some of the variation in beef palatability (Hodgson et al., 1992; Hilton et al., 1997, Wulf et al., 1997; Wulf and Page, 2000) and could be utilized to augment USDA quality grades to improve prediction of carcass palatability in a value-based marketing system (Wulf and Page, 2000). Specifically, objective color measurements are especially effective at identifying and segregating carcasses with the least palatable cooked steaks (Wulf et al., 1997; Wulf and Page, 2000). As a result, objective color measurement continues to serve as the foundation in other technologies aimed at predicting beef tenderness in a non-invasive manner.

Use of BeefCam™ Technology to Assess Beef Tenderness

Researchers at Colorado State University initiated pilot work with Hunter Associates Laboratory (manufacturers of the HunterLab MiniScan portable spectrophotometer) to develop a VIA system that could measure beef carcass lean and fat color using the L*, a*, and b* color scale. A bench-top VIA system first was used to obtain images of beef *longissimus* steaks for the purpose of objective color analysis. Belk et al. (1997) reported that the pilot study data confirmed that: (1) color is related to subsequent cooked palatability of beef carcasses, independent of differences in marbling or carcass maturity, and (2) VIA technology is capable of ascertaining color attributes of beef ribeyes, using the color information to augment USDA quality grades, and thereby improve the accuracy of quality grades in sorting carcasses, based on expected eating palatability of their cuts across narrow ranges of marbling scores.

Based on the results of the pilot study, Colorado State University and Hunter Associates Laboratory began development of a prototype portable video imaging system (BeefCam™), which contained hardware and software that were specifically designed for the analysis of beef carcass lean and fat color in a packing plant environment (Belk et al., 1997). Wyle et al. (2003) evaluated the prototype BeefCam™, used alone or in conjunction with USDA quality grades assigned by expert graders, as a tool for sorting beef carcasses into expected palatability groups. Both prototype BeefCam™ models effectively lowered the percentage of carcasses producing tough steaks for those carcasses certified as tender compared to that of the entire sample carcass population (Wyle et al., 2003). Additionally, Wyle et al. (2003) reported that both models were able to generate subpopulations of carcasses that had steaks with lower frequencies of tough steaks when compared to the steaks from the entire carcass population. However, both BeefCam™ models failed to certify a large percentage of steaks that were actually tender (Wyle et al., 2003). Wyle et al. (2003) concluded that the regression models were developed from a carcass population that produced a very low percentage (13.9%) of steaks that were actually tough and were validated on a set of carcasses that produced an even lower percentage (7.9%) of steaks that were actually tough; therefore, a reduced opportunity for regression models to explain carcass toughness and an increased chance of not certifying carcasses that were actually tender existed.

Vote et al. (2003) conducted a study using BeefCam™ technology that was integrated into an existing VIA system (CVS BeefCam™) to predict tenderness of beef steaks using on-line measurements obtained at chain speeds. In comparison to the study conducted by Wyle et al. (2003), carcasses utilized by Vote had a much higher incidence of carcasses producing tough (WBSF $\geq$ 4.5 kg) *longissimus* muscle steaks. However, results of the two studies were similar. Vote et al. (2003) also concluded that the CVS BeefCam™ technology was able to certify as tender up to 80% of the carcasses in the sample population and that sorting reduced the chance of encountering a tough steak in comparison to such chance in an unsorted population of carcasses. Despite this, a significant portion of carcasses that actually produced tender (WBSF $<$ 4.5 kg) steaks were not certified as being tender by use of the CVS BeefCam™ technology (Vote et al., 2003).

In summary, using the BeefCam™ technology to segregate and certify carcasses as being "tender" provides a clear advantage to not sorting carcasses based on tenderness (Wyle et al., 2003; Vote et al., 2003). However, a significant percentage of carcasses with steaks that are actually tender are not certified by use of BeefCam™ technology (Wyle et al., 2003; Vote et al., 2003), and BeefCam™ has not been shown to identify tough steaks with 100% accuracy. At a minimum, branded beef programs that are willing to establish thresholds for tenderness and BeefCam™ outputs, could utilize this technology to increase the consistency and tenderness of their products (Wyle et al., 2003; Vote et al., 2003). However, further research to increase the accuracy of BeefCam™ is warranted before it could be widely adopted by the U.S. beef industry as an objective system for predicting the tenderness of steaks from individual carcasses.

Instrument Assessment of USDA Marbling Score

USDA marbling score is the most variable factor influencing the value of graded beef carcasses in the U.S. today. Unlike the determination of USDA yield grade (USDA YG) where at least some of the factors used to assess overall carcass yield can be objectively measured using a tool, determination of marbling score is quite different, because no true measuring device is used to aid expert determination. Marbling photographs published by NCBA illustrating standards for individual marbling scores are utilized heavily by USDA graders today, but an overwhelming amount of variation in the volume and distribution of marbling in carcasses requires USDA graders to also use subjective judgment to determine marbling score. The subjective nature of a human's visual assessment of marbling can lead to discrepancies in quality grade assignment between USDA graders when exposed to different environmental conditions and cattle populations (Cross et al., 1984). A limited amount of published research has been aimed directly at assessing marbling score with the use of instrumentation. However, technological advances in VIA have made the concept of instrument assessment of beef carcass marbling scores a readily approaching reality.

Video Image Analysis (VIA) Assessment of USDA Marbling Score

Early studies assessing only the amount of marbling in the 12^{th} rib interface with the use of VIA demonstrated very little association between expert assigned marbling scores and VIA predictions (Cross et al., 1983; Jones et al., 1992). Researchers have noted that in addition to the amount of marbling in the assessment of marbling score, expert evaluators take into account the size and distribution of marbling depots (Jones et al., 1992), as well as lean and fat color (Ferguson, 2004). Marbling score prediction, using VIA technology, would need to utilize multiple variables in an equation, which actually defines how expert evaluators see marbling. Researchers have recently utilized VIA outputs indicating amount of marbling and other visible attributes of beef carcass ribeyes in regression analysis to predict marbling score with considerable accuracy (Moore, 2006).

Studies conducted by Steiner (2002) and Shackelford et al. (2003) separately evaluated the ability of three VIA systems to determine USDA marbling scores of beef carcasses. Results of both studies showed the ability of VIA systems to be moderate to high in explaining variation in marbling score. These scientists also found VIA system measurements of marbling to be highly repeatable. Nonetheless, both studies determined that the current VIA systems were unable to assign USDA quality grades with an acceptable level of accuracy. Therefore, scientists concluded that VIA systems were not a viable option to replace or even augment the application of USDA marbling scores (Steiner, 2002; Shackelford et al., 2003).

With previous research indicating that VIA systems' prediction abilities lacked the accuracy needed for assignment of USDA marbling scores for quality grade determination, Moore (2006) assessed the improvements in predictive capabilities for the Computer Vision System (CVS; Research Management Systems, USA, Inc., Fort Collins, CO), in conjunction with the evaluation of recommendations regarding USDA approval requirements for instruments to augment the current quality grading system. Moore (2006) conducted a study in three phases to develop prediction equations for USDA marbling score and tested them for accuracy, precision and repeatability.

Prediction equations developed by Moore (2006) utilized VIA instrument variables in a regression analysis relating to the amount, size, and distribution of marbling, as well as the color of the lean and fat within the visible *longissimus* muscle area. Despite that the newly developed prediction equations were more accurate that those developed by Steiner (2002), new equations failed to meet initial USDA instrument performance standards with only a moderate ability to explain variation in marbling score (Moore, 2006). Moore (2006) implied that the initial equations developed using a single marbling score could be improved by redeveloping prediction equations using expert marbling scores determined by a three-member expert panel. It was also identified that the accuracy and precision of expert marbling scores are vital to the development of more accurate prediction equations (Moore, 2006).

As reported by Moore (2006), the initial equation and three additional equations, exhibited much greater accuracy (greater than 89%) and precision than any other instrument previously used to predict marbling score with an extremely high level of repeatability (greater than 99.5%). Despite the fact that many equations met USDA requirements for accuracy and repeatability (USDA, 2006a), none of the equations were able to fully meet USDA instrument performance standards, which included additional statistical requirements. At this point, Moore (2006) identified that regression analysis was unsuitable for evaluating instrument marbling score assignment due to the subjective nature and inherent variance found in the expert assessment of marbling score. Essentially, Moore (2006) identified that the initial USDA instrument performance standards (USDA, 2006a) expected instruments to perform at a higher level of accuracy and precision than expert graders establishing the "Gold Standard" marbling score. As a result, Moore (2006) suggested the use of a method comparability approach that would allow for a more accurate assessment of accuracy and precision associated with the instrument predictions.

Following the suggestions made by Moore (2006), USDA published performance requirements for instrument marbling evaluation known as PRIME I (USDA, 2006b) using a method comparability approach. Final instrument performance criteria were established as a result of consultation with an industry working group comprised of representatives of USDA, the National Cattlemen's Beef Association (NCBA), beef processing companies, cattle producers, technology providers, and academia. The instrument approval process as outlined in PRIME I (USDA, 2006b) involved two phases: Phase I: Demonstration of the repeatability of marbling score prediction on stationary beef carcasses; Phase II: Demonstration of the accuracy and precision of marbling score prediction at line speeds. A USDA instrument trial was conducted in 2006 to test two VIA systems seeking USDA approval in the determination of marbling score using VIA, the CVS system and the VBG2000 (E+V Technology, Oranienburg, Germany).

Utilizing the approved prediction equation, the CVS system was over 98% repeatable at commercial production speeds (Moore, 2006). The most accurate approved CVS equation utilized 14 variables relating to the amount, size, and distribution of fat present within the exposed ribeye, as well as variables describing color of lean and fat (Moore, 2006). The approved CVS technology exhibited a high degree of accuracy and precision across all degrees of marbling, and variance in CVS marbling score remained fairly constant across all degrees of marbling (Moore, 2006).

In summary, as an objective measure, modern VIA technologies exhibit the greatest ability to provide an assessment of the amount of marbling, lean and fat color measurements, as well as some quantification of the spatial characteristics of marbling in determining marbling score. Additionally, alternative techniques were established to better determine the accuracy and precision of instruments' ability to objectively predict expert marbling scores (Moore, 2006). Once this technique was identified, USDA was able to establish reasonable standards for assessing the ability of VIA instruments to determine marbling score. Based on proven accuracy and precision in marbling score assignment, two VIA technologies have been approved for the determination of marbling score by USDA (USDA, 2006c). When implemented, approved VIA systems to assign marbling score will increase the consistency of grade placement within individual packing facilities and between facilities. The reproducibility and objectiveness gained through the use of VIA technology in the assignment of quality grade will bring the beef industry closer to a true value-based marketing system.

Instrument Assessment of Beef Yield Traits

Carcass yield and/or cutability make reference to the percentage of boneless, closely trimmed retail products or retail product yield obtained from an individual beef carcass. For graded beef, USDA yield grades (YG) are routinely applied to carcasses to represent estimated individual carcass yield. Assigned YG range in numerical value from 1.0 to 5.9 and are sometimes calculated to the nearest tenth of a YG unit. Assignment of YG to beef carcasses can be determined somewhat objectively (with the use of measuring devices). When assigned by trained evaluators, allowed ample time to measure and precisely determine YG factors accurately, USDA YG account for 70% to greater than

80% of the variation in beef carcass cutability (Abraham et al., 1980; Cannell et al., 1999; Cannell et al., 2002). Nonetheless, current production practices with chain speeds in excess of 450 carcasses per hour do not permit precise USDA YG assignment. Research has shown that in actual application, 25 to 30 years ago, SDA YG were are often applied in error (Cross et al., 1980; Cross et al, 1984). Therefore, it is imperative that instrument assessment be utilized for yield estimation and the application of YG to enhance a value-based marketing system. Belk et al. (1996) concluded that without an instrument that is completely capable of calculating YG and replacing USDA graders, the ability of technologies to augment the application of carcass yield grades should be evaluated.

Video Image Analysis (VIA) for Yield Assessment

VIA systems have been developed and tested in several countries to predict meat yield percentage using output data resulting from the processing of digital images of either the entire side of a hot beef carcass, the cross-section of the rib interface after a beef carcass has been chilled, or by combining data from both digital images (Jones et al., 1995; Borggaard et al., 1996; Shackelford et al., 1998; Cannell et al., 1999; Cannell et al., 2002; Steiner et al., 2003a; Steiner et al., 2003b; Vote, 2003). Cross et al. (1983) and Wassenberg et al. (1986) performed the initial research on the first generation VIA systems that utilized the chilled 12th rib interface and reported considerable potential of VIA as a yield grading device for commercial or research purposes. Both scientists found that VIA had greater or equal success predicting lean muscle, when compared to USDA expert grader evaluations. Cross et al. (1983) and Wassenberg et al. (1986) also identified actual and adjusted fat thickness as the most important non-instrument traits and concluded that VIA performance could be improved considerably when fat thickness is adjusted subjectively. In retrospect, both Cross et al. (1983) and Wassenberg et al. (1986) identified the value in using instrumentation and, specifically, VIA technology in an augmented system to predict yield characteristics.

In recent years, the majority of the research conducted on yield prediction has been with the use of VIA technologies and has been aimed specifically at augmenting current YG applications and improving carcass cutout estimation and prediction. Without the use of instrumentation, Belk et al. (1998) conducted a study to simulate and assess the effectiveness of using carcass assessment technology to augment on-line beef carcass USDA YG application to improve accuracy and precision of grade placement. Belk et al. (1998) determined that instrument augmentation could be used to increase repeatability, accuracy, and precision of on-line graders and would be most beneficial if it could accurately assess muscling characteristics (REA) of beef carcasses. Belk et al. (1998) also found that on-line graders were more capable of accurately assessing whole number YG than calling all of the individual YG factors to compute YG to the nearest tenth of a grade. Belk et al. (1998) explained that this was not surprising because on-line USDA graders are trained to evaluate carcasses at rapid speeds, but they cannot generally be expected to accurately assess all of the individual factors for YG and compute the final YG at the high rates of speed normally encountered in a commercial packing facility. Therefore, Belk et al. (1998) suggested using an augmented YG system to determine YG to the nearest tenth of a grade, offering greater predictive sensitivity, rather than whole number grades.

With a significant amount of research suggesting that USDA graders serve as the best evaluators of adjusted (overall) carcass fatness (Cross et al., 1983; Wassenberg et al., 1986; Belk et al., 1996; Belk et al., 1998), Belk et al. (1998) evaluated differences between measured preliminary yield grades (PYG) and APYG, as determined by an expert panel at their leisure to determine why on-line graders may be able to determine levels of carcass fatness more accurately than instruments. Belk et al. (1998) determined that 94.4% percent of the sample population required PYG adjustments to better represent overall carcass fatness, and 11.0% of the population required an adjustment to the measured PYG of over .5 YG units. Therefore, the primary reason that USDA graders are more accurate at assessing adjusted or overall fatness of beef carcasses is that there is a certain level of subjectivity that instruments were not capable of estimating to determine the effects of slaughter defects and other irregularities to the exterior of beef carcasses for a significant percentage of the entire population. Considering USDA graders' superior ability to determine APYG and the need for a more accurate assessment of REA, combined with the instruments' ability to accurately assess REA and quickly calculate yield grade factors to a final YG to the nearest tenth, Belk et al. (1998) determined that the most realistic estimate of how instrument augmentation could be expected to improve the accuracy and precision of YG determination included: 1) on-line graders' determination of the APYG and 2) instrument-measured values for all other yield grade factors.

With the identification of the potential for added accuracy and precision for an instrument augmented yield prediction system by Belk et al. (1998), subsequent research has evaluated multiple techniques to predict carcass and subprimal yields to increase the viability of, and producer and consumer confidence in a value-based marketing system. Shackelford et al. (1998) conducted an experiment to determine whether VIA of the 12th

rib cross-section used for tenderness classification could accurately evaluate carcass cutability, *longissimus* area (REA), and subprimal cut weights. Image analysis performed by the VIA system described by Shackelford et al. (1998) accurately determined REA, more effectively explained retail product yield than calculated YG. Due to the fact that most all beef carcasses are merchandised as boxed-beef in the U.S., Shackelford et al. (1998) suggested that estimating subprimal cut weights with VIA technology, in combination with appropriate price extension, would allow the beef industry to more accurately estimate true carcass value.

Cannell et al. (1999) evaluated the ability of a dual-component VIA system to predict differences in fabricated yields in beef carcasses and to augment the application of USDA YG. The system used by Cannell et al. (1999) was a technology developed by the Australian Meat Research Corporation (VIASCAN) which is currently utilized in Australian meat grading systems. As described by Cannell et al. (1999), the dual-component VIASCAN system is made up of two cameras; one video camera (hot assessment system; HAS) that obtains an image of carcasses in their unchilled state as they pass by on the rail leaving the slaughter floor, and a second video camera (chiller assessment system; CAS) obtains an image from the interface of the $12^{th}/13^{th}$ rib from chilled carcasses at the time of grading.

In agreement with numerous previous studies, Cannell et al. (1999) identified that measured fat thickness taken ¾ opposite the ribeye served as a poor indication of carcass fatness due to hide pulls and dressing defects. With the same research, Cannell et al. (1999) reported that expert grader adjusted fat thickness (APYG) accounted for a greater percentage of variance in fabricated yields than any other individual factor evaluated by expert grader or VIASCAN measurement. CAS more accurately (exceeding those of the HAS system) determined individual USDA yield grade factors with CAS REA being very highly correlated to expert REA; however, HAS was able to accurately segregate hot carcasses into high-, intermediate-, and low-yielding groups prior to chilling and carcass fabrication (Cannell et al., 1999). The ability of HAS to segregate hot carcasses could prove useful in estimating boxed-beef cutouts earlier in the supply chain allowing for forward sales of product. Perhaps the most noteworthy finding was that in a simulated augmented system, utilizing the single component CAS-REA in combination with expert APYG and KPH factors and known HCW, precision greater than expert yield grade to the nearest tenth was achieved (Cannel et al., 1999).

In a very similar study, Cannell et al. (2002) evaluated the effectiveness of another dual-component VIA system to assess wholesale cut yields. In this study, Cannell et al. (2002) were able to combine measurements from CAS and HAS (fully objective) to predict wholesale cut yields with equal accuracy of USDA expert YG (to the nearest tenth) and far exceeded (greater than 25%) the ability of whole-number YG applied by graders at commercial production speeds. The success of the instrument prediction scenario can be at least partially explained by the ability of the system utilized in this study to measure fat thickness at three separate locations at the 12th rib to explain expert APYG with significant precision. The results reported by Cannell et al. (2002) indicated a great deal of promise for the CVS-Dual Component System to augment or even replace USDA on-line graders for YG application.

With numerous studies showing VIA instrument determined LMA to be highly correlated with expert determined REA or LMA (Belk et al., 1998; Cannel et al., 1999;

Cannel et al., 2002; Shackelford et al., 2003) coupled with the fact that numerous studies had suggested the use of instrument determined REA in augmented grading systems (Belk et al., 1998; Cannel et al., 1999; Cannel et al., 2002), Steiner et al. (2003a) conducted a study to determine the accuracy and repeatability of instrument determined LMA. Steiner et al. (2003a) found that VIA accurately determined REA with excellent repeatability. VIA instruments were able to measure LMA with less variance than compared to commonly-used techniques for LMA measurement (Steiner et al., 2003a). With the accuracy and repeatability of VIA instrument-measured LMA being validated (Steiner et al., 2003a), and USDA YG calculated to the nearest tenth having demonstrated the ability to explain high amounts of variation in actual wholesale cutout yields (Cannell et al., 1999; Cannell et al., 2002) , Steiner et al. (2003b) utilized two VIA instruments in a two-part study to: Phase I) determine the ability of each instrument to augment and improve the accuracy of the placement of USDA YG; and Phase 2) to evaluate accuracy and precision of predicted cutout yields when YG was assigned to the nearest tenth of a grade using an on-line, real-time instrument augmented YG system.

As a result of what was learned Phase I, Steiner et al. (2003b) determined that USDA graders would only be expected to determine APYG and QG; therefore, a greater amount of time to accurately evaluate these two carcass traits. Ultimately, results compiled by Steiner et al. (2003b) showed that augmenting the application of YG with VIA technology significantly improved YG placement accuracy, thus allowing the assignment of YG to the nearest tenth to carcasses at commercial processing speeds. Moreover, the augmented application of YG (to the nearest tenth) had no effect on USDA on-line grader application of QG when compared with expert QG (r-value of .69 for both traditional and augmented methods) (Steiner et al., 2003b).

Steiner et al. (2003b) found similar results in Phase II as were found in Phase I. Phase II results indicated that an augmented system that utilized on-line grader APYG and VIA measured LMA achieved accurate placement of USDA YG. VIA systems allowed for YG to be assigned to carcasses to the nearest tenth at commercial chain speeds with greater accuracy than traditional on-line grading practices. When compared to traditional grading practices, augmented final YG also improved the accuracy of subprimal yield prediction by 5 to 8% (Steiner et al., 2003b).

Shackelford et al. (2003) evaluated the ability of the MARC beef carcass image analysis system (cold carcass VIA system that imaged the 12th rib interface) to predict calculated YG, LMA, PYG, and APYG under commercial beef processing conditions. Shackelford found that the MARC system was able to accurately determine actual REA and PYG as well as explain a significant amount of variation in APYG (88%) and expert YG (to the nearest tenth). The MARC system was also reported to have a superior ability to identify carcasses with calculated YG less than 2.0 including carcasses that had calculated YG less than 1.0, providing opportunity for more extensive and accurate carcass segregation than whole number YG applied by on-line graders (Shackelford et al., 2003).

In summary, research conducted in recent years pertaining to the use of VIA as an objective method to assess the yield characteristics of beef carcasses indicated an extremely consistent and unanimous conclusion that VIA technologies are effective.

Various VIA instruments and instrument systems estimated overall carcass cutability and predict subprimal yields with a significant level of accuracy (Cross et al., 1983; Wassenberg et al., 1986; Shackelford et al., 1998; Cannell et al., 1999; Cannell et al., 2002; Steiner et al., 2003b; Shackelford et al., 2003; Vote, 2003). Additionally, VIA technology was superior to subjective methods for assessing LMA/REA with accuracy and precision (Cross et al., 1983; Wassenberg et al., 1986; Shackelford et al., 1998; Cannell et al., 1999; Cannell et al., 2002; Steiner et al., 2003b; Shackelford et al., 2003; Vote, 2003). Despite the fact that some research has shown VIA technology to exhibit considerable ability to predict overall fatness (APYG) of beef carcasses (for example, that of Shackelford et al., 1998; Cannell et al., 2002), it has been well established that VIA instruments have not indicated the ability to assess the overall fatness (APYG) of beef carcasses to the same level as human, subjective measures (Cross et al., 1983; Wassenberg et al., 1986; Shackelford et al., 1998; Cannell et al., 1999; Cannell et al., 2002; Steiner et al., 2003b, Vote, 2003). With APYG and LMA/REA serving as two of the most important factors influencing subprimal yield prediction and USDA YG, researchers have suggested the use of VIA technology in an augmented system to facilitate beef carcass segregation in the U.S. value-based marketing system (Cross et al., 1983; Wassenberg et al., 1986; Belk et al., 1998; Shackelford et al., 1998; Cannell et al., 1999; Cannell et al., 2002; Steiner et al., 2003b; Shackelford et al., 2003; Vote, 2003). Researchers concluded that VIA LMA/REA utilized in an augmented system designed to increase accuracy and precision of USDA YG application is the single most effective objectively measured factor, with a specific focus on applying USDA YG to the nearest tenth of a YG unit (Cross et al., 1983; Wassenberg et al., 1986; Shackelford et al., 1998;

Cannell et al., 1999; Cannell et al., 2002; Steiner et al., 2003b, Vote, 2003). The application of USDA YG to the nearest tenth with VIA augmentation has been shown to more accurately predict carcass cutting yields and as a result, carcass value (Cannell et al., 1999; Cannell et al., 2002; Steiner et al., 2003b). An augmented system for USDA YG application with the use of VIA technology not only provides greater accuracy in the assessment of individual carcasses, but also allows additional time for USDA-AMS to evaluate or even replace the current method of assessing carcass yield.

Factors Influencing the Palatability of Market Cows

Beef from mature market cows constitutes a considerable portion of the product being produced in the U.S. For the calendar year 2007, USDA Market News statistics reported that market cows were16.85% of the total number of cattle harvested in the U.S. Of the 16.85%, beef-type cows were 56.02% of total market cow slaughtered and dairy-type cows were 43.98% of all market cows slaughtered. These percentages translated to a total number of market cows harvested exceeding 5.6 million and over 2.5 billion pounds of beef produced from market cows. The amount of beef produced each year from market cows is substantial and the importance of identifying palatability characteristics of this beef should be realized.

Beef's palatability is defined by its eating characteristics including tenderness, juiciness, and flavor, and the term palatability is often used synonymously with beef quality. In describing the standards for grades of carcass beef, USDA (1965) defined the term "quality" as follows: "The terms 'quality' are used to refer only to the palatability-indicating characteristics of the lean." USDA quality grades for beef carcasses (including the complete range of USDA quality grades) have been shown to be effective for explaining the variation beef palatability (Smith et al., 1986). Smith et al. (1986) showed that with decreasing USDA quality grade, the likelihood of obtaining a loin steak with desirable palatability was decreased. The data reported by Smith et al. (1986) specifically showed that when USDA quality grade is decreased to a level that included carcasses with advanced maturity scores (Commercial, Utility, and Cutter), the amount of variation in palatability increased and the probability of having a desirable palatability experience decreased. Because of 1) the inherent variation in palatability characteristics in beef produced from mature beef animals (Smith et al., 1986), 2) existing USDA quality grades do not reflect common trade practices in the market cow beef industry, and 3) the expense of grading (payment for services of USDA-AMS personel and added facility and labor costs) is not cost-effective (Wise, 1994), almost none of the market cows in the U.S. are not quality graded. Instead, in the U.S., cow carcasses are subjectively sorted by company personnel based on perceived carcass quality characteristics. Sorting decisions are most commonly determined by the evaluation of carcass traits that indicate the level of feeding that cows have received prior to slaughter including fat color, lean color, amount of muscling, and degree of LM marbling.

A significant amount of research supports the reasoning of sorting market cows on fat color, lean color, amount of muscling, and degree of LM marbling. Researchers have shown each of the aforementioned factors to indicate the level of concentrate of the diet and the duration of the finishing period are known to contribute to lean and fat composition and ultimately the sensory attributes of beef resulting from mature cows

(Hilton et al., 1998; Hodgson et al., 1992; Patten et al., 2008; Schnell et al., 1997; Stelzleni et al., 1997). Most of the published research agrees that market cows that have received a high-energy, grain based diet for 30 or more days prior to harvest have greater overall palatability than market cows that have received diet that was predominantly forage-based (Hilton et al., 1998; Hodgson et al., 1992; Patten et al., 2008; Schnell et al., 1997; Stelzleni et al., 1997). The two primary muscle characteristics that have been shown to influence cow palatability are meat flavor and muscle tenderness.

Factors Influencing Market Cow Meat Flavor

A recent summary funded by beef checkoff dollars (NCBA, 2007a) described flavor as: "flavor results from the combination of basic tastes (sweet, sour, bitter, salt, and umami) derived from water-soluble compounds and odor derived from a myriad of substances present in the food product from the onset or derived via various reactions". Differences in the flavor have been shown to be explained by breed (Gorraiz et al., 2002), sex (Westerling and Hedrick, 1979), anatomical location of muscles (Yancey et al, 2005; Westerling and Hedrick, 1979), and diet (Brown et al., 1979; Larick and Turner, 1990; Melton et al., 1982; Westerling and Hedrick, 1979). In a review of literature, Melton (1990) determined that high-energy grain diets produce more acceptable flavor in red meats than low-energy forage or grass diets, and Bruce et al. (2005) reported that more than 40% of the variation in beef flavor between grass and grain-finished beef has been accounted for by diet. Studies have shown that beef from cattle finished on low energy diets with high forage contents has an undesirable flavor (Brown et al., 1979; Dolezal et al., 1982; Hedrick et al., 1983; Larick et al., 1987; Melton et al., 1982; Schroeder et al., 1980).

The diet of the ruminant animal is known to influence the composition of fat in meat. The fat in meat affects flavor in two ways (Smith et al., 1983): 1) fatty acids, upon oxidation, can produce carbonyl compounds (free radicals) that are potent flavor contributors; and 2) fat may act as a storage depot for odoriferous compounds that are released at the time of heating or cooking. Fats are composed of fatty acids and are a known source of flavor constituents, both directly (unmodified) and indirectly (reaction products). Smith and Carpenter (1976) reported that as animals aged, flavor precursors may have been concentrated in the fat depots (subcutaneous, intermuscular, and intramuscular) and intense flavors or odors may result. Smith et al. (1983) showed that as maturity increases, flavor desirability decreases and that flavor desirability increases as intramuscular fat increases. As a result, there has been a considerable amount of research aimed at identifying the differences in the fatty acid composition of meat produced from market cows.

It has been well documented that the fatty acid composition of tissues from monogastric animals, especially fat tissues, tends to be a reflection of their diet, whereas the fatty acid composition of ruminant tissues is less affected by dietary lipid composition. Nonetheless, a considerable amount of research illustrating the differences between the fatty acid composition of muscle from forage-fed and concentrate (grain) fed beef cattle have identified compositional differences. In a study that analyzed fatty acids of muscle and adipose tissue from mature cows, Eichhorn et al. (1986) reported that lipids in muscles from animals that had been fed a maintenance diet (consisting of forages only) contained higher percentages of polyunsaturated fatty acids (PUFA) and lower percentages of saturated fatty acids (SFA) than animals that had been fed an ad libitum diet. In a review of literature, Melton (1983) concluded that steers finished on a low-energy, forage-based diet was a higher percentage of 18:0 and lower percentage of 18:1 than muscle samples from animals on a high-energy, concentrate rations. Melton et al. (1983) also concluded that beef produced on grass pasture usually has less desirable flavor and shorter shelf life, due to oxidative off-flavor development, when stored at refrigeration or frozen temperatures. Findings of other researchers have demonstrated that beef produced from forage-based diets contained an increased amount of C18:0, C18:3, C20:3, C20:4, and C22:5 and less C16:0 and C17:0 on a percent of total fatty acid basis (Brown et al., 1979; Westerling and Hedrick, 1979).

Factors Influencing Market Cow Muscle Tenderness

The tenderness of beef steaks that are prepared using a dry-heat cookery method is significantly affected by the amount of connective tissue it contains. Connective tissue in muscle is comprised of collagen, elastin, and reticulin fibrils in a watery, mucopolysaccharide fluid that surrounds muscle fibers, muscle bundles, and whole muscles (enodmysium, perimysium, and epimysium, respectively). The total amount of collagen (determined from muscle hydroxyproline content) has been linked to the tenderness of muscles resulting from mature cows (Hilton et al., 1998; Hodgson et al., 1992; Schnell et al., 1997; Stelzleni et al., 2007). Several studies have shown that the amount of soluble (heat labile) collagen in bovine skeletal muscle decreased as the animal matures, but cattle fed high energy diets see increases in the protein synthesis and have an increase in soluble collagen (Aberle et al., 1981; Miller et al., 1987, Schnell et al., 1997). Schnell et al. (1997) illustrated the increase in collagen solubility in muscle from cows between 0 and 28 d on feed and a decrease in total collagen content for cows realimented with high energy diets.

Table 2.1. System proposed by Wulf and Page for beef carcass classification (color augmentation).

System #1	System #2
Minimum requirement for Choice:	**Minimum requirement for Choice:**
1. Must be "A" or "B" overall maturity	1. Must be "A" or "B" overall maturity
2. Must have a minimum marbling score of Small^{00}.	2. If L* is from 36.0 to 40.0 then must have a minimum marbling score of Small^{50}
3. Must have a minimum L* value of 36.0.	3. If L* is > 40.0, then must have a minimum marbling score of Slight^{50}
4. Must have a hump height < 8.9 cm	4. Must have a hump height < 8.9 cm
Minimum requirement for Select:	**Minimum requirement for Select:**
1. Must be "A" or "B" overall maturity.	1. Must be "A" or "B" overall maturity.
2. Must have a minimum marbling score of Slight^{00}.	2. Must have a minimum marbling score of Slight^{00}.
3. Must have a minimum L* value of 38.0.	3. Must have a minimum L* value of 36.0.
4. Must have a hump height < 8.9 cm.	4. Must have a hump height < 8.9 cm.

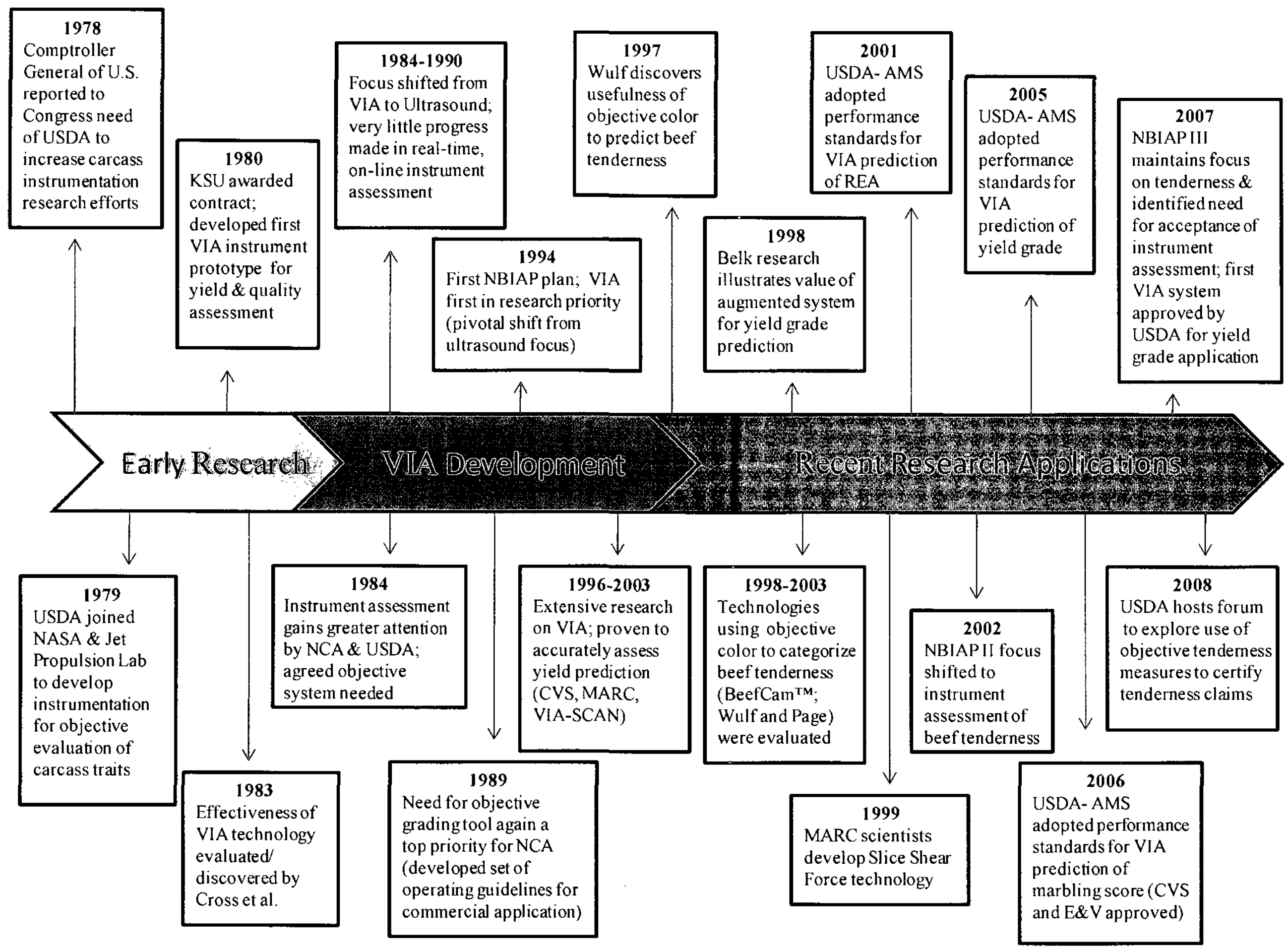

Figure 2.1. Instrument Assessment Timeline. Source: Woerner and Belk (2008)

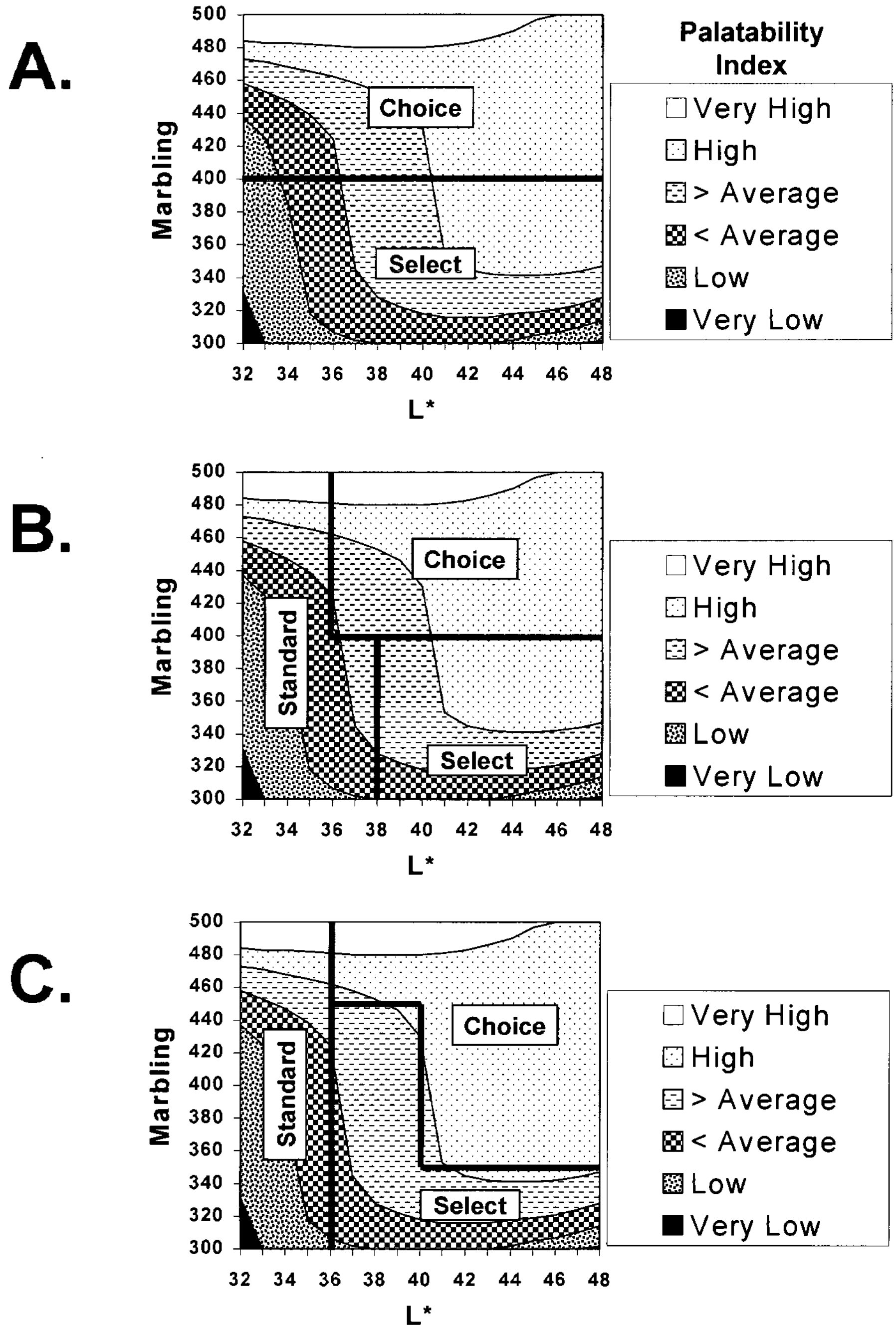

Figure 2.2. Surface response function for marbling score x lean color L* values and carcass segmentations using the current quality grading standards **(A)**, and the proposed Wulf and Page system No. 1 **(B)** and No. 2 **(C)**. Source: Wulf and Page (2000)

CHAPTER III

Use of Video Image Analyses to Characterize Carcass Characteristics and Sensory Quality of Beef Products Generated From Mature Cow Carcasses

ABSTRACT

Market cows representing three pre-harvest management strategies were used to evaluate the ability of video image analysis (VIA) to identify the impacts of pre-harvest management (MGMT) on carcass muscle and beef sensory characteristics. Cow MGMT groups were as follows: 1) Non-fed cows (n = 104) (NON-FED; beef-type cows entering the slaughter facility as culls from sale barns and/or ranching operations); 2) Fed cows (n = 108) (FED; beef-type cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period); 3) Dairy cows (n = 113) (DAIRY; cows entering the slaughter facility directly from dairies as culls). FED market cows were fatter, heavier, and more muscular than either NON-FED or DAIRY cows. DAIRY cows were slightly fatter (in the carcass), heavier, and less muscular (alive, muscle score) than were NON-FED beef cows. FED beef cows had the most desirable ; lean color scores, the most tender LM steaks, and had whiter colored fat than NON-FED beef cows. DAIRY cows were the most youthful (lowest SKELMAT and dentition scores) at the time of harvest and produced carcasses that had similar marbling and fat color scores to those of FED beef cow carcasses. NON-FED beef cows produced the lowest marbling scores, the toughest LM steaks, and the most yellow colored fat. Correspondingly, fat from NON-FED beef cows had the highest concentrations of

vitamin A and β-carotene in the fat. NON-FED cows had the greatest probability of producing beef with undesirable flavor attributes but no meaningful differences were found among MGMT groups in fatty acid composition. Cow LM representing all MGMT groups responded to postmortem muscle-aging ($P < 0.001$) whereas the PM did not ($P = 0.075$). A MGMT × postmortem muscle aging time interaction existed for the INFRA ($P < 0.042$). A significant interaction of MGMT × evaluation method (USDA grader vs. VIA instrument) existed for marbling score, LMA, and 12th rib fat thickness. Compared to USDA grader determined values, VIA instrument scores were higher for marbling score and lower for LMA. A prediction model developed from VIA instrument outputs demonstrated the ability to characterize the MGMT of cow with less than 13% error. The findings of this research warrant the continued development VIA instruments to identify cow carcass characteristics and sensory quality.

INTRODUCTION

Market cows (including beef and dairy animals) comprise a significant portion of U.S. beef production. In 2008, 18.3% of all cattle harvested in the U.S. were cows, totaling over 6 million animals (USDA, 2009). The National Market Cow and Bull Beef Quality Audit – 2007 indicated that 100% of audited cow plants were producing and marketing middle-meat products for potential use as whole-muscle steak and roast items (NCBA, 2007b). It has been well documented that significant variation exists in the eating qualities of beef from carcasses of mature cows (Hodgson et al., 1992; Hilton et al., 1998; Stelzleni et al., 2007). As indicated by the findings most recent national market cow and bull beef quality audit (NCBA, 2007b) an increased number of steak and roast items are being produced from market cows. With the increase in production of these type of items, it is imperative that carcasses producing higher quality, more desirable products be identified to ensure a positive beef eating experience.

In the U.S., cow carcasses are subjectively sorted by company personnel based on perceived carcass quality characteristics. Sorting decisions are most commonly determined by the evaluation of carcass traits that indicate the level of feeding that cows have received prior to slaughter including fat color, lean color, amount of muscling, and degree of marbling. Video image analyses (**VIA**) has been shown to be a highly effective tool in the fed beef industry for identifying beef carcass quality and yield characteristics (Woerner and Belk, 2008). The effectiveness of VIA instruments to measure similar traits on carcasses resulting from mature cows has not been demonstrated. Potentially, VIA instruments could provide an objective evaluation of carcass traits leading to a more accurate assessment of pre-harvest management and subsequent sensory quality of cow beef.

It is widely accepted that pre-harvest management and feeding practices of market cows influence subsequent carcass quality. The level of concentrate in the diet and duration of the finishing period are known to contribute to lean and fat composition and ultimately the sensory attributes of beef resulting from mature cows. According to Dunne et al. (2008), "Beef production systems depend on climatological and socioeconomic factors which frequently dictate management practices and decisions, and thus are a composite of combined and interacting factors that relate intrinsically to the biology of the bovine such as its breed, gender, age at slaughter and carcass weight and fatness as well as extrinsic nutritional and environmental factors." This study was conducted to characterize the effects of pre-harvest management on cow carcass quality and the subsequent eating quality of meat produced from their carcasses and to ultimately determine the effectiveness of VIA technology for identifying carcass characteristics that influence eating quality.

Materials and Methods

Animal Care and Use Committee approval was not obtained for this study because data were collected from products collected at a commercial packing plant. The experiment was conducted in a 5 d period (February 2009) at Caviness Beef Packers, Ltd., located in Hereford, TX.

Animals and Experimental Design

Market cows were identified to represent three pre-harvest management strategies. The pre-harvest management groups (**MGMT)** were as follows: (1) Non-fed cows (**NON-FED**; beef-type cows entering the slaughter facility as culls via sale barns and/or ranching operations); (2) Fed cows (**FED**; beef-type cows entering the slaughter facility from a finishing yard having received a corn-based, high-energy diet for a 95 d ± 1 d period); (3) Dairy cows (**DAIRY**; cows entering the slaughter facility directly from dairies as culls). NON-FED cows were transported to the processing facility from a multitude of locations including ranches and sale barns located in Texas, New Mexico, Oklahoma, Kansas, and Wyoming. FED cows were transported to the packing plant from a single custom finishing yard located within 50 km of the slaughter facility. FED cows received a finishing diet that consisted of 48.2% steam-flaked corn, 30.0% corn silage, 13.0% corn gluten pellet, 2.0% supplement, 6.5% alfalfa hay, 0.3% micro ingredients (rumensin and tylosin). FED cows did not receive any growth promoting agents during the finishing period. DAIRY cows were transported to the harvest facility from multiple dairy operations in the surrounding area with the majority of animals originating from operations in the Texas panhandle and eastern New Mexico. An existing ear tag, sale barn hip tag, or a hip tag placed on an individual animal by Colorado State University (**CSU**) personnel was utilized to identify individual animals within management groups. Individual animal identification was maintained.

Live Animal Evaluation

Immediately prior to slaughter, a 3 member panel [United States Department of Agriculture (**USDA**) – Agricultural Marketing Service (**AMS**), Livestock and Seed Division (**LS**), Market News personnel] determined the breed type for each animal. Breed classifications for NON-FED and FED cows were as follows: (1) British (**BRIT;** purebreds or crosses visually exhibiting predominantly British beef breed characteristics); (2) continental (**CONT**; purebreds or crosses visually exhibiting predominantly continental breed characteristics); and (3) Brahman (**BRAH;** purebreds or crosses visually exhibiting 25% or more *Bos indicus* breed characteristics). The DAIRY cow breed classifications were as follows: (1) Holstein (dairy cows visually exhibiting Holstein breed characteristics); (2) Brown Swiss (dairy cows visually exhibiting predominantly Brown Swiss breed characteristics); and (3) Jersey (dairy cows visually exhibiting Jersey breed characteristics). At the same time, each panel member individually estimated 12^{th} rib fat thickness (estimated to the nearest 0.10 inch), body condition score (**BCS;** a 9-point body condition scale where 9 = excessive fat cover, 5 = average/optimum fat cover, and 1 = minimum/thin fat cover), frame score (**FS;** a 3-classification description including small, medium, and large scored to the nearest 10 percent), and muscle score (**MS;** a 9-point muscle score scale where 9 = thick+, 5 = average^{o}, and 1 = thin-) for each live animal. Individual live animal scores for 12thRIBFAT, BCS, FS, and MS were determined by computing the mean of the 3 individual evaluations.

Dentition and Pregnancy.

Following live animal evaluations, cows were humanely slaughtered using conventional procedures. At the time of head removal, trained CSU personnel evaluated carcasses for dentition, and the number of permanent incisors was recorded for each animal. Immediately following evisceration, each animal was determined to be pregnant or not pregnant by trained CSU personnel. Animals were determined to be PREG when a fetus was visible in the reproductive track. In the event that the pregnancy status of an animal was questionable, assistance from USDA – Food Safety Inspection Service (**FSIS**) personnel was solicited.

Carcass Selection and Carcass Data Collection.

Carcasses were chilled for a minimum of 18 h with accelerated air (air temperature 2°C) and were intermittently sprayed with chilled water. Carcasses from animals with complete live evaluation, dentition, and pregnancy data were randomly selected (n = 325) and cows representing each MGMT group were obtained on each collection day. One hundred and four, 113, and 108 carcasses were selected for NON-FED, FED, and DAIRY MGMT strategies, respectively. The left side of each selected carcass was ribbed to expose the 12^{th}-13^{th} rib interface of the longissimus muscle (**LM**). Following a minimum bloom period of 20 min, the exposed LM was assessed using the Computer Vision System Cold Camera (**CVS**; Research Management Systems, USA, Inc., Fort Collins, CO). Three CVS images were taken of the 12^{th}-13^{th} rib interface for each carcass. Individual images and respective data were stored by CVS. Immediately following CVS assessment, 3 individual objective color measurements were obtained from the lean of the LM as well as the fat (including measurement of subcutaneous and intermuscular fat) in the exposed12^{th}-13^{th} rib interface using a portable spectrophotometer equipped with a 6 mm measurement port (Miniscan XE Model 45/0-L, Hunter Laboratories, Reston, VA). Final color values for the lean and fat portions were recorded as the mean of 3 individual L*, a*, and b* readings. Additionally, subjective LM lean color (8-point scale where 1 = the lightest, pinkish-red, 2 = cherry red, and 6 = the darkest, purplish-red) and subcutaneous fat color (9-point scale where 0 = the brightest, whitest, 5 = pale yellow, and 8 = darkest, yellowish-orange) scores were determined by CSU personnel using the AUS-MEAT Chiller Assessment Meat and Fat Colour Standards (Version 3.1, Aus-Meat Limited, Murarrie QLD, Australia). Following all color assessments, an employee of the USDA-AMS, LS, Standards, Analysis, and Technology Branch determined USDA quality and yield grading factors (USDA, 1997) including skeletal maturity (**SKELMAT**), lean maturity (**LEANMAT**), marbling score, preliminary yield grade (**PYG**), adjusted PYG (**APYG**), and LM area (**LMA**; using a grid) for each carcass. Kidney, pelvic, and heart fat was removed from the carcasses during the slaughter process and was not evaluated. Hot carcass weight (**HCW**) was recorded for each carcass by CSU personnel.

Sample Collection and Preparation.

Following carcass data collection, 100 g of subcutaneous fat was collected from the rib primal at the 12^{th}-13^{th} rib interface and placed in a Whirl-Pak bag (Nasco, Ft. Atkinson, WI), labeled for Vitamin A (**VITA**) analysis, frozen, and stored at -28°C. Frozen VITA samples were shipped frozen to a commercial laboratory for analysis. A striploin (IMPS 180, USDA, 1996), peeled tenderloin (IMPS 189A, USDA, 1996), and a chuck clod (IMPS 114, USDA, 1996) were collected from each carcass. Subprimal cuts were individually vacuum-packaged and transported under refrigeration to the CSU Meat Laboratory.

At the Meat Laboratory, a 0.6 cm slice was removed from the anterior end of each striploin, placed in a Whirl-Pak bag (Nasco, Ft. Atkinson, WI), labeled for pH measurement, frozen, and stored at -28°C. Then, each striploin was faced to square the end of the LM. The faced LM portion was placed in a Whirl-Pak bag (Nasco, Ft. Atkinson, WI), labeled for myoglobin (**MYOG**) and intramuscular fat (**IMF**) analyses, frozen, and stored at -28°C. Then, 4 sections (each 5.1 cm) were sequentially fabricated followed by the fabrication of an additional 2.54 cm steak. Each 5.1 cm LM section was randomly assigned to 1 of 4 postmortem aging treatments (14, 21, 28, and 35 d), individually vacuum packaged, and stored for the appropriate period of time at 2°C. The single 2.54 cm LM steak was individually labeled for collagen analysis, vacuum packaged, stored at 2°C for 28 d postmortem, frozen, and stored at -28°C. The remaining posterior end of each striploin was individually packaged, stored for 14 d postmortem at 2°C, frozen, and stored at -28°C.

The butt portion was removed from the posterior end of the tenderloin and 4 sections (each 5.1 cm) were sequentially fabricated from the posterior end of the remaining anterior portion. Each 5.1 cm *psoas major* (**PM**) section was randomly assigned to 1 of 4 postmortem aging treatments (14, 21, 28, and 35 d), individually vacuum packaged, and stored at 2°C. The butt portion and remaining tail portion from each PM was individually packaged, stored for 14 d postmortem at 2°C, subsequently frozen, and stored at -28°C.

The *infraspinatus* muscle (**INFRA;** IMPS 114D, USDA, 1996) was isolated from each chuck clod. Four flat iron steaks (NAMP 1114D PSO 1, NAMP, 2007) were fabricated from the center-most portion of the INFRA. Each INFRA steak was randomly assigned to 1 of 4 postmortem aging periods (14, 21, 28, and 35 d), individually vacuum-packaged, and stored at 2°C. INFRA end pieces were individually packaged, stored for

14 d postmortem at 2°C, frozen, and stored at -28°C. At the conclusion of each designated aging period, LM sections, PM sections, and INFRA steaks were frozen, and stored at -28°C. Using a band saw (model 400, AEW-Thurne, AEW Engineering Co. Ltd., Norwich, UK), frozen LM sections and PM sections were fabricated into 2.54-cm-thick steaks for slice shear force (**SSF**) determination. Frozen steaks were individually vacuum packaged and stored at -28°C.

For each animal, the 14 d-aged striploin end-piece, the PM butt and tail portion, and the INFRA end-pieces were thawed and sprayed with a 5% lactic acid solution at 172 kPa for 10 s using a commercial spray cabinet (Chad Co., Olathe, KS) and allowed to drain for a minimum of 5 min. Muscle pieces were trimmed free of external fat and connective tissue. One hundred twenty-five grams of lean tissue from each muscle (equal portions of LM, PM, and INFRA) were mixed and ground using a table top meat grinder equipped with a 3.175 mm plate (Model MG100, Waring Consumer Products, East Windsor, NJ). Ground trimmings were formed into 3 patties (each 113 g), using a single hamburger press. Individual patties were randomly labeled for 1 of 3 analyses [flavor panel evaluation, cooked fatty acid (**CKDFFA**) analysis, or raw fatty acid (**RAWFFA**) analysis], individually frozen, vacuum sealed, and stored at -28°C. Additionally, control patties (**CONT**), produced from equal portions of LM, PM, and INFRA obtained from conventionally produced USDA Choice beef carcasses, were prepared identically to patties from NON-FED, FED, and DAIRY animals.

Sample Analysis.

Vitamin A (VITA) and beta-carotene (**βCAR**) content was determined for subcutaneous fat samples labeled for VITA analysis using AOAC methods modified for VITA and βCAR in foods (AOAC, 2001; Tee and Lim, 1992).

For each animal, following 7 d of storage at 2°C, pH was determined by diluting 13th rib LM pieces 10:1 with double-distilled deionized (**DI**) water (10 ml DI water and 1 g LM) and then homogenizing (Model 1120 Waring Blender, Dynamics Corp., New Hartford, CT) (Bass *et al.*, 2008). The pH of the homogenate was determined using a pH meter (Orion 2 Star pH Benchtop, Thermo Electron Corp., Waltham, MA).

For each animal, faced LM pieces designated for MYOG and IMF analysis were thawed at 2°C for 24, refrozen with liquid nitrogen, and homogenized using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc., Ridgeland, MS), labeled, placed in a Whirl-Pak bag (Nasco, Ft. Atkinson, WI), and stored at -28°C. For MYOG analysis, 2 g of frozen muscle sample were homogenized (model T25 basic, IKA Works Inc., Wilmington, NC) for 20 s with 20 ml of 0.04M phosphate buffer. Homogenized samples were allowed to rest for 1 h at 2°C; then, samples were centrifuged at 3,000 rpm for 20 min (Krzywicki, 1982; Warriss, 1979). The supernatant was filtered through a paper filter (Grade No. 1, Whatman, Inc., Florham Park, NJ) and placed in a 96-well plate (type 446612, Fisher Scientific, Pittsburgh, PA). Absorbance was read at 4 different wavelengths (525, 545, 565 and 572 nm) on a spectrophotometer (Synergy HT, BioTek Instruments, Inc., Winooski, VT). Total lipid was extracted for each sample by the Folch et al. (1957) method as modified by Bligh and Dyer (1959).

Composite patties (equal portions of LM, PM, and INFRA) designated for RAWFFA determination were thawed for 24 h at 2°C. Thawed patties were refrozen in liquid nitrogen and homogenized using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc., Ridgeland, MS). Raw homogenized samples were placed in a Whirl-Pak bag (Nasco, Ft. Atkinson, WI), labeled, and stored at -28°C. Composite patties designated for CKDFFA were thawed for 24 h at 2°C, cooked for 2.5 min to an internal temperature of 71°C using electric grills (Salton Clamshell Grill Model No. GR39A, Salton Inc., Lake Forest, IL), allowed to temper for 1 h at 21°C, frozen in liquid nitrogen, and homogenized using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc., Ridgeland, MS). Cooked homogenized samples were placed in a Whirl-Pak bag (Nasco, Ft. Atkinson, WI), labeled, and stored at -28°C. Total lipid was extracted from RAWFFA and CKDFFA samples by the Folch et al. (1957) method as modified by Bligh and Dyer (1959). The fatty acids were methylated as described by Parks and Goins (1994) and the resulting fatty acid methyl esters were analyzed by use of gas chromatography using a Hewlett Packard (Avondale, PA) Model 6890 series II gas chromatograph fixed with a series 7863 injector and flame ionization detector. Fatty acid methyl esters were separated with a 100-m x 0.25-mm (id) fused silica capillary column (SP-2560 Supelco Inc. Bellefonte, PA) with hydrogen as the carrier gas (flow rate = 1 mL per min). The carrier gas ramping temperatures and flows were identical to those outlined by Duckett et al. (2002). The injector and detector were maintained at 250°C. Fatty acids were quantified by incorporating an internal standard (C12:0; lauric acid) into each sample prior to methylation. Lauric acid was not detected when standards were omitted from the unknown samples. Identification of the fatty acids was made by comparing the relative retention times of fatty acid methyl ester peaks from samples with those standards. These were calculated as normalized area percentages of fatty acids.

Frozen LM steaks designated for collagen analysis were thawed at 2°C for 36 h and trimmed free of subcutaneous fat and connective tissue. Each LM collagen steak was cut into medial and lateral halves. Each half was designated for raw collagen (**RAWCOL**) or cooked collagen (**CKDCOL**) analysis. RAWCOL steaks were cut into 1 cm cubes, frozen in liquid nitrogen, and homogenized using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc., Ridgeland, MS). RAWCOL homogenized samples were labeled, placed in a Whirl-Pak bag (Nasco, Ft. Atkinson, WI), and stored at -28°C. LM steak halves designated for CKDCOL analysis were cooked to an internal temperature of 71°C using electric grills (Salton Clamshell Grill Model No. GR39A, Salton Inc., Lake Forest, IL). Internal temperatures were monitored using a type K thermocouple (Model HH-21 Hand-Held Microprocessor Digital Thermometer, Omega Engineering Inc., Stamford, CT). CKDCOL halves were allowed to temper for 1 h at 21°C. Then, CKDCOL halves were cut into 1 cm cubes, frozen in liquid nitrogen, and homogenized using a commercial food processor (Blixer 4V, Robot Coupe USE, Inc., Ridgeland, MS). CKDCOL homogenized samples were labeled, placed in a Whirl-Pak bag (Nasco, Ft. Atkinson, WI), and stored at -28°C. Hydroxyproline content was determined following procedures outlined by Switzer et al. (1991) and absorbances were read at 565 nm wavelength from a 96-well plate (type 446612, Fisher Scientific, Pittsburgh, PA) using a spectrophotometer (Synergy HT, BioTek Instruments, Inc., Winooski, VT). Collagen content was calculated by multiplying the hydroxyproline content of supernatant by 7.52 (Cross et al., 1973).

Shear Force Determination.

Frozen LM steaks designated for SSF determination were thawed for 36 h at 2°C and cooked to a target internal peak temperature of 71°C using electric grills (Salton Clamshell Grill Model No. GR39A, Salton Inc., Lake Forest, IL). Peak cooked temperatures were monitored using a type K thermocouple (Model HH-21 Hand-Held Microprocessor Digital Thermometer, Omega Engineering Inc., Stamford, CT) and recorded for each steak. Within 5 min of recording cooked peak temperature, a 1-cm thick, 5-cm long slice was removed from each steak parallel to the muscle fibers (Shackelford et al., 1999). Each slice was sheared perpendicular to the muscle fibers using a universal testing machine (Model 4443, Instron Corp.) equipped with a flat, blunt-end blade (crosshead speed: 500 mm/min) resulting in a single SSF measurement for each steak.

Frozen PM and INRA steaks designated for SSF determination were thawed and cooked identically to LM steaks. Similar to the procedures described by Shackelford et al.(1999), within 5 min of recording cooked peak temperature, a 1-cm thick, 5-cm long slice was removed from each PM and INFRA steak parallel to the muscle fibers. For PM and INFA steaks from which a 5-cm long piece could not be obtained, a 1-cm thick slice was taken at the maximum length of the individual muscle. Each slice was sheared using procedures identical to those outlined for LM steaks.

Trained Flavor Attribute Panel.

Panelists were subjected to conditions identical to those approved by the Human Use in Research Committee of CSU. Prior to conducting the flavor panel, potential panelists were trained similarly to procedures outlined by AMSA (1995) to identify the following predetermined flavor attributes: beef fat, grassy, liver/organy, fishy, rancid/warmed-over, sour, and serumy. Trained panelists were screened to ensure that they could identify each of the predetermined flavor attributes. Panel screening was conducted using a triangle test where panelists were asked to identify the flavor attribute of the odd sample. Panelists that could correctly identify the odd sample and the determined flavor attribute with 70% accuracy were selected to participate on the actual panel.

For each MGMT group, 50 composite ground beef patties designated for flavor panel evaluation were randomly chosen to be served to panelists. For each panel session, 5 test samples (samples originating from a NON-FED, FED, or DAIRY animal) were randomly chosen to be served with a CONT sample. Three panel sessions were performed each d for 10 d with 6 samples served per session (N = 180). A minimum of 8 trained panelists participated in each session.

For each panel session, frozen composite ground beef patties were allowed to thaw for 24 h and cooked for 2.5 min to an internal temperature of 71°C using electric grills (Salton Clamshell Grill Model No. GR39A, Salton Inc., Lake Forest, IL). After cooking, patties were individually wrapped in aluminum foil and held at 65°C for a maximum of 20 min. Immediately prior to serving, cooked patties were cut into 12 equal wedge-shaped portions and served from a warm ceramic bowl.

Panelists were instructed to identify the presence of any and all of the aforementioned, predetermined notes in each sample. Panelists were also instructed to mark “none” in the event that any of the aforementioned attributes could not be identified. Panelists were separated by partitions in a clean sensory panel room equipped with individual red incandescent lights for each panelist. Saltine-style crackers with unsalted tops, double distilled water, and unsweetened apple juice were offered to panelists for palate cleansing.

Statistical Methods

Data for live animal characteristics, carcass characteristics, LM characteristics, fat characteristics, and fatty acid composition were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) with animal serving as the experimental unit. The study was designed to include a priori comparisons constructed specifically to examine the effects MGMT and breed on carcass traits. Orthogonal contrasts were constructed to identify the effects of breed within MGMT. All insignificant MGMT and breed interactions and other animal characteristics were analyzed as a one-way ANOVA with MGMT serving as the sole fixed effect and animal serving as the random effect.

Sensory panel data and pregnancy incidence data were analyzed using a logistic model. Computations were performed using the GLIMMIX procedure of SAS. Effects included in the sensory analysis model were the fixed effect of MGMT and the random effects of animal and panelist. Effects included in the pregnancy incidence model were the fixed effect of MGMT and the random effect of animal. Binomial and the logit link functions were specified as options.

SSF data were analyzed with a repeated measures model using restricted maximum likelihood estimation in the MIXED procedure of SAS. The statistical model included the fixed effects of MGMT, postmortem aging period, and the interaction of MGMT × postmortem aging period. Individual animal was used as a random effect in the model. The repeated statement designated postmortem aging period as a repeated measure and options specified for subject and type (covariance structure) were individual animal and spatial power, respectively. Cooked steak peak temperature was included in the model as a covariate.

Data comparing USDA grader determined traits versus VIA instrument determined traits were analyzed as a repeated measures model using restricted maximum likelihood estimation in the MIXED procedure of SAS. The statistical model included the fixed effects of MGMT, evaluation method, and the interaction of MGMT × evaluation method. The repeated statement designated evaluation method as a repeated measure.

For all analyses, the Kenward-Roger approximation was used to calculate denominator degrees of freedom. Least squares means were compared using the PDIFF option in SAS with a comparison-wise significance level of $\alpha = 0.05$.

Development and validation data sets were created for regression and discriminate analyses. Two hundred seventy five animals were randomly selected from the entire data set (N = 325) and designated as development data. The remaining 50 animals served as the validation data set.

Using the development data set, models for tenderness prediction were developed using the REG procedure of SAS. CVS data were used as the independent variables. Variable diagnostic analyses were conducted on the carcass calibration population (N = 275). Some relationships between the dependent variable (SSF) and the independent variables were determined to be non-linear. The non-linear variables were transformed by exponential functions to obtain an improved model relationship with SSF. Stepwise model selection was utilized with the significance level set at $\alpha = 0.10$ to select variables for the model. All CVS data were allowed to enter the model. Two prediction models were developed to classify animals into tenderness goups: 1) a model developed to predict 28 d LM SSF to segregate carcasses of all market cow types into tender (SSF $<$ 21.0 kg) and tough (SSF $\geq$ 21.0 kg) categories; 2) a model developed to predict 28 d LM SSF to segregate carcasses from beef-type cows into tender (SSF $<$ 21.0 kg) and tough (SSF $\geq$ 21.0 kg) categories. In order to test the accuracy and precision of the regression models, R^2 and predicted residual sums of squares (PRESS) statistics were computed and reported for each model developed. The effectiveness of the models developed for segregating tough and tender carcasses was tested by applying the developed models to the validation data set to determine predictive ability.

Discriminant analysis was used to test the ability of the CVS instrument to categorize cows into MGMT group. Using the STEPDISC procedures of SAS and significance levels for entry and removal set at 0.25, a stepwise discriminant analysis was used to select a candidate set of independent variables from the CVS development dataset. Candidate variables were utilized in the DISCRIM procedure of SAS, with 'crossvalidate' and 'pool=yes' options specified, to determine the discriminate function (best combination of responses). A final decision on pooling or not pooling covariance matrix estimates was based on cross-validated estimates of classification error rates. The ability of CVS to categorize cows into management groups was further evaluated by categorizing the validation data set using the developed discriminant function.

RESULTS AND DISCUSSION

The sample population in this study was constrained to market cows entering a single processing facility located in the panhandle of Texas over a 4 d period in February of 2009. For approximately twelve months prior to the time of the current study being conducted, much of the Southwest including Texas, New Mexico, and Oklahoma had been experiencing drought conditions. During the time that the study was conducted, the facility was privately owned and was processing a mix of beef and dairy type cows and bulls at an approximate rate of 150 head per h. The facility was operating a single 8 h shift 6 d a wk. Due to the size and location of the facility, cattle were received from multiple states, and each day's kill consisted of a mix of *Bos indicus*, *Bos taurus*, and dairy cattle. A significant proportion of cows harvested were beef-type cows that were purchased by the processing company from various livestock auctions (including cows from auctions in TX, OK, NM, KS, CO, and WY). Occasionally, cull cows were delivered directly from ranching and seed stock operations via gooseneck trailers. Additionally, the facility received gooseneck trailer loads of cull dairy cows from dairies in the surrounding area (dairies located in the Texas panhandle and eastern New Mexico). The processing company also maintained an inventory of grain-finished cows to fulfill orders of subprimal cuts for "white cow" steak and roast markets and also to provide ample amounts of fat to formulate ground products to customer specifications. These grain-finished cows were owned by the processing company and were received from 2 custom finishing operations located within 50 km of the processing facility.

NON-FED cows were selected for inclusion in the sample population only if they were beef-type animals (BRIT, CONT, or BRAH breeds only) that were uniquely identified (via ear tag or hip tag). All of the NON-FED cows included in the sample population resulted from groups (individual lots) of cattle that had been purchased at livestock auctions. DAIRY cows were selected for inclusion in the sample population only if they entered the facility directly from a dairy operation and only if they were uniquely identified. Dairy type cows entering the processing facility from a livestock auction were not included in the sample population. The vast majority of DAIRY cows in the sample population were lactating at the time of slaughter. The FED cows that were included in the sample population resulted from groups of beef-type cows that were assembled by the processing company in the fall of 2008. These cows were fed at a single custom finishing yard. On the morning of harvest, while being loaded on trucks, individual hip tags were fixed to the cattle for identification purposes. The only FED cows included in the sample population were cows that were uniquely identified and uniformly fed for a known period of time.

Since breed, in some cases, was unique to MGMT, the MGMT × breed interaction was not able to be estimated. However, orthogonal contrasts were constructed to evaluate breed nested within MGMT on carcass characteristics. The MGMT × breed interaction found to be significant was for REA ($P = 0.0235$; not presented in tabular form). The FED CONT cows produced carcasses with the largest REA, while both FED CONT and FED BRIT cows produced larger ($P < 0.05$) REAs than FED BRAH, DAIRY, and all NON-FED beef-type cows. The DAIRY cows produced REAs that were similar to FED BRAH cow, but produced larger REAs than all NON-FED beef-type cows. The

REAs resulting from FED BRAH did not differ ($P < 0.05$) from NON-FED beef-type cows. All other data will be presented and discussed as the main effect of MGMT.

Live Animal and Carcass Characteristics

Least squares means comparing live and carcass characteristics of NON-FED, FED, and DAIRY MGMT groups are presented in Table 3.1 and Table 3.2. FED market cows were fatter (live estimated12th rib fat thickness, body condition score, Table 3.1; adjusted Preliminary YG, Table 3.2), heavier (HCW, Table 3.2), and more muscular (muscle score, Table 3.1; LMA, Table 3.2) than either NON-FED or DAIRY cows. In this sample, DAIRY cows were slightly fatter (in the carcass—adjusted PYG, Table 3.2 but not alive—12th rib fat thickness and body condition score, Table 3.1), heavier (HCW, Table 3.2) and less muscular (alive, muscle score, Table 3.1, but not in carcass LMA, Table 3.2) than were NON-FED beef cows. FED and DAIRY cows had similar (P = 0.166) levels of marbling with both having greater marbling scores and a higher percentage of LM IMF than NON-FED cows (Table 3.2). Even though marbling scores for FED and DAIRY cows were not different in this sample, FED cows had a higher LM IMF percentage than DAIRY cows (Table 3.1).

The IMF percentages found in the present study are comparable to percentages reported by Patten et al. (2008). Patten et al. (2008) reported ether extracted LM IMF percentages of 5.45% , 7.92%, and 7.71% for non-fed beef cows with a mean marbling score of Slight^{85}, fed beef cows with a mean marbling score of Modest^{09}, and non-fed dairy cows with a mean marbling score of Small^{81}, respectively. However, with respect to marbling score, the corresponding LM IMF percentages found in the present study and the study conducted by Patten et al. (2008) on mature cows were considerably higher than values reported for young beef cattle with similar marbling scores (Savell et al., 1986; Lunt et al., 1989; Patten et al., 2008). In contrast to studies that utilized ether extraction methods to determine LM IMF percentages for marbling scores in young cattle (Savell et al., 1986; Lunt et al., 1989), the present study utilized chloroform-methanol methods (or Folch fat; Folch et al., 1957). When compared to ether extraction, chloroform-methanol extractable fat has been shown to be 6.2% higher on average than ether-extractable fat values for raw LM samples (Rhee et al., 1988). Chloroform-methanol mixtures effectively extract more than 99% of the total lipid from muscle including phospholipids and proteolipids (Rhee, 1992). Therefore, the higher levels of LM IMF can be partially explained by laboratory techniques, but may also be explained by an increased level of phospholipids in mature animals. Considering the results of the present study, further research is warranted to evaluate the effects of animal age on intramuscular lipid content.

No meaningful differences among the three MGMT types were evident in the incidence of pregnancy (Table 3.1). Despite the fact that the incidence of pregnancy was not meaningful to this study, it should be noted that the incidence of pregnancy found in this study are higher than that found in the 2007 National Market Cow and Bull Beef Quality audit (NCBA, 2007b). In contrast to the findings of this study (Table 3.1), NCBA (2007) reported that 10.20% of beef cows and 10.86% of dairy cows were pregnant. In the present study, a cow was determined to be pregnant when the presence of an embryo or fetus of any size was identified, whereas in the quality audit (NCBA, 2007b), pregnancy was determined by the presence of a fetal calf. Recording the presence of fetal calves instead of the identification of everything from embryos to near-term fetuses provides reasoning for the notable difference between the two results. Fetal calves (calves from which fetal bovine serum is collected) are much larger and more advanced in development and result from cows in a much more advanced stage of gestation. Therefore, it is realistic to conclude that a larger percentage of cows entering slaughter facilities in the U.S. are actually pregnant at the time of harvest than what was reported by NCBA (2007). Nonetheless, it should be noted that the climatological region from which the beef type cows included in the present study resulted was experiencing an extended period of drought-like conditions leading producers to make cow culling decisions without considering pregnancy.

If this sample of market cows is truly representative of the U.S. consist, dairy cows do not need to be further-fed prior to harvest to optimize overall carcass maturity (perhaps because they have been on a continuous high plane of nutrition for most of their lives and/or are harvested at younger ages; see skeletal and lean maturity scores in Table 3.2.) or marbling (see marbling score and LM intramuscular fat, Table 3.2; again, because of their diet) but beef cows do (Table 3.2).

Feeding beef cows a high energy, concentrate-based diet for an extended period was necessary to increase HCW (Table 3.2), and to optimize carcass muscling (live muscle score, Table 3.1; LM area, Table 3.2), lean color (lean maturity score, Table 3.2; LM lean color score, Table 3.3), carcass maturity (lean maturity score and overall maturity score, Table 3.2), and marbling (marbling score, Table 3.2). In agreement with the findings of the present study, recently performed research has shown that feeding mature beef cows improves carcass muscling and carcass quality traits (Patten et al., 2008; Stelzleni et al., 2007).

While DAIRY cows were more youthful than beef cows at harvest (number of permanent incisors, Table 3.1; skeletal maturity score, Table 3.2), LEANMAT scores caused the overall maturity scores for DAIRY and FED cows to be similar (Table 3.2). In the U.S. beef grading system, lean maturity scores are balanced with skeletal maturity scores to indicate the animal's physiological age (USDA, 1997). Rather than explaining more advanced LEANMAT and overall maturity scores with the age of DAIRY cows, the difference in these factors may be better explained by a less desirable lean color resulting from other physiological factors including long-term stress. Similarly, the depletion of muscle glycogen levels prior to slaughter due to long term stress, likely resulting from a lower plane of nutrition, helps to explain the darkest, least desirable LEANMAT scores found in NON-FED cows as well as the lightest, most desirable LEANMAT scores in FED cows (Table 3.2).

Longissimus Muscle Color Characteristics

Least squares means comparing LM lean color characteristics of NON-FED, FED, and DAIRY MGMT groups are presented in Table 3.3. Individual LM lean color measurements (L*, a*, b*, and subjective LM lean color scores) were all affected by MGMT ($P < 0.05$). FED market cows had the lightest, most desirable LM lean color (L*, LM lean color score, Table 3.3) and the lowest LM ultimate pH (Table 3.3), while DAIRY cows had the darkest (L*, Table 3.3), reddest (a*, Table 3.3), LM lean color with the highest concentration of MYOG (myoglobin content, Table 3.3). LM a* values indicated that NON-FED and FED carcasses were similar in LM redness ($P = 0.801$). Subjective LM lean color scores indicate that NON-FED and DAIRY carcasses had comparable LM visible lean color ($P = 0.151$). In agreement with the findings of the present study, Patten et al. (2008) and Stelzleni et al. (2007) found lean color to be lighter in muscles from fed beef cows than muscles from non-fed and dairy cows. Patten et al. (2008) and Stelzleni et al. (2007) also reported that visible lean color was similar for non-fed beef cows and non-fed dairy cows. In the present study, subjective LM lean color scores and LEANMAT (USDA determined) were contradictory. Subjective lean color scores (Table 3.3) indicated that DAIRY cows had similar LM color whereas USDA lean maturity scores indicated that DAIRY cows had a lighter, more youthful colored lean (Table 3.2). The disagreement between subjective lean color scores and LEANMAT scores for DAIRY and NON-FED cows may be partially explained by the USDA grader having a tendency to assign more youthful LEANMAT scores to carcasses with more youthful skeletal maturity scores (Table 3.2). No meaningful differences among LM ultimate pH and LM MYOG content existed to explain LM color differences.

Fat Color Characteristics and Fat Carotenoid Content

Least squares means comparing fat color characteristics of MGMT groups are presented in Table 3.3. Subjective fat color scores and fat a*, and b* values were affected by MGMT ($P < 0.001$). NON-FED market cows had the yellowest fat (fat color score, b* value, Table 3.3). Correspondingly, NON-FED cows had the highest a* values indicating a higher level of redness that contributed to a more yellowish-orange visual appearance (Table 3.3). FED and DAIRY market cows had similar ($P = 0.776$) subjective fat color scores as well as similar fat a* and b* values (Table 3.3). Along with the yellowest fat color, NON-FED cows had the highest levels of β-CAR and VITA in fat whereas FED carcasses were higher ($P < 0.001$) than DAIRY carcasses for the same traits. FED carcasses had the highest retinol concentrations in fat (Table 3.3).

The findings of the present study relative to fat color characteristics and fat carotenoid content were expected. Concentrate feeding of cattle is generally associated with white carcass fat color (white fat), whereas grass-finishing is generally associated with yellow carcass fat color (yellow fat). While beef fat color (yellowness) is dependent upon multiple intrinsic and extrinsic variables including biological type, breed type, and chronological age, animals that have regularly consumed a diet consisting primarily of forages produce carcass fat with increased yellowness. This yellowness is predominantly caused by chemical compounds in forages known as carotenoids. Carotenoids produce distinctively yellow and orange colors in beef fat. β-carotene is the primary pigment responsible for the development of yellow fat color in beef (Dunne et al., 2008). Therefore, fat color evaluation could prove useful in determining the extent of grass-finishing and to estimate β-carotene levels in beef fat. To explain the observed differences between FED and DAIRY cow fat carotenoid content, generally speaking, in addition to being younger, most dairy cows have spent most of their lives on a high plane of nutrition with higher levels of concentrates than forages in their diet. This would contribute to lower concentrations of βCAR and VITA in their fat. Perhaps most relevant to this study, relationships between βCAR levels and VIA instrument outputs could be identified in order to classify carcasses according to MGMT and general carcass quality. Specifically, as fat color transitions from white to yellow or orange, the incidence of consumer dislike and off-flavors increases (Hilton et al., 1998; Hodgson et al., 1992; Stelzleni et al., 2007).

Muscle Tenderness

There is an abundance of research that documents the effectiveness of postmortem muscle-aging to increase muscle tenderness in conventionally produced, young beef animals (Smith et al., 1978; Savell et al., 1981; Calkins and Seideman, 1988; Gruber et al., 2006). However, a minimal amount of research has demonstrated the effects of postmortem muscle-aging on muscles from mature cow carcasses. Because muscle toughness associated with increased animal age is predominantly due to reduced collagen solubility, longer postmortem muscle-aging periods may be required to achieve acceptable tenderness levels in muscles intended for production of steaks to be prepared via dry-heat cookery. Therefore, the effects of extended postmortem muscle-aging and MGMT were evaluated for beef resulting from this sample of mature market cows. A MGMT × muscle-age (days of postmortem muscle-aging) interaction existed for the INFRA muscle ($P = 0.042$) and least squares mean comparisons of SSF are presented in Table 3.4. INFRA steaks from all MGMT groups and postmortem muscle-aging periods were tender (SSF < 23.0 kg; Shackelford et al., 1999a). For NON-FED INFRA steaks, a response to muscle-aging was noticed between 21 d and 28 d (Table 3.4), while DAIRY INFRA steak tenderness did not improve until steaks had been aged for greater than 28 d. Postmortem muscle-aging did not consistently affect the tenderness of FED INFRA steaks. For FED INFRA steaks, SSF was not different for 14, 21, and 35 d muscle-aging periods. However, unexplainably, 28 d-aged FED INFRA steaks were found to be more tender ($P < 0.05$) than 14, 21, and 35 d-aged steaks.

INFRA muscle response to postmortem aging treatments was somewhat inconsistent perhaps because of high levels of connective tissue and differential muscle fiber orientation in this muscle. Considering the outcome of this study, SSF methods (Shackelford et al., 1999) may not be an acceptable method for determination of INFRA muscle tenderness.

A MGMT × muscle age interaction did not exist for LM SSF ($P = 0.498$), therefore, least squares means for the main effects of MGMT and postmortem muscle age were reported. Least squares means for the main effect of MGMT ($P < 0.001$) on LM SSF are presented in Table 3.5 and the main effect of postmortem muscle age on LM SSF are presented in Table 3.6. In this sample population of market cows, feeding beef-type cows a high energy, concentrate-based diet for an extended period effectively increased LM tenderness (FED LM SSF vs. NON-FED LM SSF, Table 3.5). FED market cows had the most tender LM steaks with the least intramuscular collagen (raw collagen content, Table 3.5) whereas LM steaks from NON-FED cows were the toughest with the highest levels of collagen in cooked LM steaks (Table 3.5). In comparison to beef-type cows, DAIRY cows had intermediate LM SSF values and had LM steaks with raw collagen contents similar to NON-FED cows ($P = 0.247$). Postmortem muscle-muscle aging effectively reduced LM SSF values from d 14 to d 35 (Table 3.6). LM SSF did not differ for 21 d-aged steaks and 28 d-aged steaks. It is speculation that the initial increase in LM tenderness may be related to improvements in myofibrillar tenderness (the time where μ-calpain activity is the greatest) whereas the plateau in SSF decline followed by another increase in tenderness may be attributed to increased stromal protein tenderness and the increased solubility of collagen.

The findings of the present study are consistent with the findings of previously published research results which showed that cows fed a high energy diet produced lower LM shear force values and that tenderness was in association with LM connective tissue and/or collagen content (Hilton et al., 1998; Hodgson et al., 1992; Schnell et al., 1997; Stelzleni et al., 2007). Schnell et al. (1997) specifically illustrated the increase in collagen solubility in muscle from cows between 0 and 28 d on feed and a decrease in total collagen content for cows realimented with high energy diets. The advantage in LM tenderness for FED cows in this study may be related to collagen solubility. Collagen solubility was not evaluated in the present study.

Least squares means for the effect of MGMT on PM steak SSF are presented in Table 3.5. Market cow MGMT affected PM SSF values ($P < 0.001$); however, the main effect of postmortem muscle-aging was not significant ($P = 0.075$; Table 3.6). Mean SSF values for PM steaks suggest that the PM was compartively tender (SSF < 21.0 kg, Table; Shackelford et al., 1999) regardless of MGMT. Nonetheless, PM steaks from DAIRY cows were the most tender while PM steaks from beef-type cows (FED vs. NON-FED) were not different ($P > 0.05$; Table 3.5).

Flavor Attributes

Mean probabilities for the main effect of MGMT on individual flavor attributes are presented in Table 3.7. In a review of literature, Melton (1990) determined that high-energy grain diets produce more acceptable flavor in red meats than low-energy forage or grass diets, and Bruce et al. (2005) reported that more than 40% of the variation in beef flavor between grass and grain-finished beef has been accounted for by diet. Studies have shown that beef from cattle finished on low energy diets with high forage contents has an undesirable flavor (Brown et al., 1979; Dolezal et al., 1982; Hedrick et al., 1983; Larick et al., 1987; Melton et al., 1982; Schroeder et al., 1980). In the present study, beef from NON-FED market cows had the greatest probability ($P < 0.05$) of producing grassy and fishy flavor attributes and also had the lowest probability of producing beef without any characterized flavor (Table 3.7). If this sample of market cows is truly representative of the U.S. consist, consumers consuming beef from NON-FED cows would have 89.9% probability of detecting an undesirable note (probability of no note detected, Table 3.7); including grassy and fishy flavor attributes (Brown et al., 1979; Larick et al., 1987; Melton et al., 1982; Schroeder et al., 1980). While beef from FED and DAIRY market cows had comparable probabilities for not having a detectable flavor attribute, DAIRY cows had a higher likelihood of producing beef with livery/organy flavor attributes than FED cows. Therefore, beef produced from FED and DAIRY cows had a higher likelihood of being desired by U.S. consumers than beef from NON-FED cows. In support of the findings of the present study, research has shown that decreasing off-flavors and increasing desirable flavors in beef can be achieved by feeding grain to beef animals (Maruri and Larick, 1992; McMillin et al., 1991). Additionally, Stelzleni et al. (2007) found non-fed beef cows resulted in the strongest off-flavors and Hilton et al. (1998) reported that grassy and fishy flavors increased with overall carcass maturity and that the incidence of grassy flavors deceased with increased levels of marbling. Each of these findings provides strong evidence supporting the increased incidence of off-flavors in NON-FED beef in this study.

Fatty Acid Composition

Least squares means of weight percent of fatty acids by MGMT group are presented in Table 3.8. Lipids are composed of fatty acids and are a known source of flavor constituents, both directly (unmodified) and indirectly (reaction products). Differences in the flavor of beef resulting from different breeds (Gorraiz et al., 2002), different sex (Westerling and Hedrick, 1979), different muscles (Yancey et al, 2005; Westerling and Hedrick, 1979), and different animal diets (Brown et al., 1979; Larick and Turner, 1990; Melton et al., 1982; Westerling and Hedrick, 1979) have all been linked to lipid composition. Fatty acids in raw meat serve as precursors to flavor and aroma resulting from volatile compounds that are produced when the meat is heated (cooked). In the present study, minimal differences fatty acid composition were detected for raw ground beef samples from NON-FED, FED, and DAIRY market cows (Table 3.8). MGMT strategy only affected the percentage of stearic acid (18:0; $P < 0.001$). Ground beef from FED market cows had the lowest ($P < 0.05$) percentage of stearic acid while NON-FED and DAIRY cows had similar levels of the same fatty acid. In a study intended to identify differences in chemical composition to explain flavor differences in grass and grain fed beef, Melton et al. (1982) also found a higher level of stearic acid in ground beef samples with the most desirable flavor. Otherwise, the results of the present study are not supported by the findings of other researchers (Brown et al., 1979; Westerling and Hedrick, 1979) that have demonstrated that beef produced from utilizing forages contains increased amounts of C18:0, C18:3, C20:3, C20:4, and C22:5 and less C16:0 and C17:0 on a percent of total fatty acid basis. However, it should be noted that all of the aforementioned research was performed on young cattle and results may not serve as an appropriate comparison for the results of the present study. In this study, despite the fact that FED cows received a high-energy, grain-based diet for a considerable period prior to slaughter, FED cows most likely consumed a diet that consisted primarily of grass and other forages for a period of several years prior to slaughter which may contribute to the inconsistent findings of the current study. Additionally, the findings of this research suggest that research aimed to determine the period of time required to change the fatty acid composition of mature cows vs. young beef animals with a high energy, concentrate-based diet is warranted.

Video Image Analyses (VIA)

VIA systems have been developed and tested in several countries to predict meat yield percentage using output data resulting from the processing of digital images of either the entire side of a hot beef carcass, the cross-section of the rib interface after a beef carcass has been chilled, or by combining data from both digital images (Jones et al., 1995; Borggaard et al., 1996; Shackelford et al., 2003; Cannell et al., 1999; Cannell et al., 2002; Steiner et al., 2003a; Steiner et al., 2003b; Vote, 2003). Research conducted in recent years pertaining to the use of VIA as an objective method to assess the yield characteristics of beef carcasses indicated an extremely consistent and unanimous conclusion that VIA technologies are effective. Various VIA instruments and instrument systems estimate overall carcass cutability and predict subprimal yields with a significant level of accuracy (Cross et al., 1983; Wassenberg et al., 1986; Shackelford et al., 1998; Cannell et al., 1999; Cannell et al., 2002; Steiner et al., 2003b; Shackelford et al., 2003; Vote, 2003). In addition, with previous research indicating that VIA systems' prediction abilities lacked the accuracy needed for assignment of USDA marbling scores for quality grade determination, Moore (2006) assessed the improvements in predictive capabilities for the Computer Vision System (CVS; Research Management Systems, USA, Inc., Fort Collins, CO), in conjunction with developing recommendations regarding USDA approval requirements for instruments to augment the current quality grading system. Moore (2006) conducted a study in three phases for prediction equation development as well as testing for accuracy, precision and repeatability. Moore (2006) reported that the current CVS VIA system exhibited much greater accuracy (greater than 89%) and precision than any other instrument previously used to predict marbling score with an extremely high level of repeatability (greater than 99.5%). In the present study, the CVS system was utilized to capture data for market cow carcasses. Prior to this study, the effectiveness of the CVS system to determine yield and quality characteristics on mature cows had not been reported.

Least squares means for CVS determined market cow carcass yield and quality characteristics by MGMT strategy are presented in Table 3.9. CVS identified comparable trends in market cow carcass composition. Similarly to USDA grader determined carcass characteristics (Table 3.2), CVS data found FED market cows to be fatter (12^{th} rib fat, Table 3.9) and more muscular (LM area, Table 3.9) than NON-FED and DAIRY market cows. Also in agreement with USDA grader determined carcass traits (Table 3.2), CVS identified DAIRY carcasses as having greater LMA. Additionally, a ratio computed from CVS-determined LM length and LM width (LM length:width, Table 3.9) indicated that FED cows produced carcasses with the most symmetrically-shaped LM whereas DAIRY LM were more symmetrical than NON-FED LM. With the added information of LM shape, market cow carcasses may be more accurately sorted to meet product specifications for muscling. Larger LMAs and rounder, more symmetrical shapes provides evidence of cows receiving a higher plane of nutrition prior to harvest as well as carcasses that will produce subprimal loin cuts that are more desirable for the production of steaks. Similarl to USDA grader determined LM marbling scores and Folch IMF fat percentages for the LM, the VIA instrument identified NON-FED cows as having the least amount of marbling (LM marbling score, Table 3.9) and the lowest percentage of IMF (LM intramuscular fat, Table 3.9). However, in contrast to USDA grader determined factors and Folch fat percentages for the LM of FED and DAIRY cows, CVS indentified DAIRY carcasses as having the highest degree of marbling and the greatest amount of IMF in the LM (LM intramuscular fat, Table 3.9). Interestingly, CVS marbling scores more closely represented the Folch LM IMF% (Table 3.2) than USDA grader determined marbling score (Table 3.2). Additionally, CVS marbling fat percentage (Table 3.9) and CVS IMF (Table 3.9) indicated that not all of the visible fat in the LM is considered to be marbling. The CVS LM IMF percentages indicated that there was a considerably greater amount of IMF in the LM that was not marbling (Table 3.9). This IMF may include intermuscular fat extending into the LM or even the lipid bilayers of the muscle fibers (cells). Alternatively, it may be speculated that VIA instruments may have a greater ability to identify marbling in the LM of carcasses that vary a great deal in composition, age, and appearance.

Least squares means for VIA instrument determined LM and 12^{th}-rib fat color stratified by MGMT are presented in Table 3.10. VIA instrument LM color scores (Table 3.10) were comparable to those determined using a spectrophotometer (Table 3.3). Similar to spectrophotometer-determined LM color scores, when compared to FED and NON-FED cows, CVS outputs also identified DAIRY carcasses as having the darkest colored LM lean color (LM L*, Table 3.10). In agreement with previously reported data for fat color (Table 3.3), CVS outputs for fat color indicated that, when compared to FED and DAIRY cows, NON-FED cows had the darkest, most yellowish-orange colored fat (Fat L*, Fat a*, and Fat b*, Table 3.10). Additionally, the VIA instrument identified DAIRY cows as having the least yellowish-orange fat (Fat a*, Fat b*, Table 3.10) which corresponds with the β-CAR, VITA, and objective color scores discussed earlier (Table 3.3). Consequently, these results indicate VIA instruments may be utilized to distinguish differences in LM and fat color in mature cows.

Comparisons of VIA Instrument and USDA Grader Determined Carcass Traits

Significant MGMT × evaluation method (methods = VIA instrument and USDA grader) interactions existed for marbling score, LMA, and 12^{th} rib fat thickness and are reported in Table 3.11. VIA instrument marbling scores for NON-FED, FED, and DAIRY market cows were higher ($P < 0.001$) than marbling scores determined by the USDA grader (Table 3.11). VIA marbling scores were in agreement with the LM IMF percentages (Table 3.2) and correspond with previously published data for marbling score and IMF (Savell, et al., 1986; Lunt et al., 1989). These results indicate that VIA instrument determined marbling scores are a more accurate assessment of intramuscular lipid content. Additionally, the significant interaction of MGMT × evaluation method for marbling scores indicated that the USDA grader exhibited bias toward calling higher marbling scores for carcasses resulting from FED cows (as evidenced by a smaller difference between higher CVS marbling scores and lower USDA grader marbling scores for FED cows, Table 3.11) and lower marbling scores for NON-FED and DAIRY carcasses.

USDA grader determined LMAs for NON-FED, FED, and DAIRY carcasses were larger ($P < 0.001$) than VIA instrument determined LMAs (Table 3.11). The significant interaction of MGMT × evaluation method for LMA resulted from differences between VIA instrument determined LMA and USDA grader determined LMA being larger for FED cows than for NON-FED and DAIRY cows. Means comparing USDA grader adjusted 12th rib fat thickness and CVS determined 12th rib fat thickness indicated that USDA grader and VIA instrument assessment of fat thickness for FED beef cows were similar ($P = 0.529$). The similarities in USDA grader and instrument12th rib fat assessment may be explained by 12th rib fat thicknesses of FED cows most closely resembling conventionally produced young beef carcasses (when compared to NON-FED and DAIRY carcasses) and because the CVS instrument was developed using conventionally fed beef carcasses. VIA assessed 12th rib fat thickness means indicated a greater level of fatness for NON-FED and DAIRY carcasses than USDA grader determined adjusted 12th rib fat thickness (Table 3.11). The VIA instrument utilized an actual measurement of fat opposite the LM at a point three-fourth of the distance from the chine to determine 12th rib fat thickness, whereas USDA grader determined fat thickness for each carcass was back-calculated from an APYG score. For a considerable amount of NON-FED and DAIRY carcasses, APYG scores indicated a negative (< 0.0 cm) amount of adjusted12th rib fat thickness which contributed to lower mean 12th rib fat thicknesses determined by the USDA grader. Therefore, a true difference in measureable fat may not exist between the VIA instrument and the USDA grader.

VIA Model Development

In this study and other studies (Hilton et al., 1998; Hodgson et al., 1992; Schnell et al., 1997; Stelzleni et al., 2007), the effects of pre-harvest management on cow carcass quality attributes have been clearly identified. In today's U.S. beef industry, carcasses from mature cows are subjectively sorted by company personnel based on perceived carcass quality characteristics. Sorting decisions are most commonly determined by the evaluation of carcass traits that indicate the level of feeding that cows have received prior to slaughter including fat thickness, fat color, lean color, amount of muscling, and degree of marbling. VIA instruments have been shown to be highly effective tools in the fed beef industry for identifying beef carcass quality and yield characteristics (Woerner and Belk, 2008). With the capabilities of current, commercially available VIA instruments developed for the assessment of beef carcasses, accurate prediction models may be developed to identify pre-harvest production management practices that subsequently affect carcass sensory desirability. VIA instruments equipped with prediction models that can identify pre-harvest management may serve as an effective means of objectively and accurately segregating carcasses from mature cows into palatability groups.

Using individual animal data and CVS outputs generated from this study, a discriminant analysis was performed to determine the ability of CVS to categorize individual market cows by MGMT strategy. CVS was able to correctly categorize 84.88, 92.31, and 85.87 % of NON-FED, FED, and DAIRY cows in the development data set, respectively (Table 3.12). When the discriminate functions were applied to the validation data set, 95.00, 76.47, and 95.00 % of NON-FED, FED, and DAIRY cows were correctly categorized, respectively (Table 3.13). Using VIA instruments to correctly identify 95% of NON-FED and DAIRY cows shows that these instruments could be a useful tool for the beef industry. By effectively classifying market cow carcasses by MGMT strategy, beef packers could more effectively segregate and market beef items produced from market cows and ultimately provide a more consistent and reliable sensory experience. The findings of this study indicate that pursuing research aimed to further develop VIA systems to identify cow carcass quality characteristics is warranted.

Beef tenderness has been shown as the single most important palatability trait for determining the acceptability of steaks (Huffman et al., 1996; Platter et al., 2003). A study conducted using a similar VIA instrument as was used in this study, was effective at segregating tough and tender beef carcasses (Vote et al., 2003). Effectively identifying individual market cow carcasses as producing tender muscle (28 d LM SSF < 21.0 kg) or tough muslce (28 d LM SSF ≥ 21.0 kg) would greatly improve the consistency and marketability of beef produced from market cows. Using the data generated from this study and VIA instrument outputs, two prediction models were developed to classify tenderness for market cow carcasses. The models developed to classify all cow carcasses (NON-FED, FED, and DAIRY) and beef-type carcasses only explained 31.7% and 35.9% of variation (R^2, Table 3.14) in 28 d LM SSF values, respectively. The same models were only able to predict tenderness classification for all market cows with 54.0% accuracy and beef-type market cows with 63.0% accuracy (Table 3.14). Considering the findings of this study, the development of more advanced prediction models is needed to accurately classify market cow carcass tenderness.

Table 3.1. Least squares means comparing live animal characteristics of cattle in the sample population according to pre-harvest management strategy.

Item	Pre-harvest management[1]			SEM	$P > F_{TRT}$
	NON-FED	FED	DAIRY		
Number of animals	104	108	113		
Continental cattle, %[2]	26.9	42.6	0		
British cattle, %[3]	48.1	51.8	0		
Brahman cattle, %[4]	25.0	5.6	0		
Holstein cattle, %[5]	0.0	0.0	90.3		
Incidence of pregnancy, %[6, 7]	73.1^{a}	67.6^{ab}	56.6^{b}	0.05	0.038
Estimated fat thickness, 12^{th} rib, cm	0.53^{b}	1.31^{a}	0.51^{b}	0.03	< 0.001
Body condition score[8]	3.29^{b}	5.85^{a}	3.02^{c}	0.08	< 0.001
Frame score[9]	286^{c}	303^{b}	324^{a}	4.7	< 0.001
Muscle score[10]	3.3^{b}	5.7^{a}	2.9^{c}	0.09	< 0.001
Number of permanent incisors	7.5^{b}	7.8^{a}	7.0^{c}	0.14	< 0.001

[1] NON-FED = cows entering the slaughter facility as culls from sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.
[2] Continental (purebreds or crosses visually exhibiting predominantly continental breed characteristics).
[3] British (purebreds or crosses visually exhibiting predominantly British breed characteristics
[4] Brahman (purebreds or crosses exhibiting visually 25% or more *Bos indicus* genetic characteristics).
[5] Holstein (dairy cows visually exhibiting Holstein breed characteristics).
[6] Determined using a generalized linear mixed model for binomial data.
[7] Determined by the existence of a fetus in the reproductive tract.
[8] 9 = excessive fat cover; 5 = average/optimum fat cover; 1 = minimum/thin fat cover.
[9] Small = 100 to 199; Medium = 200 to 299; Large = 300 to 400.
[10] 9 = thick+; 5 = average°; 1 = thin-.
[a, b, c] Means in the same row without a common superscript differ ($P < 0.05$).

Table 3.2. Least squares means comparing carcass characteristics of cattle in the sample population according to pre-harvest management strategy.

	Pre-harvest management[1]				
Item	NON-FED	FED	DAIRY	SEM	$P > F_{TRT}$
Number of animals	104	108	113		
HCW, kg	251^{c}	369^{a}	311^{b}	69	<0.001
Adj. fat thickness, cm	0.2^{c}	1.3^{a}	0.4^{b}	0.05	<0.001
LM area, sq cm	56.1^{c}	79.9^{a}	64.6^{b}	1.3	<0.001
Skeletal maturity score[2]	562^{a}	566^{a}	483^{b}	8.7	<0.001
Lean maturity score[2]	540^{a}	340^{c}	445^{b}	12	<0.001
Overall maturity score[2]	555^{a}	463^{b}	471^{b}	9	<0.001
Marbling score[3]	215^{b}	362^{a}	385^{a}	12	<0.001
LM intramuscular fat, %[4]	3.56^{c}	7.02^{a}	6.28^{b}	0.26	<0.001

[1] NON-FED = cows entering the slaughter facility as culls from sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.

[2] 100 to 199 = A^{00} to A^{99}; 200 to 299 = B^{00} to B^{99}; 300 to 399 = C^{00} to C^{99}; 400 to 499 = D^{00} to D^{99}; 500 to 599 = E^{00} to E^{99}.

[3] 200 to 299 = Traces^{00} to Traces^{99}; 300 to 399 = Slight^{00} to Slight^{99}.

[4] % reported on a wet sample basis.

[a, b, c] Means in the same row without a common superscript differ ($P < 0.05$).

Table 3.3. Least squares means comparing LM and fat characteristics of cattle in the sample population according to pre-harvest management strategy.

Item	Pre-harvest management[1] NON-FED	FED	DAIRY	SEM	$P > F_{TRT}$
Number of animals	104	108	113		
LM L*[2]	36.72[b]	43.01[a]	34.37[c]	0.63	<0.001
LM a*[3]	6.82[b]	6.72[b]	9.14[a]	0.28	<0.001
LM b*[4]	8.53[b]	9.38[a]	9.58[a]	0.24	0.004
LM lean color score[5]	4.4[a]	3.5[b]	4.2[a]	0.1	<0.001
Fat L*[2]	70.70	68.41	114.02	29.00	0.432
Fat a*[3]	3.02[a]	1.51[b]	1.25[b]	0.16	<0.001
Fat b*[4]	22.14[a]	11.93[b]	10.54[b]	0.52	<0.001
Fat color score[6]	5.3[a]	2.2[b]	2.1[b]	0.16	<0.001
LM ultimate pH	5.78[a]	5.68[c]	5.72[b]	0.016	<0.001
LM myoglobin content, mmol/L	0.032[c]	0.035[b]	0.037[a]	0.0007	<0.001
Fat retinol, μg/g	0.42[b]	0.91[a]	0.51[b]	0.45	<0.001
Fat β-carotene, μg/g	11.26[a]	6.95[b]	4.05[c]	0.43	<0.001
Fat Vitamin A, IU/100 g	2018.14[a]	1463.36[b]	845.46[c]	72.97	<0.001

[1] NON-FED = cows entering the slaughter facility as culls from sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.
[2] L*: 0 = black; 100 = white.
[3] a*: negative number = green; positive numbers = red.
[4] b*: negative number = blue; positive numbers = yellow.
[5] 1 = light, pinkish-red, 2 = cherry red, and 6 = dark, purplish-red.
[6] 0 = bright white; 5 = pale yellow, and 8 = dark, yellowish-orange.
[a, b, c] Means in the same row without a common superscript differ ($P < 0.05$).

Table 3.4. Least squares means ± SEM for the pre-harvest management x postmortem muscle aging interaction[2] for shear force values (kg) of the infraspinatus muscle.

	Pre-harvest management[1]		
Age, d	NON-FED	FED	DAIRY
14	17.21 ± 0.56[ax]	17.49 ± 0.55[ax]	15.66 ± 0.53[bx]
21	17.80 ± 0.56[ax]	16.23 ± 0.55[bx]	15.03 ± 0.53[bxy]
28	15.64 ± 0.56[ay]	14.68 ± 0.56[ay]	14.38 ± 0.53[axy]
35	14.67 ± 0.55[aby]	16.14 ± 0.56[ax]	13.71 ± 0.53[by]

[1] NON-FED = cows entering the slaughter facility as culls from sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.
[2] Pre-harvest management × postmortem muscle aging interaction effect: P = 0.042.
[a, b, c] Means in the same row without a common superscript differ ($P < 0.05$).
[x,y] Means in the same column without a common superscript differ ($P < 0.05$).

Table 3.5. Least squares means comparing LM and psoas major characteristics of cattle in the sample population according to pre-harvest management strategy.

	Pre-harvest management[1]				
Item	NON-FED	FED	DAIRY	SEM	$P > F_{TRT}$
Number of animals	104	108	113		
LM SSF, kg[2]	28.27^{a}	21.20^{c}	23.75^{b}	0.59	< 0.001
Psoas major SSF, kg[2]	16.59^{a}	17.30^{a}	15.71^{b}	0.28	< 0.001
LM raw collagen content, mg/g	5.09^{a}	3.60^{b}	4.64^{a}	0.39	<0.001
LM cooked collagen content, mg/g	6.03^{a}	4.24^{b}	4.44^{b}	0.44	<0.001

[1] NON-FED = cows entering the slaughter facility as culls from sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.

[2] SSF measurements were computed across postmortem aging period (14, 21, 28, and 35 d).

[a, b, c] Means in the same row without a common superscript differ ($P < 0.05$).

Table 3.6. Least squares means of effects of postmortem muscle-aging on slice shear force (kg) values for the LM and Psoas major (PM).

	Postmortem aging treatment, d					
Muscle	14	21	28	35	SEM	$P > F_{AGE}$
LM	26.72[a]	24.18[b]	23.91[b]	22.82[c]	0.46	< 0.001
PM	16.80	16.59	16.66	16.09	0.24	0.075

[a, b, c] Means in the same row without a common superscript differ ($P < 0.05$).

Table 3.7. Mean probability[1] ± SEM of prevalence of specified flavor attributes in composite ground beef patties stratified by pre-harvest management.[2]

	Pre-harvest management[3]			
Flavor Attribute	NON-FED	FED	DAIRY	$P > F_{MGMT}$
Beef fat	0.047 ± 0.015	0.097 ± 0.027	0.064 ± 0.020	0.115
Grassy	0.362 ± 0.033[a]	0.208 ± 0.026[b]	0.265 ± 0.029[b]	< 0.001
Liver/organy	0.334 ± 0.042[a]	0.083 ± 0.018[b]	0.233 ± 0.036[a]	< 0.001
Fishy	0.169 ± 0.032[a]	0.050 ± 0.013[b]	0.031 ± 0.009[b]	< 0.001
Sour	0.045 ± 0.010	0.041 ± 0.010	0.037 ± 0.009	0.840
Oxidized/WOF[4]	0.073 ± 0.018	0.127 ± 0.027	0.085 ± 0.020	0.074
Serumy	0.036 ± 0.010	0.060 ± 0.014	0.050 ± 0.013	0.319
No flavor attribute	0.101 ± 0.019[b]	0.343 ± 0.036[a]	0.282 ± 0.033[a]	< 0.001

[1] Determined using a generalized linear mixed model for binomial data.
[2] Flavor attribute detection (0 = not detected, 1 = detected).
[3] NON-FED = cows entering the slaughter facility as culls from sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.
[4] WOF = warmed-over flavor.
[a, b, c] Means in the same row without a common superscript differ ($P < 0.05$).

Table 3.8. Least squares means of weight percent of fatty acids[1] in raw ground beef patties of cattle in the sample population according to pre-harvest management strategy.

	Pre-harvest management[2]				
Item[3]	NON-FED	FED	DAIRY	SEM	$P > F_{TRT}$
Number of animals	104	108	113		
14:0	2.49	2.49	2.50	0.04	0.936
14:1	0.48	0.55	0.54	0.04	0.234
16:0	24.97	24.94	25.02	0.13	0.831
16:1	4.64	4.63	4.60	0.04	0.590
17:0	1.50	1.47	1.51	0.04	0.493
17:1	0.50	0.52	0.50	0.04	0.788
18:0	12.99[a]	11.65[b]	12.34[a]	0.80	<0.001
18:1*trans*-10	1.49	1.50	1.51	0.04	0.856
18:1*trans*-11	1.22	1.18	1.31	0.08	0.261
18:1*cis*-9	39.42	40.21	39.72	0.46	0.221
18:1*cis*-11	1.46	1.50	1.52	0.04	0.299
18:2	1.49	1.52	1.46	0.04	0.357
18:2*cis*-9, *trans*-11	0.49	0.52	0.48	0.04	0.472
18:2*trans*-10, *cis*-12	0.13	0.13	0.14	0.004	0.492
18:2*cis*-11, *trans*-13	0.19	0.19	0.20	0.006	0.233
18:3	0.36	0.36	0.36	0.004	0.885
20:0	0.18	0.18	0.17	0.005	0.162

[1] Weight percentage values are relative proportions of all peaks observed by gas chromatography.

[2] NON-FED = cows entering the slaughter facility as culls from sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.

[3] Fatty acids are represented as number of carbon atoms:number of carbon-carbon double bonds.

[a, b] Means in the same row without a common superscript differ ($P < 0.05$).

Table 3.9. Least squares means comparing VIA instrument[1] outputs of carcass characteristics of cattle in the sample population according to pre-harvest management strategy.

Item	Pre-harvest management[2]			SEM	$P > F_{TRT}$
	NON-FED	FED	DAIRY		
Number of animals	104	108	113		
12th rib fat, cm[2]	0.32[b]	1.11[a]	0.40[b]	0.07	<0.001
LM area, sq cm	53.00[c]	73.68[a]	60.45[b]	0.61	<0.001
LM length, cm[3]	12.69[c]	13.63[a]	13.27[b]	0.18	<0.001
LM width, cm[4]	6.10[c]	7.55[a]	6.73[b]	0.15	<0.001
LM length:width, cm	2.15[a]	1.83[c]	2.02[b]	0.05	<0.001
Marbling score[5]	403[c]	443[b]	513[a]		<0.001
Marbling fat, %[6]	2.14[c]	3.27[b]	4.42[a]	0.27	<0.001
LM intramuscular fat,%	4.69[c]	6.34[b]	8.79[a]	0.46	<0.001

[1] Computer Vision System Cold Camera (Research Management Systems, USA, Inc., Fort Collins, CO).
[2] NON-FED = cows entering the slaughter facility as culls from sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.
[3] Maximum length of LM from its medial origin to its lateral termination.
[4] Maximum width of LM from its most dorsal point to its most ventral point.
[5] 400 to 499 = Small[00] to Small[99]; 500 to 599 = Modest[00] to Modest[99].
[6] The area of fat within the LM identified as marbling expressed as a percentage of the total LM area.
[7] The area of all fat within the LM expressed as a percentage of the total LM area.
[a, b, c] Means in the same row without a common superscript differ ($P < 0.05$).

Table 3.10. Least squares means comparing VIA instrument[1] outputs for LM color and 12th-rib fat color according to pre-harvest management strategy.

	Pre-harvest management[1]				
Item	NON-FED	FED	DAIRY	SEM	$P > F_{TRT}$
Number of animals	104	108	113		
LM L*[3]	29.71[b]	32.63[a]	28.66[c]	0.30	<0.001
LM a*[3]	21.10[b]	24.09[a]	21.00[b]	0.34	<0.001
LM b*[3]	11.26[ab]	11.61[a]	10.92[b]	0.20	0.002
Fat L*[3, 4]	63.11[c]	68.72[a]	66.44[b]	0.59	<0.001
Fat a*[3, 4]	8.72[a]	8.62[a]	6.50[b]	0.27	<0.001
Fat b*[3, 4]	17.32[a]	15.44[b]	11.57[c]	0.56	<0.001

[1] Computer Vision System Cold Camera (Research Management Systems, USA, Inc., Fort Collins, CO).

[2] NON-FED = cows entering the slaughter facility as culls sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.

[3] Red, green, and blue color scores are computed by CVS for each pixel and are used to calculate L*, a*, and b* values. L*: 0 = black; 100 = white; a*: negative number = green; Positive numbers = red; b*: Negative number = blue; Positive numbers = yellow.

[4] Fat colors were measured using all visible fat in the 12th-13th rib interface including subcutaneous, intermuscular, and intramuscular fat.

[a, b, c] Means in the same row without a common superscript differ ($P < 0.05$).

Table 3.11. Least squares means ± SEM for the pre-harvest management[1] × evaluation method[2] interaction for marbling score[3], LMA[4], and 12th rib fat thickness[5].

Item	Evaluation method: VIA instrument[6]	Evaluation method: USDA grader	$P > F_{METHOD}$
Marbling Score[7]			
NON-FED	401 ± 11.17^z	215 ± 11.09^z	< 0.001
FED	443 ± 10.88^y	362 ± 10.88^y	< 0.001
DAIRY	512 ± 10.65^x	385 ± 10.64^x	< 0.001
LMA, cm^2			
NON-FED	52.49 ± 1.30^z	56.08 ± 1.29^z	< 0.001
FED	73.66 ± 1.27^x	79.94 ± 1.27^x	< 0.001
DAIRY	60.12 ± 1.24^y	64.56 ± 1.24^y	< 0.001
12th rib fat thickness, cm			
NON-FED	0.32 ± 0.05^y	0.26 ± 0.05^y	0.014
FED	1.11 ± 0.05^x	1.13 ± 0.05^x	0.529
DAIRY	0.40 ± 0.04^y	0.34 ± 0.04^y	0.023

[1] NON-FED = cows entering the slaughter facility as culls from sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.
[2] VIA instrument = carcass traits determined using the Computer Vision System Cold Camera (**CVS**; Research Management Systems, USA, Inc., Fort Collins, CO); USDA grader = carcass traits determined by an employee of the USDA-AMS, LS, Standards, Analysis, and Technology Branch.
[3] Pre-harvest management x evaluation method interaction effect: $P < 0.001$.
[4] Pre-harvest management x evaluation method interaction effect: $P = 0.002$.
[5] Pre-harvest management x evaluation method interaction effect: $P = 0.049$.
[6] Computer Vision System Cold Camera (Research Management Systems, USA, Inc., Fort Collins, CO).
[7] 200 to 300 = Slight^{00} to Slight^{99}; 400 to 499 = Small^{00} to Small^{99}; 500 to 599 = Modest^{00} to Modest^{99}.
[x,y] Means in the same column without a common superscript differ ($P < 0.05$).

Table 3.12. Error matrix indicating the number of observations correctly classified and mis-classified by a discriminate analysis using a development data set containing CVS[1] instrument outputs.

	Instrument Classification[1]			
Pre-harvest Management[2]	NON-FED	FED	DAIRY	Total
NON-FED	73	3	10	86
% Classified	84.88	3.49	11.63	100.00
FED	5	84	2	91
% Classified	5.49	92.31	2.20	100.00
DAIRY	10	3	79	92
% Classified	10.87	3.26	85.87	100.00
TOTAL	88	90	91	269
% Classified	32.71	33.46	33.83	100.00

[1] VIA instrument = Computer Vision System Cold Camera (**CVS**; Research Management Systems, USA, Inc., Fort Collins, CO)
[2] Pre-harvest management classified by performing a discriminate analysis using CVS instrument outputs as independent variables.
[3] NON-FED = cows entering the slaughter facility as culls from sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.

Table 3.13. Error matrix indicating the number of observations correctly classified and mis-classified by a discriminate analysis using a validation data set containing CVS[1] instrument outputs.

	Instrument Classification[2]			
Pre-harvest Management[3]	NON-FED	FED	DAIRY	Total
NON-FED	19	0	1	20
% Classified	95.00	0.00	7.69	100.00
FED	2	13	2	17
% Classified	11.76	76.47	11.76	100.00
DAIRY	1	0	19	20
% Classified	5.00	0.00	95.00	100.00
TOTAL	15	13	22	269
% Classified	30.00	26.00	44.00	100.00

[1] VIA instrument = Computer Vision System Cold Camera (**CVS**; Research Management Systems, USA, Inc., Fort Collins, CO)

[2] Pre-harvest management classified by performing a discriminate analysis using CVS instrument outputs as independent variables.

[3] NON-FED = cows entering the slaughter facility as culls from sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls.

Table 3.14. Independent variables, R^2, root mean square error (RMSE), and PRESS[1] statistic for best-fit regression equations developed to predict tenderness classification[2] using CVS[3] outputs.

Dependent variable	R^2	RMSE	PRESS[3]	Variables in model (partial R^2)[4]	% accuracy[5]
Tenderness classification for all cows[6]	0.317	0.105	2.453	VisFatArea (0.1652) LMAreaO4 (0.0389) LMaStarI3 (0.0314) LMaStarO8 (0.0219) LMaStari (0.0176) LMbStarI1(0.0189) LMbStarI2 (0.0125) LMAreaO1(0.0107)	54.0[5]
Tenderness classification for beef cows[6]	0.359	0.103	1.546	LMAreaO8a (0.2457) LMaStarO4 (0.0479) LMbStarI1 (0.0293) MarbI6 (0.0174) AdjMarbI1 (0.0184)	63.0

[1] Predicted residual sums of squares.

[2] Tender = 28 d LM SSF value < 21.0 kg; Tough = 28 d LM SSF value ≥ 21.0 kg.

[3] Computer Vision System Cold Camera (Research Management Systems, USA, Inc., Fort Collins, CO).

[4] VisFatArea = CVS area of fat in 12th-13th rib interface; LMAreaO4 = CVS section O4 LMA; LMaStarO8 = CVS LM a* value in section O8 of LM; LMaStarI = CVS LM a* value in section I of LM; LMbStarI1 = CVS b* value in section I1 of LM; LMbStarI2 = CVS b* value in section I2 of LM; LMAreaO1 = CVS section O1 LMA; LMAreaO8a = CVS section O8a LMA; MarbI6 = CVS marbling score in section I6 of LM; AdjMarI1 = CVS adjusted marbling score in section I1 of LM.

[5] % of correctly predicted dependent variable in the sequestered data set.

[6] All cows; NON-FED = cows entering the slaughter facility as culls from grass pasture via sale barns and/or ranching operations; FED = cows entering the slaughter facility from a finishing yard having received a corn-based, high energy diet for a 95 d ± 1 d period; DAIRY = cows entering the slaughter facility directly from dairies as culls. Beef cows = NON-FED and FED.

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