AUGMENTATION OF NEAR-INFRARED (NIR) AND IN-PLANT BEEF VIDEO IMAGE ANALYSIS (VIA) SYSTEMS TO SORT CARCASSES INTO TENDERNESS CATEGORIES

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TABLE OF CONTENTS

Chapter Page

II. REVIEW OF LITERATURE

Near-Infrared (NIR) Spectroscopy

Video Image Analysis

Consumer Preferences

III. PHASE I: INITIAL TESTING AND ACCURACY DETERMINATION

IV. PHASE II: VALIDATION OF NIR AND VIA TENDERNESS PREDICTION

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Over the past decade, technological advances in instrument grading of beef carcasses have been made to improve calculation of red meat yield. Implementing video image analysis (VIA) into an online grading system has aided packers and USDA graders in sorting beef carcasses into their appropriate quality and yield grades. However, many futile attempts to assess meat quality by quantitative measurements, especially cooked beef tenderness, have been made. Programs such as the BeefCam®, colorimeter measurements of the lean surface, as well as the U.S. Meat Animal Research Center developing slice shear force (SSF) have been unsuccessful in a real-time, in-plant environment.

Belk et al. (1996) said "Almost everyone agrees that instrument technology, combined with mechanisms to trace livestock through the processing chain would assist in developing a truly value-based, marketing system in which economic signals are transmitted across the entire production chain so that customer preferences are communicated to producers." As soon as a tenderness prediction technology is in place so that baseline data are available, then sources of variation and approaches for improving tenderness can be identified (National Cattleman's Beef Association, 2002). Developing a non-invasive tenderness prediction system would result in minimal lost product and food safety concerns. By using such a method, the meat industry could determine a better selling price according to objective data (Leroy et al., 2003).

CHAPTER II

REVIEW OF LITERATURE

Near-Infrared (NIR) Spectroscopy

Pioneering Work

Since its first application to grain analysis about 46 years ago, near-infrared (NIR) spectroscopy has been used successfully in several fields of food and feed analysis (Byrne et al., 1998). Its first application in the meat industry was the analysis of the chemical composition of meat and quantification of major components (Osborne and Fearn, 1986). Near infrared analysis seemed to give useful information on hydrogen bond interactions and hydrophobicity at the peptide bonds of the meat proteins (Hildrum et al., 1994). Hildrum et al. (1994) also observed that NIR spectroscopy could predict the sensory hardness of meat. As the comprehension of the technology grew, specific compounds became associated with overtones observed in a spectral reading. The absorption of NIR radiation by organic molecules is due to overtone and combination bands primarily of O-H, C-H, N-H and C=O groups whose fundamental molecular stretching and bending absorb in the mid-infrared region. Leroy et al. (2003) noted specific characteristic bands of water were observable at 980 nm (O-H second overtone), 1450 nm (O-H first overtone) and approximately 1950 nm (O-H combination tone). Local maxima due to fat were found at approximately 1200 nm (C-H stretch second overtone) and 1800 nm (C-H stretch first overtone) (Leroy et al., 2003). The American Meat Science Association (AMSA, 1991) indicated that the ratio of reflectance at 610 and 525 nm was an indicator of the percentage of myoglobin that was in the oxymyoglobin state.

The use of NIR spectroscopy for predicting beef tenderness was pioneered by Mitsumoto et al. (1991). A limited number of samples were used in the study (11 steers, 6 muscles per steer) (Mitsumoto et al., 1991). They collected spectral reflectance data (1100-2500 nm) on 3-d postmortem samples to predict 3-d Warner-Bratzler shear force (WBS) values (Mitsumoto et al., 1991). Samples were prepared and placed in sample holders for scanning (Mitsumoto et al., 1991). A multiple linear regression equation with four selected wavelengths predicted 3-d WBS values with R^2 values of 0.68 (Mitsumoto et al., 1991). This study showed promise and aroused broad interest in using NIR for predicting beef tenderness (Mitsumoto et al., 1991).

Tenderness Prediction

In recent years, it has become the goal of the meat industry to develop an innovative tool that could be used to predict the tenderness of a steak or roast. A number of studies have shown that consumers can differentiate beef that varies in tenderness and are willing to pay some level of premium for guaranteed tenderness (Boleman et al., 1997; Lusk et al., 2001; Shackelford et al., 2001). Some promising results have been obtained for indirect methods of predicting beef tenderness based primarily on lean color attributes (Wulf et al., 1997) that may result in a noninvasive, useful predictor of beef tenderness.

It is well known that connective tissue and myofibrillar proteins are the most important factors influencing meat tenderness (Maltin et al., 2003; Wheeler et al., 2000). These tissue structures are also the primary components of meat texture associated with the light scattering properties of meat. Therefore, light scattering could potentially be used as an indicator of beef tenderness (Hildrum et al., 1995). As NIR spectroscopy was found to be useful in the chemical analysis of meat, research needed to be conducted on how accurately it could be used to predict WBS force.

Hildrum et al. (1994) conducted a feasibility study with 10 carcasses (3 cows, 7 bulls) at three aging periods (1, 8, and 14-d). They acquired scans in the 1100-2500 nm range under controlled conditions requiring special sample preparation (Hildrum et al., 1994). They built a two-factor principal component regression model with multiplicative scatter correction (MSC) data preprocessing using 30 spectral scans (Hildrum et al., 1994). The model predicted WBS values with an R^2 value of 0.62 (Hildrum et al., 1994). They noted that 1-d spectra predicted 1-d WBS values, and 14-d spectra predicted 14-d WBS values (Hildrum et al., 1994). A high R^2 value prompted them to design a larger study using the near-infrared device as a tenderness prediction tool (Hildrum et al., 1994). In 1995, Hildrum et al. predicted tenderness of 40 carcasses (both cows and bulls) at three aging periods (1, 7, and 14-d). Thirty carcasses were chilled slowly while ten carcasses were subjected to electrical stimulation and rapid chilling (Hildrum et al., 1995). Spectra were collected from fresh samples and frozen/thawed samples (Hildrum et al., 1995). It is interesting to note that the NIR spectra collected from frozen/thawed samples predicted WBS values more accurately ($R^2 = 0.50$) than those collected fresh ($R^2 = 0.34$) (Hildrum et al., 1995). The authors speculated that the freezing step increased the difference in structure between tender and tough samples (Hildrum et al., 1995). Note that the model predicted current WBS values rather than forecasting ultimate WBS values (Hildrum et al., 1995). Since the model was set up only to predict same day tenderness levels, the feasibility of using NIR spectroscopy to predict beef tenderness was not highlighted as a useful tool (Hildrum et al., 1995). However, if they tried to use 1-d or 7-d scans to predict 14-d WBS force, the impending results may have led to an earlier breakthrough in tenderness analysis by NIR spectroscopy (Hildrum et al., 1995).

Rødbotten et al. (2000) studied the feasibility of using early (4 and 26-h) postmortem NIR spectroscopy to predict 2-d and 7-d WBS values from 127 carcasses. Spectra recorded at 4-h and 26-h postmortem exhibited some differences in the 1100-1900 nm range (Rødbotten et al., 2000). The rigor mortis process starts at about 4-h postmortem and ends before 26-h (Rødbotten et al., 2000). The authors hypothesized that the difference between the two spectra collected at the beginning and end of rigor mortis is related to the aging potential of the carcasses (Rødbotten et al., 2000). However, they found that spectra differences did not contain essential information to predict final tenderness of aged samples (Rødbotten et al., 2000). Partial least squares (PLS) models with MSC preprocessing of 4-h NIR spectra predicted 2-d and 7-d WBS readings with R^2 values of 0.25 and 0.27, respectively (Rødbotten et al., 2000). Models based on 26-h spectra predicted 2-d and 7-d WBS readings with R^2 values of 0.36 and 0.37, respectively (Rødbotten et al., 2000). They concluded that their study did not support the hypothesis that early postmortem NIR spectroscopy can be used as a predictor of final tenderness (Rødbotten et al., 2000).

Rødbotten et al. (2001) also used a spectrometer (950-1700 nm) equipped with a diode array detector to predict tenderness of 12 carcasses. Traditional NIR spectrometers use grating and require scanning to acquire complete spectra. Diode array-based spectrometers acquire spectra without scanning, making acquisition more rapid. The authors were able to acquire 150 spectra to cover the entire surface of a sample on both sides in 7 s (Rødbotten et al., 2001). Four samples were collected from each carcass. Near-infrared spectra and WBS readings were recorded at 2, 9, and 21-d postmortem (Rødbotten et al., 2001). Separate models for different aging periods predicted current tenderness with R^2 value of 0.36-0.69 (Rødbotten et al., 2001). With regard to forecasting tenderness, a 2-d spectra model predicted 9-d WBS values with moderate accuracy ($R^2 = 0.52$) (Rødbotten et al., 2001). Less accuracy was reported for forecasting 21-d WBS values ($R^2 = 0.27$) (Rødbotten et al., 2001). Special sample preparation was not required for this spectrometer (Rødbotten et al., 2001).

Byrne et al. (1998) used a scanning spectrometer (750-1098 nm) equipped with a fiber-optic probe to predict beef tenderness of 70 heifers. Due to lamp replacement during the course of this study, two separate models were developed using 20 and 50 samples, respectively. Results of the second set are described here. A 10-factor model based on 1-d spectra predicted 14-d WBS values with $R^2 = 0.68$ (Byrne et al., 1998). Models based on 2, 7, and 14-d spectra predicted tenderness less accurately ($R^2 = 0.20 – 0.45$) (Byrne et al., 1998). This result is intriguing, because 1-d spectra were able to predict 14-d WBS values more accurately than 14-d spectra (Byrne et al., 1998). This result contradicts expectations, because a 1-d spectrum is forecasting tenderness that involves the variability of aging, whereas a 14-d spectrum predicts current tenderness

(Byrne et al., 1998). They noted that at all wavelengths, absorption was higher for extremely tough than for tender samples (Byrne et al., 1998). Even the prediction accuracies of models based on 1-d and 2-d spectra were considerably different (Byrne et al., 1998). Near-infrared readings and WBS values were collected on different steaks from the same carcasses (Byrne et al., 1998). Byrne et al. (1998) suggested that collecting NIR readings and WBS values from the same meat sample would improve the accuracy.

Venel et al. (2001) acquired NIR spectra (750-1098 nm) on *longissimus dorsi* and *semimembranosus* muscles from 75 animals. Following the recommendation made by Byrne et al. (1998), the site of spectral measurement was marked with a scalpel, and WBS values were measured at the same site. Spectra and WBS values were collected at 14-d postmortem (Venel et al., 2001). Near-infrared spectroscopy was unable to predict tenderness of the *semimembranosus* muscle (Venel et al., 2001). For longissimus muscle, R^2 values for tenderness prediction ranged from 0.27-0.33 (Venel et al., 2001). When separate models were developed for each segregation of samples based on sex, grade, and pH, R^2 values of prediction were between 0.15 and 0.54 (Venel et al., 2001).

Park et al. (1998) collected NIR spectra (1100-2498 nm) and WBS values on frozen and thawed samples at either 7-d or 14-d postmortem on 119 samples. They developed a 6-factor partial least squares (PLS) model to predict tenderness with R^2 values of 0.67 and 0.63 for calibration ($n = 80$) and validation ($n = 39$) sets, respectively (Park et al., 1998). Note that 7-d spectra predicted 7-d WBS values and 14-d spectra predicted 14-d WBS values (Park et al., 1998). They reported that absorption was higher for extremely tough steaks than for tender steaks (Park et al., 1998). It was particularly true at wavelengths between 1,000 and 1,350 nm (Park et al., 1998). The PLS regression with optimal model conditions ($R^2 = 0.67$) occurred with six PLS factors (Park et al., 1998). Hildrum et al. (1995) reported that the spectra collected on the samples that were frozen and thawed predicted WBS values more accurately than those collected on fresh samples. However, in industry application, samples would not be frozen and thawed.

Liu et al. (2003) collected NIR spectra (400-2498 nm) and WBS values from 24 carcasses at 2, 4, 8, 14, and 21-d postmortem. After the appropriate aging times, steaks were cut from strip loins (*Longissimus lumborum*) and scanned with a visible-NIR spectral device (Liu et al., 2003). An 8-factor PLS model predicted WBS values with $R^2 = 0.49$ (Liu et al., 2003). It was noted that the model did not forecast aged tenderness (Liu et al., 2003). When the data were segregated into different aging periods, prediction accuracy increased ($R^2 = 0.22$-0.72) for 4-d and 21-d aging periods, while accuracy decreased for other aging periods (Liu et al., 2003). Their results indicated that the visible-NIR spectral information of steaks aged 14 and 21-d differed from those aged 2, 4, and 8-d postmortem (Liu et al., 2003). They also noted that steaks aged 2, 4, or 8-d had a higher percentage of tough meat (> 20.8%) than those aged 14 or 21-d (<10%) (Liu et al., 2003). Of the 82 samples measured with WBS force values less than 6.0 kg, 70 samples (85.4%) were predicted to have WBS force values less than 6.0 kg (Liu et al., 2003). Of the 31 samples measured to have WBS force values greater than 6.0 kg, 80.6% were predicted to have WBS force values greater than 6.0 kg (Liu et al., 2003). Therefore, their overall accuracy using visible-NIR spectroscopy as a tenderness prediction tool was 83.0% (Liu et al., 2003).

Leroy et al. (2003) used a Fourier Transform NIR spectrometer to record spectra (833-2500 nm) from 189 samples using transmission and reflectance modes at 2 and 8-d postmortem. They noted that the fiber-optic device showed significant noise at extreme wavelengths of the spectral range (Leroy et al., 2003). The spectral region of 2383-2500 nm had too small sensitivity and a high level of noise, and consequently was not used in the construction of the prediction models (Leroy et al., 2003). Therefore, calibration models were developed and evaluated using a 935-2327 nm spectral range (Leroy et al., 2003). At all wavelengths, absorption was higher for extremely tough than for tender samples (Leroy et al., 2003). Using the reflectance mode, the 2-d spectra model predicted 2-d and 8-d WBS readings with R^2 values of 0.25 and 0.19, respectively (Leroy et al., 2003). With the transmission mode, a 2-d spectra model predicted 2-d and 8-d WBS readings with R^2 values of 0.41 and 0.15, respectively (Leroy et al., 2003). They suggested that it would be of interest to segregate the sample data set according to animal grade, sex, or ultimate pH to improve predictive accuracy (Leroy et al., 2003).

In 2005, Shackelford et al. evaluated visible and near-infrared systems to classify US Select beef carcasses into tenderness categories. They justified using only US Select carcasses in the study by claiming many cuts from a US Select carcass are very tender (Shackelford et al., 2005). They collected visible-NIR spectra online at two commercial beef processing facilities (Shackelford et al., 2005). Carcasses were segregated into visible-NIR-based tenderness classes based on whether their visible-NIR predicted SSF value was less than (tender) or greater than (tough) the median predicted slice shear force (SSF) value (Shackelford et al., 2005). They found that carcasses classified as tender by visible-NIR had a lower mean SSF, were less likely to have SSF values greater than 245

N (Newtons), had higher trained sensory panel tenderness ratings, and were less likely to have trained sensory panel tenderness ratings below slightly tender than were carcasses classified as tough ($P < 0.001$) (Shackelford et al., 2005).

Xia et al. (2007) characterized beef muscles with optical scattering and absorption coefficients in the visible-NIR region. They developed a fiber-optic probe that spatially measured diffuse reflectance from beef samples within the visible-NIR bandwidth of 450-950 nm (Xia et al., 2007). Beef absorption coefficients were related to the sample chemical compositions such as the concentration of myoglobin and its derivatives (Xia et al., 2007). Optical scattering coefficients depended on meat structural properties such as sarcomere length and collagen concentration (Xia et al., 2007). They found a higher scattering coefficient was associated with a higher cooked WBS force (Xia et al., 2007). Furthermore, a linear regression analysis showed that sample scattering coefficients were significantly ($P < 0.0001$) correlated to the corresponding WBS force with a coefficient of determination (R^2) of 0.59 (Xia et al., 2007).

To summarize, several studies reported moderate to promising results in predicting current-status tenderness (Mitsumoto et al., 1991; Hildrum et al., 1994, 1995; Rødbotten et al., 2001; Park et al., 1998; Liu et al., 2003). Only one study (Byrne et al., 1998) reported success in forecasting tenderness. However, another study from the same research group (Venel et al., 2001) reported failure in predicting current tenderness. Three studies reported failure in forecasting tenderness (Rødbotten et al., 2000, 2001; Leroy et al., 2003).

Description of the Instrument

The visible-near-infrared (VIS-NIR) spectrometer (Field Spec Pro Jr., Analytical Spectral Devices, Inc., Boulder, CO) is capable of collecting light in the visible and near infrared regions (400-2,500 nm). A fiber-optic contact probe is used to transmit light reflected from the beef surface to three internal detectors. The detectors consist of a silicon photodiode array, a thermoelectrically (TE) cooled Indium Gallium Arsenide (InGaAs), and a TE-cooled extended InGaAs to measure the 350-1,000 nm, 1,001-1,670 nm, 1,671-2,500 nm wavelength domains, respectively.

Inside the instrument, a diffraction grating splits the reflected light into narrow wavelength bands. A 512-channel silicon photodiode array is geometrically positioned to receive light within a narrow bandwidth (1.4 nm) in the region of 350-1,000 nm. The photodiodes convert the accumulated light to an electronic signal. The signal is digitized by and transferred to the computer. Spectral resolution in this region is 3 nm.

The two InGaAs connectors are the scanning type. They differ from the first sensor in that they measure wavelengths sequentially, rather than simultaneously. Each sensor consists of a concave holographic grating and a single TE-cooled InGaAs detector. The gratings are mounted on a shaft which oscillates with a period of 200 ms (100 ms/scan). As the grating oscillates, the detector measures different wavelength bands. The resolution in these spectral regions is 30 nm (ASDI, 2002). The spectrometer is carried in a backpack with the laptop computer positioned ahead of the operator. The contact probe provides broadband light from an internal tungsten-halogen light source.

Instrument Operation-Optimization of Parameters

Integration time (IT) is an important parameter for the photodiode array detector. Integration time, also known as exposure time, is defined as the time during which the photodiode array accumulates the signal. The higher the IT, the greater the signal. However, the photodiode array begins to saturate if the signal exceeds the dynamic range of the detector. Therefore, optimization of the IT is required. The contact probe is placed on a white reference plate (Spectralon® Diffuse Reflectance Targets, LabSphere, Inc., North Sutton, NH) that reflects light across the spectrum of interest. The spectrometer automatically adjusts the IT to allow maximum signal without saturation.

A certain amount of electric current is generated by thermal electrons, called dark current, and is added to the signal generated by reflected light. Dark current is a property of the detector and associated electronics (not the light source) and varies with temperature. It also varies linearly with the integration time for the photodiode array. Dark current is produced by the detector when the mechanical shutter blocked the entrance slit of the spectrometer. This signal is detected from all readings to eliminate the effect of temperature variation. Dark current is read every 5 min during spectral collections.

Another factor, that is used to optimize instrument spectral capabilities, is a white reference plate. Because a white surface reflects nearly 100% of incident light, the resulting is a measure of incident light intensity (I_o). White reference spectra are collected every 5 min during carcass spectral readings. To avoid soiling the white plate, it is protected with a 1.59-mm cover glass made of fused quartz borosilicate. This glass has more than 90% transmission over the spectral range of interest.

Reflectance

The spectrum reflected from the sample (I) must be collected under conditions similar to those used for the white reference. Because a cover glass is placed over the white reference plate, a glass plate with identical specifications is placed over the sample. By dividing the reflected spectrum by incident light (white reference spectrum), reflectance (I/I_o) is obtained. The acquired reflectance is the property of the material as well as the design of the probe and spectrophotometer, which is the fraction of incident light that is reflected from the beef surface. In addition, for a given scan, 10 spectra are collected consecutively and averaged to minimize the effect of electronic noise.

The median of three spectra are calculated and saved as a reflectance spectrum for that sample. Median calculations aid in the prevention of outlier data points such as spectra over a thick marbling spot or connective tissue, or low signal at water absorption bands. Reflectance (R) is converted to absorbance (1/R) by log transformation. This transformation is commonly employed to linearize the relationship between the concentration of an absorbing compound and the absorption spectrum.

Video Image Analysis (VIA)

Pioneering Work

As part of its effort to implement value-based marketing, the beef industry began investigating use of instruments to improve characterization, sorting, and pricing of cattle and beef carcasses nearly three decades ago (Cross and Whittaker, 1992). The National Beef Instrument Assessment Planning Symposium determined that reliable, accurate tools for instrument assessment hold the promise of more accurately measuring factors that contribute to consumer satisfaction with beef, while reducing production costs and waste, and testing experimental technology under real-world conditions is critical to achieving commercial success (Belk et al., 2000a). The video image analysis systems that are used in today's meat industry are manufactured by several companies. Smart

Machine Vision in Reston, VA and Research Management Systems USA in Fort Collins, CO integrated features contained in the prototype BeefCam into the Computer Vision System (CVS). This system has proven useful in predicting the composition of beef carcasses under commercial conditions (Cannell et al., 2002). Another company that has found a niche in the meat industry is the German company, E+V Technologies. In order for a value-based marketing system such as the one envisioned by Cross et al. (1992) to work, both the producer and the packer must be confident that the subjectivity of the assignment of USDA Quality Grades and Yield Grades has been minimized (Smith, 1999).

Video image analysis got its start in the determination of water holding capacity (WHC) in meat. Irie et al. (1996) used VIA and simple formulations to measure WHC in duck, pork, beef, and chicken meat. They observed the *biceps femoris* in chickens; *pectoralis superficialis* in ducks; *longissimus dorsi* in beef; and *longissimus dorsi*, *gluteus medius*, *biceps femoris*, *psoas major*, *semimembranosus*, *semitendinosus*, and *latismus dorsi* in pork (Irie et al., 1996). Muscle samples were placed onto filter paper and sandwiched between two plastic plates (Irie et al., 1996). A VIA system (video camera, a pair of video lights, an image analyzer, a video monitor, a digitizer, and a personal computer) was used to capture an image of the filter paper, producing a 640 x 480 pixel image (Irie et al., 1996). The meat/liquid area ratio was correlated ($P < 0.01$, $r = 0.92$) with the WHC measurements obtained by conventional formulations including sample moisture (Irie et al., 1996). They concluded that VIA analysis was a rapid and stable technique for measuring WHC (Irie et al., 1996).

Computer vision and video image analysis also showed promise for application in the beef industry as a tool to measure other physiochemical properties in beef carcasses. Kuchida et al. (2000) reported that computer image analysis could successfully measure crude fat content in images obtained on beef longissimus samples. Other properties that could be explained by these technologies were color differences (Gerrard et al., 1996; Belk et al., 2000a) and textural properties (Li et al., 1999) which could be used to explain differences in cooked beef palatability.

Belk et al. (1998) determined whether an instrument could be used to augment and improve the accuracy of USDA Yield Grade placement. They observed that Yield Grade, called by line-graders at line speed, was correct 68% of the time; Yield Grade, computed using line-grader estimated of Yield Grade factors, was correct 81% of the time; and Yield Grade computed by providing line-graders with actual ribeye area measurements and combining those with line-grader estimates of the remaining Yield Grade factors, was correct 93% of the time (Belk et al., 1998). Belk et al. (2000b) reported that a prototype video imaging system (BeefCam) could identify carcasses that would yield steaks that would be "tender" after aging and cooking. However, this prototype BeefCam did have limitations that prevented its use in a commercial setting. Vote et al. (2003) also evaluated the BeefCam module equipped with a computer vision system to predict beef tenderness. They conducted four experiments in two commercial packing plants and compared beef tenderness prediction using an online VIA system and the BeefCam system. They reported that BeefCam lean color measurements, a* and b*, were effective ($P < 0.05$) in all experiments for segregating carcasses into groups that produced steaks differing in WBS force values (Vote et al., 2003). Additionally, the CVS

BeefCam output variable for longissimus area was correlated ($P < 0.05$) with WBS force values in all experiments (Vote et al., 2003).

Tatum et al. (1997) sorted beef carcasses using Hunter b* values and successfully identified carcasses likely to produce tough top sirloin and top loin steaks in four postmortem-aging (3, 7, 14, and 21-d) groups. George (1998) found that categorization of carcasses into three predicted tenderness classes using Hunter b* values successfully identified carcasses that produced tough steaks.

Li et al. (2000) extracted texture features from fresh beef images taken by a computer vision system and used them to classify steaks into tough and tender groups. Strip loin images were taken and then transformed using the red, green, blue (RGB) and the hue, saturation, and intensity (HSI) systems and image features were enhanced through the use of a wavelet-based method that decomposed the textural image into textural primitives of different sizes (Li et al., 2000). Differences in image texture resulted in variations in the primitive fractions (Li et al., 2000). They correctly classified 83.3% of the steaks into tenderness categories and noted that texture features could be significant members in a set of indicators that would lead to adequate tenderness prediction (Li et al., 2000).

Instrument grading (particularly, VIA) has shown the potential to improve objectivity predictions of palatability and cutability by employing technology to segment or sort carcasses into quality and/or yield groups (Smith, 1999). Computer vision also has advantages in cost, accuracy, efficiency and acceptability. Utilizing a system that will be a cost benefit to the packer can also translate into savings for the consumer at the retail market by correctly identifying cuts that are superior in quality, thus establishing a repeat buyer's market.

Consumer Preferences

Perception

Undoubtedly, appearance determines how consumers perceive quality and significantly influences purchasing decisions (Carpenter et al., 2001). In a study conducted by Grunert (1997), the most important product characteristic which consumers base their quality evaluations on are the appearance attributes: fat content and color. Additionally, several other attributes enter a consumer's thoughts when they are about to purchase a meat product. Consumers expect a consistent quality and an optimal quality/price ratio (Leroy et al., 2003). However, it is not sufficient to state that a product has a "high quality" to motivate a consumer (Issanchou, 1996). Rather, quality must be supported by a specific concrete benefit for the consumer.

Issanchou (1996) pointed out that in a purchase situation the consumer has at one's disposal cues that can be observed: intrinsic cues which are part of the physical product and extrinsic cues such as price and marketability. Price can be a cost factor but can also be a quality indicator (Issanchou, 1996). According to Steenkamp (1989), each potential buyer of a given product has two price limits in mind: an upper limit beyond which he/she would find the product too expensive and a lower limit below which the quality would be suspect. Depending on previous information and experience, quality cues are used, at the point of purchase, to infer expected quality attributes (Issanchou, 1996). To be effective, the information supplied on the label must be read, understood, and accepted (Issanchou, 1996).

There are several factors that affect the perceived quality of meat. The National Consumer Retail Beef Study (Savell et al., 1987, 1989) clearly revealed the importance of flavor, tenderness, and juiciness traits to the consumer in the purchasing-decision process. In addition to the palatability aspects of the final cooked product, factors such as convenience, food safety, and healthiness of the product are taken into account. In today's society, consumers look for meat products that could be easily prepared in a short period of time. In general, consumers do little planning of meals (National Cattleman's Beef Association, 2002). Consumers wait until the last minute to plan their meals; most decisions are made the day of the dinner and at the end of the day (Resurreccion, 2003). Today, more consumers are choosing to eat away from home or purchase more products that are prepared or partially prepared outside the home (Resurreccion, 2003). The two major reasons cited for serving prepared meals at home are “not enough cooking time” and “other uses for my time” (Resurreccion, 2003). However, during the last few years, supermarkets have started offering a variety of value-added, prepackaged and case-ready meat products.

From a food safety standpoint, the majority of consumers are not anxious about product safety, although a certain fear is always present in a latent state. Such present doubts about meat safety have already had a considerable impact on sales of beef. With the ever rising concerns about bovine spongiform encephalopathy (BSE), *E. coli* O157:H7, and other pathogenic bacteria, consumers are slowly developing a sense of urgency when it comes to overall meat safety.

But in today's trendy society, the topic of concern stems from the healthiness of food products that consumers are purchasing. Beliefs about healthiness are formed from information provided by friends, but more importantly, the media. The terms “saturated fat”, “high cholesterol” and “coronary heart disease” have been communicated by nutritionists to be associated with the consumption of red meats, especially beef (Unnevehr and Bard, 1993). This is often cited as the cause of beef consumption decline in many industrialized countries (Porin and Mainsant, 1996). However, it is still up to the consumer to wager aspects of healthiness with overall eating satisfaction. Thus, the ability to deliver a product that maximizes customer satisfaction, maintains customer loyalty, and increases patronage is a very complex issue that the meat industry faces.

In coupling these factors with the ever growing concern about changes in consumer preference, the industry as a whole becomes an evolving system that is faced with a new challenge on a daily basis. One of the major challenges that the beef industry deals with is the rising popularity of chicken consumption. A large part of the increase in poultry consumption may be due to the poultry industry’s catering to consumers through its emphasis on producing value-added convenient products (Resurreccion, 2003). Statistics show a decrease in per capita beef consumption coupled with an increase in per capita consumption of chicken. These trends indicate that beef now must compete more directly for each dollar spent on meat than was the case 20 years ago (Resurreccion, 2003). A study completed by Menkhaus et al. (1993) indicated that consumer concerns regarding beef were related to cholesterol, calorie content, artificial ingredients, convenience characteristics (microwaveable and storage), how beef is displayed in the store, and price (too expensive). Each of these factors exhibited a statistically significant negative effect on the quality perception of beef compared to other meats.

Research

Consistency in palatability is a problem which has plagued the beef industry for several decades (Jeremiah et al., 2003). Muscles in some beef cuts differ considerably in both textural and histological properties (Paul et al., 1970). Research has demonstrated that tenderness varied between beef muscles and occasionally within muscles (Ramsbottom et al., 1945). More recent research has demonstrated muscles of the beef forequarter to be extremely variable in palatability (Johnson et al., 1988). Other reports have indicated beef muscles responded differently to postmortem aging (Koohmaraie et al., 1988; Olson et al., 1976). Differences have also been reported among beef muscles in flavor intensity (Carmack et al., 1995; Crouse et al., 1984) and juiciness (Carmack et al., 1995; Crouse et al., 1984; Ritchey and Hostetler, 1964). If better value can be delivered via improved quality, consistency or price then revenue for the meat industry might be expected to increase (Polkinghorne, 2006).

Carmack et al. (1995) evaluated sensory attributes of beef flavor intensity, tenderness, and juiciness of several major muscles from US Select and Choice steers. They looked at the *biceps femoris*, *psoas major*, *gluteus medius*, *semimembranosus*, *triceps brachii*, *rectus femoris*, *longissimus lumborum*, *serratus ventralis*, *infraspinatus*, *semitendinosus*, *pectoralis profundus*, and *supraspinatus* (Carmack et al., 1995). They found that panelists rated certain muscles to be significantly different from each of the sensory attributes (Carmack et al., 1995). Tenderness was easiest to differentiate as the *psoas major* was the most tender ($P < 0.05$) followed by the *infraspinatus*, *longissimus lumborum*, and *rectus femoris* which were similar ($P > 0.05$) (Carmack et al., 1995). The *serratus ventralis* was juicier ($P < 0.05$) than all muscles, except for the *infraspinatus* (Carmack et al., 1995). The *semimembranosus* and *semitendinosus* were the least juicy, but were not different (P > 0.05) from the *triceps brachii*, *rectus femoris*, *gluteus medius*, and *biceps fermosis* (Carmack et al., 1995). Thus, the determination was that muscles from the chuck and loin were juicier than those from the round (Carmack et al., 1995).

Shackelford et al. (2001) conducted a study identifying tender cuts within the US Select Quality Grade. They found that consumers showed a strong willingness to pay a premium for "Tender Select" cuts that combine superior tenderness with the leanness of Select quality (Shackelford et al., 2001).

As most consumers peruse the meat market case for a product to take home to prepare and/or serve for dinner, many factors begin to take shape in the selection process. Factors such as specie, price, convenience, portion size, product quality, and what dish to prepare with the meat product of choice are just a few of the thoughts that are taken into consideration. Grunert (2006) put together a simulated retail shopping environment using a computer and panel of consumers. The simulated environment incorporated informational characteristics about a specific meat product and the supermarket setting (Grunert, 2006). The computer screen displayed four sets of pork chops and each picture had a command button the consumer could press to find out information about four extrinsic quality factors: price, origin, animal welfare in the production process, and guarantees for the absence of pesticide residues in the meat (Grunert, 2006). Each consumer had to choose one of the packs of pork chops under simulated time pressure, as visualized by a running 45 second time bar (Grunert, 2006). This was to simulate the way consumers can obtain information by taking up and handling packs of meat (Grunert, 2006). He reported that the average time for making a decision was 20.2 seconds (Grunert, 2006). During that time, respondents managed to click, on average, 3.1 times to get price information, 2.7 times to get information on origin, and 0.9 times to get information on residues or on animal welfare (Grunert, 2006). He concluded that a majority of the respondents used the “traditional” extrinsic factors price and origin, even though the decisions were made very fast (Grunert, 2006). The fact that decisions of meat purchasing are made very fast and under time pressure did not seem to prevent consumers from having a look at several extrinsic quality factors (Grunert, 2006).

Boleman et al. (1997) conducted a study to evaluate consumer perception of beef top loin steaks from known categories of tenderness and how buying trends were modified by the tenderness and price variations of these steaks. They wanted to address the issue of whether consumers would be more satisfied and more importantly willing to pay more in the marketplace for beef that is guaranteed tender (Boleman et al., 1997). Steaks sorted into color groups based on their WBS force and then given to recruited consumers (Boleman et al., 1997). Results indicated that consumers were able to differentiate between the three categories of tenderness ($P < 0.05$) (Boleman et al., 1997). Consumers gave higher ($P < 0.05$) juiciness and flavor ratings to tender steaks (Red color group) than to tough (Blue color group) steaks (Boleman et al., 1997). They also conducted a simulated marketplace trial and asked consumers if they were going to purchase a meat product based on the panel results, which steak color would they buy and how much would they be willing to pay for it (Boleman et al., 1997)? Tender (Red) steaks were purchased 94.6%, intermediate (White) 3.6%, and tough (Blue) 1.8% of the time (Boleman et al., 1997). These results suggest that consumers could discern between categories of tenderness and were willing to pay a premium for improved tenderness (Boleman et al., 1997).

There have been studies conducted on a national level to assess the monetary value that consumers placed on tenderness. Miller et al. (2001) evaluated consumer thresholds for establishing the value of beef tenderness. They sampled consumer populations in three supermarkets of five major metropolitan cities (Miller et al., 2001). Consumers were asked to evaluate beef steaks from each tenderness category (tender, intermediate, and tough) for overall and tenderness acceptability, overall quality, beef flavor, juiciness, initial tenderness, how much they would pay for the steak, if they would pay more than the current market price if guaranteed tender, and to estimate the number of meals in a two week period that included beef (Miller et al., 2001). They found that consumer acceptability increased as WBS force values decreased ($P < 0.05$) (Miller et al., 2001). The transition in consumer perception from tender to tough beef occurred between 4.3 and 4.9 kg of WBS force (Miller et al., 2001). Data suggested that consumer WBS force tenderness values of < 3.0, 3.4, 4.0, 4.3, and > 4.9 kg would result in 100, 99, 94, 86, and 25% customer satisfaction for beef tenderness respectively (Miller et al., 2001). They also reported that 78% of the consumers would purchase steaks if the retailer guaranteed them to be tender (Miller et al., 2001). This resulted in the opportunity for a premium to be paid for a guaranteed tender carcass (Miller et al., 2001).

Cooked Beef

Cox et al. (1997) observed how the final degree of doneness affected consumer acceptability of beef steaks in a restaurant-style setting. Consumers, who selected beef steak menu items at nine restaurants, were surveyed on their attitudes to beef and their assessment of beef steak meals (Cox et al., 1997). Consumers rated the meal for tenderness, taste, overall satisfaction, value for money and intent to repurchase (Cox et al., 1997). The majority of the steaks in the survey were from the rump (78%) followed by the cube roll (12%), tenderloin (7%) and sirloin (3%) (Cox et al., 1997). The average ordered degree of doneness for all consumers was medium (Cox et al., 1997). Twenty to thirty percent of consumers ordered and received well-done steaks, while only about 5% of consumers ordered and received steaks in the rare category (Cox et al., 1997). The interaction between ordered and delivered degree of doneness had a highly significant ($P < 0.001$) effect on consumer scores for tenderness, taste, overall satisfaction, value for money and intent to repurchase (Cox et al., 1997). They reported that while tenderness is often considered as the major factor affecting consumer satisfaction (Chrystall, 1994), the results from this study demonstrate the importance of degree of doneness (Cox et al., 1997). They also recommend that using a continuous color band, or series of photographic standards which cover the doneness categories may be more beneficial when trying to communicate doneness preference (Cox et al., 1997).

Jeremiah et al. (2003) assessed the palatability attributes of 33 muscles from 25 Canada AA steer carcasses. After roasting each muscle to an internal temperature of 72ºC, panelists rated sensory attributes for each muscle (Jeremiah et al., 2003). They reported that initial tenderness ranged from tender to moderately tough (Jeremiah et al., 2003). All of the tenderloin, butt tender, ribeye cap, and cross rib samples were rated tender and juicy overall, but 40% or less of the shoulder and round cuts were rated juicy (Jeremiah et al., 2003). To the extent desirability to the panel utilized is representative of consumer acceptance, only the tenderloin, butt tender, ribeye cap, cross rib, and ribeye either met or came close to meeting the Canadian Cattleman's Association's goal of 95% acceptance based upon palatability (Jeremiah et al., 2003). They concluded that effective postmortem intervention techniques or alternative cooking methods must be developed and applied to improve the palatability of most beef muscles, if the aforementioned goal is to be achieved (Jeremiah et al., 2003).

Implications

Through information gathered from numerous studies, factors which determine purchasing preferences of beef have been noted for wholesale and retail situations. Of the factors identified, tenderness has been noted as one of the most powerful driving reasons why consumers are willing to pay premiums for very palatable beef. Establishing programs that identify very tender beef is the next step that packers and retail chains would like to take. Several companies have begun this process by conducting daily SSF analysis on selected populations of cattle. However, this process is very time consuming and every animal is not sampled for SSF analysis. Thus, a percentage of the population is still left in the tender/tough balance. Other companies are incorporating VIA color measurements in classifying beef into expected tenderness groups. Color measurements have been noted to be correlated to tenderness however, the results from those studies mentioned previously were not very accurate. A true assessment of tenderness needs to measure the results from VIA against results from SSF analysis. This would, in turn, give us information about intrinsic factors that play a role in ultimate tenderness. This is where NIR spectroscopy can be of benefit to the assessment of tenderness. By measuring beef carcasses with a NIR camera, quantitative information on fat, water, protein, and collagen could be calculated and used to estimate how they contribute to the overall ultimate tenderness of the animal.

CHAPTER III

PHASE I: INITIAL TESTING AND ACCURACY DETERMINATION

Introduction

Recent surveys have shown that consumers have difficulty in selecting beef because they are unsure of its quality, particularly its tenderness (Dransfield, 1994). In the particular case of meat, various researchers have demonstrated high correlations between near-infrared (NIR) spectral data and a number of quality attributes (Mitsumoto et al., 1991; Beck et al., 1991; Hildrum et al., 1995), showing potential of NIR as a quality indicator. Near infrared spectroscopy has been successful in the analysis of food and feed components (Byrne et al., 1997). Its use has been in the detection of specific compounds in meat such as deoxymyoglobin, oxymyoglobin, sulfmyoglobin, water, and oxygen-hydrogen overtones (Liu et al., 2000). The development of fast, non-destructive, accurate, and on-line techniques to assess quality are being desired at an ever increasing rate by the industry. Near infrared spectroscopy could form the basis for such techniques due to the speed, ease of use, and less interferences from moisture or color of meat samples (Liu et al., 2003). Video image analysis (VIA) is currently used in most major processing plants to aid USDA graders in the application of quality and yield grades. Video image analysis has been reported to measure crude fat content (Kuchida et al., 2000), color (Gerrard et al., 1996; Belk et al., 2000b), and textural properties (Li et al., 1999), all of which could explain differences in cooked beef palatability. According to the National Beef Instrument Assessment Planning Symposium (NLSMB, 1994), for an instrument to be successful, it must be tested under real-world conditions. Thus, the objective of this study was to determine the feasibility of using VIA, data along with NIR data, to accurately predict 7-d and 14-d tenderness ratings.

Methodology

Meat Samples

In Phase I, beef carcasses (n = 51) were randomly selected from a local processing plant (National Beef Inc., Dodge City, KS). Following a 24-h chill (1°C) period, carcasses were ribbed between the 12th and 13th rib and were allowed to bloom for approximately 15 minutes before reaching the grading stand. The *m. longissimus thoracis* (LT) of right sides were scanned with an in-plant VIA camera at the 12th-13th rib interface. Selected carcasses were individually identified and railed off onto separate rails. It should be noted that the US Quality Grades of the tested carcasses (US Prime = 2, US Choice = 28, US Select = 18 and US Standard = 3) were selected primarily to reflect typical quality grade distributions of US beef processing plants (McKenna et al., 2002). As carcasses were moved onto the separate rails, NIR scanning was conducted on the same LT surface (right side) that had been scanned with the VIA camera. In an effort to avoid connective tissue and approximate where shear force measurements were to be taken, one NIR scan was taken close to the geometric center of each LT. Reflected light was collected through an Analytical Spectral Devices (ASD, Inc., Model 135090) 2 m long fiber-optic jumper cable that consisted of a bundle of forty-four 200 μm fibers.

Each carcass spectral scan was identified and saved on a laptop computer for subsequent analysis.

After NIR scanning, carcass grade data factors were collected for preliminary yield grade, adjusted fat thickness, kidney, pelvic, and heart fat percentage, lean maturity, skeletal maturity, and marbling score as evaluated and stamped by USDA graders (USDA, 1997). Hot carcass weight and carcass identification numbers were recorded directly from plant identification tags. Once grade data collection was complete, a 7.5 cm ribeye section was removed from the right side of each carcass, individually bagged, packed into refrigerated chests with ice packs, and transported to the Oklahoma State University (OSU) Food and Agricultural Products Research Center (FAPC). At approximately 48-h postmortem, two 2.54-cm steaks were cut from the anterior end of each ribeye section using a band saw. The first steak cut was designated for a 7-d aging period and the second steak was designated for a 14-d aging period. Steaks were individually identified, placed in polyethylene bags, vacuum-packaged, and placed in cardboard boxes designated by aging period. Boxes were covered and stored in refrigerated rooms (4ºC) until aging periods were completed. At the end of each aging period, boxes were placed into freezers and steaks were frozen (-20°C) for further analysis.

<u>Slice</u> <u>Shear</u> <u>Force</u> <u>Measurement</u>

The slice shear force (SSF) method was used to determine overall LT shear force. Steaks were removed from boxes, placed on plastic trays, and thawed for 24-h at 4°C. Upon completion of thawing, steaks were removed from their vacuum bags and cooked on a belt-fed impingement oven (TBG060 Magigrill, MagiKitch'n Inc., Quakertown, PA) as described by Wheeler et al. (1998). Preliminary test cooking was conducted to determine appropriate cooking times to reach 70°C internal temperature. After the steaks exited the belt grill, they were held at room temperature for two minutes for post-cooking temperature rise to complete the cooking process. Slice shear force was measured after the cooked steaks were allowed to chill for at 4°C for 24-h. Using the procedures outlined by Shackelford et al. (1999), a first cut was made approximately 1 cm from the lateral end of the cooked steak. The SSF sample was removed at an angle of 45° using a knife with two parallel blades separated by a 1 cm space. This procedure generated a cooked meat sample measuring 5 cm in length by 1 cm in thickness and 2.5 cm in width. This sample location was selected so that limited connective tissue would be located within the slice shear sample. Slice shear force was measured using a flat, blunt-end blade (SSF blade) mounted on an Instron Universal Testing Machine (Instron Corp., Canton, MA). Force required to shear the muscle fibers of the slice was recorded as kg of force.

Model Development

The data analysis was performed using the Unscrambler software package (version 9.7, Camo A.S., Trondheim, Norway.) Each spectrum generated 2,150 data points, or independent variables. In order to accommodate this scale of variables, a multivariate dimensionality reduction technique was employed to avoid over-fitting. The spectra data set was subjected to a principal component analysis (PCA) and the sample scores were examined for outlying or unusual spectra. Partial least squares (PLS) regression was used to produce new features. These features were linear combinations of original spectral data points yielding new factors that were not correlated and that explained most of the variation in both the dependent and independent variables (PLSplus, 2000). The PLS procedure was applied directly to the log(1/R) spectra with the wavelength region 770-2500 nm. Predictive models were generated by both PCA and PLS using the optimal number of components in each case. Full cross-validation was employed to select the number of PLS factors included in the models and for prediction of error estimation. For cross-validation, each sample was temporarily removed from the data set, one sample at a time. Model performance was reported as the standard error of calibration (SEC) and the coefficient of determination (R^2). For the calibration performance, the SEC was calculated as

$$\mathrm{SEC} = \sqrt{\left(\frac{\sum (Y_i - R_i)^2}{n - f - 1}\right)}$$

where Y_i and R_i are the predicted and observed shear force values for sample i, respectively. The value of n is the number of samples, and f is the number of factors in the model.

Evaluation of Statistical Model

Slice shear force categories were established beforehand based on previous research. Steaks were classified with 7-d or 14-d SSF greater than 25 kg as “tough”, 19-25 kg as “intermediate”, and less than 19 kg as “tender.” In the description that follows, “observed values” refers to the reference SSF values. “Predicted values” refers to the 7-d or 14-d shear force predicted by the spectral reflectance system.

Principal components generated by PCA were merged with VIA and SSF data in a spreadsheet. The VIA camera analyzes ribeye surfaces as a whole and separates the surface into 16 geometric sections. The VIA camera produced 126 independent variables that covered ribeye area, fat thicknesses, color of fat, lean, and marbling, and additional color and area information of the 16 sections. The data set was imported into SAS (SAS Inst. Inc., Cary, NC) where mean SSF values and marbling scores within each quality grade were determined using PROC MEANS. Analysis of the predictive model and VIA data was conducted using the PROC REG procedure in a stepwise format with measured (actual) SSF as the dependent variable. Independent variables that were deemed significant ($P < 0.05$) along with their coefficients were reported in the regression output. Once significant independent variables were identified, they were separated out of the original data set and put into a new spreadsheet where the regression equation was applied to the data set. The output that was generated was termed the "Predicted" SSF. The "Actual" and "Predicted" SSF values were plotted against each other on a scatter-plot where an R^2 value was generated and used to explain how much of the variation was accounted for in the study.

Results

Summary values for meat quality data generated by VIA and USDA grader are presented in Table 3.1. The average back fat thickness ranged from 0.38 to 2.59 cm, ribeye area ranged from 69.36 to 111.90 cm^2, hot carcass weight ranged from 332.02 to 454.50 kg, and yield grade ranged from 1.07 to 4.16. Percentage of yield grade among the population was 9.80% yield grade one, 37.25% yield grade two, 47.06% yield grade three, and 5.88% yield grade four. Ribeye color L^* values ranged from 33.13 to 40.84, a^* ranged from 23.77 to 28.31, and b^* ranged from 7.59 to 11.07. Fat color L^* values ranged from 65.80 to 75.01, a^* ranged from 3.60 to 8.65, and b^* ranged from 8.54 to 13.18. A standard deviation of 2.18 was noted for fat L^* which may indicate that the visual readings of the most exterior layer of fat may be darker than layers of fat lying closer to the interior of the animal. If this was the case, the darker colors on the exterior layer of back fat may be due to oxidation of fat molecules or could be due to effects of the steam pasteurization cabinet. The lowest quality grade observed by the USDA grader was high standard, the highest was low prime, and the average was low choice. Thus, we were successful in establishing a quality grade range that encompassed all quality grades, but centered more on what the industry is producing on a daily basis.

Table 3.1. Means and standard deviations (SD) of image-based measurements on the 12th rib surface and USDA grader characteristics (n = 51)

Variables	Min	Max	Mean	SD[2]
Image-based measurements				
Average fat thickness (cm)	0.38	2.59	1.31	0.48
Rib eye area (cm^2)	69.36	111.90	92.92	8.71
Percent fat area (%)	0.80	5.74	3.07	1.18
Rib eye L* (2-d)	33.13	40.84	36.34	1.51
Rib eye a* (2-d)	23.77	28.31	26.41	1.16
Rib eye b* (2-d)	7.59	11.07	9.68	0.72
Fat L* (2-d)	65.80	75.01	71.42	2.18
Fat a* (2-d)	3.60	8.65	6.63	0.95
Fat b* (2-d)	8.54	13.18	11.27	1.12
Calculated yield grade	1.07	4.16	2.96	0.75
USDA characteristics				
Hot carcass weight (kg)	333.02	454.50	387.10	27.05
Marbling score[1]	150	650	376	61.94

[1] Marbling Score: 700 = Moderately Abundant; 600 = Slightly Abundant; 500 = Moderate; 400 = Modest; 300 = Small; 200 = Slight; 100 = Traces

[2] SD = Standard Deviation

Slice shear force data for each day of age are presented in Table 3.2. Steaks aged both 7-d and 14-d, had an average SSF value of about 19 kg of force (intermediate tenderness category), regardless of quality grade. Traditionally, we would expect the 14-d aged steaks to be more tender than the 7-d aged steaks. However, SSF values for steaks aged 7-d were not significantly different ($P > 0.05$) from steaks aged 14-d. Additionally, tender and tough steaks were observed in both aging periods. Minimum SSF values were 12.53 kg and 14.19 kg for steaks aged 7 and 14-d, respectively. Maximum SSF values were 34.15 kg and 31.05 kg for steaks aged 7 and 14-d, respectively. This range indicates that all three of the tenderness categories were met and it was up to the instrument to sort steaks into their correct tenderness category.

Table 3.2. Slice shear force (kg) data for the *Longissiumus thoracis* muscle samples

Variables	n	Mean	Min	Max	SD
SSF[1] (7-d)	51	19.48[a]	12.53	34.15	4.25
SSF[1] (14-d)	51	19.65[a]	14.19	31.05	3.95

[1] SSF = Slice shear force

[a] Means with differing superscripts were significantly different ($P < 0.05$).

The distribution of SSF for each aging period is displayed in Figure 3.1. For each aging period, the majority of steaks had SSF values that fell into the tender category (58.8% 7-d and 54.9% 14-d). Furthermore, the amount of steaks that had SSF values in the tough range was very low (5.9% 7-d and 9.8% 14-d) and may have attributed to some bias in model development.

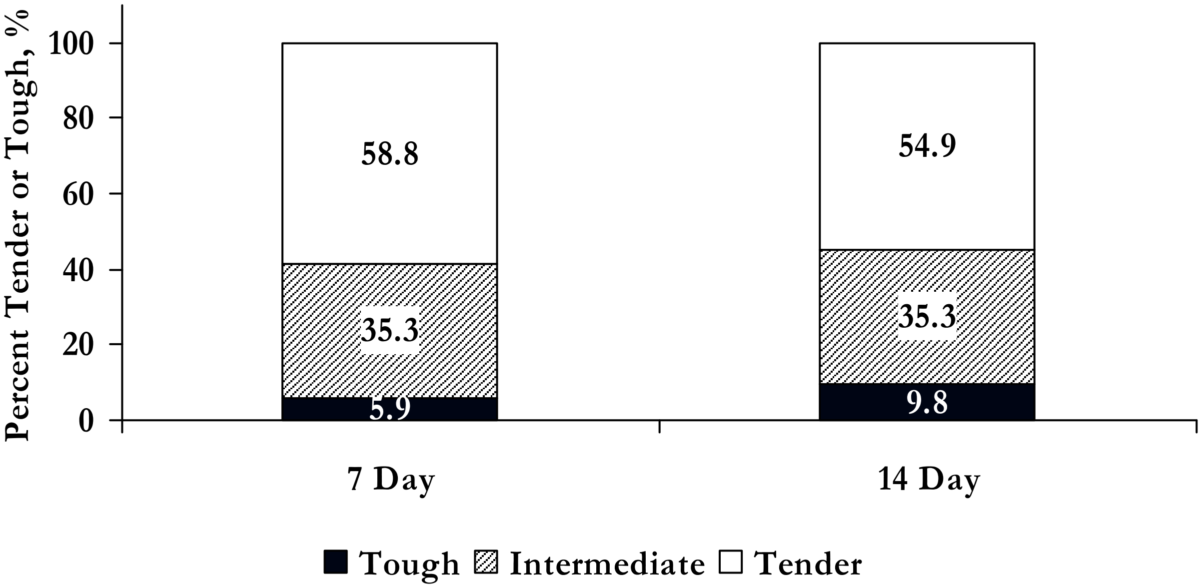

Figure 3.1. Distribution of actual 7-d and 14-d SSF values (n = 51)

After obtaining SSF values for each steak, they were logged into a spreadsheet and combined with video image analysis data and principle component data. Following an examination of the relevant principle components score plots, no unusual or outlying samples were detected in this sample set. The data were imported into SAS (Cary, NC) and a regression analysis was conducted with video image analysis data and principle components being regressed on actual SSF values. The resulting regression equation generated 11 significant ($P < 0.05$) independent variables (Table 3.3) that could be used to predict 7-d SSF and 9 significant ($P < 0.05$) independent variables (Table 3.4) that could be used to predict 14-d SSF value. In both equations, four principle components were deemed significant ($P < 0.05$) in the prediction of SSF value. Thus, the data generated by the NIR camera was significant in providing information about traits that may be linked to overall tenderness ratings.

Video image lean b*, marbling, adjusted marbling, and area variables of specific sections of lean were significant ($P < 0.05$) as well as fat b* ($P = 0.02$) for 7-d of age. The video image variables found to be significant for the 14-d aging period were very similar to the 7-d variables with the exception that lean a* sections were significant and b* sections were not. Lean color b* values have been identified as a useful parameter in the association with shear force. Wulf et al. (1997) reported that b* values showed the highest correlation with shear force as compared to L* and a* values. Tatum et al. (1997) sorted beef carcasses using b* values and successfully identified carcasses likely to produce top sirloin and top loin steaks in four postmortem aging groups. Additionally, George (1998) found that categorization of carcasses into three predicted tenderness classes using b* values successfully identified carcasses that produced tough steaks. The inclusion of these variables with the principle components provided regression equations that were very successful in the prediction of 7-d ($R^2 = 0.90$) and 14-d ($R^2 = 0.91$) tenderness.

Table 3.3. Independent variables deemed significant ($P < 0.05$) for 7-d aged steaks

Variables	Parameter Estimate	SE	P > F
Intercept	20.80	4.74	< 0.0001
PC 1	0.12	0.01	< 0.0001
PC 2	0.18	0.02	< 0.0001
PC 3	0.36	0.03	< 0.0001
PC 4	0.30	0.03	< 0.0001
b* I1[1]	-1.49	0.38	0.0004
b* I2[1]	2.18	0.51	0.0001
b* I8[1]	-1.46	0.29	< 0.0001
Adjusted Marbling I2[1]	0.91	0.26	0.0012
Marbling I7[1]	-0.29	0.11	0.0104
Fat b*	0.50	0.21	0.0215
Area I4[1]	3.47	1.69	0.0473

[1] I = Inside sections of ribeye sectioned into eight sections

Table 3.4. Independent variables deemed significant ($P < 0.05$) for 14-d aged steaks

Variables	Parameter Estimate	SE	P > F
Intercept	24.68	4.34	< 0.0001
PC 1	0.15	0.02	< 0.0001
PC 2	0.18	0.03	< 0.0001
PC 3	0.13	0.01	< 0.0001
PC 4	0.28	0.03	< 0.0001
Marbling O7[1]	-0.43	0.14	0.0030
Adjusted Marbling O3[1]	0.45	0.20	0.0320
a* I6[2]	-0.73	0.25	0.0056
a* O8[1]	0.46	0.23	0.0502
Area O8[1]	3.97	1.78	0.0316

[1] O = Outside sections of ribeye sectioned into eight sections
[2] I = Inside sections of ribeye sectioned into eight sections

Based on the results from the regression equation, the NIR and VIA data correctly predicted 26 out of 30 (86.7%) steaks to be tender and 3 out of 3 (100%) steaks to be tough for the 7-d aging period (Table 3.5). These results are in agreement with Subbiah et al. (2002) as they found 79% of beef longissimus steaks were correctly classified into two tenderness categories by a computer vision system using full images. Additionally, steak tenderness classification was enhanced when using close up images and correctly placed 92% of the longissimus steaks into the correct tenderness category (Subbiah et al., 2002). However, the equation predicted 4 steaks to be intermediate in tenderness, when in actuality, they were tender. This was due to 3 of those steak's actual SSF values falling on the tender/intermediate threshold. The fourth steak was, in fact, incorrectly predicted to be intermediate when it should have been classified as tender. This error in prediction is to be expected due to some bias in the model. If the study was more balanced between tender, intermediate, and tough samples, the expected error of prediction might be lower. Thus, the chance that a consumer in a restaurant would have a bad eating experience would be lessened. According to George et al. (1999), the odds of obtaining a tough beef loin steaks based solely on quality grade is 0% for US Prime, 1 in 10 (10%) for upper ⅔ Choice, 1 in 5 (20%) for low Choice, and 1 in 4 (25%) for US Select. Thus, the natural error within quality grade was further reduced by sorting carcasses based off of NIR and VIA data.

Steaks aged for 14-d exhibited similar results for tenderness prediction as 7-d aged steaks. The NIR and VIA data correctly predicted 24 out of 28 (85.7%) steaks to be tender and 5 out of 5 (100%) steaks to be tough (Table 3.6.). Again, 4 steaks were classified as intermediate when they should have been classified as tender. We also observed 2 more steaks classified as tough after 14-d age compared with the 7-d age group. After identification of steaks in the data set, those two steaks had SSF values approaching the tough range during the 7-d aging period. After 14-d of age, these two steaks were in the tough classification. This was an unexpected result as steaks should be more tender as the length of aging period increases. However, the regression equation was very successful in prediction of the tough classified steaks for both days of age. Elimination of tough classified steaks or carcasses from branded programs or high end product lines could improve consumer perception and acceptance of beef guaranteed to be tender.

Table 3.5. Actual and predicted 7-d slice shear force separated by tenderness classification (n = 51)

Shear Force Classification (kg)	Actual SSF	Predicted SSF
Tender (< 19)	30	26
Intermediate (19 -24.99)	18	22
Tough (> 25)	3	3

Table 3.6. Actual and predicted 14-d slice shear force separated by tenderness classification (n = 51)

Shear Force Classification (kg)	Actual SSF	Predicted SSF
Tender (< 19)	28	24
Intermediate (19 -24.99)	18	22
Tough (> 25)	5	5

Figures 3.2 and 3.3 show predicted SSF versus measured SSF for the model where post rigor spectra were used, with 51 carcass samples. As mentioned previously, we observed successful tenderness prediction for each aging period. Correlation coefficients calculated in the case of SSF and day of age of the steaks were high and suggest that the combination of NIR and VIA data may have potential for the prediction of SSF. These results are in accordance with Byrne et al. (1998). They also observed high correlation coefficients with the use of NIR spectroscopy to predict Warner-Bratzler shear (WBS) force and sensory attributes of beef steaks (Byrne et al., 1998). They also stated that a model that could predict the tenderness and sensory properties of meat after

14-d of storage would enable prediction of meat properties sometime in advance of sale or trading and therefore provide processors with greater information about the likely quality of meat samples (Byrne et al., 1998). On examination of both regression plots, a definitive cluster of samples can be observed at a lower tenderness rating for 14-d aged steaks, whereas the samples seem to be spread out amongst the entire tenderness range for 7-d aged steaks. This trend should be expected with a longer aging period but will need to be confirmed with controlled studies.

Performing the cross-validations using a specified wavelength range was very significant in the prediction analysis. Eliminating any wavelengths in the visible range (330-770 nm) from the VIS-NIR data set improved the accuracy of tenderness prediction. Using only wavelengths between 770 and 2300 nm enhanced NIR data that was specific to compounds associated with water, fat, and collagen which have been shown to be correlated to meat tenderness. Rødbotten et al. (2000) stated that the major absorbencies for fat were at 1152-1248, 1376-1460, 1676-1776, and 2248-2440 nm. Furthermore, Leroy et al. (2003) stated bands of water were observable at 980, 1450, and 1950 nm. Thus, taking into account a wavelength range that excluded the visible region of light in the NIR data eliminated any variation that could be attributed to overlapping from color variables generated by the VIA system. Combining color variables from the VIA system with the NIR data worked better ($R^2 = 0.90$, 7-d; $R^2 = 0.91$, 14-d) than using only the NIR data set that included the visible and near-infrared regions ($R^2 = 0.49$, 7-d; $R^2 = 0.51$, 14-d).

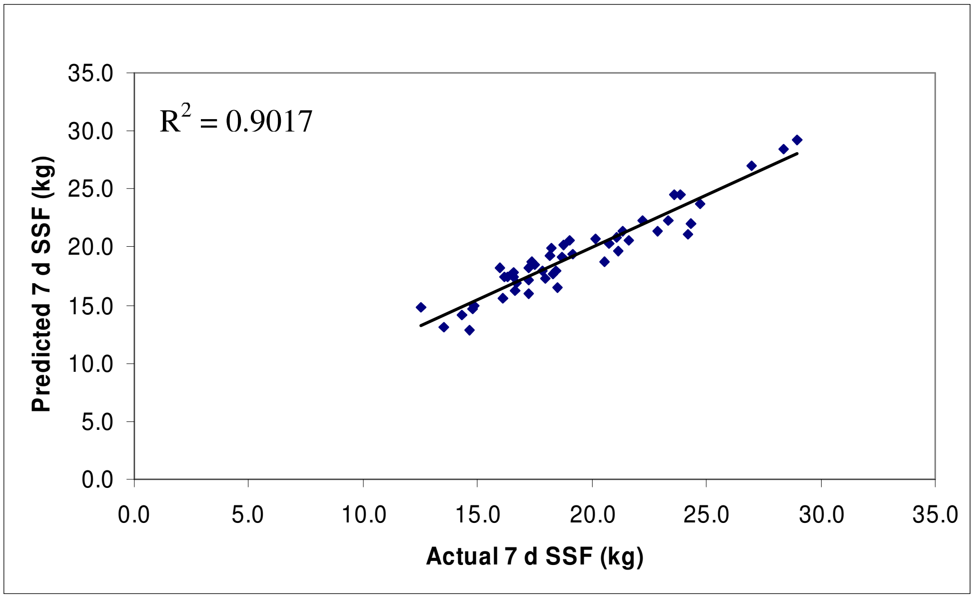

Figure 3.2. Actual SSF vs. Predicted SSF for 7-d of age (n = 51)

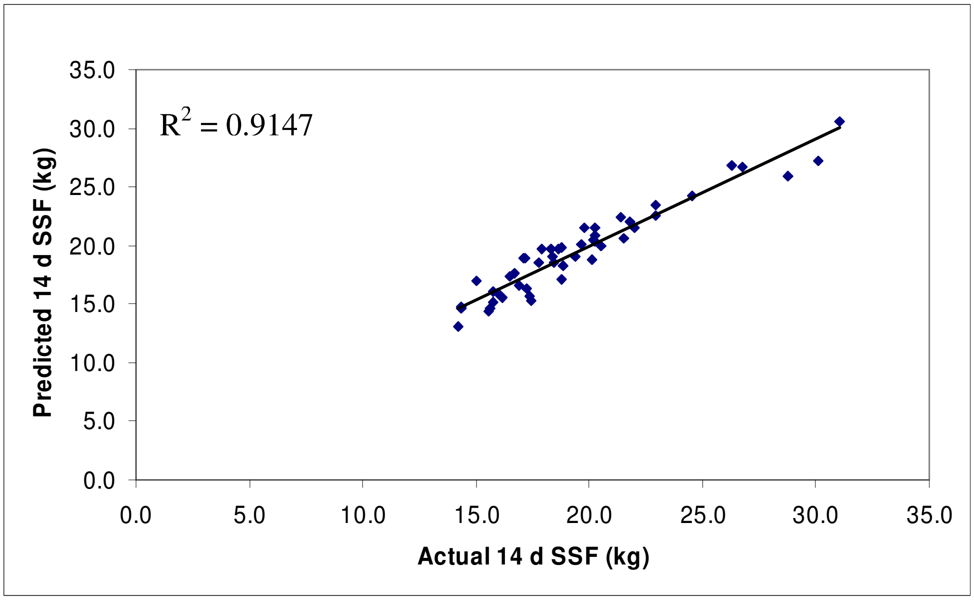

Figure 3.3. Actual SSF vs. Predicted SSF for 14-d of age (n = 51)

Conclusions

Incorporation of video imaging into online quality assessment of beef carcasses has provided beneficial results for beef producers and packers. Verification of a NIR system used in an instrument grading or tenderness prediction program must be conducted on large sample populations to ensure that the model that is generated for 14-d tenderness prediction is correct for future prediction. Increasing the number of samples classified as "tough" in the next study would accomplish this goal. This balance of tenderness category distribution could be achieved by increasing the number of tough samples to match the number of tender samples. This would eliminate or minimize any biasness generated by the model.

The significance of the NIR system is that it is a non-invasive method of informing the producer that specific carcasses can be sorted into tenderness categories. These preliminary results show promise for developing a beef tenderness prediction program that will sort out tough steaks and ensure consumers they are purchasing a "guaranteed tender" product. However, further research must be conducted to validate the accuracy of using the NIR system for commercial use.

CHAPTER IV

PHASE II: VALIDATION OF NIR AND VIA TENDERNESS PREDICTION

Introduction

When consumers browse a meat market's products, several factors play a role in the selection process. One factor identified in consumer surveys that seems to be the predominant reoccurring theme is the overall eating experience of the meat product. Research has shown that good eating experiences can be highly related to how tender the cut of meat is perceived during mastication. The one concern for the meat industry is, "how can we, as an industry, improve the quality of our products and guarantee that the product purchased will be tender and flavorful?" In the recently completed National Beef Tenderness Survey (Savell et al., 2006), improvements in cooked beef tenderness appear to have occurred during the past 5 years. However, due to the combinational effect that carcasses are becoming heavier and, in turn, cuts are heavier, more individual cuts are being generated from the chuck and round, and approximately 1/3 of all beef is being aged for ≤ 14 days, many new challenges occur in the beef tenderness area. For example, according to Steve Fleming, National Beef Company Case-Ready Division, "We generate approximately 322 retail cuts from a single beef carcass." Using that logic, if only 1% of the U.S. steer and heifer beef carcass population (33 million head) is "tough", in excess of 106 million "tough" retail cuts would be generated in single calendar year. If "tough" carcasses could be routed out of the “tender” population, the packer could provide consumers a product that is consistently “tender”, which would establish the “repeat buyer” in a retail meat market. Thus, the objective of this experiment was to validate the effectiveness of augmenting an in-plant, video image analysis (VIA) system with a near-infrared (NIR) system to obtain an accurate 14-d tenderness prediction.

Methodology

Meat Samples

In Phase II, native beef steer and heifer carcasses (n = 191) from US Prime (n = 5), Premium Choice (n = 28), Low Choice (n = 60), US Select (n = 89), and US Standard (n = 9) quality grades were randomly selected at the National Beef, Inc. processing facility in Dodge City, KS. Following a 24-h chill (1°C) period, carcasses were ribbed between the 12th and 13th ribs and were allowed to bloom for approximately 15 minutes before reaching the grading stand. Beef *m. longissimus thoracis* (LT) right sides were scanned with an in-plant VIA camera on the 12th-13th rib interface. Selected carcasses were individually identified, tagged, and railed off onto separate rails. As carcasses were moved onto the separate rails, NIR scanning was conducted on the same LT surface (right side) that had been scanned with the VIA camera. In an effort to avoid connective tissue and approximate where shear force measurements were to be taken, one NIR scan was taken close to the geometric center of each LT. Reflected light was collected through an Analytical Spectral Devices (ASD; Model 135090) 2 m long fiber-optic jumper cable that consisted of a bundle of forty-four 200 μm fibers. Reflectance measurements were recorded over the 330-2500 nm wavelength range at 2 nm intervals.

Each carcass spectral scan was identified and saved on a laptop computer for subsequent analysis.

After NIR scanning, carcass grade data factors were collected for preliminary yield grade, adjusted fat thickness, kidney, pelvic, and heart fat percentage, lean maturity, skeletal maturity, and marbling score as evaluated and stamped by USDA graders (USDA, 1997). Hot carcass weight and carcass identification numbers were recorded directly from plant identification tags. Once grade data collection was complete, a 7.5 cm ribeye section was removed from the right side of each carcass, individually bagged, placed into refrigerated chests with ice packs, and transported to the Oklahoma State University Food and Agricultural Products Research Center. At approximately 48-h postmortem, LT sections were cut perpendicular to the muscle fiber orientation to produce one, 2.54-cm steak which was designated for a 14-d aging period. Steaks were individually identified, placed in polyethylene bags, and vacuum-packaged. Following vacuum packaging, steaks were allowed to age for 14-d at 4ºC before freezing at -20°C until further analysis.

Slice Shear Force Measurement

The slice shear force (SSF) method was used to determine overall LT shear force. Steaks were removed from boxes, placed on plastic trays, and thawed for 24-h at 4°C. Upon completion of thawing, steaks were removed from their vacuum bags and cooked on a belt-fed impingement oven (TBG060 Magigrill, MagiKitch'n Inc., Quakertown, PA) as described by Wheeler et al. (1998). Preliminary test cooking was conducted to determine appropriate cooking times to reach 70°C internal temperature. After the steaks exited the belt grill, they were held at room temperature (23ºC) for two minutes for post-cooking temperature rise to complete the cooking process. Steaks were cooled at 4°C for 24-h after cooking, to allow for better slices, and then were trimmed of visible connective tissue and epimysium to expose the muscle fiber orientation. Using the procedures as outlined by Shackelford et al. (1999), a first cut was made approximately 1 cm from the lateral end of the cooked steak. The SSF sample was removed at an angle of 45° using a knife with two parallel blades separated by a 1 cm space. This procedure generated a cooked meat sample measuring 5 cm in length by 1 cm in thickness and 2.5 cm in width. This sample location was selected so that limited connective tissue would be located within the slice shear sample. Slice shear force was measured using a flat, blunt-end blade (SSF blade) mounted on an Instron Universal Testing Machine (Instron Corp., Canton, MA). Force required to shear the muscle fibers of the slice was recorded as kg of force.

Model Development

The data analysis was performed using the Unscrambler software package (version 9.7, Camo A.S., Trondheim, Norway.) Each spectrum generated 2,150 data points, or independent variables. In order to accommodate this scale of variables, a multivariate dimensionality reduction technique was employed to avoid over-fitting. The spectra data set was subjected to a principal component analysis (PCA) and the sample scores were examined for outlying or unusual spectra. Partial least squares (PLS) regression was used to produce new features. These features were linear combinations of original spectral data points yielding new factors that were not correlated and that explained most of the variation in both the dependent and independent variables (PLSplus, 2000). The PLS procedure was applied directly to the log(1/R) spectra with R being reflectance and the wavelength range was 770-2500 nm. Predictive models were generated by both PCA and PLS using the optimal number of components in each case. Full cross-validation was employed to select the number of PLS factors included in the models and for prediction of error estimation. For cross-validation, each sample was temporarily removed from the data set, one sample at a time. Model performance was reported as the standard error of calibration (SEC) and the coefficient of determination (R^2). For the calibration performance, the SEC was calculated as

$$\text{SEC} = \sqrt{\left(\frac{\sum (Y_i - R_i)^2}{n - f - 1}\right)}$$

where Y_i and R_i were the predicted and observed shear force values for sample i, respectively. The value of n was the number of samples, and f was the number of factors in the model.

Evaluation of Statistical Model

Slice shear force categories were established beforehand based on previous research. Steaks were classified into tenderness categories, with 14-d SSF greater than 25 kg as “tough”, 19-25 kg as “intermediate”, and less than 19 kg as “tender.” In the description that follows, “observed values” refers to the reference SSF values. “Predicted values” refers to the 14-d shear force value predicted by the spectral reflectance system. Principal components generated by PCA were merged with VIA and SSF data in a spreadsheet. The VIA camera analyzes ribeye surfaces as a whole and separates the surface into 16 geometric sections. The VIA camera produced 126 independent variables that covered ribeye area, fat thicknesses, color of fat, lean, and marbling, and additional color and area information of the 16 sections. The data set was imported into SAS (SAS

Inst. Inc., Cary, NC) where mean SSF values and marbling scores within each quality grade were determined using PROC MEANS statement. Analysis of the predictive model and VIA data was conducted using the PROC REG procedure in a stepwise format with measured (actual) SSF as the “y” variable. Independent variables that were deemed significant ($P < 0.05$) along with their coefficients were reported in the regression output. Once significant independent variables were identified, they were separated out of the original data set and put into a new spreadsheet where the regression equation was applied to the data set. The output that was generated was termed the “Predicted” SSF. The “Actual” and “Predicted” SSF values were plotted against each other on a scatter-plot where an R^2 value was generated and used to explain the how much of the variation was accounted for in the study.

Results

Summary values for meat quality data generated by VIA, USDA grader, and SSF are presented in Table 4.1. The average back fat thickness range was 2.04 inches, ribeye area range was 55.80 cm^2, hot carcass weight range was 278.05 kg, and yield grade range was 4.50. There was a large standard deviation observed for ribeye area (SD = 10.04). This large standard deviation can also explain the large range of calculated yield grade. Percentage of yield grade among the population was 6.28% yield grade one, 32.46% yield grade two, 41.36% yield grade three, 17.80% yield grade four, and 2.09% yield grade five. Ranges for ribeye color were 11.29 for L*, 7.27 for a*, and 4.11 for b*. The ranges for fat color values were 8.48 for L*, 5.44 for a*, and 7.33 for b*. As observed in Phase I, a standard deviation above 2 was only noted for fat L* from data recorded by the VIA camera. Again, the findings support what was stated in Phase I in that greater variation in subcutaneous fat L* readings might be attributable to a darkening or oxidation of the most exterior layer of fat. Another explanation is that heat and pressure from the steam pasteurization cabinet caused some breakdown of fat that resulted in lipid compounds becoming more susceptible to oxidation. The lowest quality grade observed by the USDA grader was low standard, the highest was low prime, and the average was low choice. Thus, we were successful in establishing a quality grade range that encompassed all quality grades, but centered more on what the industry is producing on a daily basis.

Table 4.1. Means and standard deviations of image-based measurements on the 12th rib surface, USDA grader characteristics, and slice shear force (n = 191)

Variables	Min	Max	Mean	SD
Image-based measurements				
Average fat thickness (cm)	0.38	2.42	1.22	0.44
Rib eye area (cm^2)	61.38	117.18	87.65	10.04
Percent fat area (%)	1.13	9.06	4.08	1.62
Rib eye L* (2-d)	31.46	42.75	36.03	1.73
Rib eye a* (2-d)	21.13	28.40	26.10	1.19
Rib eye b* (2-d)	8.66	12.77	10.84	0.86
Fat L* (2-d)	67.95	76.43	72.91	2.13
Fat a* (2-d)	3.28	8.72	5.81	1.04
Fat b* (2-d)	4.73	12.06	8.20	1.33
Calculated yield grade	1.13	5.63	3.29	0.84
USDA characteristics				
Hot carcass weight (kg)	239.95	518.00	389.13	59.05
Marbling score[1]	130	610	299	85.44
Slice shear force				
14-d SSF (kg)	13.03	41.21	21.76	4.98

[1] Marbling Score: 700 = Moderately Abundant; 600 = Slightly Abundant; 500 = Moderate; 400 = Modest; 300 = Small; 200 = Slight; 100 = Traces

Significant differences in SSF value were observed between quality grades (Table 4.2). As expected, higher quality samples had SSF values closer to the tender category, while samples from low Choice, US Select, and US Standard cattle had SSF values closer to the intermediate and tough categories. Steaks from upper 2/3 Choice (Premium Choice) had the lowest average SSF value but they were not significantly different ($P > 0.05$) from US Prime steaks. Additionally, US Prime and premium Choice steaks had SSF values that were significantly different ($P < 0.05$) from low Choice, US Select, and US Standard steaks. This finding can be explained by the low number of US Prime samples used in this study. A greater number of US Prime steaks included in the study may have lowered the average SSF value for the US Prime group. Regardless, both groups of quality fell into the expected tenderness category. However, some tough samples were observed in both the US Prime (Max = 25.04 kg of force) and premium Choice (Max = 32.60 kg of force) categories. The tough sample observed in the US Prime group fell on the intermediate/tough threshold and was classified as tough. However, the tough samples observed in the Premium Choice group were well above the tough threshold indicating that even though superior quality was achieved, other intrinsic factors such as water holding capacity, connective tissue, and state of the myofibril play very significant roles in the overall tenderness outcome.

Steaks in the low Choice group had SSF values that were not significantly ($P > 0.05$) different from steaks in the US Select group. However, both low Choice and US Select steaks had SSF values that were significantly different ($P < 0.05$) from US Standard steaks. Both low Choice and US Select steaks had SSF values that fell in the intermediate tenderness category. Again, this was expected as quality grade does have a role in the overall tenderness of meat. As the amount of intramuscular fat is decreased, muscle fiber bundles become more tightly packed, collagen cross-linking becomes more prevalent between muscle bundles, and interspatial free water is pushed out causing background toughness to have a bigger impact in overall tenderness. Since the majority of the steaks sampled in this study were geared to reflect what the industry produces, there was a larger range between tender and tough steaks for both quality grades. Steaks in the low Choice and US Select grades had SSF values associated with tender beef and some associated with tough beef. Thus, there is a need for a non-invasive system to sort out these steaks that are three or four standard deviations away from the mean and place them into classifications that more accurately reflect their tenderness rating.

Table 4.2. Actual 14-d SSF values (kg) separated by quality grade

Quality Grade	n	Mean	Min	Max	SD
Prime	5	19.55^{a}	13.84	25.04	3.81
Premium Choice	28	18.98^{a}	13.03	32.60	4.54
Low Choice	60	21.51^{b}	14.13	41.21	5.16
Select	89	22.54^{b}	13.38	35.90	4.54
Standard	9	24.73^{c}	19.11	38.71	6.71

^{abc}Means with differing superscripts were significantly different ($P < 0.05$).

Slice shear force values for steaks in the US Standard group were significantly different ($P < 0.05$) from the other four quality grade groups. Furthermore, the majority of the steaks in the US Standard group had SSF values that approached the intermediate/tough boundary. Even with a small population of US Standard samples, the average SSF value was 24.73 kg of force which re-establishes the fact that marbling plays an integral role in tenderness. Although the maximum SSF value for US Standard (38.71 kg of force) was not as high as the one observed for low Choice (41.21 kg of force), the minimum SSF value observed for US Standard (19.11) still fell into the intermediate category indicating that the prevalence of tender steaks in the US Standard quality grade is not as likely as finding tough steaks in the US Prime quality grade.

After obtaining SSF values for each steak, they were logged into a spreadsheet, sorted, and combined with VIA data and principle component data. No unusual or outlying samples were detected in this sample set following an examination of the relevant principle components score plots. The data was imported into SAS (Cary, NC) and a regression analysis was conducted with VIA data and principle components being regressed on actual SSF values. The resultant regression equation generated 16 significant ($P < 0.05$) independent variables (Table 4.3) that could be used to predict 14-d SSF value. Five principle components were deemed significant ($P < 0.05$) in the prediction of SSF value. Thus, the data generated by the NIR camera was highly significant in providing information about traits that may be linked to overall tenderness ratings.

Multiple variables generated from the VIA system were significant in the prediction of 14-d tenderness. Hot carcass weight, the only variable not generated by the VIA system, was also significant ($P < 0.05$) in the prediction equation. However, hot carcass weight was obtained in the VIA system output by reading the trolley tracking system and merging the information for each carcass with the readings obtained by the VIA camera. Video image ribeye length, area, a*, b* marbling, and adjusted marbling of specific sections within the ribeye image were also significant ($P < 0.05$) in the tenderness prediction equation. Just as in Phase I, area, b*, marbling, and adjusted marbling of specific sections have shown to contain information about tenderness and reflect their significant role in tenderness prediction. Furthermore, a* values also provided significant information used in the prediction equation in this study. Having three areas where a* values were considered significant (a* I8, P = 0.02; a* O3, P = 0.001; a* O6, P = 0.02) might be a reflection of the amount and state of myoglobin which can be related to an estimation of the overall lean maturity of the animal (Aberle et al., 2001). According to Aberle et al. (2001), as an animal gets older myoglobin deposition increases and overall meat tenderness tends to decrease. Other independent variables such as hot carcass weight (P = 0.02), ribeye length (P < 0.0001), and area O8 (P = 0.03) were also considered to be significant to tenderness prediction. These variables are known to be associated with lean yield calculation of a beef carcass. Therefore, variation in yield within a sampled population seems to give enough information about expected overall tenderness.

As noted previously, quality grade within this population contains significant information regarding tenderness. The significant independent variables generated from marbling and adjusted marbling in certain areas of the image contain information that coincide with results observed for SSF (Table 4.2). As marbling in the LT decreased, the SSF values increased. Thus, supporting the fact that marbling becomes a key component in the overall tenderness of a sample.

The combination of these significant independent variables provided a regression equation that accounted for about 80% of the variation in the model ($R^2 = 0.8024$). This decrease in R^2 value for 14-d SSF prediction was expected as the sample size increased from 51 (Phase I) to 191 (Phase II). However, the resulting R^2 value is higher in this study than in previous studies evaluating the same objectives (Byrne et al., 1998; Park et al., 1998; Hildrum et al., 1994). After comparing regression equations from Phases I and

II, certain variables were noted to be significant in both equation in the prediction of tenderness. Area, marbling, and adjusted marbling in specific sections were found to be highly significant for both equations. Again, this goes back to the aspect of how yield and quality grades play important roles in the overall tenderness, palatability, and eating experience of beef.

Table 4.3. Independent variables deemed significant ($P < 0.05$) for 14-d aged steaks

Variables	Parameter Estimate	SE	P > F
Intercept	44.95	6.11	< 0.0001
PC 1	104130	10277	< 0.0001
PC 2	108080	9747.84	< 0.0001
PC 3	112270	10218	< 0.0001
PC 4	124324	14133	< 0.0001
PC 5	91595	13760	< 0.0001
Hot Carcass Weight	0.01	0.01	0.0232
Ribeye Length	-3.03	0.70	< 0.0001
Area O8[1]	5.16	2.39	0.0323
a* I8[2]	-0.49	0.21	0.0193
a* O3[1]	0.86	0.26	0.0012
a* O6[1]	-0.62	0.27	0.0224
b* I3[2]	-0.84	0.25	0.0008
Marbling I1[2]	-0.14	0.07	0.0445
Marbling O1[1]	0.19	0.07	0.0054
Marbling O4[1]	-0.11	0.06	0.0425
Adjusted Marbling O5[1]	-0.38	0.14	0.0073

[1] O = Outside sections of ribeye sectioned into eight sections

[2] I = Inside sections of ribeye sectioned into eight sections

The accuracy of the regression equation utilizing VIA and NIR data is shown in Table 4.4. Overall, 141 out of 191 samples (73.8%) were correctly predicted and placed into their tenderness category. Within the tender group, 42 out of 63 samples (66.7%) were correctly predicted, leaving 21 samples that were incorrectly placed into intermediate or tough tenderness categories. In the intermediate group, 63 out of 80 samples (78.8%) were correctly predicted, leaving 17 samples (14 predicted tender; 3 predicted tough) that were incorrectly placed into tender or tough tenderness categories.

In the tough group, 36 out of 48 samples (75.0%) were correctly predicted, leaving 12 samples that were incorrectly placed into tender or intermediate tenderness categories. These results are comparable to results observed by Liu et al. (2003). They observed an average of 83.0% accuracy classification of beef steaks into tender or tough categories using a partial least squares analysis.

Table 4.4. Accuracy of VIA and NIR systems to correctly place samples into tenderness categories

SSF Category	# Predicted Correctly	Total # of Samples	% Predicted Correctly
Tender (< 19 kg)	42	63	66.6
Intermediate (19-24.99 kg)	63	80	78.8
Tough (> 25 kg)	36	48	75.0
Total	141	191	73.8

The number of samples that were incorrectly predicted are shown in Table 4.5. A total of 50 out of 191 samples (26.2%) were incorrectly placed into a tenderness category. Most of the incorrect classifications were due to sample SSF values approaching the tender/intermediate and intermediate/tough boundaries. There were, however, samples that the regression equation completely missed. Likely reasons for this finding is due to variances during data collection by the camera, over-cooking during SSF analysis, or physiochemical traits (background toughness, extreme cook loss, etc.) that were made more prevalent during the aging and cooking periods. The inaccuracies due to these conditions should be noted as minimal. The largest number of incorrect predictions was observed in samples that were predicted to be intermediate when they should have been classified as tender. Again, this number was largely attributed to a majority of the samples having SSF values very close to 19 kg of force. However, this result was also somewhat expected as tender samples can sometimes fall into the intermediate range based on the amount of state of the myofibrils as well as quantity of marbling. Regardless, the results indicate that the regression equation had an easier time predicting and sorting tough samples compared to tender samples. This is justified by the incorrect classification of only 12 samples as intermediate but had actual SSF values associated with the tough range (> 25 kg of force). Whereas, 21 samples were classified as intermediate and were actually tender and 17 samples were classified as tender or tough and were actually intermediate. The most significant note is that no steaks were predicted to be tender and were actually tough and no steaks were predicted as tough and were actually tender. Thus, confirming the range of variance was due to only a few samples that were above or below SSF boundaries.

Table 4.5. Samples incorrectly classified into predicted tenderness outcome groups

Actual SSF Category	Predicted SSF Category	# Predicted Incorrectly	Total # of Samples	% Predicted Incorrectly
Tender[a]	Intermediate[a]	21	63	33.4
Intermediate[a]	Tough[a]	3	80	3.7
Intermediate[a]	Tender[a]	14	80	17.5
Tough[a]	Intermediate[a]	12	48	25.0
Total		50	191	26.2

[a] kg ranges = Tender (< 19 kg); Intermediate (19-24.99 kg); Tough (> 25 kg)

Based on the results generated by SSF analysis, the distribution of tender, intermediate, and tough samples was more evenly distributed in Phase II than in Phase I. This was one of the objectives to be met to ensure that bias in model formation was minimized. According to the measured SSF values, the distribution of tenderness categories was 63 tender samples, 80 intermediate samples, and 48 tough samples. The carcasses sampled in this study exemplified a more "bell-shaped" curve for tenderness prediction. This trend can be exemplified even more when the prediction accuracy is separated by quality grade (Table 4.6). As noted previously, a greater number of tender samples were associated with higher quality grades. In the US Prime quality grade, all 5 samples were correctly placed into their actual SSF category. Three samples were tender and 1 sample was intermediate which is expected with such a high quality grade. It was interesting to note that 1 of the US Prime samples had a 14-d SSF value greater than 25 kg of force. This unusually higher than expected SSF measurement could be due to the slice shear sample containing large amounts of connective tissue which could raise the evaluated SSF value. Regardless, the regression equation did predict the sample to be tough indicating that at 2-d postmortem, the sample was properly identified and would have been sorted out of the tender population, thus aiding the correlation between US Prime and tender beef and providing the processor with a "guaranteed tender" population.

Based on actual 14-d SSF values, steaks in the other quality grades were successfully placed into tenderness categories. In the premium Choice grade 20 out of 28 (71.4%) steaks were correctly placed into tenderness outcome groups (Table 4.6). A majority of the steaks in this quality grade had SSF values less than 19 kg of force which was expected. This trend began to change for steaks in the low Choice quality grade. An increase in the number of intermediate and tough samples was noted for low Choice steaks compared to tender steaks. Regardless, 42 out of 60 steaks (70.0%) were correctly placed into tenderness categories. The accuracy was moderately improved for steaks in the US Select sample population. In the US Select grade, 67 out of 89 steaks (75.2%) were correctly placed into tenderness categories. Again, a larger number of intermediate and tough samples were observed in the US Select grade. In the US Standard grade, 7 out of 9 steaks (77.7%) were correctly placed into tenderness categories. As expected, all of the samples in this grade were either intermediate or tough. Thus, 14-d of aging was not beneficial in improving tenderness in the US Standard group. Overall, the system was very successful in sorting samples into correct tenderness groups and this concept was highlighted by the success observed within each quality grade.

Table 4.6. Accuracy of VIA and NIR systems to correctly place samples into tenderness categories within quality grade

Quality Grade	Actual SSF Category	Predicted SSF Category	# Predicted Correctly	% Predicted Correctly
Prime (n = 5)				100.0
	Tender	Tender	3	
	Intermediate	Intermediate	1	
	Tough	Tough	1	
Premium Choice (n = 28)				71.4
	Tender	Tender	12	
	Intermediate	Intermediate	6	
	Tough	Tough	2	
Low Choice (n = 60)				70.0
	Tender	Tender	14	
	Intermediate	Intermediate	17	
	Tough	Tough	11	
Select (n = 89)				75.2
	Tender	Tender	13	
	Intermediate	Intermediate	35	
	Tough	Tough	19	
Standard (n = 9)				77.8
	Tender	Tender	0	
	Intermediate	Intermediate	4	
	Tough	Tough	3	

As quality grade decreased, the number of tough samples began to increase. Keeping in mind the number of steaks sampled in each quality grade, tougher steaks were predicted at a higher level of accuracy in all five quality grade groups than tender or intermediate steaks. As expected, the greatest variation in tenderness prediction occurred in the US Select group. A total of 20 steaks were incorrectly classified for all three tenderness prediction categories (Table 4.7). These results were expected as the US Select grade has been shown to produce samples that were either very tender or very tough (Shackelford et al., 2001). They sampled 104 US Select strip loins and found the range for SSF was 12.6 to 28.3 kg of force (Shackelford et al., 2001). The greatest inconsistencies were observed for steaks predicted to be intermediate when they had actual SSF values in the tender or tough ranges (Shackelford et al., 2001). In the premium Choice, low Choice, and US Select grades, 2, 11, and 8 steaks, respectively, were predicted to be intermediate when they were tender as measured by SSF. Furthermore, in the low Choice and US Select grades, 4 and 8 steaks, respectively, were predicted to be intermediate when they were tough as measured by SSF. This variation in tenderness prediction was mostly due to steaks having SSF values that just barely crossed the tender/intermediate or intermediate/tough boundaries. These incorrect classifications would affect the consumer's overall eating experience in a negative way only minimally as a total of 12 steaks were incorrectly classified as intermediate when they were actually tough. Thus, if a processor removed all tough steaks from shipments going to retail markets or restaurants, there would only be a 6.3% chance (12 out of 191 steaks) that the consumer would be purchasing a tough steak.

Incorrect prediction of tender steaks was observed in each quality grade except US Prime. A total of 14 steaks were classified as tender when they had SSF values in the intermediate range. This would distort the actual price retailers should be paying for tender product and cause the producer to incur a false profit. This could be mediated by quality and yield grade breaks as most of the intermediate steaks predicted to be tender came from the premium Choice grade.

Table 4.7. Analysis of steaks within quality grade incorrectly placed into tenderness categories based on the regression equation generated from the VIA and NIR systems

Quality Grade	Actual SSF Category	Predicted SSF Category	# Predicted Incorrectly	% Predicted Incorrectly
Premium Choice (n = 28)				28.6
	Tender	Intermediate	2	
	Intermediate	Tender	6	
Low Choice (n = 60)				30.0
	Tender	Intermediate	11	
	Intermediate	Tender	2	
	Intermediate	Tough	1	
	Tough	Intermediate	4	
Select (n = 89)				24.8
	Tender	Intermediate	8	
	Intermediate	Tender	4	
	Intermediate	Tough	2	
	Tough	Intermediate	8	
Standard (n = 9)				22.2
	Intermediate	Tender	2	

In contrast to intermediate steaks incorrectly classified as tender, the samples classified as tough when they actually had SSF values in the intermediate range were minimal. A total of 3 steaks from two quality grades fell into this situation. Thus, 3 out of 191 (1.6%) carcasses would have been purposefully eliminated from retail market supplies and routed to programs dedicated toward utilizing beef in other fashions (case ready program, ground beef, hotels, restaurants, and institutions, etc.). That is about 1.5 carcasses incorrectly classified as tough for every 100 carcasses. If a packer harvests 6000 head per day, 90 carcasses would be incorrectly classified as tough. Even though producers would suffer a false cost, new programs could be generated from this technology to recoup losses based on NIR and VIA tenderness prediction. Another method to regain monetary value is to have onsite research facilities that could conduct SSF analysis on the tough predicted carcasses selected for retail supply elimination. This would act as a safety net to catch carcasses that met intermediate criteria and then could be placed back into the retail market population.

Using principal component regression and the optimal number of components in each case combined with VIA data, the results obtained via linear regression analysis are shown in Figure 4.1. Utilizing the 17 significant independent variables in the regression equation produced an $R^2 = 0.8024$. A definitive cluster was observed between 15 and 30 kg of force. The chemometric treatment of this data set seems to confirm the general predictive ability of NIR data as described in Phase I ($R^2 = 0.91$, 14-d). While the regression coefficient in this data set is lower than in Phase I, the difference in standard errors of prediction is not generally significant. This was expected due to an increase in natural variation which stems from an increase in sample size, thus a decrease in the regression coefficient between the two phases was observed. However, the regression coefficient for Phase II was much higher compared to other studies that have tried to utilize NIR as a tool for tenderness prediction.

Limiting the wavelengths used in the cross-validations was again very significant in the prediction analysis. Again, any wavelengths in the visible range (330-770 nm) were eliminated from the VIS-NIR data set. Implementing this step improved the R^2 value of the model from 0.65 to 0.80. Thus confirming our hypothesis that variance generated from having two sets of data (one from NIR, one from VIA) that explained the same variable would decrease the accuracy of tenderness prediction. Having only one set of data explaining variables associated with visible light improved the R^2 of the model by eliminating any irrelevant independent variables from the model, thus improving tenderness prediction. Having said that, color data generated by the VIA camera was more useful in tenderness prediction than NIR visible data. This improved accuracy may be due to the VIA camera's ability to more precisely analyze L*, a*, and b* of lean and fat. Similar results have been noted by Wulf et al. (1997). They found that L*, a*, and b* values measured on the exposed longissimus muscle of beef carcasses were related to beef carcass palatability. However, Wulf et al. (2000) conducted another study utilizing tenderness prediction by obtaining Minolta color values (L*, a*, and b*) of beef carcass ribeyes and supplementing them with USDA quality grade standards, pH, and hump height. When evaluated under "carefully-controlled" bloom times, it was reported that this augmentation system could only predict longissimus WBS force ($R^2 = 0.36$) measures following 7-d of postmortem aging. Using only the NIR data set that included the visible and near-infrared regions provided moderately successful tenderness prediction results ($R^2 = 0.54$, 14-d). Again, the current study confirms that combining color variables from the VIA system with the NIR data was successful in predicting 14-d tenderness ratings ($R^2 = 0.80$).

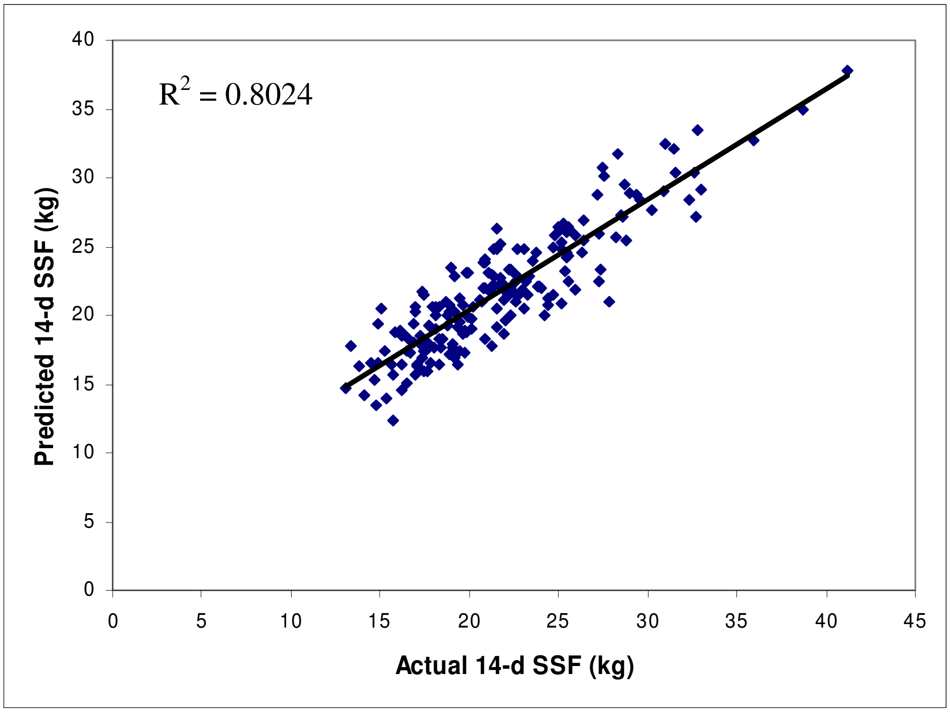

Figure 4.1. Actual SSF vs. Predicted SSF for 14-d of age (n = 191)

Conclusion

Over the years, NIR spectroscopy has been developed and applied considerably in quality management of beef meat products (Mistumoto et al., 1991). Success has only been observed to a minimal degree. More research is being conducted to test the parameters of the true capability of NIR spectroscopy to provide information about specific compounds in meat. The feasibility of using NIR spectroscopy to predict beef tenderness has been the topic of concern at several of the recent instrument assessment meetings. Most of the studies that have tried to predict meat tenderness have been inconsistent (Mitsumoto et al., 1991; Hildrum et al., 1995; Liu et al., 2002; Liu et al., 2003). However, results observed from Phases I and II show promising results for incorporating NIR spectroscopy into a VIA camera that could be used in a commercial processing facility. Based on the results from Phases I and II, tough steaks have been easier to identify and correctly predict than tender or intermediate steaks. Eliminating tough steaks from the retail population would give retailers the ability to market beef as a premium quality product that is guaranteed to be tender, juicy, and flavorful.

The ultimate goal of this research was to accurately predict longissimus tenderness which would translate into carcass tenderness. At the packing plant level, this application would be very beneficial monetarily as carcasses could be sorted into quality grade groups and then into tenderness groups. Beef from carcasses classified as "guaranteed tender" with high quality would garner elite status among other cuts in the retail case. Implementing this type of program would improve and reduce the variation in beef quality. Variation observed at the packing plant level could be even further minimized with regulatory SSF testing of carcasses predicted to be tough. Although it is a tedious task, the monetary gain for reclassifying carcasses into the correct tenderness categories would outweigh the monetary cost for conducting a SSF analysis on a certain number of carcasses per day. As evidenced by results observed in Phase II, this number of carcasses would be no greater than approximately 90 head per day on a 6000 head per day facility. Costs associated with regular SSF testing could be offset by premium prices on "guaranteed tender" products through consumer testing. Wheeler et al. (2002) stated that an additional incentive for the beef industry to identify and market beef based on accurate prediction of tenderness is provided by the increased proportion of branded beef products offered by both companies, as well as data indicating that consumers are willing to pay a premium for guaranteed tender beef.

This study indicates that the combination of NIR spectroscopy and VIA has the feasibility to predict shear force values of beef steaks during the aging process up to 14-d.

Correlations between the beef quality attributes studied and NIR data suggest that this non-destructive technique has the potential to produce useful predictive models, especially in the case of SSF. Further research must be conducted to evaluate specific consumer perceptions of “guaranteed tender” beef and their willingness to pay a premium price for these products.

CHAPTER V

PHASE III: TENDERNESS PREDICTION CORRELATION TO CONSUMER PREFERENCE

Introduction

The ability of consumers to discern varying tenderness levels is essential for establishing the value of beef (Miller et al., 2001). Establishing values associated with varying degrees of beef tenderness will provide the economic incentive for the beef industry to search for, manage, and market tenderness to consumers (Miller et al., 2001). If processors can employ an accurate method of tenderness prediction early during processing, they could use it as an economic benefit by establishing a "guaranteed tender" program. By establishing a tenderness program, consumers would enjoy the satisfaction that the meat product they purchase will be tender as well as a great eating experience. In addition, the occurrence of the repeat buyer for specific products would be more prevalent. This information would aid in the retailer's decisions on which meat products to order and what quantity to order during specific times of the year. Studies have shown that customers are willing to pay a higher price for beef with guaranteed tenderness (Boleman et al., 1997; Morgan et al., 1991). Lusk et al. (2001) reported that consumers were willing to pay an average premium of $1.84 more per pound for a steak labeled "guaranteed tender." In another consumer study, Feldkamp et al. (2005) found that consumers were willing to pay $0.95 more for the guaranteed tender steak. Thus, the objectives of this study were to determine the combined effect of near-infrared (NIR) and video image analysis (VIA) on the effectiveness of predicting 7-d and 14-d tenderness from 4 subprimals in various quality grades, observe the relationship between predicted longissimus shear force and tenderness of short-term muscles, and obtain consumer perceptions of longissimus steaks that were categorized as “tender”, “intermediate”, or “tough”.

Methodology

Meat Samples

In Phase III, native beef steer and heifer carcasses (n = 193) from upper ⅔ (Premium) Choice (n = 38), Low Choice (n = 75), US Select (n = 76), and US Standard (n = 4) quality grades were randomly selected at the National Beef, Inc. processing facility in Liberal, KS. The US Prime quality grade was not included in this study because the focus of the research was geared towards lower quality carcasses. Following a 24-h chill (1°C), carcasses were ribbed between the 12th and 13th ribs and were allowed to bloom for approximately 15 minutes before reaching the grading stand. Beef *m. longissimus thoracis* (LT) right sides were scanned with an in-plant VIA camera on the 12th rib interface. Selected carcasses were individually identified and railed off onto separate rails. As carcasses were moved onto the separate rails, NIR scanning was conducted on the same LT surface (right side) that had been scanned with the VIA camera. In an effort to avoid connective tissue and approximate where shear force measurements were to be taken, one NIR scan was taken close to the geometric center of each LT. Reflected light was collected through an Analytical Spectral Devices (Model 135090) 2 m long fiber-optic jumper cable that consisted of a bundle of forty-four 200 µm fibers. Reflectance measurements were recorded over the 300-2500 nm wavelength range at 2 nm intervals. Each carcass spectral scan was identified and saved on a laptop computer for further analysis.

After NIR scanning, carcass grade data factors were collected for lean maturity, skeletal maturity, and marbling score as evaluated and stamped by USDA graders (USDA, 1997). Hot carcass weight and carcass identification numbers were recorded directly from plant identification tags. Following grade data collection of all selected carcasses, ribeye rolls (*m. longissimus thoracis*; IMPS 112), clods (*m. triceps brachii*; IMPS 114), top sirloins (*m. gluteus medius*; IMPS 184), and inside rounds (*m. semimembranosus*; IMPS 169A) were individually identified, tagged, and fabricated using standard techniques. After collection, all subprimals were vacuum packaged, loaded into combo boxes and transported in a refrigerated carrier from the plant to the Oklahoma State University Food and Agricultural Products Research Center. On d-7 postmortem, two 2.54 cm steaks were progressively fabricated from the anterior end of each subprimal and individually identified for 7-d or 14-d aging periods. After fabrication of the steak samples that were to be used in a slice shear force (SSF) analysis, 6 additional 2.54 cm steaks were fabricated from each ribeye roll for use in a consumer study. As consumer steaks were fabricated, they were labeled by animal number, placed into individual polyethylene bags, and vacuum packaged. Following vacuum packaging, steaks were placed into boxes, aged for 14-d (1ºC), and frozen (-20ºC) until the consumer study was conducted. On d-7 and d-14 postmortem, steaks in each aging period were frozen (-20ºC) until SSF analysis. This was to ensure no further tenderization would occur by postmortem enzymatic processes.

Slice Shear Force Measurement

The SSF method was used to determine overall LT shear force. Steaks were removed from boxes, placed on plastic trays, and thawed at 4°C for 24-h. Upon completion of thawing, 7-d and 14-d aged steaks were removed from their vacuum bags and cooked on a belt-fed impingement oven (TBG060 Magigrill, MagiKitch'n Inc., Quakertown, PA) as described by Wheeler et al. (1998). Preliminary test cooking was conducted to determine appropriate cooking times to reach 70°C internal temperature. After the steaks exited the belt grill, they were held at room temperature for two minutes for post-cooking temperature rise to complete the cooking process. Steaks were cooled at 4°C for 24-h after cooking to allow for better slices, and then were trimmed of visible connective tissue and epimysium to expose the muscle fiber orientation. Using the procedures as outlined by Shackelford et al. (1999), a first cut was made approximately 1 cm from the lateral end of the cooked steak. The SSF sample was removed at an angle of 45° using a knife with two parallel blades separated by a 1.0 cm space. This procedure generated a cooked meat sample measuring 5.0 cm in length by 1.0 cm in thickness and 2.5 cm in width. This sample location was selected so that limited connective tissue would be located within the slice-shear sample. Slice shear force was measured using a flat, blunt-end blade (SSF blade) mounted on an Instron Universal Testing Machine (Instron Corp., Canton, MA). Force required to shear the muscle fibers of the slice was recorded as kg of force needed to shear through the sample.

Warner-Bratzler Shear Measurement

Steaks frozen at 7-d and 14-d of aging, were thawed at 4ºC for 24-h. Upon completion of thawing, steaks were removed from their vacuum bags and cooked on a belt-fed impingement oven (TBG060 Magigrill, MagiKitch'n Inc., Quakertown, PA) set to cook steaks to an endpoint internal temperature of 70°C. Preliminary test cooking was conducted to determine appropriate cooking times to reach 70°C internal temperature. After the steaks exited the belt grill, they were held at room temperature for two minutes for post cooking temperature rise to complete the cooking process. Steaks were cooled at 4°C for 24-h after cooking to allow for better cores, and then were trimmed of visible connective tissue and epimysium to expose the muscle fiber orientation. Cores (n = 6) of 1.27 cm in diameter were removed from each sample parallel to the muscle fiber direction with a hand coring device attached to an electric drill mounted in a drill press stand. Each core was sheared once perpendicular to the longitudinal orientation of the muscle fibers with a Warner-Bratzler shear attachment using an Instron Universal Testing machine (Model 4502, Instron Corp., Canton, MA). Individual core, peak shear force values were averaged to assign a mean peak WBSF value to each steak.

Consumer Testing

For consumer testing, no attempt was made to categorize steaks based on quality grade. Steaks used in the consumer study part of the project were placed into one of the following categories based on their respective NIR predicted 14-d SSF values: 1) ≤ 18.99 kg (tender); 2) 19.00 to 24.99 kg (intermediate); and 3) ≥ 25 kg (tough). Tender (Category 1) steaks were color-coded with red labels, intermediate (Category 2) steaks with white labels, and tough (Category 3) steaks with blue labels. Two hundred panelists from the state of Oklahoma (4 different locations, 50 panelists per location) were recruited to serve as consumers for the study. Specific demographics of the panelists were not obtained. One steak from each category was picked up by each panelist at a central distribution center for each location. Panelists were informed two weeks prior to pick up as to what day steaks would be distributed by OSU personnel. Steaks were identified to the panelists only by their color-coded labels. Therefore, panelists associated their likes and dislikes with a particular color category. To account for sampling variation, the panelists were instructed as to the recommended procedure of how steaks should be evaluated. At the time of pick up, OSU personnel instructed the consumers as to how to complete the evaluation form, both orally and in written form. Upon completion of all evaluation forms, panelists were instructed to place the forms in the pre-stamped, pre-labeled envelope that was given to them at the pick up location and place it in the mail. OSU personnel answered any questions and made certain that panelists completely understood the requirements of their participation. Each panelist was given three weeks to prepare and evaluate the steaks. After evaluating each steak, the panelist was asked to complete an evaluation form for each steak. Evaluations were made concerning the consumer's likeness of the product for overall tenderness, juiciness, and flavor using a 9-point scale (9 = extremely like; 1 = extremely dislike). Panelists were also asked how the steaks were thawed, cooked, endpoint degree of doneness for each steak, and how much they would be willing to pay for each steak based on the average prices from all stores in the cities during the time of the study.

Model Development

The data analysis was performed using the Unscrambler software package (version 9.7, Camo A.S., Trondheim, Norway). Each spectrum generated 2,150 data points, or independent variables. In order to accommodate this scale of variables, a multivariate dimensionality reduction technique was employed to avoid over-fitting. The spectra data set was subjected to a principal component analysis (PCA) and the sample scores were examined for outlying or unusual spectra. Two carcasses were eliminated from the data set because their unusual spectral graphs because the NIR instrument did not accurately capture a useful image of the ribeye surface of those two carcasses. In order to use linear regression efficiently on these data, the dimensionality must be reduced. PCA models the variation between the observed carcasses as if originating from a smaller number of principal component variables.

Partial least squares (PLS) regression was used to produce new features. These features were linear combinations of original spectral data points yielding new factors that were not correlated and that explained most of the variation in both the dependent and independent variables (PLSplus, 2000). The PLS procedure was applied directly to the log(1/R) spectra with the wavelength region 770-2500 nm. Wavelength areas where sensor change-over occurred were also taken out to eliminate unwanted external variation by the machine. The data set was smoothed by using the first derivative option as well as a Savitzky-Golay transformation prior to PLS regression analysis. Predictive models were generated by both PCA and PLS using the optimal number of components in each case. Full cross-validation was employed to select the number of PLS factors included in the models and for prediction of error estimation. For cross-validation, each sample was temporarily removed from the data set, one sample at a time. Model performance was reported as the standard error of calibration (SEC) and the coefficient of determination (R^2). For the calibration performance, the SEC was calculated as

$$\mathrm{SEC} = \sqrt{\left(\frac{\sum (Y_i - R_i)^2}{n - f - 1}\right)}$$

where Y_i and R_i were the predicted and observed shear force values for sample i, respectively. The value of n was the number of samples, and f was the number of factors in the model.

Evaluation of Statistical Model

Slice shear force categories were established beforehand based on previous research. Steaks were classified with 7-d and 14-d SSF values ≥ 25 kg as "tough", 19-24.99 kg as "intermediate", and ≤ 19 kg as "tender." In the description that follows, "observed values" refers to the reference SSF values. "Predicted values" refers to the 7-d or 14-d shear force predicted by the spectral reflectance system. Principal components generated by PCA and PLS were merged with VIA and SSF data in a spreadsheet. The VIA camera analyzes ribeye surfaces as a whole and separates the surface into 16 geometric sections. The VIA camera produced 273 independent variables that covered ribeye area, fat thicknesses, color of fat, lean, and marbling, and additional color measurements of the 16 sections. The data set was imported into SAS (SAS Inst. Inc., Cary, NC) where mean SSF and WBS values, marbling scores within each quality grade, and consumer panel data were determined using PROC MEANS. Differences between days of age for SSF and WBS within each subprimal were generated using the GLM procedure of SAS where LSMeans were computed and pairwise differences were used to separate means when appropriate. Analysis of the predictive model and VIA data was conducted using the PROC REG procedure in a stepwise format with measured (actual) SSF as the "y" variable. Independent variables that were deemed significant ($P < 0.05$), along with their coefficients, were reported in the regression output. Once significant independent variables were identified, they were separated out of the original data set and put into a new spreadsheet where the regression equation was applied to the data set. The output that was generated was termed the "Predicted" SSF. The "Actual" and "Predicted" SSF values were plotted against each other on a scatter-plot where an R^2 value was generated and used to explain how much of the variation was accounted for in the study. Furthermore, WBS values from top butts, clods, and inside rounds were converted to SSF values and analyzed for tenderness prediction using the 7-d and 14-d regression equations generated from ribeye spectral data. The output that was generated was termed the "Predicted" SSF. The "Actual" and "Predicted" SSF values were plotted against each other for each subprimal on a scatter-plot where an R^2 value was generated and used to explain the how much of the variation was accounted for in the study.

Differences in consumer panel tenderness, juiciness, and flavor for each colored ballot was determined using the Mixed procedure of SAS. The fixed effects were city and ballot and the random effect was panelist. When the tests of fixed effects indicated significance ($P \leq 0.05$), least squares means were used to determine differences between ballots for tenderness, juiciness, and flavor.

Results

Summary values for meat quality data generated by VIA, USDA grader, WBS, and SSF are presented in Table 5.1. The average for back fat thickness range was 1.79 cm, for ribeye area range was 64.50 cm^2, for hot carcass weight range was 213.65 kg, and for yield grade range was 4.33. As noted in Phases I and II, there was a large standard deviation observed for ribeye area (SD = 11.56). Ranges for ribeye color were 12.52 for L*, 8.31 for a*, and 5.09 for b*. The lowest quality grade observed by the USDA grader was low standard, the highest was high choice, and the average was low choice.

Table 5.1. Means and standard deviations of image-based measurements on the 12th rib surface, USDA grader characteristics, slice shear force, and Warner-Bratzler shear force (n = 191)

Variables	Min	Max	Mean	SD
Image-based measurements				
Average fat thickness (cm)	0.39	2.18	1.24	0.93
Rib eye area (cm^2)	55.42	119.92	87.46	11.56
Ribeye L* (2-d)	26.32	38.84	31.89	2.67
Ribeye a* (2-d)	20.01	28.32	24.25	1.95
Ribeye b* (2-d)	7.86	12.95	9.57	0.83
Ribeye Red (2-d)	104.16	160.87	131.33	8.92
Ribeye Green (2-d)	50.83	82.84	66.54	5.76
Ribeye Blue (2-d)	40.66	66.08	53.27	4.70
Calculated yield grade	1.00	5.33	3.17	0.77
USDA characteristics				
Hot carcass weight (kg)	270.79	484.44	370.55	43.49
Marbling score[1]	160	550	319	84.07
Slice shear force				
Ribeye 7-d SSF (kg)	11.83	36.01	19.94	4.44
Ribeye 14-d SSF (kg)	10.83	33.78	19.55	4.23
Warner-Bratzler shear force				
Clod 7-d WBS (kg)	3.67	7.65	5.11	0.72
Clod 14-d WBS (kg)	2.95	8.76	4.78	0.81
Top butt 7-d WBS (kg)	4.08	8.08	5.74	0.71
Top butt 14-d WBS (kg)	3.74	8.60	5.76	0.82
Inside round 7-d WBS (kg)	3.38	8.48	5.46	0.88
Inside round 14-d WBS (kg)	3.63	11.48	5.54	1.05

[1] Marbling Score: 700 = Moderately Abundant; 600 = Slightly Abundant; 500 = Moderate; 400 = Modest; 300 = Small; 200 = Slight; 100 = Traces

Differences between days of age for SSF and WBS for each subprimal is displayed in Table 5.2. There was no difference (P = 0.38) in SSF value for 7-d and 14-d aged ribeye steaks. This was unexpected as the 14-d aging process should have decreased SSF values in ribeye steaks. Although, due to the large number of tender steaks found in each quality grade, this result was anticipated. Furthermore, there were no differences observed in WBS between aging periods for top butt (P = 0.78) and inside round (P = 0.44) steaks. However, 14-d aged clod steaks were more tender (P < 0.0001) than 7-d aged clod steaks. These results are comparable to results observed by Gruber et al. (2006). They observed no significant differences between WBS values for top butt, ribeye, inside round, and shoulder clod steaks in US Choice and US Select grades that were aged 6-d and 14-d (Gruber et al., 2006).

Table 5.2. LSMean values for 7-d and 14-d shear force (kg) values (n = 191)

Subprimal	LSMean	P > F
Slice shear force		
Rib eye 7-d SSF (kg)	19.94^a	0.38
Rib eye 14-d SSF (kg)	19.55^a	0.38
Warner-Bratzler shear force		
Clod 7-d WBS (kg)	5.11^a	< 0.0001
Clod 14-d WBS (kg)	4.78^b	< 0.0001
Top butt 7-d WBS (kg)	5.74^a	0.78
Top butt 14-d WBS (kg)	5.76^a	0.78
Inside round 7-d WBS (kg)	5.46^a	0.44
Inside round 14-d WBS (kg)	5.54^a	0.44

^{ab}Means with differing superscripts, within a subprimal, were significantly different ($P < 0.05$).

Independent variables generated from the VIA system were significant in the prediction of 7-d and 14-d tenderness. A total of 28 independent variables for the 7-d aged steaks and 22 independent variables for the 14-d aged steaks were significant for regression equations used to predict SSF. For the 7-d prediction equation (Table 5.3), number of fat pieces corrected and a* of the 5th inside section of the ribeye were the only two of the 21 significant variables generated from the VIA camera that were not used to predict marbling of a specific area. The other 19 variables that were significant were used to describe marbling in the 8 inside and 8 outside sections on the 12th rib interface. All variables used in the equation were significant ($P < 0.05$). Additionally, all 7 principle components generated from the NIR were significant ($P < 0.0001$) for the 7-d prediction equation. As in Phase II, marbling data of specific sections have shown to contain information about tenderness and reflect their significant role in tenderness prediction.

The regression equation was accurate in the prediction of 7-d SSF values of ribeye steaks (Figure 5.1). Predicted SSF was regressed on actual SSF values which generated an $R^2 = 0.8212$. This result is similar to the explained variation noted in 7-d SSF prediction of Phase I ($R^2 = 0.9017$). However, it seems that the NIR instrument is very accurate at analyzing quantities and states of compounds in the LT that can translate into useful information to explain and predict 7-d SSF. Furthermore, these results are very similar to findings reported by Byrne et al. (1998). They noted when they scanned beef carcasses with a NIR camera on d-2 postmortem, they observed a decrease in R^2 value from their first study ($R^2 = 0.82$, n = 84) to their second study ($R^2 = 0.73$, n = 145) when trying to predict WBS of strip loin steaks aged 7-d and 14-d (Byrne et al., 1998). They also noted that the principle components generated in both studies were highly significant in the prediction analysis of WBS force (Byrne et al., 1998). Furthermore, it is important to note that the high R^2 value observed in the current study for 7-d SSF prediction is due not just to NIR spectroscopy, but also to the VIA camera data. Changing the hardware and software of cameras did not seem to greatly affect 7-d SSF prediction. The decrease in R^2 value was the same as what was observed in Phase II when sample size increased from Phase I for 14-d SSF prediction.

Table 5.3. Independent variables deemed significant ($P < 0.05$) for 7-d aged steaks

Variables	Parameter Estimate	SE	P > F
Intercept	9.96	4.13	0.0170
PC 1	1718.85	326.71	< 0.0001
PC 2	4480.25	675.95	< 0.0001
PC 3	11698	1057.01	< 0.0001
PC 4	14774	1228.54	< 0.0001
PC 5	15892	1544.11	< 0.0001
PC 6	12561	1747.28	< 0.0001
PC 7	18576	1963.49	< 0.0001
a* I5[1]	0.08	4.13	0.0220
# Fat Pieces Corrected	0.08	0.04	0.0263
O1S07766[2]	-0.0001	0.04	0.0010
O1S07921[2]	0.04	0.00003	0.0064
I2A05514[1]	-0.002	0.02	0.0017
I2A08269[1]	-0.20	0.001	0.0021
I2A17073[1]	0.21	0.06	0.0257
I4A00616[1]	-0.001	0.10	0.0499
I4A08209[1]	0.27	0.001	0.0049
O3A00616[2]	0.003	0.09	0.0078
O3A06033[2]	-2.08	0.001	0.0036
O3A06390[2]	-0.01	0.003	0.0055
O3A13388[2]	-0.03	0.01	< 0.0001
O4A06033[2]	-1.31	0.33	< 0.0001
O5A02491[2]	0.17	0.04	< 0.0001
O5A05514[2]	-0.001	0.0003	0.0413
O6A06390[2]	-0.01	0.001	< 0.0001
O6A17073[2]	0.32	0.08	< 0.0001
O7A06045[2]	2.32	0.69	0.0010
O7A06390[2]	-0.001	0.001	0.0343
O8A14087[2]	-0.07	0.03	0.0211

[1] I = Intside sections of ribeye sectioned into eight sections

[2] O = Outside sections of ribeye sectioned into eight sections

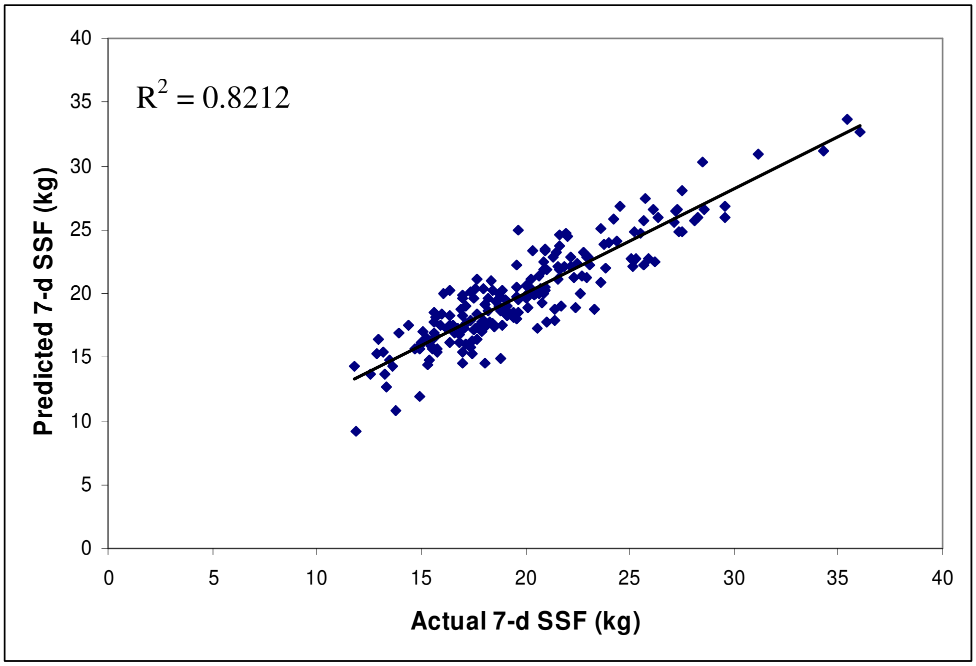

Figure 5.1. Actual SSF vs. Predicted SSF for 7-d of age (n = 191)

In the 14-d prediction equation, lean a* of the 5th inside section was found to be significant for the prediction equation (Table 5.4). Noting that a* of the 5th inside section was significant for both 7-d and 14-d prediction equations might explain important information about tenderness from a color and equipment standpoint. The 5th inside section would be in the middle of the ribeye, right where the lens of the camera opens and allows light reflectance to be measured. This section is also where the SSF sample was taken for analysis. Thus, a* in this section might provide useful information in forming a prediction equation. The variables fat corrected in the ribeye area ½ and ⅔ of the way up the ribeye were also significant in the 14-d prediction equation. These variables took into account large pieces of coarse marbling and eliminated them from the marbling value generated by the VIA camera. Thus, having only fine marbling in the equation eliminated some variation generated by coarse marbling. Furthermore, these two variables also are representations of marbling in the area where a SSF sample was taken.

Information from these marbling variables have been shown to be significant ($P < 0.05$) when describing tenderness.

All seven principle components were significant for the 14-d prediction equation. Having seen that seven principle components were significant for both 7-d and 14-d regression equations, we can justify that data obtained by the NIR camera was very influential in describing amounts and states of compounds (N-H, O-H, C=O, C-H) that could not be detected by the VIA camera. Additionally, of the 22 significant independent variables, 12 of the variables were used to describe marbling in the 16 sections. Again, this was expected as similar results were observed in previous equations and other independent variables that were used to describe marbling in the total ribeye area were also noted as significant.

The regression equation was accurate in the prediction of 14-d SSF values of ribeye steaks (Figure 5.2). Predicted SSF was regressed on actual SSF values which generated an $R^2 = 0.6352$. Phase III was not compared to Phases I and II because different variables were generated in the E+V camera compared to the RMS, Inc. camera used in Phases I and II. Area and adjusted marbling of the 16 different sections were not obtained in the E+V camera. However, in the RMS camera, they were obtained and proved to be significant in the SSF prediction equation. At the time Phase III was conducted, E+V had not developed their camera to obtain area and adjusted marbling of the 16 sections. The R^2 value noted for Phase III was very comparable to other research (Byrne et al., 1998; Park et al., 1998).

Table 5.4. Independent variables deemed significant ($P < 0.05$) for 14-d aged steaks

Variables	Parameter Estimate	SE	P > F
Intercept	8.36	5.60	0.0137
PC 1	1011.72	472.01	0.0335
PC 2	4429.85	1163.02	0.0002
PC 3	4377.50	1061.26	< 0.0001
PC 4	8487.42	1541.44	< 0.0001
PC 5	13695	2133.06	< 0.0001
PC 6	8837.45	1733.12	< 0.0001
PC 7	12188	2218.61	< 0.0001
a* I5[1]	0.07	0.05	0.0131
REA ½ FC[2]	0.04	0.01	0.0002
REA ⅔ FC[3]	-0.08	0.02	< 0.0001
I1A00616[1]	0.004	0.002	0.0074
I1A02491[1]	0.19	0.07	0.0047
I1A14087[1]	-0.41	0.12	0.0002
I4A00616[1]	-0.01	0.001	< 0.0001
I4A14087[1]	0.35	0.12	0.0037
I5A13388[1]	-0.004	0.002	0.0458
I8A00187[1]	0.13	0.04	0.0044
O1A04793[4]	-0.12	0.06	0.0320
O1S06378[4]	0.000007	0.000003	0.0071
O1S07766[4]	-0.0002	0.00007	0.0029
O1S07921[4]	0.06	0.02	0.0049
O6S04657[4]	0.001	0.0007	0.0107

[1] I = Inside sections of ribeye sectioned into eight sections

[2] REA ½ FC = Fat corrected ½ way up the ribeye

[3] IREA ⅔ FC = Fat corrected ⅔ way up the ribeye

[4] O = Outside sections of ribeye sectioned into eight sections

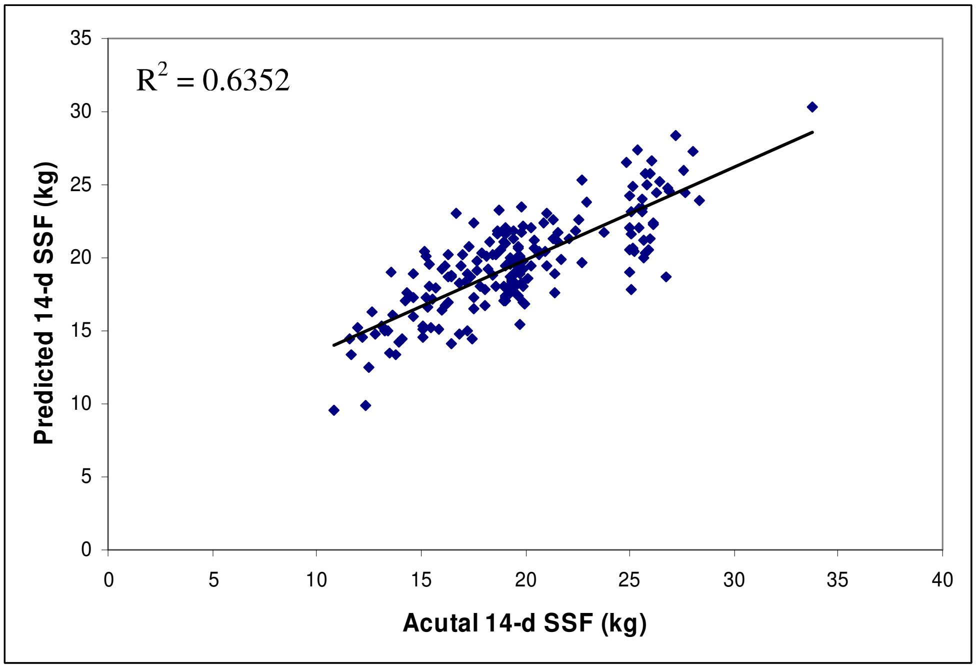

Figure 5.2. Actual SSF vs. Predicted SSF for 14-d of age (n = 191)

As noted previously, quality grade within this population contains significant information regarding tenderness. There was an overall grade effect (P = 0.05) for ribeye SSF value. However, there was no difference (P = 0.38) between days of age within each quality grade for ribeye SSF value. Thus, further aging from 7-d to 14-d did not provide any added SSF benefits within each quality grade. Within each day of age, as marbling in the LT decreased, the SSF values increased (Tables 5.5 and 5.6). This observation was expected due to the absence of intramuscular fat which would provide intermediaries between collagen cross-linking and prevent parallel binding of muscle fibers which could produce a tough evaluation upon consumption. One exception was noted in that the US Standard quality grade as a lower 7-d SSF value was noted compared to US Choice and US Select grades. These observations were most likely due to a couple of tender steaks in this grade and having a low number of observations. However, this trend was not observed for 14-d SSF values.

Table 5.5. Actual 7-d SSF values (kg) separated by quality grade

Quality Grade	n	Mean	Min	Max	SD
Premium Choice	38	19.28^{a}	11.87	36.01	4.71
Low Choice	75	19.93^{b}	11.83	28.59	4.07
Select	76	20.51^{c}	13.35	35.42	4.53
Standard	4	18.26^{a}	12.85	25.69	6.43

^{abc}Means with differing superscripts were different ($P < 0.05$).

Table 5.6. Actual 14-d SSF values (kg) separated by quality grade

Quality Grade	n	Mean	Min	Max	SD
Premium Choice	38	18.47^{a}	10.83	33.78	5.01
Low Choice	75	19.46^{b}	11.69	27.55	3.80
Select	76	20.25^{b}	12.18	28.35	4.01
Standard	4	20.03^{c}	13.58	26.32	6.57

^{abc}Means with differing superscripts were different ($P < 0.05$).

The accuracy of the 7-d regression equation utilizing VIA and NIR data is shown in Table 5.7. Overall, 145 out of 191 samples (75.9%) were correctly predicted and placed into their tenderness category. This result was somewhat lower than results observed in Phase I 7-d SSF prediction accuracy (92.2%). However, a smaller sample set was used in Phase I, thus a lower accuracy with a larger set was expected. Within the tender group, 73 out of 91 samples (80.2%) were correctly predicted, leaving 18 samples that were incorrectly placed into the intermediate tenderness category. In the intermediate group, 54 out of 71 samples (76.1%) were correctly predicted, leaving 17 samples (14 predicted tender; 3 predicted tough) that were incorrectly placed into tender or tough tenderness categories. In the tough group, 18 out of 29 samples (62.1%) were correctly predicted, leaving 11 samples that were incorrectly placed into the intermediate tenderness category. Again, it appears that the prediction system had an easier time predicting the tough steaks than the tender or intermediate steaks. This assumption is somewhat biased due to the small number of tough 7-d steaks. Although, the tough percent predicted correctly is lower than the tender and intermediate groups, the tough percentage could have been higher if more steaks would have had actual SSF values greater than 25 kg rather than exactly 25 kg of force. This may have led to the system more easily and accurately predicting tough steaks rather than predicting intermediate steaks.

Table 5.7. Accuracy of VIA and NIR systems to correctly place 7-d aged samples into tenderness categories

Actual SSF Category	Predicted SSF Category	# Predicted Correctly	Total # of Samples	% Predicted Correctly
Tender	Tender	73	91	80.2
Intermediate	Intermediate	54	71	76.1
Tough	Tough	18	29	62.1
Total		145	191	75.9

The number of samples that were incorrectly predicted for 7-d aged steaks is shown in Table 5.8. A total of 46 out of 191 samples (24.1%) were incorrectly placed into a tenderness category. Most of the incorrect classifications were due to sample SSF values approaching the tender/intermediate and intermediate/tough boundaries. There were, however, samples that the regression equation completely miss classified. Likely reasons for this finding is due to variances during data collection by the camera, over-cooking during SSF analysis, or physiochemical traits (background toughness, extreme cook loss, etc.) that became more prevalent during the aging and cooking periods. As seen in Phases I and II, the largest number of incorrect predictions was observed in samples that were predicted to be intermediate when they should have been classified as tender. Again, this number was largely attributed to a majority of the samples having

SSF values very close to 19 kg of force. The results indicate that the regression equation more accurately predicted and sorted tough samples compared to tender samples.

Table 5.8. Samples incorrectly classified into predicted 7-d tenderness outcome groups

Actual SSF Category	Predicted SSF Category	# Predicted Incorrectly	Total # of Samples	% Predicted Incorrectly
Intermediate	Tough	3	71	4.2
Intermediate	Tender	14	71	19.7
Tough	Intermediate	11	29	37.9
Tender	Intermediate	18	91	19.8
Total		46	191	24.1

The accuracy of the 14-d regression equation utilizing VIA and NIR data is shown in Table 5.9. Overall, 110 out of 191 samples (57.6%) were correctly predicted and placed into their tenderness category. It appears that the system had difficulty sorting and finding tough samples in the 14-d age group. In the tough group, 9 out of 39 samples (23.1%) were correctly predicted, leaving 30 samples that were incorrectly placed into tender or intermediate tenderness categories. In Phase III, only 23.1% of the tough samples were correctly predicted into the “tough” classification. After reviewing the raw data, over 90% of the tough samples had SSF values between 25.00 and 25.99 kg of force. This close range may be the reason why such a high number of tough steaks were incorrectly classified as intermediate.

Within the tender group, 57 out of 81 samples (70.4%) were correctly predicted, leaving 24 samples that were incorrectly placed into the intermediate tenderness category. Just as in 7-d aged steaks, the highest percentage of steak tenderness classification was observed in the tender category. From the data collected with this research it appears that the system is above average in sorting and correctly identifying tender steaks compared to other research (Byrne et al., 1998; Hildrum et al., 1994). In the intermediate group, 44 out of 71 samples (62.0%) were correctly predicted, leaving 27 samples that were incorrectly placed into tender or tough tenderness categories. This was expected as the majority of steaks in the intermediate classification had actual SSF values on the tender/intermediate (19.00-19.99) or intermediate/tough (25.00-25.99) boundaries.

Table 5.9. Accuracy of VIA and NIR systems to correctly place 14-d aged samples into tenderness categories

Actual SSF Category	Predicted SSF Category	# Predicted Correctly	Total # of Samples	% Predicted Correctly
Tender	Tender	57	81	70.4
Intermediate	Intermediate	44	71	62.0
Tough	Tough	9	39	23.1
Total		110	191	57.6

The number of samples that were incorrectly predicted for 14-d aged steaks is shown in Table 5.10. A total of 81 out of 191 samples (42.4%) were incorrectly placed into a tenderness category. Most of the incorrect classifications were due to sample SSF values approaching the tender/intermediate (19.00-19.99) and intermediate/tough boundaries (25.00-25.99). In this set of 14-d aged steaks, the majority of the observed tough samples had SSF values that were between 25.00 and 25.99 kg. This close value range seemed to cause the equation to classify more samples as intermediate tenderness, when they were actually tough.

Table 5.10. Samples incorrectly classified into predicted 14-d tenderness outcome groups

Actual SSF Category	Predicted SSF Category	# Predicted Incorrectly	Total # of Samples	% Predicted Incorrectly
Intermediate	Tough	2	71	2.8
Intermediate	Tender	25	71	35.2
Tough	Intermediate	28	39	71.8
Tough	Tender	2	39	5.1
Tender	Intermediate	24	81	29.6
Total		81	191	42.4

Prediction accuracy of 7-d aged samples separated by quality grade is shown in Table 5.11. In the premium Choice grade 27 out of 37 (73.0%) steaks were correctly placed into tenderness outcome groups. An increase in the number of tender, intermediate, and tough samples was noted for low Choice steaks. A total of 59 out of 74 steaks (79.7%) were placed into correct tenderness categories.

Table 5.11. Accuracy of VIA and NIR systems to correctly place 7-d aged ribeye steaks into tenderness categories within quality grade

Quality Grade	Actual SSF Category	Predicted SSF Category	# Predicted Correctly	% Predicted Correctly
Premium Choice (n = 37)				73.0
	Tender	Tender	17	
	Intermediate	Intermediate	9	
	Tough	Tough	1	
Low Choice (n = 74)				79.7
	Tender	Tender	29	
	Intermediate	Intermediate	23	
	Tough	Tough	7	
Select (n = 76)				73.7
	Tender	Tender	25	
	Intermediate	Intermediate	21	
	Tough	Tough	10	
Standard (n = 4)				75.0
	Tender	Tender	2	
	Intermediate	Intermediate	1	
	Tough	Tough	0	

The accuracy for steaks in the US Select sample population resembled that of steaks in the premium Choice population. In the US Select grade, 56 out of 76 steaks (73.7%) were placed into correct tenderness categories. Again, a large number of intermediate and tough samples were observed in the US Select grade. In the US

Standard grade, 3 out of 4 steaks (75.0%) were correctly placed into tenderness categories. Overall, the system was very successful in sorting 7-d aged samples into correct tenderness groups and this concept was highlighted by the success observed within each quality grade. Thus, it seems that differences in quality grade did not hinder the system's ability to accurately classify steaks into tenderness groups. This logic suggests that one equation could be used to accurately classify 7-d aged ribeye steaks into correct tenderness groups.

Prediction accuracy of 14-d aged samples separated by quality grade is shown in Table 5.12. In the premium Choice grade, 23 out of 37 (62.2%) steaks were correctly placed into tenderness outcome groups. A total of 44 out of 74 Low Choice steaks (59.5%) were correctly placed into tenderness categories. Unlike 7-d aged steaks, the accuracy was for steaks in the US Select sample population resembled that of steaks in the low Choice population. This effect was also observed in Phase II for 14-d aged steaks. In the US Select grade, 42 out of 76 steaks (55.3%) were correctly placed into tenderness categories. This value is quite lower than the accuracy observed in Phase II (75.2%). In the US Standard grade, only 1 out of the 4 steaks (25.0%) was correctly placed into its tenderness category.

Table 5.12. Accuracy of VIA and NIR systems to correctly place 14-d aged ribeye steaks into tenderness categories within quality grade

Quality Grade	Actual SSF Category	Predicted SSF Category	# Predicted Correctly	% Predicted Correctly
Premium Choice (n = 37)				62.2
	Tender	Tender	17	
	Intermediate	Intermediate	5	
	Tough	Tough	1	
Low Choice (n = 74)				59.5
	Tender	Tender	22	
	Intermediate	Intermediate	18	
	Tough	Tough	4	
Select (n = 76)				55.3
	Tender	Tender	17	
	Intermediate	Intermediate	21	
	Tough	Tough	4	
Standard (n = 4)				25.0
	Tender	Tender	1	
	Intermediate	Intermediate	0	
	Tough	Tough	0	

A total of 46 7-d aged steaks were incorrectly classified for all three tenderness prediction categories (Table 5.13). The greatest inconsistencies were observed for steaks predicted to be intermediate when they had actual SSF values in the tender or tough ranges. In the premium Choice, low Choice, and US Select grades, 4, 5, and 9 steaks, respectively, were predicted to be intermediate when they were tender as measured by SSF. Furthermore, in the premium Choice, low Choice, US Select, and US Standard grades, 5, 2, 3, and 1 steaks, respectively, were predicted to be intermediate tenderness when they were tough as measured by SSF. This variation in tenderness prediction was mostly due to steaks having SSF values that just barely crossed the tender/intermediate or intermediate/tough boundaries.

Table 5.13. Analysis of 7-d aged steaks within quality grade incorrectly placed into tenderness categories based on the regression equation generated from the VIA and NIR systems

Quality Grade	Actual SSF Category	Predicted SSF Category	# Predicted Incorrectly	% Predicted Incorrectly
Premium Choice (n = 37)				27.0
	Tender	Intermediate	4	
	Intermediate	Tender	1	
	Tough	Intermediate	5	
Low Choice (n = 74)				20.3
	Tender	Intermediate	5	
	Intermediate	Tender	5	
	Intermediate	Tough	3	
	Tough	Intermediate	2	
Select (n = 76)				26.3
	Tender	Intermediate	9	
	Intermediate	Tender	8	
	Tough	Intermediate	3	
Standard (n = 4)				25.0
	Tough	Intermediate	1	

These incorrect classifications would affect the consumer's overall eating experience in a negative way only minimally as a total of 11 steaks were incorrectly classified as intermediate tenderness when they were actually tough. Thus, if a processor removed all tough steaks from shipments going to retail markets or restaurants, there would only be a 5.8% chance (11 out of 191 steaks) that the consumer would be purchasing a tough steak. Furthermore, a total of 14 steaks were classified as tender when they had SSF values in the intermediate range. Thus, the packer and retailer would incur a false profit 7.3% on steaks guaranteed to be tender due to inaccuracies by the prediction equation.

A total of 81, 14-d aged steaks were incorrectly classified for all three tenderness prediction categories (Table 5.14). As observed in Phase II and 7-d aged steaks of Phase III, the greatest inconsistencies were observed for steaks predicted to be intermediate when they had actual SSF values in the tender or tough ranges. In the premium Choice, low Choice, US Select, and US Standard grades, 4, 10, 9, and 1 steaks, respectively, were predicted to be intermediate when they were tender as measured by SSF. Furthermore, in the premium Choice, low Choice, US Select, and US Standard grades, 5, 8, 13, and 2 steaks, respectively, were predicted to be intermediate when they were tough as measured by SSF. Again, this variation in tenderness prediction was mostly due to steaks having SSF values that just barely crossed the tender/intermediate or intermediate/tough boundaries.

These incorrect classifications would affect the consumer's overall eating experience in a negative way only minimally as a total of 28 steaks were incorrectly classified as intermediate when they were actually tough. Thus, if a processor removed all tough steaks from shipments going to retail markets or restaurants, there would be a 14.7% chance (28 out of 191 steaks) that the consumer would actually be purchasing a tough steak. This increase from 5.8% for 7-d aged steaks to 14.7% for 14-d aged steaks is opposite of trends and perceptions observed in the meat industry. According to Aberle et al. (2001), as meat ages, muscle structure begins to break down causing an increase in tenderness. The chance of having a poor eating experience with a steak that has been aged for 14-d days should be less than the chance of having a poor eating experience with a steak that has been aged for 7-d. Therefore, consumers would expect 14-d steaks to be more accurately classified into tenderness categories than 7-d steaks. Furthermore, a total of 25 steaks were classified as tender when they had SSF values in the intermediate range. Thus, the packer and retailer would incur a false profit of 13.1% on steaks guaranteed to be tender due to inaccuracies by the prediction equation.

Table 5.14. Analysis of 14-d aged steaks within quality grade incorrectly placed into tenderness categories based on the regression equation generated from the VIA and NIR systems

Quality Grade	Actual SSF Category	Predicted SSF Category	# Predicted Incorrectly	% Predicted Incorrectly
Premium Choice (n = 37)				37.8
	Tender	Intermediate	4	
	Intermediate	Tender	4	
	Intermediate	Tough	1	
	Tough	Intermediate	5	
Low Choice (n = 74)				40.5
	Tender	Intermediate	10	
	Intermediate	Tender	11	
	Tough	Tender	1	
	Tough	Intermediate	8	
Select (n = 76)				44.7
	Tender	Intermediate	9	
	Intermediate	Tender	10	
	Intermediate	Tough	1	
	Tough	Tender	1	
	Tough	Intermediate	13	
Standard (n = 4)				75.0
	Tender	Intermediate	1	
	Tough	Intermediate	2	

The regression equation generated from spectral data on the ribeye surface was used in the attempt to predict other subprimal shear force values. For each subprimal, WBS values were converted in SSF values by way of an equation obtained from U.S. Meat Animal Research Center. These values were then imported into the spreadsheet and the significant independent variables found for the 7-d and 14-d aged regression equations were regressed on each subprimal's SSF value. The results are shown in Table 5.15. The results observed in this study were similar to others based on previous correlation data. The correlation data presented no significant correlations between subprimals for WBS. For each day of age, the ribeye regression equation was not useful in predicting WBS values of other subprimals. Thus, each subprimal must be scanned in order to accurately predict tenderness levels.

Table 5.15. Accuracy of VIA and NIR systems to correctly place 7-d and 14-d aged samples into tenderness categories using the regression equation generated from ribeye scans

Subprimal	Days of Age	R^2
Semimembranosus	7	0.2340
Triceps Brachii	7	0.1908
Gluteus Medius	7	0.1550
Semimembranosus	14	0.0665
Triceps Brachii	14	0.0729
Gluteus Medius	14	0.1149

Consumer data is shown in Tables 5.16 and 5.17. For the entire sample set, consumers were able to distinguish differences between classes of tenderness for overall tenderness, juiciness, and flavor. A total of 166 out of 200 panelists (83% return rate) evaluated and completed the surveys in this study. Three of the cities sampled averaged above 90% return, whereas one city had a 62% return rate. Samples that were classified as tender (Red) had "liked" (value = 7) ratings, on average, for all three traits. Samples classified as intermediate (White) and tough (Blue) had "somewhat liked" (value = 6) ratings, on average, for all traits with the exception for tenderness in the tough classification. Panelists actually rated these steaks lower (value = 5; neither liked nor disliked) for the tenderness trait. This was expected as justified by the increased SSF values associated with tough steaks. Data show that panelists were able to distinguish between differing degrees of tenderness ($P < 0.05$). Ratings for overall tenderness, juiciness, and flavor all decreased as the SSF values increased. This was expected as these results are similar to research reported by Miller et al. (2001). Miller et al. (2001) reported that as WBS force values of strip loins decreased below 4.9 kg, tenderness acceptability by consumers increased. This trend became stronger as WBS force gradually decreased from 4.9 kg to 3.0 kg, overall tenderness acceptability increased from 37% to 100%.

Table 5.16. Means for overall tenderness, juiciness, and flavor for differing levels of tenderness

Ballot[1]	n	Trait[2]	Mean	Min	Max	SD
Red	166	Tenderness	7.23	3.00	9.00	1.49
		Flavor	7.26	2.00	9.00	1.48
		Juiciness	7.19	3.00	9.00	1.54
White	166	Tenderness	6.47	2.00	9.00	1.65
		Flavor	6.92	3.00	9.00	1.49
		Juiciness	6.62	2.00	9.00	1.66
Blue	166	Tenderness	5.99	1.00	9.00	2.13
		Flavor	6.48	1.00	9.00	1.74
		Juiciness	6.19	1.00	9.00	1.87

[1] Ballots = (Red = Steak SSF ≤ 18.99 kg; White = Steak SSF 19.00 – 24.99 kg; Blue = Steak SSF ≥ 25.00 kg

[2] 1 = Extremely Dislike; 2 = Strongly Disliked; 3 = Disliked; 4 = Somewhat Dislike; 5 = Neither Like nor Dislike; 6 = Somewhat Liked; 7 = Liked; 8 = Strongly Liked; 9 = Extremely Like

There were no significant differences for tenderness (P = 0.58), juiciness (P = 0.81), or flavor (P = 0.75) between cities. This was a desired result because having a location effect would have meant that consumers sampled in one area were not evenly distributed and a bias by group would have existed. However, this was not the case and consumers sampled in this study accurately reflected a typical beef purchaser. There were significant differences between tenderness, juiciness, and flavor for each level of tenderness rating (P < 0.0001). Consumers were able to accurately identify steaks that were tender (Red) to be more juicy and flavorful. This same trend was observed when comparing intermediate (White) and tough (Blue) classified steaks.

Table 5.17. LSMeans for overall tenderness, juiciness, and flavor for differing levels of tenderness

Ballot[1]	Trait[2]	LSMean	Pr > F
Red	Tenderness	7.20^{a}	< 0.0001
White	Tenderness	6.45^{b}	< 0.0001
Blue	Tenderness	6.00^{c}	< 0.0001
Red	Flavor	7.24^{a}	< 0.0001
White	Flavor	6.91^{b}	< 0.0001
Blue	Flavor	6.47^{c}	< 0.0001
Red	Juiciness	7.18^{a}	< 0.0001
White	Juiciness	6.61^{b}	< 0.0001
Blue	Juiciness	6.20^{c}	< 0.0001

[1] Ballots = (Red = Steak SSF ≤ 18.99 kg; White = Steak SSF 19.00 – 24.99 kg; Blue = Steak SSF ≥ 25.00 kg

[2] 1 = Extremely Dislike; 2 = Strongly Disliked; 3 = Disliked; 4 = Somewhat Dislike; 5 = Neither Like nor Dislike; 6 = Somewhat Liked; 7 = Liked; 8 = Strongly Liked; 9 = Extremely Like

[abc] Means within a trait, with differing superscripts were significantly different (P < 0.05)

The evaluation forms completed by each consumer provided information concerning thawing methods, cooking methods, and degree of doneness. However, no attempt was made to determine how these preparation methods may have influenced customer satisfaction. Thawing methods by panelists of each classification of steak are described in Figure 5.3. Thawing in the refrigerator was the most common method used by panelists, representing 61.8% of all steaks evaluated, followed by setting steaks on the countertop at room temperature (15.3%), setting steaks on the countertop and then placing into the refrigerator (8.8%), using the defrost setting on the microwave (5.9%), running under warm water (2.9%), running under cold water (1.8%), placing in lukewarm water in the sink (1.8%), and thawing in the oven at a warm setting (0.6%). Just as expected, the majority of consumers thawed steaks in the refrigerator for at least 12 hours. The average number of hours steaks were thawed in the refrigerator was 24 and the maximum was 72 hours. Short-term thawing methods comprised 11.2% of methods used for steaks that were to be eaten within 6 hours of cooking. Although short-term thawing methods are not recommended, consumers continue to use this method simply for convenience.

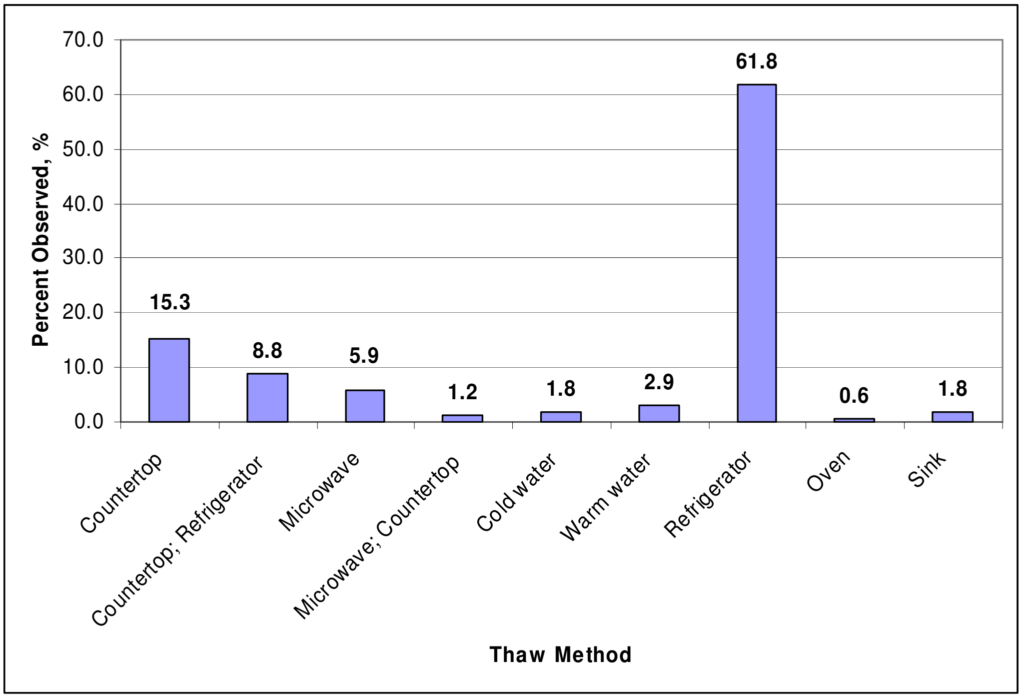

Figure 5.3. Panelist's thawing methods expressed as a percentage of the entire consumer study

Cooking methods by panelists of each classification of steak are described in Figure 5.4. Gas grilling was the predominant cooking method used by panelists, representing 55.9% of all steaks cooked, followed by charcoal grilling (15.3%), George Foreman Grill® cooking (9.4%), pan broiling (8.2%), pan frying (6.5%), Jenn-Aire® electric grilling (2.9%), oven baking (1.2%), and cooking over a wood fire (0.6%). Similar findings were reported by Neely et al. (1995). They found that the most common method of cookery for beef consumers of top loin steaks was outdoor grilling (50%) (Neely et al., 1995). This high percentage of gas grilling is likely due to the mild winter-like conditions observed when this consumer study was conducted. Furthermore, charcoal and gas grilling comprised 71.2% of the cooking methods used to evaluate ribeye steaks, suggesting that consumers enjoy the experience of cooking middle meat steaks over an open flame.

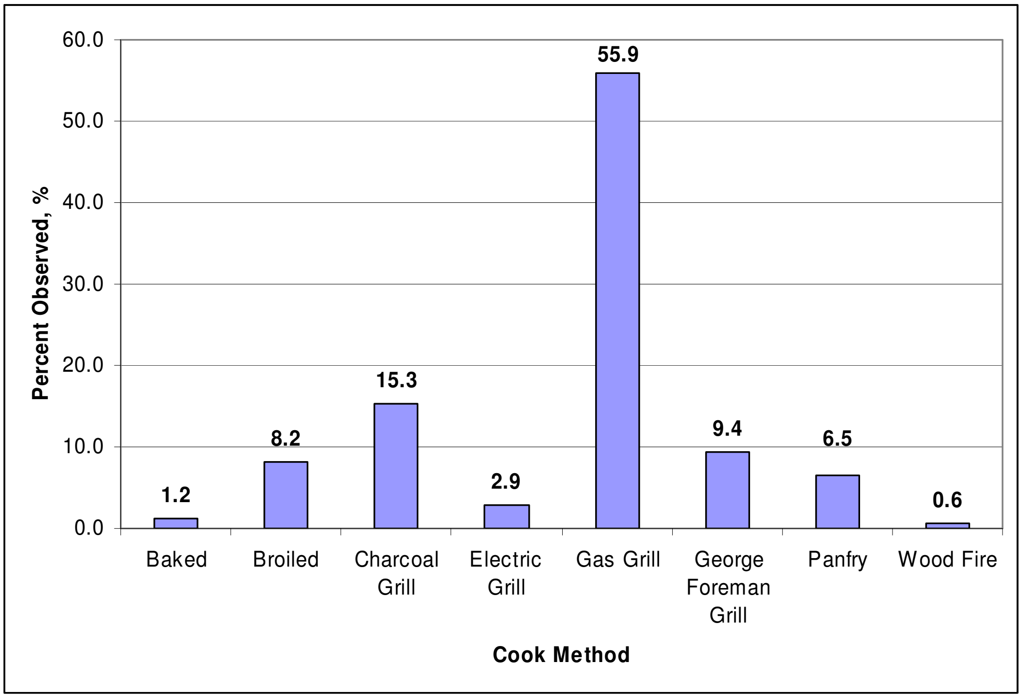

Figure 5.4. Panelist's cooking methods expressed as a percentage of the entire consumer study

Degree of doneness frequencies revealed that consumers cooked 45.8% of steaks to a medium degree of doneness (Figure 5.5). These results are similar to results observed by Boleman et al. (1997). Boleman et al. (1997) documented that 42.6% of consumers cooked top loin steaks to a medium or medium-well degree of doneness. The following are frequencies by degree of doneness for the current study: very rare, 0.6%, rare, 5.4%, medium rare, 19.6%, medium, 45.8%, and well done, 28.6%. Again, these results are comparable to other research (Boleman et al., 1997; Neely et al., 1995) with most consumers cooking their steaks to a medium degree of doneness or higher.

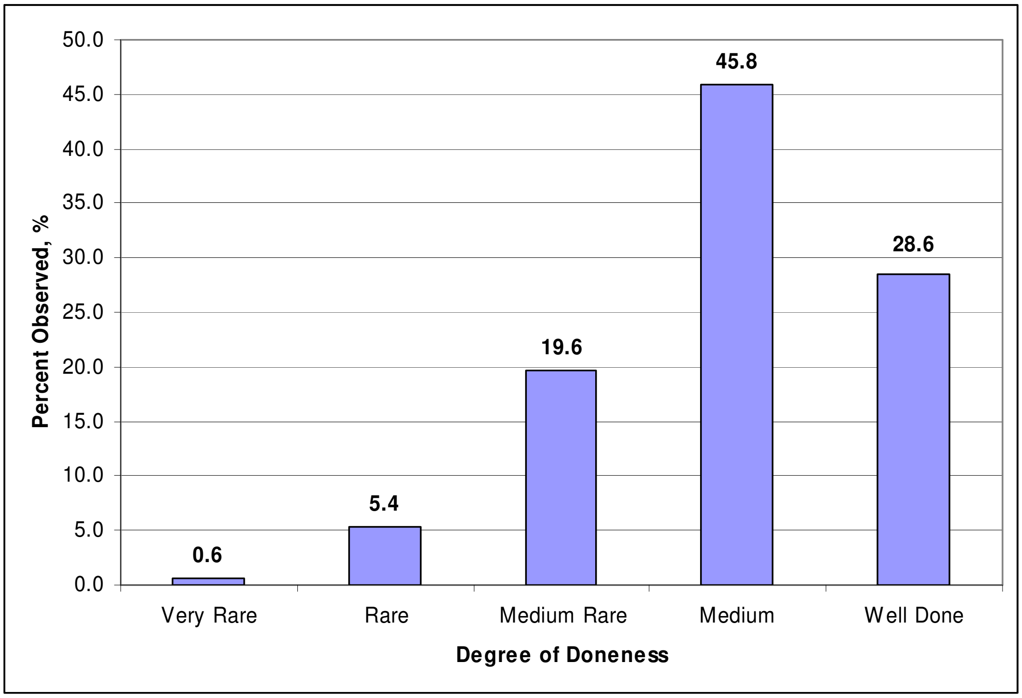

Figure 5.5. Panel degree of doneness expressed as a percentage of the entire consumer study

Consumer willingness to pay a premium for steaks of known tenderness were evaluated for each level of tenderness. On each ballot the panelist was asked, *Suppose there were 2 products available for sale. Product A is exactly the same as the product you just tasted and it sells for $ x/lb. Product B is a typical, unbranded product found in a grocery store that is of unknown tenderness, juiciness, and flavor and it sells for $8.99/lb. Assuming you were going to buy beef, which product would you buy, A or B?* The market price of $8.99/lb. was based on US Choice ribeye steak prices surveyed from local grocers at the time of the study. Based on previous research (Boleman et al., 1997; Miller et al., 2001; Shackelford et al., 2001), pricing thresholds were setup for each level of tenderness. Panelists were asked if they would pay $1.23/lb. more for tender steaks, $0.75/lb. for intermediate steaks, and $0.25/lb. for tough steaks. These prices were established based on previous research (Unnevehr et al., 1993; Boleman et al., 1997;

Miller et al., 2001; Shackelford et al., 2001). Consumers did not have prior knowledge of the tenderness classification of each steak. The goal was to observe if consumers could accurately separate tender from tough steaks and if each steak in each tenderness category met their expectations for tenderness, would they be willing to pay a premium for more tender beef.

Figure 5.6 contains the percentages of consumers willing to purchase tender steaks at a higher cost. According to all red (tender) ballots received, 63.9% of panelists voted they would purchase the same meat product they just evaluated for \$10.22/lb. (Product A) compared to a similar, unbranded product with unknown tenderness, juiciness, and flavor found in the grocery store that sells for \$8.99/lb (Product B). According to this data set, consumers would be willing to pay a premium of \$1.23/lb for steaks identified as tender. However, 36.1% of panelists said they would not be willing to pay more for this level of tenderness and would only purchase the steak if it was priced at its retail cost of \$8.99/lb. These results are similar to findings reported by Shackelford et al. (2001). They reported that 89% of consumers would definitely pay or probably pay \$0.50/lb. more for "Tender Select" steaks (Shackelford et al., 2001).

Figure 5.7 contains the percentages of consumers willing to purchase intermediate steaks at a higher cost. According to all white (intermediate) ballots received, 64.7% of panelists voted they would purchase the same meat product they just evaluated for \$9.74/lb. (Product A) compared to a similar, unbranded product with unknown tenderness, juiciness, and flavor found in the grocery store that sells for \$8.99/lb (Product B). According to this data set, consumers would be willing to pay a premium of \$0.75/lb for steaks identified as intermediate. However, 35.3% of panelists said they would not be willing to pay more for this level of tenderness and would only purchase it if it was priced at its retail cost of $8.99/lb. Although the percentage of consumers willing to pay a higher price for intermediate tenderness steaks is higher than consumers willing to pay a higher price for tender steaks, the price difference above the retail price ($8.99/lb.) is what led to this result. It is expected that if consumers could purchase tender steaks at the intermediate premium price of $9.74/lb., an increase in percentage of consumers purchasing the tender product would be expected.

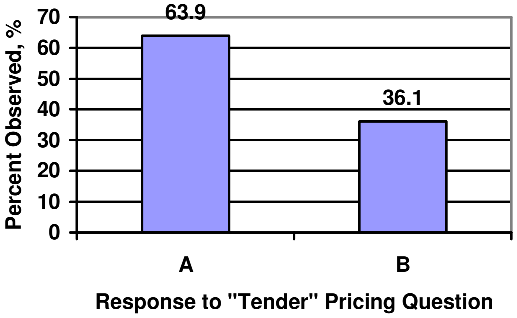

Figure 5.6. Consumer willingness to pay for steaks identified as "Tender"

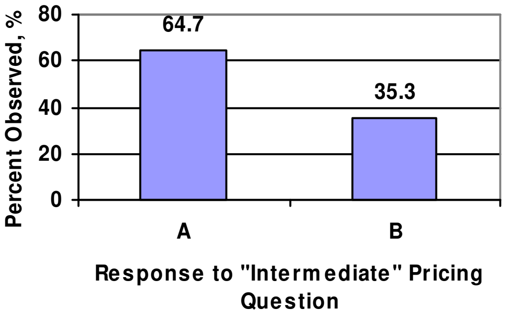

Figure 5.7. Consumer willingness to pay for steaks identified as "Intermediate"

Figure 5.8 contains the percentages of consumers willing to purchase tough steaks at a higher cost. According to all blue (tough) ballots received, 51.2% of panelists voted they would purchase the same meat product they just evaluated for $9.24/lb. (Product A) compared to a similar, unbranded product with unknown tenderness, juiciness, and flavor found in the grocery store that sells for $8.99/lb (Product B). According to this data set, consumers would be willing to pay a premium of $0.25/lb for steaks identified as tough. However, 48.8% of panelists said they would not be willing to pay more for this level of tenderness and would only purchase it if it was priced at its retail cost of $8.99/lb.

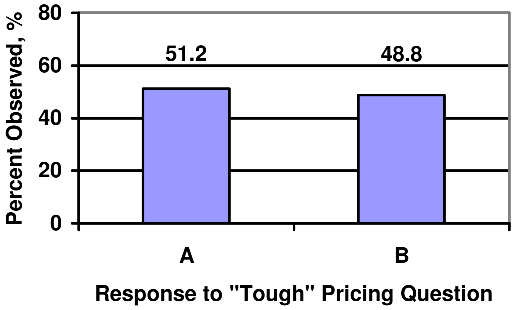

Figure 5.8. Consumer willingness to pay for steaks identified as “Tough”

Conclusions

Incorporating VIA with NIR has been shown to be very successful in the predicting and sorting of carcasses into tenderness categories. Previous work suggests that NIR spectroscopy provides useful information about factors that can be linked to tenderness evaluation (Byrne et al., 1998; Mitsumoto et al., 1991; Liu et al., 1993). Marketing a tender product by assessment by an instrument has been the task of packers and the USDA for the last decade. Other researchers have tried to establish thresholds for tenderness classifications for which consumers would accept a meat product and become a repeat buyer (Boleman et al., 1997; Miller et al., 2001; Killinger et al., 2004; Shackelford et al., 2001; Wyle et al., 2003). However, there has been no standard set up for the entire industry to market carcasses based on predicted tenderness outcome groups. Results from this study have implicated several factors that may change this scenario in which programs will be established for tenderness classifications.

Near-infrared and VIA technology is very useful in giving detailed information that can translate into tenderness assessment. However, further research must be conducted on the E+V camera to refine and improve the software. Measuring ribeye area and marbling that has been adjusted (coarse marbling removed from the assessment) of each of the 16 sections was significant in the 14-d SSF predictions of Phases I and II. Our findings concluded that if these variables were incorporated into the E+V software, the explained variance in 14-d SSF prediction may increase. Furthermore, it is imperative that NIR measurements be taken for each carcass. Just as in Phases I and II, principle components generated from spectra between 770 and 2500 nm were highly significant in every prediction equation.

After studying each of the subprimals WBS classifications, a prediction analysis using the equation generated from the ribeye was used to predict tenderness ratings of each of the subprimals. This method exhibited small or no significance in trying to predict tenderness rating of other subprimals of the same carcass. It is the conclusion of this study that other subprimals in the carcass possess multiple muscle structures and fat deposits that alter the tenderness of those steaks which can not be related back to ribeye tenderness ratings. However, using a regression equation generated from scans on the 12th rib surface may be accurate in giving an overall tenderness classification for that muscle. Thus, a scan of the ribeye could place all middle meats (rib and loin) into a tenderness category. This method could add value to a section of the carcass which could then be marketed into a "guaranteed tender" program. Ribeye, t-bone, porterhouse, and tenderloin steaks could then be merchandized at a higher value based on quality and yield grades and tenderness classification.

The consumer study provided very useful information about consumer's attitudes towards beef from various quality grades and tenderness categories. Although quality grade was not used to sort steaks to specific consumers in specific regions, consumers still placed more emphasis in evaluations on overall acceptability of tenderness. Results showed that even high quality steaks that were tough could still be found by the consumer as an unacceptable or unpleasant eating experience. Labeling tender steaks in the market could be beneficial to the retailer and the consumer. The fact that more steaks would be purchased pre-identified as “tender” or “intermediate” follows the results of the tenderness evaluations. Thus, incorporating a system that can guarantee the tenderness of beef steaks for sale in the retail market is significant as consumers have shown that even though beef may be priced higher, they would be more apt to purchase a beef product that would produce an enjoyable eating experience.

The goal of this project was to accurately classify longissimus steaks into tenderness categories using NIR and VIA, to observe if the prediction equation generated from the ribeye scan could be used to predict the tenderness levels of other muscles, and to evaluate consumer perception of steaks sorted by tenderness classification. Results from this study should provide packers and producers with confidence that the technology to sort carcasses based on tenderness is in the near future. Further, packers and retailers should begin to formulate a system that will be able to utilize a “guaranteed tender” program in the near future. It is the recommendation of this research that further research must be conducted to validate and standardize one type of VIA camera. Evaluation of higher quality cuts by NIR and VIA prediction might be more valuable to packers and retailers than lower quality cuts.

CHAPTER VI

CONCLUSION

Technology is the new tool that will shape the meat industry in the years to come. Streamlining the production, processing, and marketing systems will be the new wave of future generations. In the current market situation, the USDA has employed VIA technology to augment quality and yield grading of beef carcasses. If this is to be the trend, NIR spectroscopy could find its niche in tenderness evaluations and could be marketed as innovative and price savvy. However, it is up to the producer, packer, and consumer to understand and accept this new technology before it can be put into action. Through research and consumer input, use of VIA and NIR technologies can become a main staple in the meat industry.

Over the years, NIR spectroscopy has been developed and applied in quality management of beef meat products (Mitsumoto et al., 1991; Park et al., 1998; Rødbotten et al., 2001; Venel et al., 2001). It has only been within the last decade that researchers have begun to understand the potential of NIR spectroscopy as an evaluation instrument of specific compounds of organic substances. The results from the studies herein suggest that NIR spectroscopy is a valuable tool in assessing beef tenderness. The use of NIR spectroscopy in an on-line system would be a great benefit to producer, packer, retailer, and consumer. However, its implementation is still a few years away. Further research must be conducted with companies that produce the VIA system in order to eliminate or minimize variation between the two cameras as well as extrinsic variation caused by differences in software. Additionally, this system will only work if it would be standardized by the USDA across all packing plants in the United States that utilize VIA to aid graders in assessing quality and yield grades. According to prediction results from Phases II and III, it is imperative that one VIA camera be used and standardized by all plants. When predicting 14-d ribeye SSF values in Phase III with the regression equation from Phase II, a very low R^2 square value was generated ($R^2 = 0.35$) compared to our previous results. This difference was most likely due to a change in the camera systems between phases which led to missing variables. The conclusion from Phase III also stated that variables generated from the E+V camera in Phase III may not have been as accurate or precise as variables observed with the RMS camera used in Phase II. However, over time, the issues can be resolved with more research and calibrations. Overall, the results from Phases I, II, and III inference that the VIA systems are very accurate in assessing specific marbling characteristics. If NIR technology is to be incorporated into VIA cameras, it should be of utmost importance that further research be conducted on the evaluation of marbling in specific areas of the ribeye surface and how significant each one of those areas are in formulating quality and yield grades.

Based on the results from the consumer study, we have determined that consumers can distinguish a difference between tender and tough beef. Consumers were able to detect differences in tenderness, juiciness, and flavor between classification groups. Again, the consumers that were used for this panel ranged from home economists, cattle producers, house wives, extension specialists, men, women, old, and young. Thus, the study consisted of typical beef consumers in the U.S. The fact that these beef consumers could pick up differences in tenderness implies the need to produce a consistently tender product and establish the repeat consumer. Furthermore, results state that over 63% of consumers sampled in this study indicated a willingness to pay for beef that was of known tenderness (preferably “guaranteed tender”) in the retail setting. Thus, if a product was labeled with a sticker that read “Tender” or “Guaranteed Tender”, price of the product then becomes secondary. It is believed that most retailers and packers would not hesitate to draw an increase on profit if they could sell the product they have been selling for years at a higher price due to technology of tenderness prediction and application of good marketing.

Although NIR spectroscopy is gaining acceptance in the research community, its usefulness from a practical standpoint needs further development. Currently, the time it takes to produce the prediction of a beef carcass is too long. However, software engineers and plant personnel working together, the prediction time could be reduced to a matter of 10 seconds. This amount of time would give line graders and sales cooler personnel time to correctly identify tender, intermediate, and tough carcasses and sort them off onto their respective rails. The theory is possible and in greater reach than it has been in recent years. It will have to be the USDA and packing plants that must take the “leap of faith” much like the way they did when VIA grading first made an appearance in research. It will also be up to the researchers to gain enough funding to provide repetitive results to ensure that the path they are traveling with NIR technology is feasible. Once NIR spectroscopy is implemented in a VIA camera, producers, packers, retailers, and consumers will begin to experience a revolutionary change in the meat industry.

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OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
FOR HUMAN SUBJECTS RESEARCH

Date: 07-19-07 **IRB#:** AG0726

Proposed Title: Augmentation of near-infrared (NIR) and in-plant beef video image analysis (VIA) to sort carcasses into tenderness categories

Principal Investigator: Dennis Price

Review and Processed as: Exempt

Approval Status Recommended by Reviewer(s): Approved with Provisions
APPROVAL STATUS PERIOD VALID FOR ONE CALENDAR YEAR AFTER WHICH A CONTIUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL. ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL.

VITA

Dennis Michael Price

Candidate for the Degree of

Doctor of Philosophy

Thesis: AUGMENTATION OF NEAR-INFRARED (NIR) AND IN-PLANT VIDEO IMAGE ANALYSIS (VIA) SYSTEMS TO SORT CARCASSES INTO TENDERNESS CATEGORIES

Major Field: Food Science

Biographical:

Personal Data: Born in Thibodaux, Louisiana, On February 14, 1980, the son of Majesta and JoAnne Price.

Education: Graduated from Thibodaux High School, Thibodaux, Louisiana in May 1998; received Bachelor of Science degree in Animal Science from Louisiana State University, Baton Rouge, Louisiana in December 2002. Completed the requirements for the Master of Science degree with a major in Animal Science at Louisiana State University in May 2006; Completed the Requirements for Doctorate of Philosophy in Food Science degree at Oklahoma State University in May of 2008.

Experience: Employed by Manda Fine Meats, Inc., Baton Rouge, Louisiana, as a quality assurance supervisor; employed by Louisiana State University, Department of Animal Sciences as an undergraduate and graduate research assistant; employed by Oklahoma State University, Department of Animal Science as a graduate research and teaching assistant.

Professional Memberships: American Meat Science Association, Institute of Food Technologists, American Society of Animal Science, North American College Teachers of Agriculture.

Name: Dennis Michael Price Date of Degree: May, 2008

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: AUGMENTATION OF NEAR-INFRARED (NIR) AND IN-PLANT VIDEO IMAGE ANALYSIS (VIA) SYSTEMS TO SORT CARCASSES INTO TENDERNESS CATEGORIES

Pages in Study: 114 Candidate for the Degree of Doctor of Philosophy

Major Field: Food Science

Scope and Method of Study: Near-infrared (NIR) spectroscopy and video image analysis (VIA) are useful tools that can provide information about quality, yield, and tenderness of beef carcasses. The objectives of this study were to determine the combined effect of NIR and VIA on the effectiveness of predicting 7-d and 14-d tenderness of ribeye samples in various quality grades, observe the relationship between predicted ribeye shear force and tenderness of short-term muscles, and obtain consumer perceptions of ribeye steaks that were categorized as “tender”, “intermediate”, or “tough”. Beef carcasses (Phase I, n = 51; Phase II, n = 191; Phase III, n = 191) were selected (d-2) from a commercial beef processing facility. Ribeye sections were scanned with VIA and NIR cameras following carcass presentation to in-plant USDA grading personnel. Subprimals (ribeye, Phases I & II; ribeye, clod, top sirloin, and inside round, Phase III) were fabricated from each carcass and transported to OSU. Steaks were fabricated (d-3), then individually vacuum packaged and aged at 4ºC for 7-d or 14-d prior to cooking and Warner-Bratzler and slice shear force analysis. Wavelength coefficients were generated from NIR spectral data and used with VIA and SSF data for statistical analysis by regression to predict 7-d and 14-d steak tenderness. Consumer panelists (n = 200) were asked to evaluate the tenderness, juiciness, and flavor of three steaks from tender (< 19 kg), intermediate (19-25 kg), and tough (> 25 kg) categories.

Findings and Conclusions: The regression equations were significant (Phase I, $R^2 = 0.90$; Phase III, $R^2 = 0.82$) for 7-d and (Phase I, $R^2 = 0.91$; Phase II, $R^2 = 0.80$; Phase III, $R^2 = 0.65$) 14-d tenderness prediction. The regression equation generated from ribeye NIR and VIA data was not successful in predicting the tenderness of additional subprimals ($P > 0.05$). In Phase III, consumers were able to detect differences in tenderness, juiciness, and flavor between tender, intermediate, and tough classified steaks ($P < 0.05$). Consumers were willing to pay premium prices for pre-identified tender (63.9%) and intermediate (64.7%) steaks. Scanning beef carcasses with NIR and VIA cameras were very accurate at sorting carcasses into tenderness groups.

ADVISER’S APPROVAL: J. Brad Morgan