COMPARISON OF SLICE SHEAR FORCE WITH WARNER BRATZLER SHEAR
FORCE AS PREDICTORS OF CONSUMER PANEL PALATABILITY
MEASURES IN NON-ENHANCED AND ENHANCED PORK LOIN CHOPS

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ABSTRACT

The present experiment evaluated the relationship between slice shear force (SSF) and Warner-Bratzler shear force (WBSF) as methods to determine pork tenderness and consumer sensory palatability measures. Data set one consisted of chops derived from non-enhanced pork loins (n = 607), that were purposely selected to vary in color, pH, and intramuscular fat. Data set two consisted of non-enhanced (n = 213) and enhanced (n = 207; 10% pump, 0.35% Sodium Phosphate, 0.35% Salt, and 2.25% Potassium Lactate) loins paired prior to enhancement based on similarity in pork color, pH, and intramuscular fat and alternately assigned to the enhancement treatment. Using classification criteria based on pork quality, the most posterior chop from a loin was alternately assigned to a cooked temperature of either 68.3°C or 73.8°C. Consumer palatability measurements (n = 2280 consumers, 9100 observations) and WBSF were assessed on chops from the same loin cooked to the same temperature. All chops were cooked using clam-style, George Foreman grills. Data were analyzed using correlation and mixed model procedures of SAS. Measurement scale differences for SSF and WBSF required assessment of results on a standard deviation unit basis. The correlation between SSF and WBSF within the non-enhanced data set were only moderate, but were greater (r = 0.62) at a
cooked temperature of 73.8°C when compared with 68.3°C ($r = 0.49$). Temperature did not have a significant effect on consumer palatability measurements. Predicted consumer tenderness and overall like ratings were similar across the range for both WBSF and SSF methods of tenderness assessment, but tenderness and overall like ratings declined by 0.53 and 0.32 units (8-point scale), respectively, as both SSF and WBSF increased in standard deviation unit increments from lowest to greatest. Within the non-enhanced and enhanced paired loin data set, correlations between SSF and WBSF for enhanced chops were low at a cooked temperature of 68.3°C ($r = 0.27$) and increased somewhat at 73.8°C ($r = 0.48$). In the paired non-enhanced loins, the correlations between SSF and WBS were 0.44 and 0.58 at 68.3°C and 73.8°C, respectively, similar in level to the moderate relationships observed in the larger non-enhanced data set. Enhancement improved consumer tenderness ratings by 1.00 unit when comparing ratings at each level on SSF range and 0.68 units when comparing at each level of the WBSF range. However, although the enhancement effect was larger at a given point for SSF when compared with WBSF, a standard incremental increase in WBSF resulted in a 0.51 unit reduction in consumer tenderness ratings compared to a 0.34 unit reduction for SSF. For overall like, a similar pattern of response was observed, with incremental changes in WBSF resulting in greater changes in consumer perception when compared with a standard unit change in SSF. These results suggest that WBSF and SSF are only moderately related as objective methods of tenderness assessment indicating they are not measuring the same
characteristics. In addition, WBSF, particularly when comparing enhanced and non-enhanced loins, was able to more effectively discriminate tough from tender at the consumer level than was SSF. Based on the observations from the present study, WBSF appears to be a more robust method of objective tenderness assessment.
Dedicated in memory of John H. O’Diam and Frank “Pete” Geer

and in honor of Peggy J. Geer
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CHAPTER 1

INTRODUCTION

Throughout recorded history, the consumption of meat has indicated a position of social and economic prestige among people and nations (Aberle et al., 2001). Meat is a very nutritious food that provides key minerals such as zinc and iron, protein and B-vitamins (in a bio-available form). The importance of meat can be seen by the manner in which cultures choose to use their resources; the U.S. alone devotes more than 60 percent of its resources to meat production (Aberle et al., 2001). As civilization has evolved into an industrialized society, the understanding and need of meat and meat animals has increased and the world’s needs have thereby changed. The pork industry has selected genetics that target for maximal efficiency of animal growth and production. The industry has further developed a greater understanding of the nutritional needs of these genetically superior animals, allowing them to approach their genetic potential.

Research has shown that the single most important attribute in consumer palatability is tenderness (Morgan et al., 1991; Koohmaraie, 1996; Enfalt et al.,
In response to these findings, the industry has made a conscious effort to improve upon the tenderness levels of all meat products in order to increase demand for their respective proteins. However, in order to quantify factors that influence tenderness (genetics, nutrition, environment, processing, etc), the industry first had to develop a method to objectively measure tenderness. In the early 1950's Warner-Bratzler shear force (WBSF) was developed for this purpose and has been the most widely accepted methodology for tenderness measurement. While WBSF has been the standard for assessment of tenderness, weaknesses of the technology include an extensive labor requirement, variation in quality and consistency of muscle cores used for testing, inconsistencies in protocols utilized across locations, and variation in the relationship between WBSF and consumer and trained sensory perceptions of tenderness. In response to the challenges presented with WBSF, Shackelford et al. (1999) developed a new method of assessing meat tenderness known as slice shear force (SSF) which has been described as being more highly correlated with sensory panel assessment of tenderness and providing a greater repeatability with respect to consistently matching SSF data with sensory perceptions of tenderness. The majority of research involving SSF as a method of quantifying tenderness has been in beef products (Shackelford et al., 1995; Shackelford et al., 1999a; Shackelford et al., 1999b; Wheeler et al., 2002). However, pork has been evaluated using SSF (Wheeler et al., 2000; Shackelford et al, 2004). Wheeler et al. (2000), utilized SSF, but there was no assessment of the relationship between SSF and WBSF
reported in this manuscript. Additionally, Shackelford et al. (2004) evaluated SSF vs. WBSF within pork loins but used a limited number of samples as other parameters were also evaluated within this study. Therefore, the focus of the proposed study is to assess the relationship between SSF and WBSF in the pork loin. Specifically, the objectives of the present study were: 1) Assess the relationship between SSF and WBSF techniques for assessing tenderness for non-enhanced and enhanced pork loin chops cooked to two degrees of doneness (155 and 165), 2) Compare the influence of SSF and WBSF on consumer palatability assessment, including tenderness, juiciness, and flavor.

In response to the need for further testing of this newly developed method of assessing tenderness, the objective of the present study is to assess whether SSF or WBSF force values most accurately relates to consumer taste panel and trained sensory panel evaluation, of the pork longissimus. In addition, the present study will establish guidelines to evaluate if SSF is a better predictor of tenderness than that of WBSF when using a wide range of pork quality.
CHAPTER 2

REVIEW OF LITERATURE

MEAT PALATABILITY

Pork Quality

Meat palatability describes the overall eating experience achieved when consuming a meat product. Palatability is affected by three factors: tenderness, juiciness and flavor. Ultimately, it is the individual consumer whom determines the palatability of a meat product. Consumers make their purchasing decisions based on many factors including appearance (i.e. color, marbling), smell and eating satisfaction. Often, the priority that consumers place on palatability is influenced by economic, social, and environmental factors (Jeremiah, 1998).

Several researchers have identified the importance of tenderness in multiple species. Establishing a tenderness acceptability level for consumer markets would lead to new value added marketing schemes for which a tenderness value could be placed on a beef carcass, box of beef, or retail package for sale to restaurants or the retail case (Huffman et al., 1996). Tenderness has been identified as the most important palatability attribute of meat, and the primary determinant of meat quality (Koohmaraie, 1996; Koohmaraie et al., 2002; Koohmaraie et al., 2006;
Miller et al., 1995; Platter et al., 2003). Therefore, the scientific community has placed a large amount of emphasis on research addressing the factors influencing tenderness, in order to better understand the mechanisms that control meat quality. Pre-harvest factors affecting meat quality include the genetic background, feeding practices, nutrient levels, and environmental conditions in rearing, handling, transportation and lairage, to name a few. The pork industry as a whole has selected for leaner, heavier muscled hogs due to an increased emphasis on production efficiency and the greater value of lean when compared with fat. Selection for lean has been reported to be indirectly associated with an increased proportion of excitable hogs which can also be linked to increased animal welfare concerns in auction barns and slaughter plants (Grandin 1997). Selection for lean has also brought about an increase in the incidence of pale soft and exudative (PSE) pork conditions (Pommier, et al., 1993). Moreover, Huff-Lonergan et al. (2002) reported that there was a tendency for pork carcasses that were leaner and heavier muscled to have chops that were less firm, less tender, and with less marbling, and less pork flavor than chops derived from carcasses with greater amounts of 10th rib backfat and (or) a smaller loin muscle area.

Postmortem factors occurring in the slaughter or processing plant also play a role in determining the palatability of pork. Factors that have been implicated for their role in determination of palatability include: stunning procedures, the bleeding process, length of time on the harvest floor, rate of
carcass chilling, length of postmortem product ageing, fabrication procedures, further processing, packaging and ultimately final preparation.

The majority of quality-focused research includes measures of meat color, pH, water holding capacity (WHC), intramuscular fat (IMF), and tenderness (Koohmaraie, 1996). In performing these measurements, both subjective and objective methods are utilized. The National Pork Producers Council (NPPC) has developed subjective, visual standards for color, firmness, and marbling assessment, which are common indicator traits used help predict overall pork palatability (NPPC, 2000). The use of objective measurements, including chemical IMF, muscle pH, WHC, and colorimeter readings help to assess and further quantify what the human eye cannot.

According to the National Pork Producers Council Usage study (NPPC, 1993), U.S. consumers ranked their per capita consumption of fresh pork third behind beef and poultry. In an attempt to align pork demand with poultry’s healthful image, the National Pork Producers Council under guidance of the National Pork Board launched the advertising campaign “Pork: The Other White Meat”. This campaign was extremely successful and was the fifth most recognized advertisement in the USA (NPB, 2000). However, this slogan has come under scrutiny by some within the swine industry, because they sense it has directed consumers to purchase fresh pork products that are paler in color (similar to raw chicken breast), an attribute that is frequently associated with less than desirable eating quality for pork products. The reduced palatability
observed in pale pork is attributed to drier and tougher pork at the time of consumption. Color is one of the first attributes that consumers evaluate when making a purchase. Therefore, the industry must continue to educate consumers in regard to how color influences palatability and the industry must strive to produce pork that is consistently near an ideal color target.

Pork Color

Color can be measured both subjectively and objectively. The NPPC has set forth standards for subjectively assessing color using a 6 point scale (NPPC, 2000) that describes the spectrum of color that is often observed in pork products. On the NPPC scale, a score of 1 indicates the lowest (palest) color and a 6 indicates the highest (darkest) color rating. The pork industry targets a reddish pink color (AMSA, 2001) which is approximately a score of 3 on the NPPC scale. In addition to subjective measurements, objective measures of color are obtained using devices such as a Minolta chromameter or Hunter spectrophotometer that measure the amount of light reflection of an object on $L^*$, $b^*$ and $a^*$ scales, measuring grey band, yellow band and red band respectively. Brewer and McKeith (1999) showed the correlation between visual characteristics of pork chops and instrumental values of each light band. The grey band ($L^*$) indicates the paleness/darkness of a product, and it was found that within pork, normal values were near 51.5, whereas values of 57.0 and greater identified paler product, and values of 38 and less identified darker product. Additionally, $b^*$ band (yellowness) values were found to be normal at
19.4 ± 0.32 (more yellow) when compared to light products with a value of 18.4 ± 0.94, and dark products with 13.7 ± 1.08. Finally, normal a* values were found to be at 11.1 ± 0.4 (more red) with light products having values of 8.9 ± 0.22 and dark products valued at 10.3 ± 0.31.

Color is simply the reflection of light, and it is produced when energy in the visible range (400-700 nanometer waves) is perceived by our eyes (Brewer, 1998). Brewer (1998) reported that some wavelengths of light are absorbed by an object and these absorbed wavelengths are not visible. The remaining wavelengths are reflected and produce the color that is observed and interpreted. In terms of consumer’s attitudes towards the color of pork, in general, consumers are more likely to purchase dark colored pork than light-colored pork (Brewer et al., 1999; Norman et al., 2003). Davis et al. (1975) reported that pork loins that were lighter in color, were also less juicy, less tender, had a higher percentage of cooking loss, and had a lower overall satisfaction rating. In addition, Davis et al. (1975) showed that dark colored pork had less cooking loss and greater water-holding capacity. Norman et al. (2003) reported that dark colored pork reached a greater end point cooked temperature than light colored chops when cooked at a constant time rather than constant temperature. The authors attributed this characteristic to the high pH that was associated with the “dark colored” pork in their study. High pH would have a positive impact on water-holding capacity and would thereby increase thermal conduction during cooking. Furthermore, Norman et al. (2003) reported that consumers had a higher liking of tenderness
and liking of juiciness ratings for darker colored pork chops (NPPC color scores of 5 and 6). Davis et al. (1975) stated that light reflectance (a measure of color) is significantly \((P < 0.01)\) positively correlated \((r = 0.40)\) to Warner Bratzler shear force (WBSF) tenderness measurements. Norman et al. (2003) showed that as NPPC color scores increased, WBSF mean values decreased, which is in agreement, with the earlier report of Huff-Lonergan et al. (2002) that darker colored pork had a greater propensity to be firmer, have less drip loss, and be more tender.

*Pork pH*

Another parameter used to assess pork quality and palatability is pH, a measurement that is often measured and monitored within pork packing plants to gauge pork quality and monitor plant conditions. Pork pH within the packing plant is measured either at approximately 45 minutes postmortem on the warm carcass to gauge the early postmortem rate of pH decline, or on a pork cut at \(~24\) hours postmortem to measure the final or ‘ultimate’ pH. Within packing plants, online pH measurement is difficult due to the invasive nature of pH data collection with a sensitive machine, and the challenge of collecting pH on each carcass when the line speed of some packing plants exceed pH meter reading capabilities. In an effort to address these challenges, most packing plants will sample pH within a group of pork carcasses at different times throughout a day, or week, to maintain an overview of plant and product conditions. The technology needed to measure each carcass, or a cut from each carcass, while
maintaining identification back to the producer, is still in the process of development.

In meat, the measure of pH is associated with the amount of glycogen present at the time of slaughter (Huff-Lonergan et al 2002). In living muscle, glycolysis is an anaerobic form of energy production (ATP) that yields 3 ATP per glucose molecule (split from glycogen) via two pyruvic acids (a total of 20 hydrogen ions). This method for energy production leads to a sequence of reactions found within the aerobic energy metabolism called the tricarboxylic acid cycle (TCA cycle). When the muscle is contracting slowly and there is adequate presence of oxygen, this process can yield a total of 37 ATP per molecule of glucose (including 3 ATP from glycolysis). However, if the muscle is contracting quickly and there isn’t an adequate supply of oxygen, anaerobic metabolism is the only source of energy production. Subsequently, as this reaction takes place, hydrogen ions are not able to combine with oxygen as they do in the TCA cycle. Therefore, the influx of hydrogen ions reduces the pyruvic acid, formed through glycolysis, to lactic acid (Aberle et al 2001). Lactic acid production is associated with a build-up of a tremendous amount of hydrogen ions within the muscle; therefore, resulting in a low pH (pH is a measure of the inverse log of the hydrogen ion concentration). The accumulation of lactic acid results in protein denaturation (a process that causes proteins to lose their secondary and tertiary structure), and subsequent adverse effects on pork quality (i.e. reduced water holding capacity, pale color of lean, etc.). As reported by Huff-Lonergan et al.
(2002), glycolytic potential had a significant positive correlation with Hunter L-values and drip loss, as well as being negatively correlated with pH. Glycolytic potential is an estimate of the amount of glycogen found in the muscle at the time of slaughter and, under standard postmortem conditions, muscles with greater amounts of glycogen present at time of death, have a greater potential for anaerobic glycolysis leading to the production of a greater amount of lactic acid formation. Increased lactic levels lead to denaturation of muscle proteins and lower L* values (paler colored pork) and lower, undesirable ultimate pH as a function of increased acid levels in the tissue. Lower glycolytic potential was associated with pork products that were tenderer and juicier, with more pork flavor and fewer off flavors (Huff-Lonergan et al., 2002). Norman et al. (2003) showed that pH values were negatively correlated to L*, b* and chroma values indicating that chops with a darker color had a higher pH value.

Ultimate pH is a useful measure when assessing many additional measures of quality. According to Huff-Lonergan et al. (2002), greater pork pH (taken at 24h and 48h) was associated with darker color, reduced drip loss, improved tenderness ratings, improved flavor, and reduced off-flavor. These results also provided further evidence that lower ultimate pH products are associated with lighter-colored pork, which has a higher drip loss, is less tender, and has less pork flavor and more off-flavor. Lonergan et al. (2007) reported that greater ultimate pH is associated with improved tenderness and improved chewiness scores. Low pH values tend to result in the denaturation of myoglobin
and other muscle proteins, reducing the proteins’ solubility and causing them to precipitate and then reflect light rather than absorbing light, resulting in a different color being reflected and a product that is lighter or paler in color (Honikel, 1987).

The pH decline in postmortem porcine muscle is represented by a gradual decrease from 7.4 (living muscle tissue) to a pH of 5.6 to 5.7 within 6 to 8 hours postmortem. Pork’s final or “ultimate” pH value typically lies within the values of 5.3 and 5.7 within 24 hours of harvest (Aberle et al. 2001). When comparing the normal pH decline with that of pork showing the quality attributes of PSE, in PSE pork the pH decline is much faster and has a lower ultimate pH value. Additionally, the internal temperatures of carcasses showing PSE characteristics are more than that of normal quality pork. When comparing normal pork to that of pork classified as dark, firm and dry (DFD), DFD pork has a slower initial rate of decline, and an extended rate of minimal pH decline resulting in a greater ultimate pH (Figure 2.1). Due to the dark color, DFD pork is considered to be unattractive and undesirable in the retail counter. Additionally, the added water holding capacity and higher ultimate pH create a favorable environment for bacterial growth (Aberle et al., 2001), therefore decreasing the shelf-life of DFD pork.

Muscle pH plays a large role in the water holding capacity (WHC) of pork products. Pork with an ultimate pH between 5.3 and 5.5 will typically have a lower WHC or a reduction in the ability to bind water when compared to normal quality pork. Retention of water is desirable in several different realms as it not
only prevents excessive purge loss but also helps retain moisture after cooking. A product with low WHC will tend to have an excessive amount of purge in the packaging. Purge is often wrongly perceived by the consumer as “blood”. Regardless of the misconception, purge loss is undesirable to consumers and they will tend to avoid purchasing products demonstrating excessive fluid loss within the package.

A product with a low WHC tends to have a low pH and the closer the pork pH is to the isoelectric point of 5.2 to 5.3, the poorer the WHC of the cut (Miller 1999a). At the isoelectric point, the sarcomere will have a balance of negative and positive ions and therefore, will have minimal spacing available within the muscle for water to be bound. Due to a lack of spacing within the sarcomere, meat will tend to lose moisture and increase the amount of exudates, resulting in a larger drip loss value. As a result, when low pH products are cooked by the consumer they will tend to be dry and less desirable.

Intramuscular Fat

The role of intramuscular fat (IMF), or marbling, on eating quality of pork has been a focus of many research projects (Davis et al., 1975; Hodgson et al., 1991; Morgan et al., 1991; Brewer, 1998; Rohr et al., 1999; Lonergan et al., 2007; Rincker et al., 2008). This focus is due, in large part, to the low level of intramuscular fat found in pork derived from modern swine genetic resources, and from consumer feedback that pork is considered to be dry with little flavor by
many consumers. The swine industry’s focus on carcass lean has resulted in a correlated reduction in IMF within the loin and ham which may contribute to a reduction in eating quality; therefore, an understanding of the role that IMF plays on eating quality and the interrelationships between IMF and measures of eating quality are important for the industry. Huff-Lonergan et al. (2002) reported that marbling was significantly correlated with firmness ($r = 0.37$), drip loss ($r = -0.12$), percentage cook loss ($r = -0.11$), and Star Probe measures of tenderness ($r = -0.27$). Within this study, the authors showed that marbling was most highly correlated with firmness ($r = 0.37$). The authors of this study hypothesize that chilling product with higher amounts of lipids may aid in improving the firmness of the product. This study concludes that as marbling increases, firmness increases (favorable), drip loss decreases (favorable), and tenderness values decrease (favorable). In addition, Hodgson et al. (1991) found that marbling score was significantly ($P < 0.01$) correlated ($r = -0.36$) with shear force values and DeVol et al. (1988) illustrated that increasing intramuscular fat level was the most highly and favorably related to tenderness ratings of sensory panelists and WBSF force ratings ($r = 0.32$ and $-0.29$, respectively). Candek-Potokar et al. (1998) reported that higher muscle fat concentrations (i.e. marbling) were favorably positively and favorably correlated with improved tenderness. Some studies have found that there is somewhat of a “threshold” regarding the amount of marbling required in order to satisfy consumers; Savell and Cross (1988) recommended a minimum of three percent intramuscular fat to reach a “window
of acceptability” that accommodates those whom desire more fat for flavor, as well as those concerned about fat for health reasons.

Although there are several studies that provide evidence that greater levels of IMF are related to improved tenderness, this is not the consensus within published research. In fact, there are a number of studies that have shown that IMF levels have little influence on the palatability of pork. Rincker et al. (2008) recently reported that the variation in marbling did not account for much of the variation in sensory panel tenderness and juiciness at any degree of doneness, and in contrast with the work of Savell and Cross (1988), the authors went on to explain that there was not a “threshold” level of marbling necessary to ensure a positive eating experience.

In looking at consumer’s preferences concerning marbling, Rincker et al. (2008) went on to provide evidence that nearly 50% of all consumers polled chose chops in the retail counter that had the least amount of marbling. Brewer et al. (2001) showed that consumers prefer a leaner appearing pork product with less marbling; this may be due to customers’ concern with health and nutrition as opposed to quality expectations. Although customers showed a greater intent to purchase pork with less IMF, they did rate pork loins with greater amounts of marbling as more tender, juicy and flavorful, indicating a disparity between purchase intent based on visual acceptability and sensory evaluation of cooked pork loin. Brewer went on to explain that both overall appearance acceptability and purchase intent are more highly driven by degree of marbling than by
perceived color, although it should be noted that loins in this respective study were selected to minimize lean color variation.

*Pork Tenderness*

Tenderness is measured either subjectively through consumer or trained sensory methodology, or objectively using mechanical methods. The ultimate goal of objective assessment of tenderness is to quantify variability in tenderness and relate the variability, with a high degree of confidence, to the human-based, subjective ratings of tenderness.

The process of turning muscle into meat is commonly referred to as “rigor”. Rigor has four stages: delay, onset, completion and resolution (Figure 2.2). During rigor onset, muscle tension increases as more actomyosin cross bridges form, and remain in contact, due to a decreasing supply of ATP. Actomyosin is a protein complex that forms when actin and myosin interact at the actin-myosin cross bridge (Aberle et al., 2001). Completion of rigor corresponds with the point at which the muscle exhausts ATP and, therefore, cannot relax (maximal tension or toughness). Resolution of rigor begins via the degradation of proteins through Ca$^{2+}$ dependent proteases.

There are many different enzyme systems that have been believed to play a role in postmortem proteolytic degradation of myofibrillar proteins. These systems include calpains, the multicatalytic proteinase complex, and cathepsins. However, the vast majority of published literature suggests that tenderization is
the result of calcium mediated degradation of myofibrillar and cytoskeletal proteins (Taylor et al., 1995; Koohmarraie, 1996; Aberle et al., 2001; Wheeler et al., 2000). As reported by Goll et al., (1983), proteases that might be responsible for tenderization must show all of the following criteria: 1) the protease must be endogenous to skeletal muscle cell, 2) The protease must have the ability to reproduce post-mortem changes in myofibrils in an in-vitro setting under optimum conditions, and 3) the protease must have access to myofibrils in tissue. With these specifications set forth, the only proteases that meet these requirements are the calpains (Koohmarraie, 1996; Aberle et al., 2001). In addition to the requirements of proteases, Goll (1992) reported that 90% or more of tenderization that occurred during postmortem storage occurred due to calpains. In looking at the calpain family there are two subunits, m-calpain and µ-calpain. These two types of calpains differ in their activation levels of $\text{Ca}^{2+}$ with µ-calpain requiring less $\text{Ca}^{2+}$ for activation than m-calpain. In reference to $\text{Ca}^{2+}$, Koohmarraie and Shackelford (1991) showed that higher levels of $\text{Ca}^{2+}$ within the muscle resulted in more tender meat products. When assessing the contributions of the two respective calpains, Geesink and Koohmarraie (1999) reported that proteolysis of key myofibrils was due to the action of µ-calpain, not m-calpain. Consequently, m-calpain has been reported to have no effect on tenderness as its activity level remains constant during postmortem aging while µ-calpain decreases progressively. Therefore, the underlying mechanism of post-mortem meat tenderization is controlled by the activity of µ-calpain.
Calpastatin binding has been shown to inhibit the effect of μ-calpain on protein degradation as well as regulating μ-calpain action (Geesink and Koohmaraie, 1999; Goll et al., 2003). In order to inhibit calpain, calpastatin must bind at three sites (A, B, and C) on the calpain molecule. The binding at subdomain B accounts for competitive inhibition while subdomains A and C prevent the binding of calpain to membranes (Goll et al., 2003). It has been widely accepted that a higher concentration of calpastatin has an inverse relationship with meat tenderness indicating that as calpastatin levels increase, meat is perceived to be less tender. Geesink and Koohmaraie (1999) proposed that the extent of μ-calpain induced proteolysis is modulated by, among other factors, calpastatin and the ionic strength-dependent instability of autolyzed μ-calpain.

Muscle consists of three protein fractions, myofibrillar (salt-soluble), connective tissue (acid-soluble), and sarcoplasmic (water-soluble) proteins (Koohmaraie et al., 2002). Koohmaraie et al., (2002) reported that myofibrillar protein represents the major protein fraction of skeletal muscle and it is the state of myofibrils that explains most of the variation in tenderness of longissimus. This is not to say that connective tissue does not contribute to longissimus tenderness, rather connective tissue determines background toughness. Koohmaraie (1996) reported that proteolysis of key myofibrillar and associated proteins are responsible for postmortem tenderization. Connective tissue, or stormal proteins, determines background toughness. Although muscle is
comprised of the same types of proteins, the relative contributions of each of to
tenderness is muscle dependent. Typically, stormal proteins are responsible for
tenderness of muscles such as the biceps femoris and semimembranosus but
normally are not responsible for tenderness within the longissimus. The major
determinate of longissimus tenderness is proteolysis. In contrast to the
longissimus, the major determinant of the psoas major is sarcomere length
(Koohmaraie et al., 2002). Sarcoplasmic proteins do not directly affect
tenderness as they are not structural proteins. It is believed that proteolysis of
key myofibrillar proteins is the cause of meat tenderization. These proteins are
those that are involved with inter-myofibril linkages (desmin and vinculin), intra-
myofibril linkages (titin, nebulin and possibly troponin-T) linking myofibrils to
sarcolemma by costameres (vinculin and dystrophin) and the attachment of
muscle cells to the basal lamina (laminin and fibronectin) (Koohmaraie et al.,
2002). These proteins function to maintain the structural integrity of myofibrils,
therefore, proteolytic degradation of these proteins would cause weakening and
thereby: tenderization. Sarcomere length, connective tissue content, and
proteolysis of myofibrillar proteins account for most, if not all, of the explainable
variation observed in tenderness of aged meat (Koohmaraie, 2002). Additionally,
Koohmaraie has shown that proteolysis is the major determinant of tenderness
within the longissimus, however, it should be noted that according to Shackelford
et al. (1995), the shear force of the longissimus dorsi muscle was not strongly
related to shear force of other muscles in beef (Table 2.1). Additionally, the
longissimus dorsi shear force only affected the values of the triceps brachii and
gluteus medius. Implications of this study showed that selecting for genetic improvement in longissimus tenderness may not have a large effect on tenderness of other muscles. Therefore, utilization of the WBSF for the longissimus may not be an accurate predictor of tenderness among other muscles within the carcass (Shackelford et al., 1995; Wheeler et al., 2000). Wheeler et al. (2000) preformed a similar study in pork that showed the triceps semimembranosus and the biceps femoris had the highest correlation to the longissimus tenderness values (r = 0.54 and r = 0.53, respectively). However, Shackelford et al. (1995) found that, in beef, tenderness of the longissimus was most highly correlated with tenderness of the triceps brachii followed by the biceps femoris (r = 0.56 and r = 0.43, respectively). The authors attributed this disparity between the two studies to differences between species, or due to the lack of aging time in the pork industry when compared to the beef industry. Although the longissimus might not be the best indicator of overall carcass tenderness, there is still a large amount of economic importance placed on the longissimus. For this reason, researchers use this muscle as an indicator of tenderness when assessing shear force values via WBSF as well as in sensory panels.

Additional research has shown that consumers are willing to pay more for a guaranteed tender product. According to Miller et al. (2001), consumers can segregate differences in beef tenderness, and consumers are willing to pay more for more-tender beef. As reported by Boleman et al. (1997) with the ability of
consumers to discriminate among tenderness categories and their willingness to pay a premium for tender beef, it is possible that economic incentives may be used from retailers to packers to promote the production, identification, and marketing of tender beef. There are several economic factors that are working to push the meat industry to assess product tenderness. However, tenderness is difficult to measure, especially at processing plant line speeds.

**ENHANCEMENT**

As mentioned previously, consumers of pork demand a tender, juicy, flavorful eating experience, and they tend to select pork that is very lean in appearance and dark in color. However, consumers taste panels have shown that products with higher amounts of marbling were more tender, juicy and flavorful than that of lower marbled products thereby indicating a disparity between purchase intent based on visual acceptability and sensory evaluation of cooked product (Brewer et al., 2001). In an attempt to combat this “disparity” the industry has developed methods, such as moisture enhancement of pork products with water, salt, and sodium phosphate solutions that have been observed to help ensure a pleasurable eating experience.

Enhancing meat is the process of inserting non-meat ingredients via multiple stitch injection into a meat product. The outcome of this process is a
product that has improved eating quality/palatability (juiciness, tenderness and flavor of pork) (Miller, 1998a). Wright et al. (2005) determined that enhanced pork loin chops were rated higher in every palatability trait by a group of trained panelists when compared with non-enhanced chops. Furthermore, Wright et al. (2005) showed that Hunter Lab L* and percent purge were significantly ($P < 0.05$) greater (paler and greater percentage, respectively) and pH values were significantly lower ($P < 0.05$), all of which demonstrate undesirable relationships, for the non-enhanced chops when compared with that of the enhanced chops. Enhancement of pork is not a method to improve low quality products, but is a method being used by the pork industry to improve overall quality of fresh pork in the retail meat case (Miller, 1999a).

Non-meat ingredients are typically those that carry a function in helping to increase palatability or function as shelf life extenders via anti-microbial action. Miller (1999a) presented an extensive review of non-meat ingredients and their respective functionality in enhanced pork, and the following have been taken from that report: The major ingredients used in enhanced pork are water, sodium phosphates, salt, sodium lactate, potassium lactate, sodium diacetate and varying flavoring agents. In general, water is the most abundantly used non-meat ingredient as it serves as a carrier for other non-meat ingredients (most of which are water-soluble).

Sodium phosphates (usually sodium tripolyphosphate) have traditionally been used to enhance water-holding capacity via pH alteration. Sodium
tripolyphosphate (STP) is an alkaline, and due to this fact, the addition of STP alters the pH of a meat product. The addition of STP results in an increase in the product’s ultimate pH moving it further from the iso-electric point. The addition of more negatively charged hydrogen ions allows for more spacing in the sarcomere (adding space between the actin and myosin proteins) permitting more capillary action, thus increasing WHC. Moreover, the addition of STP also results in a darker appearance as a result of the increased pH. In addition to STP, salt has historically been one of the most commonly used non-meat ingredients in the packing industry. Salt was predominantly used as a preservative for meat when refrigeration was not available. Salt, like STP, helps to increase WHC by lowering the iso-electric point of meat proteins. However, different than STP, salt does this without changing the pH of the meat product, but by allowing proteins to swell to twice their size (proteins have this ability within salt concentrations commonly used in meat processing) in order to bind more water. The swelling occurs as the chloride ion increases the electrostatic repulsive forces of the proteins and as the protein structure matrix unfolds, swelling takes place. Furthermore, salt can also contribute to meat flavor as it has been associated with increased basic salt taste.

Sodium lactate was originally used to reduce the production of botulinum toxin and currently serves several purposes in enhancement solutions. Sodium lactate extends shelf life through provision of resistance in oxidation during storage due to an increase in pH of the product because an increased pH
indirectly protects myoglobin from moving from the ferrous state to the ferric state which would result in a change to metmyoglobin. Sodium lactate also functions to limit microbial growth and alters the impact of microbes on the oxidization of myoglobin. In limiting microbial growth, sodium lactate causes an increase in the lag phase of a microbe’s growth curve. This elongated lag phase allows for a delay in the onset of logarithmic microbial growth. Sodium lactate’s mode of action is two-fold: 1) the lactic acid portion of sodium lactate incorporates into the microbial cell, thereby interfering with normal metabolic processes, and 2) it lowers the water activity of the meat product, again slowing microbial growth.

When adding these non-meat ingredients, processors must label their products in accordance with USDA/FSIS regulations. Typically, most enhancement solutions are between 7 and 15% of the meat product’s original weight or “green weight”. If processors use less than 10%, the label can read as “marinated” or “deep basted”. However, if the product contains more than 10%, processors must label the product as “containing up to (the actual added level) % of a solution”. In both cases, such claims would be followed with an ingredient statement listed in order of predominance (Miller, 1999a).

Enhancement has been shown to improve the palatability attributes of resulting products. In a review of the literature (Prestat et al., 2002; Murphy and Zerby, 2003; Robbins et al., 2003; Sheard and Tali, 2004; Hayes et al., 2005; Wright et al., 2005), consumers have been shown to consistently prefer the flavor and tenderness properties of enhanced pork. Furthermore, in helping to
guarantee a pleasurable eating experience in a setting in which consumers consistently overcook their pork, enhancement protects eating quality. According to Prestat et al. (2002), enhancement (pumping) pork loins maintains sensory attributes of chops when cooked to abusive temperatures (80°C) with few detrimental effects on physical characteristics (Table 2.2).

COOKING – METHOD AND ENDPOINT TEMPERATURE

Cooking method and endpoint temperature are determined by consumers or chefs and have been shown to influence the palatability of meat products (Lorenzen et al., 1999; Neely et al., 1999). Endpoint cooking temperature is significantly related to tenderness as measured by both objective and subjective methods. According to Norman et al. (2003) WBSF had a slightly positive correlation with cooked temperature ($P < 0.05$), indicating that a higher endpoint temperature will result in greater WBSF. The findings are in agreement with a multitude of studies (Cross et al., 1976; Boles et al., 1990; Heymann et al., 1990; Wheeler et al., 1994; Wulf et al., 1996; Savell et al., 1999; Prestat et al., 2002; Obuz et al., 2004). In the process of cooking meat, there are both tenderization and toughening processes that are taking place, all of which are time and temperature dependent. Initially, tenderization takes place due to collagen shrinkage, which decreases the collagen fibril strength and increases collagen
solubility. Conversely, if meat is rapidly heated at high temperatures (72° - 74°C) the collagen shrinkage is followed by protein hardening and thereby toughening of the product if the product is not allowed to remain heated at this high temperature for an elongated period (Aberle et al., 2001). Rincker et al. (2008) reported that as end-point cooking temperature increased, tenderness and juiciness both decreased while pork favor remained relatively constant. In addition to Rincker’s findings, it has been shown that endpoint cooking temperature is directly related to tenderness (Cross et al., 1976; Boles et al., 1990; Heymann et al., 1990; Wheeler et al., 1994; Wulf et al., 1996) (Table 2.3). While this concept is common knowledge among scientists within the field of meat science, consumers will still typically overcook their pork. This trend is likely linked to the recommendations of Food Safety and Inspection Services (FSIS) that suggests whole muscle pork be cooked to an endpoint internal temperature of 160 °F (USDA, 2007). In addition to a resulting loss of tenderness by overcooking meat products, there is an additional moisture loss during cooking to high endpoint temperatures (Boles et al., 1990) (Figure 2.3). According to Davis et al. (1975), chops with a higher initial percentage of moisture lost more weight during cooking, and were less juicy, less tender, and less satisfactory overall.

As it has been clearly demonstrated, endpoint cooking temperature has a direct relationship with tenderness and overall acceptability ratings. In addition to final internal temperature, there has a great deal of research evaluating the
effects that different cooking methodologies have on palatability. There has been a tremendous number of tenderness studies performed throughout the U.S. and World. In order for the results of these studies to be reliable, scientists must conduct their experiments in a manner that will not influence or alter treatment effects. Unfortunately, cooking method varies considerably among research reports, making interpretation of tenderness results difficult when comparing across studies. According to Cross et al. (1979), there is no difference in tenderness of beef steaks that were roasted or broiled. However, in contrast to this study, the AMSA (1995) guidelines for cookery, sensory, and tenderness measurements state that the use of high velocity, air convection cooking is not recommended as a research method because of inconsistency in the cooked product. Moreover, Wheeler et al. (1998) reported that the use of a belt grill in place of the electric broiler for cooking, when collecting research data, should increase precision of the evaluation of differences and lead to a more accurate interpretation of research results. In addition, Lawrence et al. (2001) reported, in a test comparing a belt-grill, forced-air convection, and electric broiler methods, repeatability estimates for the belt-grill and electric broiler were within the acceptable range for repeatability ($R \geq 0.60$) when compared with recommendations of the AMSA (1995). However, the forced-air convection method was deemed to be unacceptable with a repeatability ($R = 0.50$) level that was below the minimum required by AMSA (1995). Lawrence concluded that research cooking methodology for steaks should be highly repeatable without altering treatment effects. Shackelford et al. (2004) reported similar estimates of
 repeatability for open-hearth electric broilers and belt-grills (R = 0.61 and 0.59 respectively), with both techniques considered acceptable for research purposes. In reviewing the literature, there is no consistent cooking method utilized and no consensus among researchers on the most appropriate cooking methodology.

Researchers have also focused on the consumers’ methods of meat preparation and their respective effects on tenderness and overall acceptability. Savell et al. (1999) performed a study that evaluated cooking method and degree of doneness regarding meat palatability in beef. In this experiment, Savell (1999) found that indoor grilling resulted in the highest, most favorable ratings for all attributes but juiciness. Furthermore, Savell concluded that cooking method played an important role in how consumers ranked steaks based on degrees of doneness. For some cooking methods, as steaks were cooked to more advanced degrees of doneness palatability ratings declined. For other cooking methods, steaks cooked to well done or higher degrees of doneness received the highest ratings. Most consumers cooked the steaks at least to well done stage, and their satisfaction depended on the cooking method used to achieve this degree of doneness (Table 2.4).
OBJECTIVE TENDERNESS ASSESSMENT

The pork industry has improved tenderness of meat through postmortem handling including aging, enhancement, grinding, and additional further processing. However, in studying and developing these methods to improve tenderness, scientists must have a way to assess their treatments. The obvious technique for testing is by conducting consumer or trained sensory panels; however, these methods are extremely expensive and very laborious. In an attempt to find a mechanical method of assessing tenderness, the Warner-Bratzler shear force (WBSF) testing apparatus was developed (Warner, 1928, 1952; Bratzler, 1932, 1942, 1954) and has proven to be one of the most popular and acceptable methods in tenderness measurement. The WBSF method has been proven to be highly and favorably correlated with tenderness ratings of sensory panels (Shackelford et al., 1999b; Wheeler et al., 1994, 1996, 1997) (Figure 2.4).

Although the WBSF method has become the gold standard in meat tenderness assessment, it does come with some drawbacks. In conducting WBSF, researchers see a high degree of variation in the protocols institutions use to attain data (Wheeler et al., 1994). This study found that it is practically impossible to compare data from different institutions, particularly with reference to whether the shear force value indicates that the meat is tough or tender.
Furthermore, the factor affecting shear force the most was core orientation as obtaining 1.27 cm diameter cores parallel to the fiber orientation of the muscle rather than perpendicular to the steak surface. It was shown that when a core was taken improperly (perpendicular to orientation of muscle fibers) the WBSF results had a 1.80 kg greater mean shear force value and a greater standard deviation than that of cores taken properly (parallel to the muscle fibers). In a follow-up study, Wheeler et al. (1997) found that when institutes follow a standard set of protocols it was possible to obtain the same mean shear force and have a high repeatability; if a standard protocol was properly executed with calibrated equipment. For this reason, Wheeler et al. (2005) produced Warner-Bratzler Shear Force Protocols. In addition to the differing protocols that are followed, WBSF is also extremely laborious and has a vast opportunity for operator error due to fatigue (Wheeler et al., 1994, 1996, 1997). In developing a method for on-line assessment of meat tenderness, Shackelford et al. (1999a) developed a simplified technique for measuring longissimus shear force referred to as slice shear force (SSF) that is technically simpler with less opportunity for operator error than that seen within WBSF.

Shackelford (1999b) was responsible for development of SSF procedures and processes and proceeded to test a number of different methods to define the optimal set of conditions under which SSF would provide the greatest degree of accuracy and repeatability. Through the research, SSF was tested on steaks that were classified as 'hot' corresponding to a peak cooked temperature as well
at a ‘cold’ temperatures classified as holding steaks at 4°C for 24 hours. Shackelford found that “hot” SSF samples were more highly correlated with WBSF and taste panel tenderness ratings when compared to “cold” SSF samples. Furthermore, the correlation of “hot” SSF was more strongly related to taste panel ratings than WBSF values (Table 2.5). Moreover, when comparing SSF to WBSF, SSF was more strongly correlated with sensory panel ratings than that of WBSF (Figure 2.4 vs. Figure 2.5). Thus, SSF seems to be a more accurate method of measuring shear force than the Warner-Bratzler technique. Additionally, WBSF values were grouped closer to their respective means than SSF values. Ninety-one percent of WBSF values were within ± 30% of the mean WBSF value, whereas 71% of SSF values were within ± 30% of the mean SSF value. The tendency of WBSF values to be grouped close to the overall mean WBSF value may limit the ability of WBSF to predict the taste panel tenderness rating (Shackelford et al., 1999b). Also, in testing the repeatability of SSF, Shackelford showed that SSF was extremely repeatable ($R = 0.91$, Figure 2.6) when assessed in a sample of 110 beef longissimus steaks. The authors went on to conclude that when comparing WBSF procedures to that of SSF, slice shear force is technically simpler, less laborious, and more accurate, and it is likely that SSF values would be less operator dependent than WBSF values (Shackelford et al., 1999b). Shackelford et al. (2004) went on to provide evidence that SSF worked equally as well in identifying tenderness values of pork longissimus. The investigators showed that SSF was again highly repeatable ($R = 0.90$, $n = 744$) and accurate, as SSF was slightly more strongly
correlated with sensory panel tenderness than was WBSF ($r = -0.72$ and $r = -0.66$, respectively). Shackelford et al., (1999b) determined that the process of slice acquisition is completed in a few seconds rather than the approximately 5 min/sample that is required to determine fiber angle and obtain six “good” cores for WBSF. The finding that SSF will provide a highly repeatable measurement of pork longissimus tenderness indicates that researchers can make use of this tool in pork tenderness research and substantially decrease research costs. In contrast to these findings, Shackelford et al. (2004b) found that when testing lamb longissimus samples, WBSF had a higher repeatability estimate than that of SSF. Shackelford obtained additional data that supported earlier research that showed SSF to be highly repeatable ($R = 0.95$), obtaining similar numbers to that of work performed in 1999 (Shackelford et al., 2004b). In a further investigation of repeatability of SSF, Wheeler et al. (2007) evaluated the inherent differences that may exist from different institutions performing SSF. Wheeler showed that when comparing results from earlier work (Wheeler et al., 1997) that: although results were not directly comparable, results from institutions common to that study (1997) and the one reported in this paper (2007) indicate that SSF may be a more repeatable measure of tenderness than WBSF. In addition to these findings, Wheeler also reported that selection of steak location did play a role in tenderness ratings repeatability. Also, Wheeler showed that when conducting SSF, steaks should be selected from locations 6 to 25 (Figure 2.7) when testing. Moreover, Homm et al. (2005) reported that when chops taken from the posterior location of the longissimus where tested, they had the lowest WBSF value. Also,
when chops where tested from the central anterior location, they had a lower 
WBSF value than that of the central posterior chop location. In addition, Rust et 
al. (1972) demonstrated that there was no significant difference \( (P > 0.5) \) in 
juiciness or tenderness rankings in chops taken at various locations within a loin. 
However, Rust (1972) did show that there was a significant \( (P < 0.1) \) difference 
found in tenderness, juiciness, and shear values of samples taken from various 
positions within the chop.

In conclusion, tenderness assessment has been proven to be an 
important aspect of meat quality and consumer acceptance. In studying various 
effects on tenderness, researchers must be concerned with maintaining 
procedures that attain the most accurate and repeatable results. As new 
technologies emerge, scientists must test these applications and understand 
their role within the meat industry. Slice shear force is a new technology with 
reference to pork tenderness assessment. This study will evaluate SSF as a 
predictor of pork tenderness in comparison to WBSF, consumer panels and 
trained consumer panels.
<table>
<thead>
<tr>
<th>Muscle</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>CV, %</th>
<th>Min</th>
<th>Max</th>
<th>Correlation to longissimus</th>
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<tbody>
<tr>
<td>Psoas major</td>
<td>49</td>
<td>2.6</td>
<td>0.4</td>
<td>16.5</td>
<td>1.7</td>
<td>3.5</td>
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<td>Infraspinatus</td>
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<td>2.8</td>
<td>0.5</td>
<td>19.6</td>
<td>1.7</td>
<td>4.4</td>
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<td>4.2</td>
<td>0.9</td>
<td>22.3</td>
<td>2.7</td>
<td>7.0</td>
<td>0.56***</td>
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<td>Longissimus</td>
<td>49</td>
<td>5.1</td>
<td>1.3</td>
<td>25.7</td>
<td>2.9</td>
<td>8.7</td>
<td>-</td>
</tr>
<tr>
<td>Semitendinosus</td>
<td>49</td>
<td>3.9</td>
<td>0.7</td>
<td>17.5</td>
<td>2.4</td>
<td>5.2</td>
<td>0.13</td>
</tr>
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<td>Gluteus medius</td>
<td>49</td>
<td>4.2</td>
<td>1.0</td>
<td>23.1</td>
<td>2.5</td>
<td>7.0</td>
<td>0.40**</td>
</tr>
<tr>
<td>Supraspinatus</td>
<td>49</td>
<td>4.0</td>
<td>0.8</td>
<td>18.9</td>
<td>2.8</td>
<td>5.9</td>
<td>0.42**</td>
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<td>Biceps femoris</td>
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<td>0.43**</td>
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<td>7.8</td>
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<td>Quadriceps femoris</td>
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<td>4.1</td>
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<td>22.0</td>
<td>2.2</td>
<td>6.9</td>
<td>0.33*</td>
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</table>

*P < .05; **P < .01; ***P < .001

Table 2.1. Variation in shear force of various muscles and correlation of shear force of each muscle to shear force of longissimus

Shackelford et al., 1995
Table 2.2.  Endpoint temperature effects on characteristics of pork loin

Prestat et al., 2002

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>70°C</th>
<th>80°C</th>
<th>SEM&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pork flavor&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>83.45</td>
<td>87.24</td>
<td>2.15</td>
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<tr>
<td>Off-flavor&lt;sup&gt;b&lt;/sup&gt;</td>
<td>51.16&lt;sub&gt;a&lt;/sub&gt;</td>
<td>42.81&lt;sub&gt;b&lt;/sub&gt;</td>
<td>2.47</td>
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<tr>
<td>Tenderness&lt;sup&gt;b&lt;/sup&gt;</td>
<td>84.32</td>
<td>84.00</td>
<td>2.23</td>
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<td>Juiciness&lt;sup&gt;b,c&lt;/sup&gt;</td>
<td>85.18</td>
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<td>Shear (kg)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.94</td>
<td>3.78</td>
<td>0.17</td>
</tr>
</tbody>
</table>

<sup>a</sup> Standard error of the mean; <sup>b</sup> Sensory scale: 0 = none; 150 = intense; <sup>c</sup> Significant (P < 0.05) pump x temperature and pump x cooking method interactions occurred for this characteristic

Table 2.3.  Mean percentage cook yield of pork chops cooked to two end-point temperatures

Boles et al., 1900

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Cook yield, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>71</td>
<td>69.5 +/- 0.9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>77</td>
<td>64.4 +/- 0.9&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b</sup> Means with different superscripts in the same column differ (P < 0.05).
### Table 2.4. Least squares means for cooking method x degree of doneness effect on tenderness ratings (23 = extremely tender; 1 = not at all tender)

<table>
<thead>
<tr>
<th>Cooking method</th>
<th>Medium rare or less</th>
<th>Medium</th>
<th>Medium well</th>
<th>Well done or more</th>
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<tr>
<td>Outdoor grill</td>
<td>18.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>17.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>17.6&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>17.2&lt;sup&gt;cd&lt;/sup&gt;</td>
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<td>17.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>16.8&lt;sup&gt;d&lt;/sup&gt;</td>
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<tr>
<td>Indoor grill</td>
<td>18.4&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>18.0&lt;sup&gt;ab&lt;/sup&gt;</td>
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<td>17.8&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>17.5&lt;sup&gt;bc&lt;/sup&gt;</td>
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</tr>
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<td>17.1&lt;sup&gt;ca&lt;/sup&gt;</td>
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<td>18.2&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Simmer and stew</td>
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<td>17.9&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>17.8&lt;sup&gt;bc&lt;/sup&gt;</td>
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<td>18.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>18.3&lt;sup&gt;ab&lt;/sup&gt;</td>
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<sup>a,b,c,d</sup> Means lacking a common superscript letter differ ($P < 0.05$).

<sup>e</sup> Other cooking methods included oven-roasted uncovered, pan-broil, braise, and deep-fry. These cooking methods were used infrequently by the consumers in this study.

Savell et al., 1999
<table>
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<tr>
<th>Belt grill cooking rate</th>
<th>Trait</th>
<th>n</th>
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<th>SD</th>
<th>Min</th>
<th>Max</th>
<th>Correlation to</th>
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<td>10.2</td>
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<td>3.1</td>
<td>11.5</td>
<td>24.3</td>
<td>.68***, -.57***</td>
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<td>-</td>
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*Warner-Bratzler shear force; †Trained sensory panel tenderness rating; ***P < 0.001

Table 2.5. Effect of belt grill time and temperature settings and conditions of slice shear force measurement on simple statistics of slice shear force and the correlation of slice shear force with Warner-Bratzler shear force and trained sensory panel tenderness ratings

Shackleford *et al.*, 1999

Aberle et al., (2001)
Figure 2.2. Isometric tension development in muscle during phases of rigor mortis

Aberle et al., (2001)
Figure 2.3. Effects of degree of doneness and meat cut on shear force of cooked steaks

Wulf et al., 1996
Figure 2.4. Correlations of Warner Bratzler shear force with sensory panel tenderness rating.

Shackelford et al., 1999
Figure 2.5. Correlation of slice shear force with sensory panel tenderness ratings.

Shackleford et al., 1999
Figure 2.6. Repeatability of slice shear force in measuring beef LM

Shackleford et al., 1999
Figure 2.7. Location within the longissimus thoracis et lumborum of steaks used for experiments 1 (steaks 1 to 25) and 2 (steaks 7 to 20)

Wheeler et al., 2007
CHAPTER 3

COMPARISON OF SLICE SHEAR FORCE WITH WARNER BRATZLER SHEAR FORCE AS PREDICTORS OF CONSUMER PANEL PALATABILITY MEASURES IN NON-ENHANCED AND ENHANCED PORK LOIN CHOPS

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ABSTRACT

The present experiment evaluated the relationship between slice shear force (SSF) and Warner-Bratzler shear force (WBSF) as methods to determine pork tenderness and consumer sensory palatability measures. Data set one consisted of chops derived from non-enhanced pork loins (n = 607), that were purposely selected to vary in color, pH, and intramuscular fat. Data set two consisted of non-enhanced (n = 213) and enhanced (n = 207; 10% pump, 0.35% Sodium Phosphate, 0.35% Salt, and 2.25% Potassium Lactate) loins paired prior to enhancement based on similarity in pork color, pH, and intramuscular fat and alternately assigned to the enhancement treatment. Using classification criteria based on pork quality, the most posterior chop from a loin was alternately assigned to a cooked temperature of either 68.3°C or 73.8°C. Consumer palatability measurements (n = 2280 consumers, 9100 observations) and WBSF were assessed on chops from the same loin cooked to the same temperature. All chops were cooked using clam-style, George Foreman grills. Data were analyzed using correlation and mixed model procedures of SAS. Measurement scale differences for SSF and WBSF required assessment of results on a standard deviation unit basis. The correlation between SSF and WBSF within
the non-enhanced data set were only moderate, but were greater \((r = 0.62)\) at a cooked temperature of 73.8°C when compared with 68.3°C \((r = 0.49)\). Temperature did not have a significant effect on consumer palatability measurements. Predicted consumer tenderness and overall like ratings were similar across the range for both WBSF and SSF methods of tenderness assessment, but tenderness and overall like ratings declined by 0.53 and 0.32 units (8-point scale), respectively, as both SSF and WBSF increased in standard deviation unit increments from lowest to greatest. Within the non-enhanced and enhanced paired loin data set, correlations between SSF and WBSF for enhanced chops were low at a cooked temperature of 68.3°C \((r = 0.27)\) and increased somewhat at 73.8°C \((r = 0.48)\). In the paired non-enhanced loins, the correlations between SSF and WBS were 0.44 and 0.58 at 68.3°C and 73.8°C, respectively, similar in level to the moderate relationships observed in the larger non-enhanced data set. Enhancement improved consumer tenderness ratings by 1.00 unit when comparing ratings at each level on SSF range and 0.68 units when comparing at each level of the WBSF range. However, although the enhancement effect was larger at a given point for SSF when compared with WBSF, a standard incremental increase in WBSF resulted in a 0.51 unit reduction in consumer tenderness ratings compared to a 0.34 unit reduction for SSF. For overall like, a similar pattern of response was observed, with incremental changes in WBSF resulting in greater changes in consumer perception when compared with a standard unit change in SSF. These results suggest that WBSF and SSF are only moderately related as objective methods of
tenderness assessment indicating they are not measuring the same characteristics. In addition, WBSF, particularly when comparing enhanced and non-enhanced loins, was able to more effectively discriminate tough from tender at the consumer level than was SSF. Based on the observations from the present study, WBSF appears to be a more robust method of objective tenderness assessment.
INTRODUCTION

Tenderness has been shown to have a dramatic influence on the overall perception of pork longissimus palatability in both consumer (Rust et al., 1972; Enfalt et al., 1997; D’Souza et al., 2002; Bryhni et al., 2003; Aaslyin et al., 2007) and trained sensory (Van Oeckel et al., 1999; Wheeler et al., 2002; Norman et al., 2003; Shackelford et al., 2004) panel evaluations. While consumer and trained panel perceptions are critical to understanding variation in tenderness, the cost associated with conducting panel experimentation is often high due to the extensive amount of time and expense involved in recruiting and conducting consumer panels and the extensive effort involved in training and maintaining highly qualified trained panels. Efforts to predict or assess the human perception of tenderness through mechanical measurements of tenderness have included the use of Warner Bratzler shear force (WBSF) (Rust et al., 1972; Hodgson et al., 1991; Wheeler et al., 1994; Van Oeckel et al., 1999; Wheeler et al., 2002; Norman et al., 2003; Huidobro et al., 2004) and the Instron press (Wheeler et al., 1994; Lonergan et al., 1995; Stalder, et al., 1998) which have been shown to have quite variable relationships with consumer or trained panel ratings including low (Shackelford et al., 1997; Wheeler et al., 2002; Huidobro et al., 2004),
moderate (Van Oeckel et al., 1999; Shackelford et al., 1999b; Platter et al., 2003) as well as high (Shackelford et al., 1999a, Wheeler et al., 2002, Shackelford et al., 2004) relationships when assessing meat tenderness. Challenges to the use of WBSF methods include the extra time required to cool samples prior to assessment, the inconsistent nature and variability in tenderness among cores from within a chop, and difference in opinion regarding the number of cores required for assessment of tenderness. Recently, a new mechanical method of tenderness assessment, slice shear force (SSF), was developed as an alternative to WBSF and has been shown to be an accurate and repeatable methodology for mechanical evaluation of tenderness within beef (Shackelford et al., 1999b). The SSF methodology involves a single measure of force on a section of muscle removed from the chop while it is still hot and thus allowing rapid assessment on a large number of samples in shorter period of time. The implications of a rapid, accurate assessment of tenderness of pork may lead to in-plant evaluation systems that may allow categorization of tenderness and specification of products to a targeted end use.

Limited research assessing the tenderness of pork loin has shown that the relationship between SSF and trained panel tenderness in pork loins is $r = -0.77$ (Shackelford et al., 2004). Additional research is needed to assess the relationships between SSF, WBSF, and consumer palatability traits of pork loins that vary in fresh pork quality attributes as well as the influence of cooked temperature on mechanical measurements of tenderness. In addition, no
research has been reported assessing the influence of loin enhancement on the relationships between SSF, WBSF and consumer palatability measures. Therefore, the objectives of the present study were: 1) evaluate the relationship between SSF and WBSF on chops derived from non-enhanced pork loins with known variation in fresh pork quality attributes (loin ultimate pH (pH), Minolta color (L*), and chemical intramuscular fat percentage(IMF)) when assessed at two cooked temperatures (68.3°C and 73.8°C); 2) evaluate the associations between consumer palatability traits and measures of WBSF and SSF in non-enhanced pork chops assessed at two cooked temperatures (68.3°C or 73.8°C); 3) assess the relationship between SSF and WBS in enhanced and non-enhanced loin chops, derived from loins paired by similarity in fresh pork characteristics (L*, IMF, and pH) when assessed at two cooked temperatures (68.3°C or 73.8°C); and 4) evaluate the associations between consumer palatability traits and SSF and WBSF for paired enhanced and non-enhanced pork loin chops assessed at two cooked temperatures (68.3°C or 73.8°C).

MATERIALS AND METHODS

Loin selection procedures

The present study was conducted in conjunction with the National Pork Board’s Pork Quality Benchmarking Study, funded through the national pork check-off program. Pork loins (n = 826) utilized in the present study were
collected in three commercial U.S. pork packing facilities in nearly equal proportions in an attempt to represent the industry variation in type, genetic background, and size of pigs produced and harvested in the U.S.

Pork loins were selected within a packing facility to assess the overall variation in, and combinations of, fresh pork loin quality attributes observed in the pork industry for the purpose of evaluating the influence of individual traits and combinations of traits on consumer perceptions of pork palatability. Selection was based on measures of 24 h ultimate pH (pH), marbling score, and Minolta L* (L*) color. Chemically derived intramuscular fat (IMF) was used in final loin classification in substitution for marbling score. A 3 x 3 x 3 classification arrangement of pH, IMF, and L* was used create a near uniform number of loins represented within each subclass for subsequent consumer palatability assessment and mechanical tenderness evaluation utilizing Warner-Bratzler Shear and Slice Shear Force (SSF) methodologies.

To assess the impact of enhancement on consumer palatability and mechanical tenderness, loins within one packing facility were selected and paired based on pork quality measurements followed by random allocation within a pair to an enhancement (n=207) or non-enhancement (n=213) treatment. Enhancement was completed using needle injection. Final loin target inclusion rates were: 10% pump rate, 2.5% potassium lactate, 0.35% sodium phosphate, and 0.35% salt, inclusion rates that were chosen to represent the industry
average levels. Pump yields were calculated based on loin weight prior to and following injection.

Selected loins were individually vacuum packaged, weighed and shipped under refrigeration by Ohio State University personnel to The Ohio State University Meat Sciences Laboratory. Loins were stored and aged at 2 °C for 7 to 10 days.

Loin quality assessment

Whole, boneless loins were collected along the fabrication line at approximately 24 h postmortem. Using the size of the spinalis dorsi muscle as an anatomical indicator, the loin was cut at approximately the 7th rib and the cut surface was allowed to bloom for 10 min. Loin pH was measured using a portable pH meter (HI98240, Hanna Instruments, Italy) equipped with a glass-tipped pH probe (FC201D, Hanna Instruments, Italy) inserted approximately 1 cm under the cut surface and placed in the center of the longissimus muscle at the exposed 7th rib loin surface. After bloom, loin color was measured on the exposed 7th rib loin surface using a Minolta Colorimeter (CR-310, 50 mm diameter orifice, 10° standard observer, D65 light source; Minolta Company, Ramsey, New Jersey) recording L*, a* and b* values. Subjective visual color and marbling scores were collected by trained personnel using a 1 to 6 scale as outlined by the National Pork Producer Council (NPPC, 2000). A 1.25 cm-thick section of loin was cut immediately posterior to the 7th rib exposed location,
subcutaneous fat and connective tissue were removed, and the remaining muscle sample was packaged for subsequent assessment of IMF by the ether extract method using AOAC (2007) procedures.

For the IMF sample, moisture and fat amounts were attained by the air-dry oven and Soxhlet ether extraction methods, respectively. Approximately 2 g of powdered sample from each chop was added to dried, pre-weighed thimbles (filter paper #1, Whatman®, Maidstone, England) and weights were recorded. Analysis of the samples was performed in triplicate. The samples were dried in a convection oven at 100 °C for 18-24 h then removed and placed in a desiccator for cooling. Weights were taken and recorded to determine percent moisture. Samples were placed in a Soxhlet apparatus and refluxed with petroleum ether for approximately 18 h. Samples were removed and placed under a hood to allow ether to evaporate, and placed in a convection oven for approximately 12 h. Samples were removed and placed in a desiccator until cooled to room temperature. Weights were taken and recorded to determine percent fat in each sample.

*Loin processing*

Loin processing and slicing occurred on the Friday following the previous sampling week. Loins were removed from packaging and weighed to assess purge loss. Loins were then placed on racks into a -28.8° C freezer to temper the loin and allow for uniform slicing. Beginning at the anterior end, loins were sliced
into a total of 13, 2.54 cm thick chops. The 12 most anterior chops were subsequently randomly assigned to one of three experimental design end-points: 1) consumer sensory evaluation, 2) trained sensory evaluation, or 3) Warner Bratzler shear force (WBSF) assessment. Within each end-point design end-point, chops were randomly assigned to one of four end-point cooked temperatures (62.8 °C, 68.3 °C, 73.9 °C, or 79.4 °C). Random assignment of chops to a destination and end-point cooked temperature was designed to avoid potential confounding of chop location within the loin with the classification criteria for pork quality data that was collected at the ~ 7th rib location.

The 13th chop (posterior end), was designated for use in the SSF experiment. Slice shear force chops (one per loin) sorted based on loin quality indicators (pH, IMF, and L*) and alternately assigned to a designated endpoint cooked temperature (68.3° C or 73.8° C) to balance loin quality attributes across cooked temperature and allow comparisons among WBSF and consumer evaluations conducted on chops from the same loin.

After slicing and designation to treatment, loin chops were individually vacuum packaged using a roll-stock machine. Chops were frozen at -28.8° C until used in their respective experimental design endpoint.

*Mechanical tenderness assessment*

Loin chops were weighed prior to and after thawing to assess thaw purge. Chops were cooked using a clam-style cooker (George Foreman grill) to the
designated internal temperature. Internal temperatures (Digi-sense, Model # 277653 or equivalent) were monitored by copper constant thermocouplers (Digi-sense, K-type probe, 30.48 cm x 1.016 cm diameter, Code 93631-11 or equivalent) inserted into the geometric center of each chop. Chops were removed from the grill at the designated temperature with cooking time, temperature, and cooked chop weight recorded. Cook loss was measured using pre- and post-cooked weights.

For WBSF assessment, chops were cooled for four hours to a temperature of approximately 22.2 °C. Six, 1.27 cm diameter cores were removed from each chop parallel to the longitudinal orientation of the muscle fibers. Each core was sheared with a Warner-Bratzler shearing device (Model TA.XT2plus, Texture Technologies, Scarsdale, New York) with a probe travel distance of 40 mm from the base, a pre-test speed of 5 mm/s, a test speed was 3.33 mm/s and a post-test speed of 20 mm/s. Warner Bratzler Shear Force (kg) was analyzed as the mean of six core measurements.

For SSF assessment, cooked chops were allowed to equilibrate until the internal temperature reached a peak (~1 to 2 minutes). A slice (1 cm thick × 5 cm long) was removed using a double bladed knife and the “slice box”. The slice was removed at a 45° angle that was consistent with the longitudinal orientation of the muscle fibers as described in the procedures outlined by Shackelford et al. (1999). The muscle slice was then immediately sheared using a flat, blunt–
ended blade (Shackelford et al., 1999) shearing device (Model TA.XT2\textsuperscript{plus}) with a crosshead speed of 500 mm/min. Maximum force (kg) was recorded.

**Consumer evaluation**

Consumer taste panels were conducted in three cities; Chicago IL, Philadelphia, PA, and Sacramento, CA. Consumer recruitment was conducted via telephone interview. Recruitment parameters included: primary household grocery shoppers, females aged 25 to 49, annual household income of $30,000+, and presence of children under 16 in the household. Male pork consumers were included in this study with a target representation of 35% to 40% of the total respondents. All respondents were regular pork consumers. Within a city, 760 consumers were secured for a total of 2280 consumers polled. Consumer evaluations occurred over a two week period in each city, with 20 consumers in each testing session and 38 sessions conducted per city. Sessions were approximately 45 min in length.

Consumers were provided samples from eight different chops with five different consumers assessing each chop. Chops were assigned to sessions using the following criteria: 1) each consumer was provided non-enhanced samples representing two chops from each packing plant (three plants represented) to balance for plant of origin, 2) each consumer was provided samples from two chops that had been enhanced, 3) chops were randomly assigned across cooked temperature and quality classification within each plant.
for both enhanced and non-enhanced chops, and 4) serving order was randomized across the eight chops assigned to a group of five respondents. Chops were cooked using the method described previously for assessment of WBSF and SSF, to their respective target internal temperature. Cooked yield, cook time, and final temperature were recorded. Immediately after cooking, chops were cut into 1.27 cm width x 1.27 cm length x 2.54 cm height cubes. A consumer sample represented two cubes provided in a serving boat.

Samples were served under red incandescent lighting to minimize sample color differences due to differing end-point cooked temperatures. Consumers were asked to cleanse their pallet prior to the first and between samples with an unsalted, saltine cracker and distilled water. The consumer ballot consisted of seven questions measured on an 8-point, end-anchored scale with the consumer marking the box of their choice. Following the ballot order, the questions were: Overall Like/Dislike, 1 = Dislike Extremely and 8 = Like Extremely; Juiciness Like/Dislike, 1 = Dislike Extremely and 8 = Like Extremely; Level of Juiciness, 1 = Extremely Dry and 8 = Extremely Juicy; Tenderness Like/Dislike, 1 = Dislike Extremely and 8 = Like Extremely; Level of Tenderness, 1 = Extremely Tough and 8 = Extremely Tender; Flavor Like/Dislike, 1 = Dislike Extremely and 8 = Like Extremely; Level of Flavor, 1 = Extremely Bland or No Flavor and 8 = Extremely Flavorful. The final ballot question asked: How likely would you be to purchase this sample if it were available at a reasonable price in your area? Likelihood of Purchase response options were: Definitely Would Not Buy,
Probably Would Not Buy, May or May Not Buy, Probably Would Buy, and Definitely Would Buy, which were labeled for data analyses as numbers 1 through 5, respectively. Data were analyzed using the mean of the five consumer responses.

Statistical Analysis

Correlation and frequency analyses were used to assess the relationships between mechanical measures of tenderness (WBSF and SSF) and measures of pork quality (pH, L*, IMF, color score, marbling score), consumer palatability (tenderness, juiciness, flavor, overall like) and intent to purchase at each cooked temperature (68.3º C or 73.8º C). Similar correlation analyses were used to assess the associations between traits of interest for enhanced loins when compared with the paired non-enhanced loin at each cooked temperature.

For the purpose of analyzing variation in SSF and WBSF, which are measured on different measurement scales, the coefficient of variation (CV) statistic was computed within the sample populations being studied. The CVs for WBSF and SSF in the non-enhanced sample population at a cooked temperature of 68.3º C were 24.1% and 28.4% and at cooked temperature of 73.8º C were 25.6% and 28.7%, respectively. Because variation around the mean was similar for WBSF and SSF at each cooked temperature, the relationships between WBSF and SSF with consumer palatability traits were analyzed in standard deviation units, including predictions of responses at the mean and at one and
two standard deviations above and below the mean, allowing for a direct comparison among SSF and WBS on a similar scale of measurement.

Mixed model procedures of SAS (2006) were used to estimate the independent effects of SSF and WBSF, individually, along with cooked temperature on dependent consumer palatability attributes. Preliminary results indicated cooked temperature was not a significant effect for any palatability attribute. However, cooked temperature remained in the mixed model to allow estimation of least squares means and standard errors for each dependent variable at each cooked temperature along the standard deviation scale. For reporting purposes, least squares means and standard errors were averaged across temperatures at each point along the standard deviation scale.

Within the paired non-enhanced and enhanced sample population, the CVs for WBSF and SSF in enhanced chops at a cooked temperature of 68.3°C were 25.3% and 29.6%, respectively, and for non-enhanced chops cooked to 68.3°C the CVs were 21.4% and 25.2%, respectively. The CVs for WBSF and SSF in enhanced chops at a cooked temperature of 73.8°C were 19.9% and 21.5%, respectively, and for non-enhanced chops at a cooked temperature of 73.8°C the CVs were 23.9% and 21.3%, respectively. Because variation around the mean was similar for both enhanced and non-enhanced chops across cooked temperatures, the relationships of WBSF and SSF with consumer palatability traits were analyzed in standard deviation units, including predictions of responses at the mean and at one and two standard deviations above and
below the mean, allowing for a direct comparison among SSF and WBS on a similar scale of measurement.

Mixed model procedures of SAS (2006) were used to estimate the independent effects of SSF and WBSF, cooked temperature, and enhancement treatment on dependent consumer palatability attributes. Preliminary results indicated cooked temperature was not a significant effect for any palatability attribute and the effect was removed from the analyses. Least squares means and standard errors for each were estimated for each enhancement treatment at the respective mean and at one and two standard deviations above and below the mean for both WBSF and SSF measurements.
RESULTS AND DISCUSSION

Non-enhanced loins

Table 3.1 provides summary statistics for LM quality attributes including objective measurements of tenderness (SSF and WBSF) from non-enhanced chops and mean consumer responses for chops from each LM when cooked to 68.3° C and 73.8° C. In the present data set, the CV for SSF at 68.3° C (28.4%) was slightly greater than the CV for WBSF (24.1%) while at a cooked temperature of the 73.8° C the CV of SSF (28.7%) was also slightly greater than the CV of WBSF (25.6%). These findings were similar to previous research reports (Shackelford, et al. 1999) that indicated the CV of WBSF ranged from 20.8% to 23.1% and the CV for SSF% ranged from 32.5% to 34.4% in beef LM steaks. In an assessment of pork LM tenderness, Shackelford et al. (2004) reported the CV of SSF (31.7%) was greater than that of WBSF (20.0%). In the present study, the frequency distribution of chops assessed across both cooked temperatures (Figure 3.1) was very similar when presented relative to the respective standard deviation units for SSF and WBSF. While the larger CV for SSF in the present study may create a slightly wider range and variance for SSF when compared with WBSF, a 3 to 4% increase in the CV was deemed feasible for comparison of SSF and WBSF in standard deviation units.

Relationships between mechanical tenderness assessment methods (Table 3.2) for non-enhanced chops indicated that WBSF and SSF were moderately correlated at a cooked temperature of 68.3° C (r = 0.49), with a slight
improvement in the relationship (r = 0.62) when chops were cooked to a greater
degree of doneness (73.8º C). Previous research (Shackelford et al., 1999) has
shown the correlation between SSF and WBSF to range from r = 0.65 to 0.68 for
cold SSF of beef steaks cooked using a belt grill at very rapid and rapid cooking
rates, respectively. They reported a substantial improvement in the correlation
between SSF and WBSF (r = 0.80 to 0.87) when SSF was measured on the hot
beef steak cooked at a rapid and very rapid rate, respectively. Of note, the
correlation coefficients observed by Shackelford et al. (1999) were on beef
steaks representing 30 animals, with steaks collected representing adjacent cuts
within the LM. In contrast, within the present study, SSF chops represented the
most posterior LM chop, confounding the location of SSF with respect to the
randomly assigned chops cooked for WBSF assessment. Wheeler et al. (2007)
tested the repeatability of SSF from beef steaks taken from different portions of
the beef LM, and suggested that when conducting tenderness studies,
researchers should evaluate steaks taken nearer to the anterior rather than the
posterior of the LM. Previous research has indicated that chops represented
from the posterior end of the pork LM had lower shear force (Homm et al., 2005);
however, the authors feel confident, based on the limited reporting of information
regarding SSF use in pork and the similarity in the frequency distribution of LM
chop between SSF and WBSF, that the comparisons utilized in the present study
are valid indicators of associations and responses for the data set utilized. In
addition, the lower correlation coefficients observed in the present study
represented over 270 chops per cooked temperature × mechanical tenderness
technique subclass and included a significant range of and combination of fresh pork quality measures observed in the U.S. pork packing industry. Based on the moderate correlation coefficients observed in the present study, the results indicate that SSF and WBSF are likely measuring different attributes of the muscle and SSF may not be an adequate substitute for WBSF as an objective indicator of pork tenderness.

Of the fresh pork quality traits used to classify the loins utilized in the present study, SSF and WBSF were significantly correlated only with LM pH (Table 3.2) with correlations ranging from $r = -0.22$ to $r = -0.28$ across cooked temperatures, indicating that increased pH was associated with less WBSF and SSF. Enfalt et al. (1996) had previously reported a similar correlation between pH and WBSF of -0.29 in LM from pigs. Loin pH was moderately correlated with consumer perceptions of overall acceptability ($r = 0.20$ to 0.25), juiciness like and level ($r = 0.24$ to 0.30) and tenderness like and level ($r = 0.31$) across cooked temperatures indicating that greater LM pH was associated with an improved consumer perception of pork palatability. Consumer assessments of flavor characteristics were weakly ($r = 0.12$ to 0.17) or not significantly correlated with pH in the present study.

With the exception of a significant correlation between WBSF and marbling score ($r = -0.17$ at 68.3° C and $r = -0.19$ at 73.8° C), SSF and WBSF were not significantly correlated with measures of pork quality. These findings are in contrast with Enfalt et al. (1996) who reported IMF was highly negatively
correlated with WBSF ($r = -0.68$), but in agreement with a report by Rincker et al. (2007) who showed levels of marbling within pork LM chops did not account for much variation in sensory panel tenderness or juiciness even when cooked to high degrees of doneness ($80^\circ$ C) having an $R^2$ values of only 0.10 and 0.04, respectively.

At a cooked temperature of $68.3^\circ$ C, both SSF and WBSF were negatively correlated with consumer perceptions of palatability ($r = -0.26$ to -0.42), indicating that as SSF and WBSF increased (tougher) consumer responses were rated less favorable. At a cooked temperature of $73.8^\circ$ C, relationships for SSF and WBSF were very similar in magnitude and direction ($r = -0.32$ to -0.47) with those reported at $68.3^\circ$ C, providing evidence in the present data set that cooked temperature had a limited influence on consumer ratings in comparison with mechanical measures of tenderness. In all scenarios, correlations between mechanical measurements of tenderness were greater when assessing consumer ratings for level of tenderness ($r = -0.42$ at $68.3^\circ$ C and $r = -0.47$ at $73.8^\circ$ C). Using a data set designed to maximize variability in pork tenderness, Shackelford et al. (2004) reported greater correlations between consumer panel tenderness scores and SSF ($r = -0.72$) and WBSF ($r = -0.66$) than observed in the present study; however, given a sample size of only 23 loins, the correlations observed may be inflated as a function of a larger than normal variance in SSF and WBS which creates a concurrent and predictable divergent response in consumer perceptions. Shackelford et al. (1999a) reported the correlations of
WBSF and SSF of beef LM steaks with trained sensory panels were $r = -0.72$ and $r = -0.76$ on a set of 60 and 30 steaks, respectively which are much greater than observed in the present study. Enfalt et al. (1996) in an experiment using pork LM and comparing outdoor- and indoor-raised and sire effects reported the correlation between sensory panel score and WBSF was $r = -0.60$, while Van Oeckel et al. (1999) reported that the correlation between WBSF and sensory panel ratings varied from depending on WBSF method whereby LM chops cooked to an internal temperature of 74°C on a grill after storage for several months at -18°C had a correlation of -0.53 with trained panel scores for tenderness.

A consumer’s intent to purchase was positively and highly correlated with all other consumer palatability measures at both cooked temperatures, most notable, a consumer’s likelihood of purchase was highly correlated ($r = 0.87$ at 68.3°C and $r = 0.85$ at 73.8°C) with overall like. Likelihood of purchase was moderately associated with SSF ($r = -0.25$ to -0.29) and WBSF ($r = -0.28$ to -0.30) across temperatures, correlations that were similar to individual consumer perceptions of palatability.

Analysis of variance procedures to estimate the influence of cooked temperature and either SSF or WBSF on consumer response attributes indicated that cooked temperature was not a significant effect in the ANOVA model. However, to estimate the influence of WBSF or SSF on consumer response attributes, cooked temperature was included in the final models to allow
estimation of least squares means and to perform mean separation procedures for both WBSF and SSF measurements at their respective means and at points one and two standard deviations above and below the means. Figures 3.2 to 3.9 contain least squares means for SSF and WBSF averaged across cooked temperatures and are presented on the same graph for direct comparison.

Figures 3.2 and 3.3 describe the influence of incremental changes in SSF and WBS on the estimated consumer rating for tenderness like and tenderness level, respectively. Increasing SSF and WBSF by one standard deviation unit reduced the estimate of tenderness like levels by ~ 0.53 units and tenderness level ratings by ~ 0.55 units, resulting in predicted means for tenderness like and level being on the favorable side of the measurement scale only when SSF and WBSF values were one or more standard deviations below their respective mean levels. This finding clearly suggests that SSF and WBSF were able to predict similar consumer response levels for tenderness attributes in the present study. In addition, consumers had an unfavorable impression of chops measured at the mean and as SSF and WBSF increased above the mean. The figures show that tender pork was more desirable by sensory panelists while tougher pork was less desirable for consumers a relationship that has been shown in previous literature reports (Rust et al., 1972; Enfalt et al., 1997; D'Souza et al., 2002; Bryhni et al., 2003; Aaslyin et al., 2007).

Figures 3.4 and 3.5 describe the effect of incremental, standard deviation unit changes in SSF and WBSF on the estimated consumer rating for juiciness
like and level, respectively. Both SSF and WBSF had a similar, unit adjusted, rate of change per standard deviation unit for juiciness like (~ 0.40 units) and level (~0.42 units), following a trend similar to the effects observed for consumer tenderness ratings. Juiciness, while only moderately associated with SSF (r = 0.33 to 0.38) and WBSF (r = 0.34 to 0.37) was highly correlated with tenderness ratings across mechanical force assessment methods (r = 0.79 to 0.82) which may result in the similar patterns of estimated response at the consumer level.

Figures 3.6 and 3.7 describe the effect of incremental, standard deviation unit changes in SSF and WBSF on the estimated consumer rating for flavor like and level. Similar mean responses were observed for both SSF and WBSF as predictors of flavor components; however, incremental changes in SSF and WBSF resulted in relatively small, but significant (0.22 unit) changes in flavor response when compared with juiciness and tenderness attributes. Mean response levels for flavor attributes were less than five on the measurement scale, indicating consumers were not favorably rating flavor regardless of SSF or WBSF measurements.

Figure 3.8 describes the effect of incremental, standard deviation unit changes in SSF and WBSF on the estimated consumer rating for overall like/dislike. Both SSF and WBSF had a similar, unit adjusted, rate of change per standard deviation unit (- 0.31 and -0.34 units of overall like, respectively) and predicted mean responses that were very similar across the distribution of measurements. At the mean for SSF and WBSF, consumers rated chops just
under a five rating, a level considered on the undesirable side of the measurement scale. Reducing WBSF and SSF by one standard deviation (more tender) resulted in an improvement of the estimated overall like rating to a mean level of just over five on the 8-point scale, moving the responses to the favorable side of the measurement scale.

Within non-enhanced loins, selected for variation in LM IMF, pH, and L* color, the results of the present study suggest that variation in SSF and WBSF were similar relative to their respective means, and although the correlation between the measurements was not large, both methods were nearly equally effective in discriminating and describing variation in consumer palatability and probability of purchase attributes. Previous research (Shackelford et al., 1999b) has suggested that SSF, being less labor intensive and highly repeatable measure of tenderness may be a better measure than WBSF in research studies. Based on the results of the present study, SSF appears to have equal value when compared with WBSF for assessment of tenderness and the ability to predict consumer palatability attributes.

*Enhanced and non-enhanced loins*

Enhanced and non-enhanced paired loins summary statistics for LM quality attributes and objective measures of tenderness (SSF and WBSF) when averaged across both cook temperatures (68.3º C and 73.8º C) are presented in table 3.3. Similar to the non-enhanced loin results presented previously, the CV
for SSF of non-enhanced loins averaged across both cook temperatures (68.3º C and 73.8º C) was slightly larger (23.8%) than that of WBSF (22.6%). This relationship held true when paired loins were enhanced, with SSF continuing to have a slightly larger CV (26.1%) than WBSF (22.8%). In the present study, while the CV for SSF was slightly greater than that of WBSF, the frequency distribution of chops assessed across both cooked temperatures (Figure 3.11) was very similar when presented relative to the respective standard deviation units for SSF and WBSF.

In the present study (Table 3.3) non-enhanced chops had greater (tougher) SSF and WBSF values (10.97 and 2.52 kg, respectively) when compared with enhanced chops (7.92 and 1.62 kg, respectively). Consumer sensory responses further reinforced the effect of enhancement on palatability as ratings for enhanced chops averaged 1.38 units more favorable on an 8 point scale and averaged 0.88 units greater on a 5 point scale for probability of purchase when compared with the non-enhanced chops of similar pork quality. The improvement in consumer palatability attributes for enhanced chops is of great importance to the pork industry, because in the non-enhanced loins, only three of seven palatability attributes received mean ratings above 5, an indication that they were on the unfavorable side of the scale. Through enhancement, chops received mean consumer ratings of well above 5, moving the responses to the favorable side of the range. In agreement with these results, Prestat et al., 2002 showed that when pork was enhanced to a 10% pump level and cooked to
70.0° C, sensory ratings of pork flavor increased by 23 units, tenderness by 26 units, and juiciness by 14 units on a 150 mm line scale. Enhancement has been demonstrated to improve LM quality in previous studies (Wright et al., 2005; Baublits et al., 2006; Jensen et al., 2003; Hayes et al., 2006).

Ultimate pH of the paired loins, on average, prior to enhancement was equal (pH = 5.78) indicating that the pairing procedure was successful in assigning loins to treatments. Following enhancement, loin pH increased by 0.13 units (5.78 vs. 5.91), a level of change that was similar to previous research by Jensen et al. (2003) who reported a pH change of up to 0.21 units, Baublits et al. (2006) who showed a change of 0.14 units and Wright et al., 2005 who demonstrated a 0.11 unit change in pH.

Relationships of non-enhanced paired loins between mechanical tenderness assessment methods at both cook temperatures (68.3° C and 73.8° C; Table 3.4 and Table 3.5, respectively) indicate that the association of WBSF and SSF improved as cook temperature increased from 68.3° C to 73.8° C (r = 0.44 and r = 0.58, respectively). Sensory panels rating of palatability attributes showed that consumer’s evaluation of overall like/dislike was lowly and not significantly related to SSF at 73.8° C. However, consumer’s rating of overall like/dislike was significantly related to WBSF measures at both cook temperatures. Consumer’s assessments of juiciness (like and level) were significantly associated with SSF and WBSF at both cook temperatures. However, when chops were cooked to 73.8° C, the relationship between SSF...
juiciness attributes were lower and marginally significant ($P = 0.03$ and $0.04$) when compared to that of chops cooked to $68.3^\circ C$. Consumer tenderness attributes (like and level) associations with mechanical tenderness assessments were consistent for SSF and WBSF at both temperatures ($r = -0.33$ to $-0.41$). Sensory flavor ratings were not significantly related to either SSF or WBSF at both cook temperatures with the exception of a moderately significant ($P = 0.04$), low correlation ($r = -0.20$) between flavor level and WBSF at $68.3^\circ C$. Probability of purchase was not significantly correlated with SSF at either cook temperature. In contrast, WBSF was moderately correlated ($r = -0.25$) with likelihood of purchase at $68.3^\circ C$ and was marginally significantly correlated at $73.8^\circ C$ ($P = 0.03$, $r = -0.21$). Fresh pork loin quality attributes were only significantly related to SSF and WBSF within loin pH. Mechanical tenderness assessment (SSF and WBSF) was significantly correlated with loin pH at $73.8^\circ C$. However, only WBSF was significantly related to loin pH at $68.3^\circ C$.

Evaluation of enhanced paired loins relationships between mechanical tenderness measures and consumer palatability attributes at both cooked temperatures ($68.3^\circ C$ and $73.8^\circ C$; Table 3.4 and Table 3.5, respectively) indicate that the association between SSF and WBSF was stronger when chops were cooked to a greater degree of doneness ($r = 0.46$ at $73.8^\circ C$ and $r = 0.27$ at $68.3^\circ C$). This relationship may suggest that variation in SSF and WBSF increased in enhanced loins as cooked temperature increased. Consumer attribute ratings showed that WBSF was significantly and positively correlated
with measures of juiciness and tenderness at both cooked temperatures. In contrast, SSF was not significantly correlated with consumer measures of juiciness and was only marginally significantly correlated with tenderness level at both 68.3°C and 73.8°C ($P = 0.04$ and $0.08$; $r = -0.20$ and $-0.17$, respectively). Muscle quality measurements for enhanced loins were not significantly correlated with SSF or WBSF at each temperature, with the exception of correlations of SSF with $L^*$ ($P = 0.01$; $r = 0.23$), color ($P = 0.03$; $r = -0.20$) and loin pH ($P = 0.08$; $r = -0.17$) at 68.3°C and correlations of WBSF with loin pH ($P = 0.03$; $r = -0.21$) at 68.3°C.

Figures 3.11 and 3.12 describe the influence of SSF and WBSF for enhanced and non-enhanced loins, paired by fresh pork quality attributes pH, IMF, and $L^*$, on consumer responses for tenderness like and tenderness level, respectively. Enhancement improved predicted mean tenderness like ratings by 0.68 units for WBSF and 1.00 units for SSF when compared with the rating for non-enhanced loins with similar LM quality measures (Figure 3.11). Slightly greater responses were observed for predicted mean tenderness level ratings whereby enhancement increased ratings by 0.72 units for WBSF and 1.08 units when assessing SSF (Figure 3.12). Enhancement allowed consumer perceptions of tenderness like and level to maintain predicted mean responses, for both SSF and WBSF, of greater than five (favorable) across the variation present in the data set, while predicted mean responses for non-enhanced chops were less than five (unfavorable) for WBSF and SSF measured at one standard
deviation unit greater than the mean (tougher). Previous research (Wright et al., 2005; Baublits et al., 2006; Prestat et al., 2002; Jensen et al., 2003; Hayes et al., 2006) has also provided evidence of improved tenderness in enhanced LM.

The change in consumer responses with a one standard deviation change in WBSF for tenderness like (0.51 units) and tenderness level (0.57 units) were greater than the change observed in SSF per standard deviation unit change in tenderness like (0.34 units) and tenderness like (0.38 units), resulting in greater discrimination in consumer scores across the range of WBSF measures when compared with SSF measures on chops from the same LM. In both SSF and WBSF, a change of one standard unit resulted in significant changes in consumer responses for each unit change. Based on this observation, it appears that WBSF may be a more valuable measure of consumer assessment of tenderness than SSF.

Figures 3.13 and 3.14 represent the influence of SSF and WBSF for enhanced and non-enhanced loins, paired by fresh pork quality attributes pH, IMF, and L*, on consumer responses for juiciness like and juiciness level, respectively. Similar to the consumer responses for tenderness ratings, predicted mean responses were greater for enhanced chops and the difference between enhanced and non-enhanced chops was greater when assessed relative to SSF (1.01 units for juiciness like, 1.11 units for juiciness level) than when assessed relative to WBSF (0.66 units for both juiciness like and level). The consistent relationship between consumer juiciness and tenderness
attributes are likely a function of the strong correlations among consumer attribute responses ($r = 0.82$ to 0.84) in the present data set. Enhanced chops were predicted by consumers to have favorable juiciness like and juiciness level ratings of greater than five across the range of WBSF and SSF measures, while predicted means for paired non-enhanced chops approached or were less than five at WBSF and SSF levels one standard unit greater than the mean (tougher).

While the difference in juiciness like and level between SSF of non-enhanced and enhanced chops was greater than the difference in WBSF at a given level of each trait, the effect of changing SSF one standard deviation on juiciness like and level ratings was reduced by over one half (0.21 vs 0.44 for juiciness like and 0.50 vs 0.23 for juiciness level) when compared with changing WBSF by a standard deviation unit. The result of the increased rate of change per standard deviation unit change in WBSF (0.44 units for juiciness like, 0.50 units for juiciness level) is a significant and greater change in consumer responses as WBSF levels at each increment of measurement as well as a greater change across the range observed. The smaller regression coefficients for SSF’s influence on juiciness like and level responses results in non-significant differences between adjacent standard deviation points along the SSF range for both enhanced and non-enhanced chops. These results indicate that WBSF was able to discriminate consumer perceptions of juiciness more effectively than SSF in the present study.
Figures 3.15 and 3.16 describe the influence of SSF and WBSF for enhanced and non-enhanced loins, paired by fresh pork quality attributes pH, IMF, and L*, on consumer responses for flavor like and flavor level. Enhancement improved consumer perceptions of flavor like and level by 1.27 units and 1.11 units, respectively when evaluated at the described WBSF levels and 1.56 units and 1.38 units, respectively when evaluated at the described SSF levels. In contrast with juiciness and tenderness perception attributes, SSF was not a significant model effect when assessing flavor attributes across the range of measurements as may have been expected given the few significant correlations between SSF and consumer attributes (Tables 3.4 and 3.5) observed in the present data. Alternatively, consumer ratings for flavor attributes were significantly influenced by WBSF, with a reduction in predicted mean responses as WBSF increase across the range. These findings suggest and underlying difference in either variability or rank correlation between SSF and WBSF that result in SSF measurements not maintaining a similar relationship with flavor in the data set.

Enhancement increased predicted mean consumer ratings for overall like (Figure 3.17), a culmination of tenderness, juiciness, and flavor attributes, significantly in relation to SSF (1.14 units) and WBSF (0.82 units) in the present study. Previous research (Baublits et al., 2006; Hayes et al., 2006; Wright et al., 2005; Prestat et al., 2002) has indicated that enhancement improved consumer perceptions of overall acceptability.
Changing WBSF one standard deviation unit resulted in an incremental change in the predicted mean overall like rating (0.33 units) while changing SSF by one standard deviation unit resulted in a smaller incremental change (0.13) in the predicted mean overall like rating. The smaller relative slope of the best fitting regression for SSF is reflected in significant differences in mean responses only occurring when levels of SSF differ by greater than three standard deviation units. In contrast, a change of one standard unit of WBSF results in a significant reduction in predicted mean responses for overall like. These results are not unexpected, given that SSF had no influence on flavor attributes, while flavor attributes were highly correlated ($r = 0.75$ to $0.88$; Tables 3.4 and 3.5) with overall like in both enhanced and non-enhanced chops across the two cooked temperatures.

Results comparing non-enhanced and enhanced chops in the present study suggest that enhancement appeared to negatively impact the relationship between SSF and WBSF as predictors of consumer palatability attributes regardless of the cooked temperature evaluated. When compared with assessment completed only on non-enhanced LM chops, consumer responses for juiciness, flavor and overall like were not of the same magnitude in relation to standard incremental changes in SSF when compared with the magnitude of standard incremental changes in WBSF.
CONCLUSION

Results of the present study indicate that SSF and WBSF measurements were moderately correlated within the non-enhanced pork loin sample data set. Correlations within the non-enhanced sample data set were slightly greater when pork chops were cooked to a greater degree of doneness, but at both cooked temperatures the correlations were consistently less than previous research reports that utilized either pork or beef cuts cooked to similar endpoint temperatures. Reasons for the reduction in the observed relationship between SSF and WBSF in the present study may be related to the larger sample size evaluated when compared with published reports or may simply be an indication that SSF and WBSF are not measuring the same muscle parameters. However, within the non-enhanced sample set, SSF and WBSF had very similar correlations with the consumer palatability attributes measured in the present study, which was supported by similarities in estimated consumer response ratings when comparing SSF and WBSF influences along a standard scale of measurement used. In addition, the correlations of SSF and WBSF with a consumer's direct assessment of tenderness traits were moderate \( r = \sim 0.40 \) and greater than other individual consumer attributes measured, indicating that both techniques are nearly equally predictive of consumer tenderness, the trait of emphasis in the present study.

The correlations between SSF and WBSF in the quality based, paired enhanced and non-enhanced loins were less at each cooked temperature,
particularly the relationship for the enhanced loins when compared with the non-enhanced loins at a given cooked temperature. Correlations between SSF and consumer traits in the quality based, paired enhanced and non-enhanced loin sample set were generally not different from zero, while WBSF relationships were significant but relatively low. The absence of significant relationships between SSF and consumer traits was directly observed in relation to the much reduced influence of a standard unit of change in SSF on predicted consumer ratings when compared with the change observed for WBSF. These findings suggest that WBSF may be a more sensitive measure of consumer attributes, particularly in relation to utilization in enhanced products, when compared with SSF. The results suggest that SSF is not as effective as WBSF in the assessment of consumer tenderness or related palatability attributes. Identification of the cause for the discrepancies from previous research is warranted.

The authors feel the dichotomy in the results observed across the two sets requires further inquiry and research to fully comprehend the probable cause. If the relationships between SSF and WBSF do not hold in enhanced product, the value of SSF technology at the industry level may be questionable, regardless of the proposed savings in time when this method is utilized.
<table>
<thead>
<tr>
<th>Trait&lt;sup&gt;a&lt;/sup&gt;</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
<th>Cooktime</th>
<th>Cookloss</th>
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Table 3.1. Mean values of mechanical measures of tenderness, consumer palatability measures and fresh loin quality of non-enhanced pork chops, average of 68.3º C, or 73.8º C cook temperatures.

<sup>a</sup> Trait: SSF = slice shear force, kg; WBSF = Warner-Bratzler shear force, kg; OLIKE = consumer overall like/dislike rating, 8 point scale (1 = dislike extremely and 8 = like extremely); JLIKE = consumer juiciness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); JLEVEL = consumer juiciness level rating, 8 point scale (1 = Extremely Dry and 8 = Extremely Juicy); TLIKE = consumer tenderness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); TLEVEL = consumer tenderness level rating, 8 point scale (1 = Extremely Tough and 8 = Extremely Tender); FLEVEL = consumer flavor level rating, 8 point scale (1 = Extremely Bland or No Flavor and 8 = Extremely Flavorful); FLIKE = consumer flavor like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); PPURCH = probability of purchase, 1 = Definitely Would Not Buy, 2 = Probably Would Not Buy, 3 = May or May Not Buy, 4 = Probably Would Buy, and 5 = Definitely Would Buy); Lstar = Minolta L*; PH = loin ultimate pH; IMF = Ether extract chemical fat composition, %; COLOR = visual color score, 1 = Very pale and 6 = dark purplish red (NPPC, 2000); MARB = visual marbling score, 1 = 1% and 6 = 6% intramuscular fat;.
**Table 3.2. Correlations between measures of fresh pork quality, mechanical measures of tenderness, and consumer assessments of palatability for non-enhanced loin chops cooked to 68.3° C (n = 327, above the diagonal) and 73.8° C (n = 280, below the diagonal)**

<table>
<thead>
<tr>
<th>Trait</th>
<th>SSF</th>
<th>WBSF</th>
<th>OLIKE</th>
<th>JLIKE</th>
<th>JLEVEL</th>
<th>TLIKE</th>
<th>TLEVEL</th>
<th>FLEVEL</th>
<th>FLIKE</th>
<th>PPURCH</th>
<th>LSTAR</th>
<th>pH</th>
<th>IMF</th>
<th>COLOR</th>
<th>MARB</th>
</tr>
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<tbody>
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<td>SSF</td>
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<td>0.49</td>
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<td>-0.40</td>
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<td>-0.22</td>
<td>0.01*</td>
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</tr>
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<td>WBSF</td>
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<td>-0.34</td>
<td>-0.34</td>
<td>-0.38</td>
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<td>-0.30</td>
<td>0.07*</td>
<td>-0.29</td>
<td>-0.08*</td>
<td>-0.15</td>
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<tr>
<td>OLIKE</td>
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<td>-0.33</td>
<td>-</td>
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<td>0.87</td>
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<td>-0.02*</td>
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<td>0.03*</td>
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<tr>
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<td>-</td>
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<td>0.73</td>
<td>0.66</td>
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<td>0.03*</td>
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<td>-</td>
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<td>0.18</td>
<td>0.02*</td>
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<td>TLEVEL</td>
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<td>-0.46</td>
<td>0.72</td>
<td>0.79</td>
<td>0.78</td>
<td>0.95</td>
<td>-</td>
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<td>0.62</td>
<td>0.78</td>
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<td>0.31</td>
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<td>0.21</td>
<td>0.05*</td>
</tr>
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<td>FLEVEL</td>
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<td>-0.21</td>
<td>0.88</td>
<td>0.69</td>
<td>0.60</td>
<td>0.69</td>
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<td>-</td>
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<td>0.82</td>
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<td>-0.00*</td>
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<td>0.05*</td>
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<td>0.60</td>
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<td>-</td>
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<td>0.05*</td>
</tr>
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<td>0.66</td>
<td>0.73</td>
<td>0.70</td>
<td>0.83</td>
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<td>LSTAR</td>
<td>-0.01*</td>
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<td>-0.06*</td>
<td>-0.08*</td>
<td>-0.09*</td>
<td>-0.07*</td>
<td>-0.07*</td>
<td>0.01*</td>
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<td>-0.02*</td>
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<td>-0.61</td>
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<td>0.25</td>
<td>0.30</td>
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<td>0.29</td>
<td>0.31</td>
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<td>-0.03*</td>
<td>-0.06*</td>
<td>0.00*</td>
<td>0.02*</td>
<td>0.09*</td>
<td>0.06*</td>
<td>0.04*</td>
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<td>-</td>
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<tr>
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<td>0.09*</td>
<td>0.11*</td>
<td>0.11*</td>
<td>0.10</td>
<td>0.11</td>
<td>0.02*</td>
<td>0.07*</td>
<td>0.05*</td>
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<td>-</td>
<td>0.12</td>
</tr>
<tr>
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<td>0.01*</td>
<td>-0.03*</td>
<td>0.03*</td>
<td>0.06*</td>
<td>0.07*</td>
<td>0.07*</td>
<td>0.06*</td>
<td>0.07*</td>
<td>0.07*</td>
<td>0.71</td>
<td>0.12</td>
<td>-</td>
</tr>
</tbody>
</table>

* Trait: SSF = slice shear force, kg; WBSF = Warner-Bratzler shear force, kg; OLIKE = consumer overall like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); JLIKE = consumer juiciness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); JLEVEL = consumer juiciness level rating, 8 point scale (1 = Extremely Dry and 8 = Extremely Juicy); TLIKE = consumer tenderness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); TLEVEL = consumer tenderness level rating, 8 point scale (1 = Extremely Tough and 8 = Extremely Tender); FLEVEL = consumer flavor level rating, 8 point scale (1 = Extremely Bland or (continued)
Table 3.2 (continued). No Flavor and 8 = Extremely Flavorful; FLIKE = consumer flavor like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); PPURCH = Probability of purchase, 1 = Definitely Would Not Buy, 2 = Probably Would Not Buy, 3 = May or May Not Buy, 4 = Probably Would Buy, and 5 = Definitely Would Buy); Lstar = Minolta L*; PH = loin ultimate pH; IMF = Ether extract chemical fat composition, %; COLOR = visual color score, 1 = Very pale and 6 = dark purplish red (NPPC, 2000); MARB = visual marbling score, 1 = 1% and 6 = 6% intramuscular fat.

* Correlation did not differ (P > 0.10)
Table 3.3. Mean values of mechanical measures of tenderness, consumer palatability measures and fresh loin quality of non-enhanced (above line) and enhanced (below line) pork chops, average of 68.3º C, or 73.8º C cook temperatures.

| Trait | Non-enhanced | | | | | | | | Enhanced | | | |
|-------|--------------|---------|-------|-------|---------|-------|-------|-------|--------------|---------|-------|-------|-------|-------|-------|-------|-------|
| N     | Mean         | SD      | Min   | Max   | Cooktime | Cookloss |          |          |              |          |          |          |          |          |          |          |          |
| WBSF  | 212          | 2.52    | 0.57  | 1.35  | 4.98      | 307.53   | 11.72  |      | 207          | 1.62    | 0.37   | 0.91  | 3.32  | 317.15 | 6.53  |      |          |              |          |          |          |
| OLIKE | 213          | 4.93    | 1.04  | 1.20  | 7.80      | -        | -      |      | 207          | 6.21    | 0.98   | 3.40  | 8.00  | -      | -     |      |          |              |          |          |          |
| JLIKE | 213          | 5.27    | 1.11  | 1.60  | 7.60      | -        | -      |      | 207          | 6.50    | 0.86   | 3.20  | 8.00  | -      | -     |      |          |              |          |          |          |
| JLEVEL| 213          | 5.13    | 1.17  | 1.60  | 7.20      | -        | -      |      | 207          | 6.48    | 0.89   | 4.00  | 8.00  | -      | -     |      |          |              |          |          |          |
| TLIKE | 213          | 5.07    | 1.19  | 1.40  | 7.40      | -        | -      |      | 207          | 6.43    | 0.88   | 3.80  | 8.00  | -      | -     |      |          |              |          |          |          |
| TLEVEL| 213          | 4.98    | 1.22  | 1.40  | 7.60      | -        | -      |      | 207          | 6.47    | 0.94   | 4.00  | 8.00  | -      | -     |      |          |              |          |          |          |
| FLEVEL| 213          | 4.50    | 1.06  | 1.20  | 6.80      | -        | -      |      | 207          | 5.89    | 1.01   | 2.75  | 7.80  | -      | -     |      |          |              |          |          |          |
| FLIKE | 213          | 4.23    | 1.11  | 1.20  | 7.40      | -        | -      |      | 207          | 5.77    | 1.06   | 2.25  | 7.80  | -      | -     |      |          |              |          |          |          |
| PPURCH| 213          | 2.94    | 0.71  | 1.00  | 5.00      | -        | -      |      | 207          | 3.82    | 0.65   | 2.00  | 5.00  | -      | -     |      |          |              |          |          |          |
| LSTAR | 213          | 53.7    | 4.52  | 43.8  | 65.4      | -        | -      |      | 207          | 53.1    | 4.42   | 41.6  | 67.5  | -      | -     |      |          |              |          |          |          |
| pH    | 213          | 5.78    | 0.23  | 5.34  | 6.48      | -        | -      |      | 207          | 5.78    | 0.24   | 5.34  | 6.65  | -      | -     |      |          |              |          |          |          |
| IMF   | 213          | 3.10    | 1.30  | 0.61  | 6.86      | -        | -      |      | 207          | 3.16    | 1.40   | 0.22  | 6.84  | -      | -     |      |          |              |          |          |          |
| COLOR | 213          | 3.08    | 1.08  | 1.00  | 5.00      | -        | -      |      | 207          | 3.23    | 1.01   | 1.00  | 6.00  | -      | -     |      |          |              |          |          |          |
| MARB  | 213          | 2.46    | 1.19  | 1.00  | 6.00      | -        | -      |      | 207          | 5.91    | 0.23   | 5.24  | 6.47  | -      | -     |      |          |              |          |          |          |

Table 3.3. Mean values of mechanical measures of tenderness, consumer palatability measures and fresh loin quality of non-enhanced (above line) and enhanced (below line) pork chops, average of 68.3º C, or 73.8º C cook temperatures.

 Trait: SSF = slice shear force, kg; WBSF = Warner-Bratzler shear force, kg; OLIKE = consumer overall like/dislike rating, 8 point scale (1 = dislike extremely and 8 = like extremely); (continued)
Table 3.3 (continued). JLIKE = consumer juiciness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); JLEVEL = consumer juiciness level rating, 8 point scale (1 = Extremely Dry and 8 = Extremely Juicy); TLIKE = consumer tenderness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); TLEVEL = consumer tenderness level rating, 8 point scale (1 = Extremely Tough and 8 = Extremely Tender); FLEVEL = consumer flavor level rating, 8 point scale (1 = Extremely Bland or No Flavor and 8 = Extremely Flavorful); FLIKE = consumer flavor like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); PPURCH = probability of purchase, 1 = Definitely Would Not Buy, 2 = Probably Would Not Buy, 3 = May or May Not Buy, 4 = Probably Would Buy, and 5 = Definitely Would Buy); Lstar = Minolta L*; PH = loin ultimate pH; IMF = Ether extract chemical fat composition, %; COLOR = visual color score, 1 = Very pale and 6 = dark purplish red (NPPC, 2000); MARB = visual marbling score, 1 = 1% and 6 = 6% intramuscular fat; POSTPH = loin ultimate pH following enhancement.
Table 3.4. Correlations between measures of fresh pork quality, mechanical measures of tenderness, and consumer assessments of palatability for non-enhanced (n = 111, above the diagonal) and enhanced (n = 107, below the diagonal) loin chops cooked to 68.3\(^\circ\) C.

<table>
<thead>
<tr>
<th>Trait (^a)</th>
<th>SSF</th>
<th>WBSF</th>
<th>OLIKE</th>
<th>JLIKE</th>
<th>JLEVEL</th>
<th>TLIKE</th>
<th>TLEVEL</th>
<th>FLEVEL</th>
<th>FLIKE</th>
<th>PPURCH</th>
<th>LSTAR</th>
<th>pH</th>
<th>IMF</th>
<th>COLOR</th>
<th>MARB</th>
</tr>
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<tbody>
<tr>
<td>SSF</td>
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<td>0.44</td>
<td>-0.20</td>
<td>-0.28</td>
<td>-0.29</td>
<td>-0.35</td>
<td>-0.33</td>
<td>-0.08</td>
<td>-0.04*</td>
<td>-0.15*</td>
<td>0.10*</td>
<td>-0.10*</td>
<td>0.02*</td>
<td>-0.04*</td>
<td>-0.05*</td>
</tr>
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<td>-0.15*</td>
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<td>-0.28</td>
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</tr>
<tr>
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<td>-</td>
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<td>0.82</td>
<td>0.78</td>
<td>0.84</td>
<td>0.75</td>
<td>0.89</td>
<td>-0.12*</td>
<td>0.22</td>
<td>-0.14*</td>
<td>0.16*</td>
<td>-0.04*</td>
</tr>
<tr>
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<td>0.82</td>
<td>0.68</td>
<td>0.60</td>
<td>0.76</td>
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<td>0.18</td>
<td>-0.09*</td>
</tr>
<tr>
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<td>-</td>
<td>0.84</td>
<td>0.85</td>
<td>0.64</td>
<td>0.57</td>
<td>0.73</td>
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<td>0.29</td>
<td>-0.10*</td>
<td>0.20</td>
<td>-0.03*</td>
</tr>
<tr>
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<td>0.73</td>
<td>-</td>
<td>0.94</td>
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<td>0.66</td>
<td>0.89</td>
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<td>0.07*</td>
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<td>0.77</td>
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<td>0.06*</td>
<td>0.04*</td>
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<td>0.04*</td>
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<tr>
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<td>-0.01*</td>
<td>0.03*</td>
<td>-0.00*</td>
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<td>0.05*</td>
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<td>0.73</td>
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<td>0.05*</td>
<td>0.03*</td>
<td>0.00*</td>
<td>0.05*</td>
<td>-0.09*</td>
<td>-0.08*</td>
<td>-0.14*</td>
<td>-0.87</td>
<td>0.71</td>
<td>-0.27</td>
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<td>-0.02*</td>
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<tr>
<td>MARB</td>
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<td>-0.02*</td>
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<td>-0.05*</td>
<td>0.08*</td>
<td>-0.00*</td>
<td>0.68</td>
<td>0.10*</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^a\) Trait: SSF = slice shear force, kg; WBSF = Warner-Bratzler shear force, kg; OLIKE = consumer overall like/dislike rating, 8 point scale (1 = dislike extremely and 8 = like extremely); JLIKE = consumer juiciness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); JLEVEL = consumer juiciness level rating, 8 point scale (1 = Extremely Dry and 8 = Extremely Juicy); TLIKE = consumer tenderness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); TLEVEL = consumer tenderness level rating, 8 point scale (1 = Extremely Tough and 8 = Extremely Tender); FLEVEL = consumer flavor level rating, 8 point scale (1 = Extremely Bland or No (continued)
Table 3.4 (continued). Flavor and 8 = Extremely Flavorful); FLIKE = consumer flavor like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); PPURCH = probability of purchase, 1 = Definitely Would Not Buy, 2 = Probably Would Not Buy, 3 = May or May Not Buy, 4 = Probably Would Buy, and 5 = Definitely Would Buy); Lstar = Minolta L*; PH = loin ultimate pH; IMF = Ether extract chemical fat composition, %; COLOR = visual color score, 1 = Very pale and 6 = dark purplish red (NPPC, 2000); MARB = visual marbling score, 1 = 1% and 6 = 6% intramuscular fat. * Correlation not significant (P > 0.10)
Table 3.5. Correlations between measures of fresh pork quality, mechanical measures of tenderness, and consumer assessments of palatability for non-enhanced (n = 102, above the diagonal) and enhanced (n = 100, below the diagonal) loin chops cooked to 73.8º C.

<table>
<thead>
<tr>
<th>Trait</th>
<th>SSF</th>
<th>WBSF</th>
<th>OLIKE</th>
<th>JLIKE</th>
<th>JLEVEL</th>
<th>TLIKE</th>
<th>TLEVEL</th>
<th>FLEVEL</th>
<th>FLIKE</th>
<th>PPURCH</th>
<th>LSTAR</th>
<th>pH</th>
<th>IMF</th>
<th>COLOR</th>
<th>MARB</th>
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Trait: SSF = slice shear force, kg; WBSF = Warner-Bratzler shear force, kg; OLIKE = consumer overall like/dislike rating, 8 point scale (1 = dislike extremely and 8 = like extremely); JLIKE = consumer juiciness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); JLEVEL = consumer juiciness level rating, 8 point scale (1 = Extremely Dry and 8 = Extremely Juicy); TLIKE = consumer tenderness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); TLEVEL = consumer tenderness level rating, 8 point scale (1 = Extremely Tough and 8 = Extremely Tender); FLEVEL = consumer flavor level rating, 8 point scale (1 = Extremely Bland or No Flavor and 8 = Extremely Flavorful); FLIKE = consumer flavor like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely); PPURCH = probability of purchase, 1 = Definitely Would Not Buy, 2 = Probably Would Not Buy, 3 = May or May Not Buy, 4 = Probably (continued)
Table 3.5 (continued). Would Buy, and 5 = Definitely Would Buy; Lstar = Minolta L*; PH = loin ultimate pH; IMF = Ether extract chemical fat composition, %; COLOR = visual color score, 1 = Very pale and 6 = dark purplish red (NPPC, 2000); MARB = visual marbling score, 1 = 1% and 6 = 6% intramuscular fat.

* Correlation did not differ (P > 0.10)
Figure 3.1. Non-enhanced pork chop frequency, average of 68.3° C, or 73.8° C cook temperatures for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.2. Least squares means for consumer assessment of non-enhanced pork chop tenderness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely, average of 68.3º C, or 73.8º C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
LSMEANS within a WBSF column and enhancement treatment without common superscripts differ \((P < 0.10)\)

LSMEANS within SSF column and enhancement treatment without common superscripts differ \((P < 0.10)\)

Figure 3.3. Least squares means for consumer assessment of non-enhanced pork chop consumer tenderness level rating, 8 point scale (1 = Extremely Tough and 8 = Extremely Tender, average of 68.3° C, or 73.8° C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.4. Least squares means for consumer assessment of non-enhanced pork chop juiciness like rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely, average of 68.3º C, or 73.8º C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.5. Least squares means for consumer assessment of non-enhanced pork chop juiciness level rating, 8 point scale (1 = Extremely Dry and 8 = Extremely Juicy, average of 68.3º C, or 73.8º C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.6. Least squares means for consumer assessment of non-enhanced pork chop consumer flavor like rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely, average of 68.3°C or 73.8°C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
LSMEANS within a WBSF column and enhancement treatment without common superscripts differ ($P < 0.10$).

LSMEANS within SSF column and enhancement treatment without common superscripts differ ($P < 0.10$).

Figure 3.7. Least squares means for consumer assessment of non-enhanced pork chop consumer flavor level rating, 8 point scale (1 = Extremely Bland or No Flavor and 8 = Extremely Flavorful, average of 68.3° C, or 73.8° C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
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<td>5.17</td>
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<td>1.98</td>
<td>2.63</td>
<td>3.28</td>
<td>3.93 (WBS, kg)</td>
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*LSMEANS within a WBSF column and enhancement treatment without common superscripts differ (P < 0.10)*

*LSMEANS within SSF column and enhancement treatment without common superscripts differ (P < 0.10)*

Figure 3.8. Least squares means for consumer assessment of non-enhanced pork chop overall like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely, average of 68.3° C, or 73.8° C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.9. Least squares means for consumer assessment of non-enhanced pork chop consumer probability of purchase, 1 = Definitely Would Not Buy, 2 = Probably Would Not Buy, 3 = May or May Not Buy, 4 = Probably Would Buy, and 5 = Definitely Would Buy, average of 68.3° C, or 73.8° C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.10. Enhanced pork chop frequency, average of 68.3°C, or 73.8°C cook temperatures for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
LSMEANS within a WBSF column and enhancement treatment without common superscripts differ ($P < 0.10$)

LSMEANS within SSF column and enhancement treatment without common superscripts differ ($P < 0.10$)

Figure 3.11. Least squares means for consumer assessment of non-enhanced and enhanced (paired) pork chop tenderness like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely, average of 68.3º C, or 73.8º C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.12. Least squares means for consumer assessment of non-enhanced and enhanced (paired) pork chop consumer tenderness level rating, 8 point scale (1 = Extremely Tough and 8 = Extremely Tender, average of 68.3º C, or 73.8º C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.

**Figure 3.12.** Least squares means for consumer assessment of non-enhanced and enhanced (paired) pork chop consumer tenderness level rating, 8 point scale (1 = Extremely Tough and 8 = Extremely Tender, average of 68.3º C, or 73.8º C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.13. Least squares means for consumer assessment of non-enhanced and enhanced (paired) pork chop juiciness like rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely, average of 68.3°C, or 73.8°C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.14. Least squares means for consumer assessment of non-enhanced and enhanced (paired) pork chop juiciness level rating, 8 point scale (1 = Extremely Dry and 8 = Extremely Juicy, average of 68.3° C, or 73.8° C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.15. Least squares means for consumer assessment of non-enhanced and enhanced (paired) pork chop consumer flavor like rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely, average of 68.3°C, or 73.8°C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.16. Least squares means for consumer assessment of non-enhanced and enhanced (paired) pork chop consumer flavor level rating, 8 point scale (1 = Extremely Bland or No Flavor and 8 = Extremely Flavorful, average of 68.3° C, or 73.8° C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.
Figure 3.17. Least squares means for consumer assessment of non-enhanced and enhanced (paired) pork chop overall like/dislike rating, 8 point scale (1 = Dislike Extremely and 8 = Like Extremely, average of 68.3°C or 73.8°C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.

abcd LSMEANS within a WBSF column and enhancement treatment without common superscripts differ (P < 0.10)

tuvwxyz LSMEANS within SSF column and enhancement treatment without common superscripts differ (P < 0.10)
Least squares means for consumer assessment of purchase, 1 = Definitely Would Not Buy, 2 = Probably Would Not Buy, 3 = May or May Not Buy, 4 = Probably Would Buy, and 5 = Definitely Would Buy, average of 68.3°C, or 73.8°C cook temperatures) for Warner-Bratzler shear force (kg) and slice shear force (kg) measured at their respective means and two standard deviations above and below their mean.


