CHARACTERIZING THE RELATIONSHIP BETWEEN EARLY POSTMORTEM PORK LOIN QUALITY ATTRIBUTES AND 14 DAY AGED LOIN QUALITY ATTRIBUTES AND SENSORY CHARACTERISTICS

BY

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THESIS

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ABSTRACT

Consumer's routinely use fresh pork color and marbling as indicators of a desirable pork loin chop, which may explain the decision to use these traits to sort loins for previous proposed grading systems. However, to effectively use these traits to determine pork loin quality, it is crucial to first evaluate their repeated capability of predicting a satisfactory eating experience. Also, the relationship between early postmortem quality traits and aged quality traits of pork loins stored under various conditions must be established. Therefore, the objective of this work was to determine the relationship between early and aged postmortem pork loin quality traits, compare aged pork quality of vacuum-packaged intact loins and case-ready packaged chops, and to determine the interactions between quality grade, packaging type, and degree of doneness on sensory traits of pork loins selected to vary in color and marbling.

Boneless loins (N = 288) were selected from two production focuses on 4 separate days using a VQG grading camera to represent a range in ventral color and marbling. Color, marbling, firmness, pH, and instrumental color values were evaluated on the ventral side of each loin at 1 d postmortem. Early ventral loin lightness (L*) values ranged from 52.42 (light) to 37.23 (dark) and extractable lipid ranged from 0.7% to 6.2%. Loins were then transported to the University of Illinois for further evaluation in two experiments. The goal of the first experiment was to compared correlation coefficients between early and aged pork quality traits from loins aged intact under vacuum packaging and loins aged as chops in case-ready packaging. Loins were assigned to one of two packaging treatments. 1) Aged as intact-loins in vacuum packaging at 4°C until 12 d PM (n = 144), removed from packaging, evaluated ventral quality parameters as described at 1 d PM, sliced into 28 mm thick chops, evaluated instrumental color on chop face surface, and individually re-vacuum packaged until 14 d PM. 2) Sliced at 2 d PM (n = 152) and

aged as chops in case-ready packaging until 12 d PM, removed from packaging, instrumental color evaluated on chop face surface, and individually vacuum packaged until 14 d PM. Chops were packaged in individual Styrofoam trays and overwrapped in polyvinyl chloride (PVC) oxygen permeable film and gas flushed in bulk packages with a gas mixture that contained approximately 0.4 % carbon monoxide, 30 % carbon dioxide, and 80 % nitrogen. Chops CRA were stored in bulk packaging at 4°C until 9 d PM, removed from the bulk packaging, and set on simulated retail display until 12 d Pm at 4°C. At 12 d PM, chops were removed from simulated retail display and their PVC packaging, individually vacuum sealed, and stored at 4°C until 14 d PM. Warner-Bratzler shear force (WBSF) and cooking loss were evaluated at 14 d postmortem. Quality parameters of both packaging treatments at early and aged time points were compared as a completely randomized block design with slaughter date as a blocking factor. Pearson's correlation coefficients between early and aged quality traits, and WBSF or cooking loss were transformed using Fisher's r to z transformation for independent correlations comparisons of packaging treatments. Dependent correlation comparisons utilized transformed Pearson's correlation coefficients between ILA ventral quality traits at 1 d PM, 12 d PM, and WBSF or cooking loss and were transformed using Fisher's r to z transformation with an additional test statistic, *t*, for dependent correlation comparisons. Loins designated to ILA were 0.29 units redder ($P = 0.03$) than CRA loins at 1 d PM, with no other differences ($P \geq 0.13$) of 1 d PM quality traits. Chops from ILA were more tender and had less cooking loss (14 d postmortem), and were darker and redder (12 d postmortem) on the chop face than CRA chops ($P < 0.0001$). Lightness and redness values on the ventral surface for ILA loins (r = 0.52 lightness; r = 0.63 redness) and CRA loins (r = 0.45 lightness; r = 0.61 redness) at 1 d postmortem were both correlated with aged lightness and redness values on the aged chop face at 12 d postmortem.

Those correlations did not differ for either lightness or redness ($P \geq 0.43$). Overall, aging intact loins in vacuum packaging improved color after 12 d of aging, while increasing tenderness and decreasing cooking loss, compared with CRA loins. Despite the differences between aging methods, the relationships between early and aged loin quality traits did not differ between aging methods. Therefore, packers need not to consider subsequent packaging and aging methods when sorting loins on early postmortem quality traits.

The second experiment's objective was to determine the interactions between packaging type and degree of doneness on sensory traits of pork loins selected to represent the newly proposed USDA quality grades. At 2 d postmortem loins were sliced into 28 mm thick chops and were randomly assigned to either individual vacuum packages or to individual Styrofoam trays and overwrapped in polyvinyl chloride (PVC) oxygen permeable film. Overwrapped PVC packaged were then placed in gas-flushed bulk packages. Bulk packages were flushed with a gas mixture that contained approximately 0.4 % carbon monoxide, 30 % carbon dioxide, and 80 % nitrogen. Vacuum-packaged chops were aged until 14 d postmortem and then evaluated for trained sensory analysis and instrumental tenderness. Chops packaged in PVC overwrap were aged until 9 d postmortem in the bulk packages, then placed on simulated retail display until for 14 d postmortem. Sensory traits and slice shear force (SSF) was evaluated after all chops were frozen and then thawed prior to evaluation. Chops from each packaging type were cooked to an internal temperature of either 63° C or 71° C. Data were analyzed as split-split plot design with production focus of the pigs, proposed USDA quality grade, packaging type, and degree of doneness as fixed effects. There were no interactions among quality grade, packaging type or degree of doneness for any traits. There were no differences in sensory tenderness ($P = 0.30$), juiciness ($P = 0.49$), flavor ($P = 0.89$), SSF ($P = 0.13$), or cook loss ($P = 0.06$) among USDA quality grades. There were no differences in sensory tenderness (*P* = 0.06), juiciness (*P* = 0.32), flavor (*P* = 0.74), SSF (*P* = 0.99), or cook loss (*P* = 0.12) between chops aged in vacuum packages or PVC packages. Chops cooked to 63° C were 4.6% more tender (*P* < 0.0001), 10.1% juicier (*P* < 0.0001), and 2.9% less flavorful (*P* = 0.01) than chops cooked to 71° C. Neither proposed USDA quality grade nor packaging type impacted eating experience. Cooking chops to 63° C rather than 71° C was a more effective way to improve eating experience than the newly proposed USDA quality grades or differing packaging types.

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CHAPTER 1: REVIEW OF THE LITERATURE

Introduction

Determining how pork quality should be evaluated and valued is an area of debate in the pork industry. Pork quality is evaluated differently depending on application. For example, the pork loin is mainly consumed as fresh meat products while the belly and ham are most commonly used for further processing applications. Therefore, the quality of these primals should be evaluated differently given their different uses. In this review, the focus will be fresh pork loin quality including what factors influence it and how it is valued. High quality loins should have the most tender, flavorful, and juiciest eating experience. Many studies have evaluated how fresh quality characteristics relate to and correlate with the sensory traits of tenderness, juiciness, and flavor (Norman et al., 2003, Lonergan et al., 2007, Wilson et al., 2017). In general, results have indicated that color, marbling, and firmness all contribution to the overall eating experience, although no single trait drives quality on its own. It can best be assessed that thresholds within each quality attribute hold the key to having a 'high' quality eating experience. Therefore, the selection of higher quality pork is not as simple as that in beef, where quality is driven primarily by marbling content.

A different approach to determining a 'high' quality eating experience may not be found within pork quality attribute. One avenue that may be affecting pork quality or the final eating experience could be found through packaging type and method to which a pork loin stored and point of retail fabrication. A second area of interest is the endpoint cooking temperature (degree of doneness) which may have strong influence on pork eating experience regardless of visual quality traits.

For the purposes of this review correlations will be considered as weak relationships if $r \leq |0.35|$, moderate relationships if $r = |0.36|$ through $|0.67|$, or strong relationships if $r \geq |0.68|$ (Taylor, 1990).

Factors Influencing Purchase Intent and Eating Quality of Fresh Pork Loin Chops

Postmortem pH decline

The measurement of hydrogen ion concentration within a mostly aqueous substance, such as muscle or meat, is referred to as pH. The pH of living muscle is around 7.2. The pH level at which a protein's charge is neutral is the isoelectric point. Proteins are positively charged above their isoelectric point and negatively below that point. In meat, positive protein charges allow for bound and immobilized water to be retained within the muscle fibers. For meat proteins a pH of approximately 5.2 is their isoelectric point. Meat pH can range from 5.2 - 6.5, with 'normal' meat having a pH of around 5.6 (Bendall and Swatland, 1988; Lonergan, 2008).

During the conversion of muscle to meat, muscles continue to contract during the onset of rigor mortis directly after exsanguination. This is due to the loss of membrane integrity, allowing calcium release from the sarcoplasmic reticulum, stimulating muscle contraction. Contracting muscle requires ATP. In the absence of oxygen due to the removal of blood, the citric acid cycle is not available. Instead, glycogen is converted to pyruvate, and then pyruvate to lactate by lactate dehydrogenase. The byproduct, lactate acid, cannot be removed from muscle without circulation and begins to lower muscle pH throughout the steps of rigor mortis until rigor is complete (Lee et al., 2010). The majority of postmortem pH decline is complete by 6 - 9 h postmortem but a final pH is typically measured at 22-24 h postmortem, termed ultimate pH, to accurately predict pork quality traits (Boler et al., 2009).

Ultimate pH is strongly influenced by ante-mortem and early post-mortem factors. Ultimate pH can be influenced by the amount of substrate, glycogen, present in in muscle at the time of slaughter (Huff-Lonergan et al., 2002). This is commonly referred to as the glycolytic potential, an estimate of the muscle glycogen concentration at time of death. An animal with an increased glycolytic potential, such as pigs carrying the RN gene ("acid meat" condition), will result in an overall lower pH level due to a higher content of lactic acid buildup after rigor mortis (Sellier and Monin, 1994). The reverse is when too little glycogen is available after slaughter due to long-term stress (Guàrdia et al., 2005). The result is a higher ultimate pH due to the lower levels of lactic acid due to the expensed glycogen stores while the animal was alive. Meat from these animals appear dark, firm, and dry (DFD) on the outside due to an increase in water-holding capacity. More moisture retained inside the muscles causes the outside to appear dry. The high content of retained water creates a firmer structure and retains a higher content of myoglobin that reflects a darker color. The rate and extent of early postmortem pH decline has a major influence on fresh pork loin quality, such as improving water-holding capacity.

Carcass temperature and the rate at which it declines is important for sustaining muscle protein structure. Without blood circulation to dissipate heat, carcasses must be eviscerated to help dissipate heat as well as move to a cooler within a reasonable time point to avoid temperature abuse (Savell et al., 2005). Thus, a lower pH coupled with a rise in temperature at the early steps of rigor mortis can lead to a greater rate of muscle protein denaturation, disrupting ion charge required for water retention and can ultimately lead to undesirable fresh pork quality characteristics such as pale lean color, soft muscle firmness, and increased exudate loss (Offer, 1991). These poor fresh quality attributes directly affect eating experience quality and can result in tough, dry, unflavorful pork.

Water-holding capacity

Water-holding capacity (WHC) is the ability of meat to retain water (Honikel 1987). Within meat, there are three water types classified on how tightly they are bound to myofibrillar proteins. Bound water (0.5%) is tightly held on charged muscle proteins. Free water makes up 10% of the total water and is retained through capillary action and thus is lost through the combination of exposed cut face surfaces and gravity. Immobilized water makes up majority of the water within a muscle (80%) and are retained through weaker charges from protein and bound water.

Water-holding capacity can be measured in several ways. Drip loss from a small section of fresh pork and purge loss in packages of fresh pork are two primary methods used to determine WHC of fresh meat. Weight lost during cooking, though not exclusively water, is also used as a measure of WHC. Ultimate pH and drip loss were positively correlated (r = 0.82 ultimate pH; r = 0.78 drip loss) to juiciness scores from trained sensory panelists consuming chops (Aaslyng et al. 2003). Moisture loss during storage or at the time of cooking is often a key variable in overall product yield and sensory characteristics.

WHC and pH are moderately correlated (r = -0.41, Schwab et al., 2006; r = -0.59, Rincker et al., 2007). Huff-Lonergan (2002) reported that increased drip loss during aging was correlated with reductions in NPPC color, instrumental and sensory tenderness, and sensory ratings of pork flavor. Kristensen and Purslow (2001) reported an increase in WHC during the first several days postmortem when a significant portion of cytoskeletons are degraded.

Color

The color of pork corresponds to the structure and quantity of myoglobin present on a cut face surface. Myoglobin is a muscle protein that binds and transports oxygen, allowing transfer of oxygen from hemoglobin in the blood stream to muscle fibers. Myoglobin is able to bind oxygen due to its structure; eight alpha-helices surrounding a centrally located iron atom with six available binding sites. Nitrogen is bound to four sites and, a proximal histidine-93 is bound to the fifth. The last site is reserved for ligand binding and can bind a variety of atoms including oxygen, carbon monoxide, carbon dioxide, and nitrogen. Additionally, the iron atom can reversibly shift from a ferrous ($Fe2+$) state to a ferric ($Fe3+$) state. The valence state of the iron atom and ligand binding last binding site determine the reflection of light of the protein, causing a change in color.

Color and visual appearance on exposed cut surfaces are directly related to the state of myoglobin (MacDougall, 1977). The state of myoglobin can change in four different ways in fresh meat dependent on atmosphere and the reaction on the iron atom (Figure 1.1). First, when no ligand is bound at the sixth site and the iron atom is in the ferrous state, it is termed deoxymyoglobin. Reflected light will be a purplish-red color. This is common in meat stored in vacuum packages or when a whole muscle is cut and the cut surface first exposed. Second, when exposed to the air, myoglobin binds oxygen through oxygenation. When bound to oxygen, the iron atom is in the ferrous state and is termed oxymyoglobin. Reflected light on pork creates a reddish-pink color, however the lightness (L^*) value of this color can vary greatly between pigs (Arkfeld et al., 2016). Third, oxidation (loss of electron) changes the iron atom state to ferric, resulting in reflected light that is a brown in color and is termed metmyoglobin. Although not detrimental in food safety or eating experience, consumers find meat with myoglobin in the metmyoglobin state to be unappealing. To extend color stability and retain consumer appeal, modified atmosphere packaging (MAP) can be used. The application of MAP allows for packers to create an atmosphere conducive to a more consumer appealing color, such as the addition of carbon monoxide. This results in the fourth possible myoglobin state in fresh meat, carboxymyoglobin. In this state, myoglobin binds carbon monoxide and the iron atom remains in the ferrous state, resulting in a color that is a bright reddish-pink color similar to that of oxymyoglobin. However unlike oxymyoglobin, if carboxymyoglobin is oxidized to metmyoglobin, it cannot be reduced back. Early post-mortem muscle pH and carcass temperature serve as two primary factors affecting fresh pork lean color (Mancini and Hunt, 2005).

Fresh pork color can be measured using both subjective and objective methods. To help standardize subjective color measurements, the National Pork Producers Council (NPPC, 1999) created a scale of pork color ranging from pale-pink, grayish (1) to a dark, purplish-red color (6). Within different global markets, several versions of a color scales have been created to meet the demand of those countries for international trade. These scales allow for trained technicians to calibrate their instruments or eyes prior to data collection and serve for comparison during observation. Use of these scales result in a subjective method to determine fresh pork color. In more recent research, objective or instrumental color can be has been recorded using either a colorimeter or photo spectrometer. Instruments that utilize the Commission Internationale de l'Eclairage (CIE) record in L*, a*, and b* units (CIE, 1978). The grey, or 'lightness', band (L*) is measured on a scale of 0 to 100, with 0 being black and 100 being white. Red band (a*) measures on a range from -60.00 to +60.00, with -60.00 being green and +60.00 being red. Yellow band (b*) measures on a range from -60.00 to +60.00, with -60.00 being blue and +60.00 being yellow. These measures can be affected by several settings on instrumentation including appropriate aperture size, degree of observer and illumination source. Aperture sizes typically range from 8mm to 3.18mm, dependent on size of surface area sampled. Interest in particular wavelength values will also dictate aperture size as reflectance percentage is lost with a decrease in size. Degree of observer is often used at 2° or 10°, with 10° more common for meat color due to the larger area of sample recorded. Source of illumination is important in the overall objectives of experiment. Illuminants are classified as either A which is the average incandescent, tungsten-fluorescent lighting (2857 K), C which relates to an average north sky daylight (6774 K), D65 which relates to daylight at noon (6500 K) or F which is fluorescent. Illuminants C and D65 are most commonly used in fresh meat evaluation. Illuminant A evaluates red wavelengths more closely, and illuminant F is important to use in shelf life studies as it replicates retail display lighting. Additional conditions can also alter color readings such as smoothness of the surface (sharpness of utensil used to reveal cut surface), if differences in background were observed, or if size of observed area was not uniform across sampled population. In a population where marbling or other cut surface attributes may cause non-uniformity issues, multiple readings are suggested to average for a more accurate value (AMSA, 2012).

To further assist in creating a consistent language of color analysis within the scientific community, these scores were assigned an objective color measurement on the L* scale. Within the NPPC scale, a pale pinkish-gray to white is an NPPC score of 1 with an L* value of 61, grayish-pink (NPPC 2, L* 55), reddish-pink (NPPC 3, L* 49), dark reddish-pink (NPPC 4, L* 43), purplish-red (NPPC 5, L* 37), dark purplish-red (NPPC 6, L* 31). Although most consumers have little to no training in distinguishing the difference between color scores or objective color values, it has been observed that the untrained eye can differentiate between colors that differ by 3 – L* units, leading researchers to utilize half score increments to more accurately assess subjective color scores (Zhu and Brewer, 1999).

Consumers use color as a predictor of eating quality in fresh pork, which can strongly influence purchasing and repeat-purchase making decisions (Fernandez et al., 1999, Mancini and Hunt, 2005). While color may influence purchasing behaviors, inconsistencies are present between consumers on what they perceive as higher quality products. Maples et al. (2017) reported more than a third of consumers selecting whiter, low marbled pork, which could be the result of years of marketing pork as "The Other White Meat". Additionally, Brewer and McKeith (1999) found that consumers held a large range for acceptable products but preferred an intense pink color. Surface exudate played a strong role in determining purchase intent as consumers preferred a more intense pink color.

In contrast, on a sensory basis consumers rate their eating experience more favorably when they consume prefer darker colored pork, finding it pork as more tender and juicy than lighter colored chops (Norman et al., 2003). However, in a more recent study, Wilson et al. (2017) reported that instrumental color alone was not predictive of sensory attributes on pork chops cooked to a medium-rare (63°C) degree of doneness. Still, darker fresh pork color and greater marbling content has been shown to drive majority of consumer purchasing intent (Brewer et al., 2001). Wood et al. (2004) found that this may be due to some consumers associating darker pork color and increased marbling with a more tender and juicy product. Recent market trends of selecting darker loins for premium-based programs may suggest an increasing demand of those products (Holmer and Sutton, 2009). While color is used by both packers and consumers as an indicator of quality, a divide must be recognized between how some consumers select for quality (lighter color) and how they perceive positive sensory traits (darker color).

Marbling

Though marbling is very influential to the assignment of beef quality grade, its role in pork loin quality is less clear. Improvement in sensory traits have been associated with increased marbling content, but with disagreement among studies. Brewer et al. (2001) reported that consumers visually preferred chops with low (1.0%) amounts of marbling, yet rated chops with high (3.5%) amounts to be more tender, juicy, and flavorful when cooked to 71°C degree of doneness. Similar results were reported that lipid content can influence sensory and instrumental tenderness, but only within an ultimate pH range of 5.50 through 5.95 (Lonergan et al., 2007). Wilson et al. (2017) found no predictive ability of utilizing only IMF to find sensory tenderness, juiciness, or flavor. Similar to color, consumers create a dilemma in what they select as acceptable marbling content and what they rate as acceptable. Rincker et al. (2008) reported that when consumers were asked to select from a range of chops with intramuscular fat of 1.5% - 5.8%, nearly half selected the chops with the least amount of intramuscular fat. Therefore, intramuscular fat contributes to overall eating experience but cannot influence sensory traits alone.

Firmness

The firmness of pork loins is often overlooked as a contributor to sensory traits because it has little influence on domestic market purchase making decision or on export market value (Murphy et al. 2015). However, in the newly proposed USDA pork quality grading scale loins subjectively measured must meet the requirement of ‘slightly firm’ to be assigned a grade of

Select, Choice, or Prime, regardless of lean color or marbling content (USDA, 2017). Rinker et al. (2007) described the need for an objective means to measure pork loin firmness to create more consistency within the industry. Weak correlations between firmness and ultimate pH (r = 0.20, Huff-Lonergan et al., 2002; r = 0.17, Boler et al., 2010) have been reported. Correlations between firmness and Warner-Bratzler shear force (r = 0.17, Arkfeld et al., 2015), and between firmness and moisture loss [drip loss (72 h) r = -0.25, cook loss r = -0.12, Huff-Lonergan et al., 2002; purge loss (21 d) r = -0.10, cook loss r = -0.22 Boler et al. 2010] are also weak. It can be postulated that muscle firmness is the result from the effect of pH on the retention or loss of water within muscle fibers (Huff-Lonergan and Lonergan, 2005). Additionally, this relates to the negative correlations between instrumental tenderness and firmness and cook loss and firmness observed by Huff-Lonergan et al. (2002) and Boler et al. (2010).

Ante-mortem and Peri-mortem Factors Influencing Pork Quality Traits

A host of ante-mortem and peri-mortem factors can influence fresh pork loin quality including genetics, diet, transport, lairage, handling prior to stunning and processing prior to chilling. In terms of pork producers influencing ultimate pork loin quality, genetics and diet are their most influential factors. Transport, lairage and handling is largely outside the control of pork producers and relies on pork processors to control.

Genetics and Management

Genetic selection focused on growth rate and efficiency can improve these traits. When discussing the genetic influence of pork quality, two particular single gene mutations are often highlighted. They include the RyR1 (ryanodine receptor skeletal) mutation, commonly referred to as the Halothane (HAL) gene, and the PRKAG3 (protein kinase subunit gamma-3) mutation, referred to the as the Rendement Napole (RN) gene. Both mutations lead to an abnormal postmortem pH decline, but through different mechanisms. Additionally, both mutations manifest in pale, soft and exudative pork. Many producers utilized genetics of leaner growing pigs that contained the mutation with no knowledge of its detrimental effect on pork quality. Pigs homozygous for the HAL gene are prone to malignant hyperthermia in high stress environments such as loading/unloading, transport, and fighting of pen mates. The increased chance of hyperthermia is due to a regulation problem found in the ryanodine receptors. The mutation alters the receptor's regulation of the release of calcium, which plays a role in the control of muscle contraction. When pigs carrying the mutation are exposed to high stress situations, calcium is released at a high rate causing continuous muscle contraction. This condition can result in sudden death of the animal and will hinder meat quality (Houde et al. 1993). A method of testing for the HAL gene is when pigs are homozygous for the mutation and are exposed to the halothane anesthesia, they undergo physiological stress and sudden death An increased incidence of pale, soft and exudative (PSE) meat has been associated with pigs carrying the HAL gene (Fernandez et al., 2002). This may be caused through the rate of postmortem pH decline that is linked to the metabolic state of the animal at the time of death. Due to the increased muscle contraction caused by receptor mutation, muscles will rapidly utilize ATP during the early onset of rigor at an increased rate. Increased muscle contraction results in rapid glycogen use and increased lactate accumulation resulting in a rapid decline in pH at relatively high postmortem temperatures. The rate at which pH decreases early postmortem greatly affects fresh quality parameters. Protein is denatured at a higher rate, releasing more bound water. The loss of water negatively affects muscle firmness and retention of water-soluble proteins such as myoglobin. As myoglobin content decreases, the reflectance of color lightens thus resulting in pale, soft, and exudative pork. The RN gene is associated in pigs with Hampshire genetic influence and contain a mutation of the protein kinase enzyme. Pork from pigs with this mutation will result in a low ultimate pH and may be referred to as ‘acid meat’. This is caused by an above average glycolytic potential due to an increase in glucose uptake caused by a mutation in AMP-activated protein kinase signaling for glucose transport and glycogen synthesis (Shen et al., 2006). Unlike the rapid decline in HAL gene, the RN gene pH rate decreases at a rate associated with normal pork but will continue to decrease over time due to the overabundance of glucose. With no access to oxygen, muscles begin to break down glucose through the lactic acid pathway rather than the Krebs cycle, causing an increase in acid content within the muscle until reaching an ultimate pH around 5.2. Acid meat can result in a higher cooking loss, lower protein extractability, and lower water holding capacity (Lundstrom and Hansson, 1996), all of which drive pork quality and consumer acceptability.

The selection of traits related to growth can inadvertently effect pork quality. This is largely due to the heritability of traits which are the source of variation among quality attributes. In a study where Yorkshire-Landrace females were sired to either Duroc or Pietrain boars, differing meat quality traits were observed in offspring (Edwards et al., 2003). Duroc sired pigs had higher pH loin chops with higher color, marbling, and firmness scores and less drip loss. Pietrain sired pigs observed less back fat at the first rib, 10th rib, and last lumbar vertebrae. Although the mentioned study does not represent the industry as a whole, it shows how different genetics can result in different pork quality. The selection of breed specific production focus lines has given companies the benefit of raising more efficient pigs but increased variation in quality.

Loading, Transport, and Lairage

Handling of pigs during loading onto trucks, in transport, and during unloading at the abattoir can influence on fresh pork loin quality (Moss, 1984). This influence is dependent on the severity of stress of the pig and the timing of these stressors in relation to stunning (Cannon et al., 1996). The management of stress on animals prior to slaughter is important as it can alter meat quality and, more importantly for pork, impair functionality of further processed products. Stress can be triggered through physical interactions, such as fighting, and cause depletion of glycogen storage in the muscles, whereas stressors related to physiological forms can result in rapid glycogen catabolism triggered by epinephrine output (Grandin, 1980). Traveling extended distances or spending long amounts of time in a trailer can have an increase of stress in pigs (Gajana et al., 2013, Lambooij, 2014). Additionally, new environments bring with it stress from changes in light, sounds, different walkway designs, and the mixing of new pigs from separate pens which can incite fighting (Goumon and Faucitano, 2017).

Lairage time can also affect fresh pork loin quality. A short lairage (< 1 h) allows little time to rest prior to slaughter. If a pig is stunned within a recent time point from unloading, a build-up of lactic acid from the stress of transport, unloading, and new environment will lead to reduced ultimate loin pH which have adverse effects on meat quality such as an increase in drip loss. Inversely, extended lairage time (>20h) will result in carcasses with more external blemishes such as bruising and fight marks (Dokmanovic et al., 2014) which could include stressful events potentially effecting meat quality. The optimal time for lairage appears to be 2-4 hours (Berg, 2006). Handling during lairage and the lead up to stunning is also an important influencer of pork loin quality. D'Souzaa et al. (1998) reported when pigs became stressed prior to slaughter due to improper handling, like the use of electric goads, pork loins exhibited higher surface exudate and greater percentage of PSE compared to pigs handled under less stressful conditions.

Stunning and Chilling

Another important consideration for optimal pork loin quality is limiting the time between stunning and the initiation of chilling. The rate of glycolysis is dependent on temperature (Lawrie, 1991). Therefore, extending the time from stunning to chilling will result in a more rapid pH decline. The recommended time from stunning to evisceration is 20 min, and the total time from stunning to the initiation of chilling should not exceed 45 min to prevent rapid pH decline (Maynard and Warner, 1996). The time it takes a carcass to be processed from stunning to chilling can have a direct effect on meat quality. If delays are made before carcasses are eviscerated, additional heat from internal organs could increase pH decline at a more rapid rate, causing more proteins to denature (D'Souzaa et al., 1998). The result is an increase in lightness and drip loss (Eldridge et al., 1993).

Packaging and Aging

Packaging of fresh meat was developed to prevent and inhibit microbial contamination, delay lipid oxidation, extend enzymatic activity for tenderness improvement, and extend color stability of fresh meats (Brody, 1997). Consumer-friendly packaging of meat products was first introduced in the 1950s after the development of self-service refrigerated cases provided consumers a new way to view steaks and roasts (McMillin, 2008). As centralized meat cutting became more popular in the 1970's, primals were shipped more often than sides and the use of vacuum packaging (VP) expanded. Soon after, the application of modified atmosphere packaging (MAP) began to be evaluated in the 1980's with intent to extend shelf life (Cole, 1986). In 2008, approximately two third of fresh meat in the US was marketed in case-ready MAP systems (McMillins, 2008).

MAP case-ready packaging contains consumer portioned retail items from fabrication facilities that are transported and stocked on refrigerated shelves for the convenience of consumers (McMillin, 1994). Although there may be potential benefits of profitability due to a 40% increase in market penetration (Brody, 2007), case-ready packaging may compromise pork quality attributes. Otto et al. (2006) reported a 5.67% increase in purge loss of pork loin chops after 7 d of storage in case-ready packaging. The addition of low (< 1%) carbon monoxide (CO) levels to packaged meat provides extended color stability. Chops were also juicier and had less purge loss when packaged in CO case-ready MAP compared to chops packaged in high oxygen case-ready MAP (Wicklund et al., 2006). However with increased stability of color, spoilage can no longer be indicated through degradation of color (Cornforth and Hunt, 2008). High oxygen (O2) levels within MAP accelerate the oxidation of lipids when compared to low O2 packaging which negatively affect color (O'Grady et al. 1998). The amount of CO2 within the headspace can become saturated in the meat product. The extent of absorption is determined by storage temperature, gas pressure, cut face surface area, and product composition (Jakobsen et al., 2002). When CO2 dissolves in water, pH is lowered, compromising the quality of the meat product.

The removal of all gases, or VP, can extend the shelf life to 21 d postmortem of fresh meat through prolonging the oxidation of lipids, while preventing microbial contamination (unless compromised prior to packaging) under refrigerated temperatures above zero (Zhou et al., 2010). Visually, VP retains meat pigment in the deoxymyoglobin state and returns pork to the unappealing purplish-red color (McMillin, 2008). Packaging meat under oxygen-depleted atmosphere packaging prevents the formation of metmyoglobin for the duration of storage (Gill, 1996). Cayuela et al. (2004) reported a 5% increase in weight loss 1 d after VP compared to MAP with high oxygen content.

It is also important to note that the monitoring and control of temperature is essential regardless of packaging to ensure prolonged product quality preservation. Temperature abuse or poor hygienic handling can put product quality and safety at risk within any production system.

Cooking Temperature

Traditionally, it was recommended that pork should be cooked to reach an internal temperature of 71°C for 1 minute to effectively inactivate the pathogen *Trichinella spiralis*. However, with changes in pork production systems resulting in the near elimination of this pathogen, the National Pork Board recommended degree of doneness for pork has changed. This change in recommendation is important due to the influence of final internal temperature of loin chops on eating quality, namely juiciness and tenderness (Hughes et al., 2014). Continued and over application of a direct heat to reach a higher endpoint temperature can cause connective tissue to bind and shrink, causing an overall tightening of sarcomeres. The result is a less desirable eating experience, with the loss of moisture pushed out of fibers and limited space between sarcomeres for mastication, both due to shrinkage of connective tissue from long exposure to a direct heat source (Crawford et al., 2010). Consumers rated an increase in sensory tenderness and juiciness on pork cooked to a medium-rare (63°C) degree of doneness (Rincker et al., 2008; Moeller et al., 2010). Rincker et al. (2008) reported that trained sensory panelists found loin chops cooked to a medium rare degree of doneness (63°C) to be 9% more tender and 14% juicier than chops cooked to a medium degree of doneness (71°C). In a similar study, Moeller et al. (2010) found that trained panelists rated medium rare cooked chops as 2% more tender and 12% juicier than medium cooked chops. Due to this research, the National Pork Board changed the recommended endpoint temperature for pork to be lowered from medium (71°C) to medium-rare (63°C). Thermal-denaturation of proteins results with moisture loss similar to that of pH on myofibrils, and immobilized water is expelled through the channels created through myofibril shrinkage (Offer et al., 1988). The hardening or increased firmness in cooked products is due to the loss of water (Hughes et al., 2014). Thus, a firmer loin can be associated with less moisture loss and a more tender eating experience.

Pork Quality Grading System

The evaluation of pork quality in the U.S. has changed drastically over the last 50 years, with further proposed changes currently under debate. Historically, the quality of pork has been determined from a calculated ratio of lean muscle to fat content. This calculation utilizes carcass weight and a single backfat measurement (Hale, 1994), with the recent addition of longissimus dorsi area (NPB, 2000). Accurate measurements of backfat depth and longissimus are can be achieved by ribbing carcasses, as is done for beef grading. However unlike beef carcasses, pork carcasses are not ribbed postmortem due to different fabrication practices between species. The value from this equation is a predicted fat-free lean percentage that is used by packers to develop pricing matrices to market carcasses that fall within the current desired lean percentile (Johnson et al., 2004). In the early 20th century, pork carcasses with excess backfat were considered desirable due to the value of lard. However, the value of lard declined after vegetable-based fats became more popular in the 1950’s as they were viewed as a healthier option. In response to these changes, the pork industry moved to value a leaner pigs. Within the last 40 years, the industry has made a drastic change to produce much leaner pigs, with fat free lean percentages up to 60% within some production practices (Johnson et al. 2004).

In 2017, the USDA proposed a new grading system (Table 1.1) that will use visual estimations of ventral loin color, marbling, and firmness to assign quality grades (Agricultural Marketing Service, 2017). The proposal of these quality grades has sparked much debate in the industry because some producers and packers are not convinced that a quality grade is needed. This is believed due to the variation among consumer preference for color and marbling. Moreover, loin quality is not necessarily indicative of quality of the ham or belly primals on the same carcass (Arkfeld et al. 2016). Therefore, the application of a carcass quality grading system may not create the results packers and consumers desire when trying to sort products into categories of higher value.

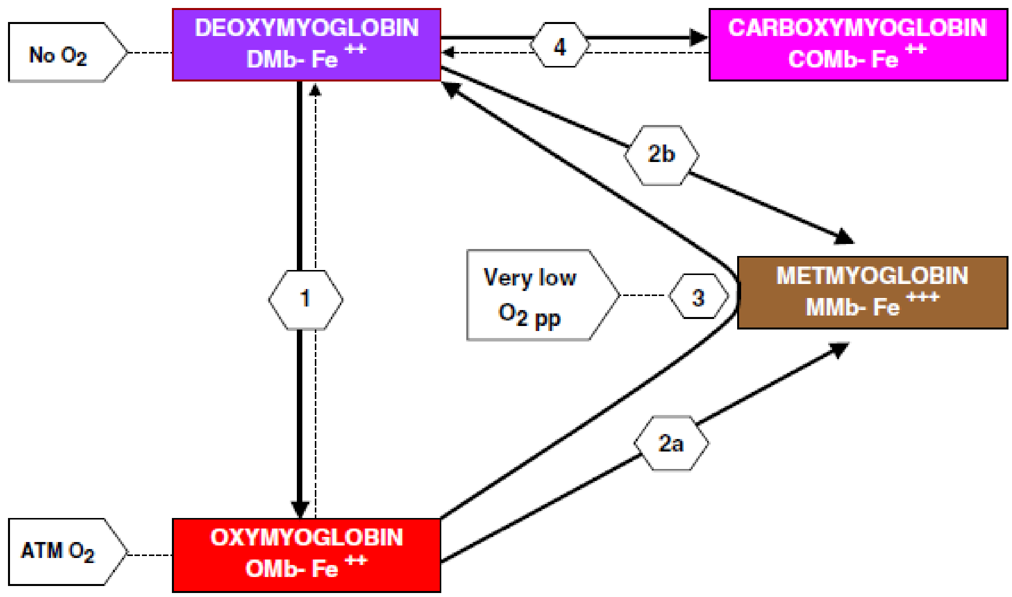
Conclusions and Objectives

Pork loin quality is currently determined by color and marbling. Color is an indicator of freshness for consumers, but also as an indicator of water-holding capacity through its relationship with myoglobin, a water-soluble protein. Attributes such as the rate of early postmortem pH decline affect WHC, resulting in lighter color values. WHC is also correlated with juiciness, and thus we can conclude that color may be an indicator of juiciness. Although marbling is used in the beef grading system to effectively separate steaks into categories of increasing eating experience, it is not as consistent within pork loins. Previous literature has described consumer's rating higher marbled chops as more tender and juicier, yet other studies show no predictive capability or little to no correlation to marbling and sensory traits. Outside of pork quality, final internal temperature has proven to consistently produce a more satisfactory eating experience at a lower degree of doneness.

Given what we know, several questions remain that require answering. How similar is color and marbling evaluated at an early time point is to an aged time point? Does this change when packaged in a different method? Does quality grade, packaging type, or degree of doneness effect eating experience? Is there any interaction between quality grade, packaging type, or degree of doneness that influence eating experience?

To answer these questions, two experiments were conducted that analyzed how visual quality traits may change overtime, and how quality traits, packaging, and cookery methods can effect eating experience. The first focused on the predictive strength of utilizing early postmortem quality or aged postmortem quality on sensory traits and if packaging type or aging method had any effect on sensory traits. The second sorted samples into groups based on the newly proposed USDA quality grading system and into different packaging types, aged and cooked to different degree-of-doneness to evaluate how it affected sensory traits by trained panelists. The first project answers the question of quality sustainability. Before a quality grading system can effectively be utilized by consumers, it is crucial to ensure that the traits used for grading will be sustained throughout the average aging period of fabrication to retail shelf. Additionally, the comparison of how pork loins are aged and their effect on quality were analyzed to provide more insight on factors that affect fresh quality at different time points and sensory traits. The second project combines factors that could possibly play a major role outside of fresh quality in determining eating experience. The two more widely used packaging types and further comparison of how the new lowered degree of doneness and old higher degree of doneness. This work is the first reported to utilize pork assigned through the proposed USDA grading scale and evaluated by trained sensory panelists. Determining the effects of the new grading system on palatability traits allows for consideration of changes to the system to more aptly provide a more satisfying eating experience. This chapter will focus on how fresh pork quality traits as well as sensory traits are affected and influenced by many factors interacting with the pig during the live phase as well as steps leading from harvest to fabrication until ending on a plate. Additionally, it will go into why the proposed grading system looks to utilize color, marbling, and firmness as its standards for quality grades.

Figure and Table



Rx 1 (Oxygenation): DMb + $O_2 \rightarrow$ OMb

Rx 2a (Oxidation): OMb + [oxygen consumption or low O_2 partial pressure] – $e^- \rightarrow$ MMb

Rx 2b (Oxidation): [DMb – hydroxyl ion – Hydrogen ion complex]+ $O_2 \rightarrow$ MMb + O_2^-

Rx 3 (Reduction): MMb + Oxygen consumption + metmyoglobin reducing activty $\rightarrow$ DMb

Rx 4 (CarboxyMb): DMb + carbon monoxide $\rightarrow$ COMb

Figure 1.1 Reduction and oxygenation reactions of myoglobin and the visual result on the cut surface of meat.[1]

[1] Adapted from Mancini and Hunt, 2005

Quality grade	Lean color score	Lean marbling score
USDA Prime	4-5	Greater than or equal to 4
USDA Choice	3	Greater than or equal to 2
USDA Select	2	Greater than or equal to 2

Table 1.1 Proposed USDA pork carcass quality grade requirements based on loin color and marbling[1]

[1]Adapted from USDA 2017

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CHAPTER 2: EFFECTS OF AGING PORK AS INTACT LOINS OR AS CASE-READY CHOPS ON AGED LOIN CHOP QUALITY AND CORRELATIONS AMONG EARLY AND AGED PORK QUALITY

Abstract

Approximately half of fresh pork sold in the U.S. arrives at the store in case-ready packages. The other half is cut and packaged at retail stores. Cutting chops from loins may increase moisture loss leading to lighter colored meat and reductions in juiciness. Therefore, case-ready packaging may decrease loin chop quality. Due to this potential change, it is possible that correlations between loin quality traits observed early postmortem (PM) and aged quality traits would differ between intact-loin aged (**ILA**) chops and case-ready aged (**CRA**) chops. Boneless loins (*N* = 288) were selected to represent a range in ventral color and marbling. Selection was achieved using a VQG grading camera to allot loins with similar ranges of ventral color and marbling to treatments. Color, marbling, firmness, pH, and instrumental color values were evaluated on the ventral side of each loin at 1 d PM. Early ventral loin lightness (L*) values ranged from 52.42 (light) to 37.23 (dark) and extractable lipid ranged from 0.7% to 6.2%. Loins were assigned to one of two packaging treatments (n=144 per treatment): ILA or CRA. All loins were transported in vacuum-packages from the slaughter facility to the university meat lab. There, ILA loins were aged as intact-loins (ILA) in vacuum packaging at 4°C until 12 d PM. Then, they were removed from packaging, evaluated for ventral quality parameters, sliced into 28 mm thick chops, evaluated instrumental color on chop face surface, and then individually re-vacuum packaged until 14 d PM. Upon arrival at the university, CRA loins were sliced at 2d PM into 28 mm thick chops, packaged in packaged in individual Styrofoam trays and overwrapped in polyvinyl chloride (PVC) oxygen permeable film and gas flushed in bulk packages with a gas mixture that contained approximately 0.4 % carbon monoxide, 30 % carbon dioxide, and 80 %

nitrogen. Chops were stored in bulk packaging at 4°C until 9 d PM, removed from the bulk packaging, and set on simulated retail display until 12 d PM. Then, chops were removed from packaging, instrumental color evaluated on chop face surface, and then were individually vacuum packaged until 14 d PM. Warner-Bratzler shear force (WBSF) and cooking loss were evaluated at 14 d postmortem. Quality parameters of both packaging treatments at early and aged time points were compared as a completely randomized block design with slaughter date as a blocking factor. Pearson's correlation coefficients between early and aged quality traits for both packaging treatments were transformed using Fisher's r to z transformation for independent correlations comparisons of packaging treatments. Dependent correlation coefficients were transformed using Fisher's r to z transformation and compared between ILA ventral quality traits at 1 d PM, 12 d PM, and WBSF or cooking loss using an additional test statistic, *t*, for dependent correlation comparisons. Loins designated to ILA were 0.29 units redder ($P = 0.03$) than CRA loins at 1 d PM, with no other differences ($P \geq 0.13$) of 1 d PM quality traits. Chops from ILA were darker and redder (12 d postmortem) on the chop face than CRA chops ($P < 0.0001$). Lightness and redness values on the ventral surface for ILA loins (r = 0.52 lightness; r = 0.63 redness) and CRA loins (r = 0.45 lightness; r = 0.61 redness) at 1 d postmortem were both correlated with aged lightness and redness values on the aged chop face at 12 d postmortem. Those correlations did not differ for either lightness or redness ($P \geq 0.43$). Overall, aging intact loins in vacuum packaging improved color after 12 d of aging compared with aging chops in case-ready packaging. Despite the differences between aging methods, the relationships between early and aged loin quality traits did not differ between aging methods. Therefore, packers need not to consider subsequent packaging and aging methods when sorting loins on early postmortem quality traits.

Introduction

Fresh pork loin color and marbling are the primary traits consumers use to make purchasing decisions, with majority of consumers associating darker pork color and increased marbling with a more tender and juicy product, further driving consumer purchasing intent (Brewer et al., 2001; Wood et al., 2004; Mancini and Hunt, 2005). Therefore, loins are often sorting during fabrication to designate darker loins with more marbling into premium-based programs. During fabrication, deboning a loin allows for fresh quality evaluations to be conducted on the ventral surface of the exposed lean (King et al., 2011). Loin quality is assessed by measuring pH, instrumental color value, or by visual appraisal of color and marbling by a trained technician. After fabrication, loins are then packaged and aged for several days before they are encountered by consumers.

Postmortem aging on pork has been well established to increase tenderness through postmortem proteolysis (Gould et al., 1965; Buys et al., 1993; Ellis et al., 1998; Bowker et al., 2010; Lonergan et al., 2010). Additionally, the relationship between postmortem pH decline and water-holding capacity influence fresh pork color as well as juiciness (D'Souza et al., 1998; Aaslyng et al., 2003). However, the relationships between early postmortem quality traits evaluated at a processing facility and aged (14 d postmortem) quality traits evaluated in retail display or sensory traits observed by consumers are less clear. Recently, using meta-analysis techniques, Harsh et al. (2018) demonstrated that early postmortem loin ultimate pH was moderately correlated to aged ventral L*, ventral subjective color, and subjective color on freshly cut chop face. Additionally, instrumental lightness (L*), redness (a*), and subjective marbling were only moderately correlated to their aged ventral or chop face counterpart. Furthermore, color and marbling were weakly correlated to sensory traits such as tenderness, juiciness, and flavor.

Potentially adding a further complication to the relationship between early and aged quality traits are different packaging and aging methods used in the pork industry. A 2004 survey identified that almost half (48.7%) of fresh pork sold in the U.S. arrives at the store in "case-ready" packages (Reicks et al., 2008). This means loins were cut into chops at early times postmortem and aged as chops, often in modified atmosphere packaging. The remaining 51.3% of fresh pork is aged in non-case-ready packaging (Reicks et al., 2008). Therefore, these loins are aged intact, most often in vacuum packaging, and then cut into chops for retail display later postmortem. Chops cut from whole muscles had increased moisture loss over time (den Hertog-Meischke et al. 1997). Increased moisture loss may also yield tougher, less juicy chops, as has been previously reported by Huff-Lonergan et al. (2002) and Aaslyng et al. (2003). Additionally, increased purge loss decreased consumer appeal due to lighter chop color (Huff-Lonergan et al., 2002; Stetzer and McKeith, 2003; Fischer, 2007). Thus, it was hypothesized that slicing and packaging chops in case-ready packages early postmortem would result in a lighter colored chop. Therefore, the objective was to compare the quality of chops from loins aged intact to those aged in case-ready packaging. Due to these potential changes, a second objective was to determine whether relationships between early postmortem ventral loin quality traits and aged chop surface quality traits differed between packaging methods.

Materials and Methods

Pigs were slaughtered at a commercial facility under the supervision of the USDA Food Safety and Inspection Service. Boneless loins were purchased from the facility and transported to the University of Illinois Meat Science Laboratory. Therefore, Institutional Animal Care and Use Committee approval was not obtained.

Processing Facility Data Collection

Pigs used for this study were from two separate production focus programs (lean growth and meat quality) similar to those described by Arkfeld et al. (2016). Pigs were immobilized using carbon dioxide and terminated via exsanguination. Carcasses were blast-chilled for ~90 min and then held in an equilibration cooler until approximately 22 h postmortem, at which point they were fabricated into primal cuts. Loins were further cut into boneless strap-on (longissimus dorsi with iliocostarum attached) center cut pork loins [NAMP # 414, PSO 3; North American Meat Institution (NAMI), 2014] and imaged using a VQG pork loin grading camera on the ventral side of the loin immediately after boning. The VQG camera was used to select variation in color and intramuscular fat content among loins. A target of 36 loins were selected from each production focus for a total of 72 loins from each collection day. Four collection days were each separated by a 3 to 4 week period in the winter-spring season, totaling 288 loins overall. Within a production focus, an equal variation in color and marbling scores were targeted for each of the designated packaging treatments: intact loins aged (ILA; n = 144) until 12 d postmortem then sliced or case-ready aged (CRA; n = 144) loins sliced at 2 d postmortem and aged until 12 d postmortem. Selected loins were removed from the de-boning line and subsequently evaluated for CIE instrumental lightness (L*), redness (a*), and yellowness (b*) (CIE, 1978), pH, visual color, marbling, and subjective firmness and weight. Ventral evaluations were measured near the area of the 10th rib. Instrumental lightness (L*), redness (a*), and yellowness (b*) scores were measured using a Konica Minolta CR-400 colorimeter (D65 light source, 10˚ observer, 8 mm aperture; Minolta Camera Company, Osaka, Japan) that was calibrated with a white tile prior to evaluations. Loin pH was measured using a MPI pH meter (Meat Probes Inc. pH-Meter, Topeka, KS) with a glass electrode probe that was calibrated prior to evaluations using pH 4 and pH 7 calibration buffers stored at 4°C. A trained technician evaluated color and marbling, using National Pork Producers Council (NPPC, 1999) color and marbling standards and subjective firmness using National Pork Producers Council (NPPC, 1991) scale. Visual color was assigned using a 6-point scale (1 = pale, grayish-pink; 6 = dark, purplish-red); visual marbling was assigned using a 10 point scale (1 = 1% intramuscular fat; 10 = 10% intramuscular fat), and subjective firmness was assigned using a 5 point scale (1 = soft; 5 = firm). All evaluations were determined in half score increments. Boneless loins were vacuum-packaged and transported in coolers with ice packs approximately 520 km to the University of Illinois Meat Science Laboratory for aging and further evaluations.

Loins Aged Intact

Loins selected to be ILA remained in vacuum packages in boxes and stored in a dark cooler (4° C) until 12 d postmortem. At 12 d postmortem, loins were removed from their packaging and allowed a minimum of 30 minutes for oxygenation of myoglobin prior to ventral loin quality evaluation. Ventral loin evaluations at 12 d postmortem were performed by the same trained technician who conducted quality evaluations on 1 d postmortem, followed the same procedures, and used the same equipment as previously described. Ventral aged evaluations consisted of CIE instrumental lightness (L*), redness (a*), and yellowness (b*), pH, subjective color, marbling, and firmness and weight. Loins were then sliced into 28 mm thick chops [NAMP # 1413, PSO 3; North American Meat Institution (NAMI), 2014] using a PUMA slicer (TREIF USA Inc., Shelton, CT). Chops were collected for meat quality evaluation starting from the anterior end of the loin, with the first selected chop containing a posterior portion of the spinalis dorsi (Figure 2.1). Chops were assigned to meat quality evaluations in the following order: Chop 1) Warner-Bratzler shear force (WBSF), Chop 2) proximate analyses, Chops 3-10) chop face surface quality evaluations. Chop 1 was vacuum-packaged and stored at 4°C until 14 d postmortem for evaluation of instrumental tenderness. Chop 2 was trimmed of subcutaneous fat, connective tissue, and accessory muscles, vacuum-packaged, and stored at -20°C until evaluation of extractable lipid content. Chops 3-10 were allowed at least 30 minutes for oxygenation of myoglobin before surface evaluations were conducted on one chop selected randomly. Evaluations for instrumental CIE lightness, redness, and yellowness and visual color, marbling, and subjective firmness used the same equipment and procedures described for 1 d postmortem evaluations.

Case-ready Aged Chops

Loins selected to be CRA were removed from their vacuum-sealed packaging at 2 d postmortem. Loins were then sliced into 28 mm chops using a PUMA slicer (TREIF USA Inc., Shelton, CT). Chops were collected and quality traits were assessed using the same protocol as whole loin aged chops. Chops were packaged with an absorbent pad (Ultra ZAP Soaker) in a 13.65cm^2 tray (polystyrene Cascades Evok) and overwrapped in polyvinyl chloride (PVC) film (O_2 transmission = 23,250 mL·m^2·d^{-1}, 72 gauge; Resinite Packaging Films, Borden, Inc., North Andover, MA). Individual overwrap packaged chops originating from the same loin were placed in a 35.56 cm x 50.80 cm vacuum sealable bag gas-flushed with 600 millibars of a gas mixture (0.2% - 0.4% carbon monoxide, 23% - 30% carbon dioxide, and 60% - 80% nitrogen). Packages were boxed and aged in a dark cooler at 4°C until 9 d postmortem. At 9 d postmortem, chops were removed from boxes and bulk packaging, and placed in simulated retail display under fluorescent lighting (General Electric 32W, 122cm fluorescent Kitchen/Bath bulb in an Utilitech

121 cm 2-light fixture suspended 30.5 cm above the chops) in the individual overwrapped packages, in order to simulate retail case conditions. At 12 d postmortem (after 3 d of simulated retail display; Figure 2.2), chops were evaluated for instrumental CIE lightness, redness, and yellowness with the same equipment and procedures described at 1 d postmortem.

Warner-Bratzler Shear Force

Chops were selected from ILA loins for Warner-Bratzler shear force analysis. Chop 1 from ILA loins when sliced at 12 d PM were vacuum sealed in individual packages, boxed, and aged to 14 d postmortem in a refrigerated cooler at 4 °C. At the end of the aging period, chops were removed from their packaging and an individual raw weight was recorded. A copper-constantan thermocouple (Type T, Omega Engineering, Stamford, CT, USA) was inserted into the geometric center of each chop to accurately monitor internal cooking temperature on a digital thermometer (model 92000-00, Barnat Co, Barrington, IL, USA). A Farberware Open Hearth grill (model 455N, Walter Kidde, Bronx, NY, USA) was used to cook chops. Chops were initially cooked to an initial internal temperature of 36 °C and then flipped. Chops were further cooked until a final internal temperature of 68 °C was reached, at which point they were immediately removed and placed on an aluminum tray for cooling. After chops cooled to ambient temperature (approximately 22°C), they were weighed. Cooking loss was calculated using the following equation: Cook Loss, % = [(raw weight – cooked weight) / raw weight] x 100. Four 1.25 cm diameter cores were collected from each chop, parallel with the muscle fiber. Cores were sheared using a Texture Analyzer HD Plus (Texture Technologies Corp., Scarsdale, NY, and Stable Microsystems, Godalming, UK) equipped with a blade speed of 3.3 mm/s and load cell capacity of 100 kg. The force of each of the 4 cores were averaged and reported as Warner-Bratzler shear force.

Proximate Analysis

Chops selected for proximate analysis were trimmed of epimysium and other muscles and the remaining denuded longissimus chops were vacuum sealed in individual packages, boxed and placed in a freezer at -20 °C. At 12 d postmortem, chops were shipped in coolers with ice packs to the USDA Meat Animal Research Center for determination of moisture and extractable lipid. Chops were tempered and diced into cubes that were approximately 5 mm x 5mm x 5 mm. Cubes were mixed and powdered with liquid nitrogen using a waring commercial blender and micro-mini (15-37 ml) blender cups. Powdered samples were maintained at -20ºC until weighed. Duplicate 1.5 g samples from each chop were weighed into pre-weighed filter bags (Ankom Technology XT4 Filter Bag). Filter bags were heat sealed (Ankom model HS), placed on a drying rack in a single layer and dried for 24 h at 102º C with a drying oven (VWR 89511-414). The filter bags were placed into a weigh tin desiccator (Ankom X49) and cooled at room temperature for 15 min and then weighed. Ether-extractable fat was removed with an Ankom XT15 system. Samples were dried for 15 min at 102ºC, returned to the weigh tin desiccator, cooled at room temperature for 15 min and then weighed. Moisture and fat percentage were calculated, agreement of duplicate samples was checked, and the average value was calculated for each loin.

Statistical Analyses

Loin quality parameters measured at 1 d postmortem after grouped by packaging treatment were compared using a one-way ANOVA in the MIXED procedure of SAS 9.4 (SAS

Inst. In., Cary, NC). The model included the fixed effect of aging treatment and the random effect of slaughter date. Each individual loin served as the experimental unit for all dependent variables. Least squares means and standard errors were reported for all measured attributes and were considered different at $P \leq 0.05$ for all analyses.

Comparison between 1 d postmortem and 12 d postmortem ventral surface loin quality (intact loin aged treatment only) using a paired T-test by way of PROC TTEST in SAS. Means were considered different at $P \leq 0.05$.

A z-test was used to compare two independent correlations as described in Kenny (1987). First, correlation coefficients (*r*) were determined between early and aged quality traits within each packaging treatment using the CORR procedure of SAS. Then, correlation coefficients were transformed with the FISHER option in SAS. The Fisher's r to z transformation equation was defined as:

Eq. 1.

$$z = \frac{1}{2} \ln \left[\frac{1+r}{1-r} \right]$$

Where *r* is the Pearson correlation coefficient, and *z* is the transformed correlation coefficient. Fisher's transformed *z* values were then merged into a single data set for comparison of independent correlation coefficients. Data were compared based on the following equation:

Eq. 2.

$$Z_{calculated} = \frac{z_{ILA} - z_{CRA}}{\sqrt{\frac{1}{n_{ILA} - 3} + \frac{1}{n_{CRA} - 3}}}$$

Where $Z_{calculated}$ is the calculated z-value, z_{ILA} is the transformed correlation coefficient of the ILA variables, z_{CRA} is the transformed correlation coefficient of the CRA variables, n_{ILA} is the number of observations for the ILA variables, and n_{CRA} is the number of observations for the CRA variables. The correlations between 1 d postmortem ventral loin traits with 14 d WBSF and cooking loss (r_{13}) was compared with the correlations between 12 d postmortem loin traits with 14 d WBSF and cooking loss (r_{23}). Because the correlations being calculated were not derived from different, independent populations and the correlations being compared shared a common trait (14 d WBSF or cooking loss), they were considered dependent. That is, r_{12} is correlated with r_{13}, therefore the influence of the relationship of between 1 d postmortem and 12 d postmortem ventral loin quality traits (r_{12}) must be accounted for when comparing r_{13} with r_{23} (Kenny, 1987). To achieve this, three sets of Pearson correlation coefficients were calculated (r_{13}, r_{23}, and r_{12}) and the correlation coefficients transformed using Fishers r to z equation (Eq. 1). Then, the test statistic, t was calculated using the following equation from Zou (2007):

Eq. 3.

$$t = \frac{(r_{23} - 0.05 r_{12} r_{13})(1 - {r_{12}}^2 - {r_{13}}^2 - {r_{23}}^2) + {r_{23}}^3}{(1 - {r_{12}}^2)(1 - {r_{13}}^2)}$$

Where t is the calculated test statistic, r_{13} is the correlation between 1 d quality traits and 14 d WBSF and cook loss, r_{23} is the correlation between 12 d quality traits and 14 d WBSF and cook loss, and r_{12} is the influence of the relationship between 1 d and 12 d postmortem. The resulting test statistic (t) was then compared with t_{critical} from a t distribution.

Correlations of the *z*- or *t*-value were considered different between packaging treatments at $P \leq 0.05$ (Kenny, 1987). Correlations were considered weak at $|r| < 0.35$, moderate at $0.36 \geq |r| < 0.67$, and strong at $|r| \geq 0.68$ (Taylor, 1990). Analysis in data sets exceeding 100 observations may result in correlation coefficients of 0.20 that have little practical importance despite being statistically different from 0 ($\alpha = 0.05$). Therefore, comparisons between correlations of early and aged postmortem loin quality by packaging treatment were considered significantly different at $P \leq 0.05$ with a corresponding correlation coefficient of $|r| \geq 0.36$ to ensure practical significance (Taylor et al. 1990).

Results

Early Postmortem Ventral Loin Evaluations

Randomly allocating the population to packaging treatments provided very few early postmortem differences (Table 2.1). At 1 d postmortem, there were no differences in ventral lightness ($P = 0.13$), yellowness, NPPC color, marbling, firmness, or pH levels ($P \geq 0.13$). Loins designated to be ILA were 0.29 units redder (had a greater a*; $P = 0.03$) than loins designated to be CRA.

Comparison of Early and Aged Loin Quality Traits

Because ILA loins were evaluated on the ventral surface by the same observer, using the same equipment, and at approximately the same anatomical location at both 1d and 12d postmortem, these values can be directly compared to determine the change in quality traits with aging. The ventral surface of ILA loins at 12 d postmortem were 7.1% lighter ($P < 0.0001$), 12.4%redder ($P < 0.0001$), and 78.9% yellower ($P < 0.0001$) when compared to 1 d postmortem

(Table 2.3). Loin pH decreased (*P* < 0.0001) from 5.73 at 1 d to 5.66 at 12 d postmortem. Subjective color and marbling scores (*P* < 0.65) did not change over the course of the aging period, but NPPC firmness scores (*P* < 0.0001) decreased from 2.81 at 1 d to 2.37 at 12 d postmortem.

Comparison of Correlations Between Early and Aged Quality Traits of Different Packaging Treatments

Early postmortem ventral lightness was moderately correlated with 12 d aged chop lightness values for both packaging treatments (ILA, *r* = 0.52; CRA, *r* = 0.45), with no difference (*P* = 0.43) in the correlation coefficients between the packaging treatments (Table 2.4). Early postmortem ventral redness was moderately correlated with 12 d aged chop redness values for both packaging treatments (ILA, *r* = 0.63; CRA, *r* = 0.61), with no difference (*P* = 0.76) between the correlation coefficients. Early postmortem ventral yellowness was moderately correlated with 12 d aged yellowness for both packaging treatments (ILA, *r* = 0.54; CRA, *r* = 0.35), with a stronger correlation (*P* = 0.04) between yellowness at 1 d and 12 d for ILA chops than CRA chops.

The correlation between ventral loin quality traits and 14 d cooked WBSF and cook loss values were compared on ILA between 1 d and 12 d postmortem (Table 2.5). No moderate correlations were found.

Discussion

Loin quality traits observed at early postmortem during fabrication are used by packers to sort loins into quality-based programs (Agricultural Marketing Service, 2017). However, it is unclear to what extent early loin quality traits, particularly color, are predictive of loin quality as viewed by the consumer following a period of aging. Moreover, packaging and aging systems can vary throughout the industry, with loins typically being packaged and aged as intact roasts in vacuum sealed bags, as chops freshly cut from such vacuum-packaged roasts, or as pre-cut chops stored in either vacuum sealed bags, MAP containers, or clear overwrap packaging (Reicks et al. 2008). Even if early postmortem loin quality is indicative of aged loin quality, it is uncertain how the aging process interacts with packaging method to effect aged loin quality as perceived by the consumer at the point of sale. Of these packaging methods, chops cut from vacuum packaged roasts and pre-cut chops stored in MAP containers are the most prevalent in the industry (Reicks et al., 2008). Therefore, in the current experiment, loins were evaluated for quality traits at 1 d postmortem and then packaged for aging either as intact loins in vacuum packaging for 12 d postmortem or pre-cut chops in clear overwrap packaging sealed in a MAP container for 9 d postmortem and then placed in simulated retail display until 12 d postmortem. It was hypothesized that intact aged loins would have greater color stability due to less moisture loss as a result of less disruption of cellular structure through remaining intact compared to pre-cut aged chops.

Loins used in the study represented a wide range of early postmortem quality with 1 d color ranging from 1.5 – 5.0, marbling from 1.0 – 4.0, and firmness from 1.0 – 4.5. A wide range was selected to best represent all possible combinations of color, marbling, and firmness within toady's industry. These ranges are similar to previous work investigating the relationship between loin quality attributes and eating quality (Wilson et al. 2017), but pigs in the current population were of different genetic backgrounds than the previous study. Additionally, loin quality traits observed on the ventral surface of the loin did change with 12d of postmortem aging. After aging, loins were lighter, redder, more yellow, less firm, and experienced a small reduction (0.07 units) in pH. Overall, these changes were small in magnitude and would not likely be noticeable to consumers. In fact, NPPC color score was unchanged with postmortem aging. Moisture loss during aging as a consequence of postmortem proteolysis (Melody et al., 2004) may explain the loss in firmness over the aging period. It is interesting to note that pH continued to decline during aging. However, this reduction was less than a tenth of a pH unit and therefore, may have little practical influence on overall quality.

Packaging type during aging did influence loin chop quality. Chops from ILA loins were darker and redder than CRA chops. While purge during aging was not quantified in this study, it is interesting to speculate that moisture loss may underlie the differences between pork quality in the two packaging methods. The disruption of cellular structure by cutting the epimysium increases the surface area available for exudation of moisture (purge), and along with it water-soluble proteins, such as myoglobin (Huff-Lonergan and Lonergan, 2005). The exudation of myoglobin in the form purge, increases lightness and reduces redness of meat (Joo et al., 1999). Therefore, the cutting of loins for packaging of CRA chops would likely lead to increased purge and thus, the observed lighter, less red chops. In the present study, the lightness difference of 6.75 units were observed between the two packaging treatments is enough to create concern in regard to consumer perception and purchasing intent (Mancini and Hunt, 2005).

In addition to visual differences, it could be expected that chops from ILA loins would be more tender with less cook loss than CRA chops. Postmortem proteolysis occurs as loins age and contributes to protein degradation (Melody et al., 2004). The degradation of myofibril proteins during postmortem storage weakens the muscle structural integrity leading to more tender meat. However, the breakdown of certain proteins will release previously bound water. The combination of an increased exposed cut surface area and the full duration of storage as a chop could explain an increase in moisture lost during cooking. Previous reports have indicated that increasing moisture loss during aging was correlated with reductions in subjective color and instrumental tenderness (Huff-Lonergan et al., 2002).

Given the changes in loin quality traits with aging and the observed differences in aged quality traits between packaging methods, the relationships between early and aged quality traits within each packaging method were estimated and then compared. The relationship between early and aged color did not differ between packaging methods for lightness (L*) or redness (a*). In each packaging method, the correlation between early and aged L* and between early and aged a* would be considered weak. There was a difference, however, between packaging methods for correlations between early and aged yellowness (b*). The correlation between these measures was moderate for CRA chops and weak for ILA chops. Overall, despite differences in the ultimate aged traits between the packaging types, the relationship between early and aged quality was not different between the two packaging methods.

Ultimately, loins are sorted into quality groups for two purposes. First, consumers desire darker loin chops with more marbling. Therefore, estimations of quality can relate to purchase intent. Then, consumers will cook and eat those chops. Therefore, sorting loins by quality should also result in differences in eating experiences to result in increases in repeat purchases of similar pork products. Thus, the relationships between early and aged quality traits on WBSF, a measure of tenderness, and cook loss, a measure of juiciness, were estimated and compared on ILA chops. Previously, early postmortem quality traits such as color and pH were moderately correlated (r = 0.30 to 0.50; Huff-Lonergan et al., 2002; Boler et al., 2010) and are suggested to predict traits of eating quality such as tenderness. Weak negative correlations between tenderness and color score were reported by Huff-Lonergan et al. (2002; r = -0.15) and Boler et al. (2010; r = -0.28), whereas Nam et al. (2009) concluded a positive correlation between Warner-Braztler shear force and color score. In the present study, only weak correlation were observed between 1 d postmortem ventral loin variables and 12 d postmortem ventral loin variables. Positive correlations between NPPC color and WBSF were observed as well as negative correlations between NPPC marbling and WBSF. Negative correlations between marbling and WBSF have been previously reported in numerous studies (Hodgson et al., 1991; r = -0.36; Huff-Lonergan et al., 2002; r = -0.27; Boler et al., 2010; r = -0.32). Given how aging increase WBSF, it is interesting that relationships between quality traits and WBSF did not differ between the two time points. This suggests that factors not analyzed in this experiment may play a larger role than previously thought.

Conclusions

Overall, aging pork loins intact and under vacuum packaging improved visual quality compared with aging loins in case-ready packaging. Although early postmortem color and marbling traits were indicative of aged quality traits, neither early nor aged postmortem quality was particularly indicative of tenderness. Therefore, packers can use early postmortem traits as indicators of potential consumer purchasing intent (color and marbling driven decisions), but understand that early postmortem quality may not be indicative of the potential for repeat purchases (eating quality driven decisions), regardless of packaging method.

Figures and Tables

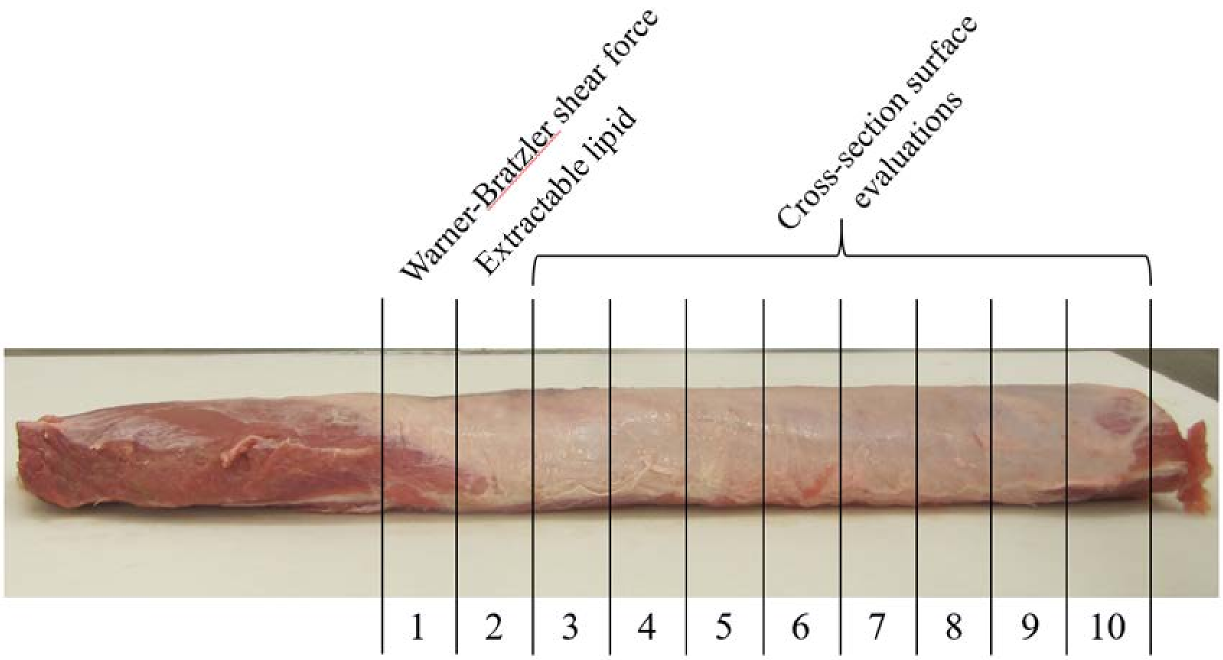

Figure 2.1. Loins sliced into 28mm thick chops were designated for different evaluations by anatomical location. Chop 1, the most anterior chop with the most posterior portion of the spinalis dorsi, was designated for Warner-Bratzler shear force. Chop 2 was selected to determine extractable lipid content. Chops 3-10 were randomly selected for chop face surface evaluations and then either packaged in individual vacuum-sealed packages (Chapter 3) or in PVC overwrapped trays packaged in gas-flushed bulk packages. A chop from each loin designated for each packaging type was cooked to either 63° C or 71° C (Chapter 3). Evaluations included visual color (NPPC 1999), visual marbling (NPPC 1999), subjective firmness, and instrumental lightness, redness, and yellowness (CIE 1978).

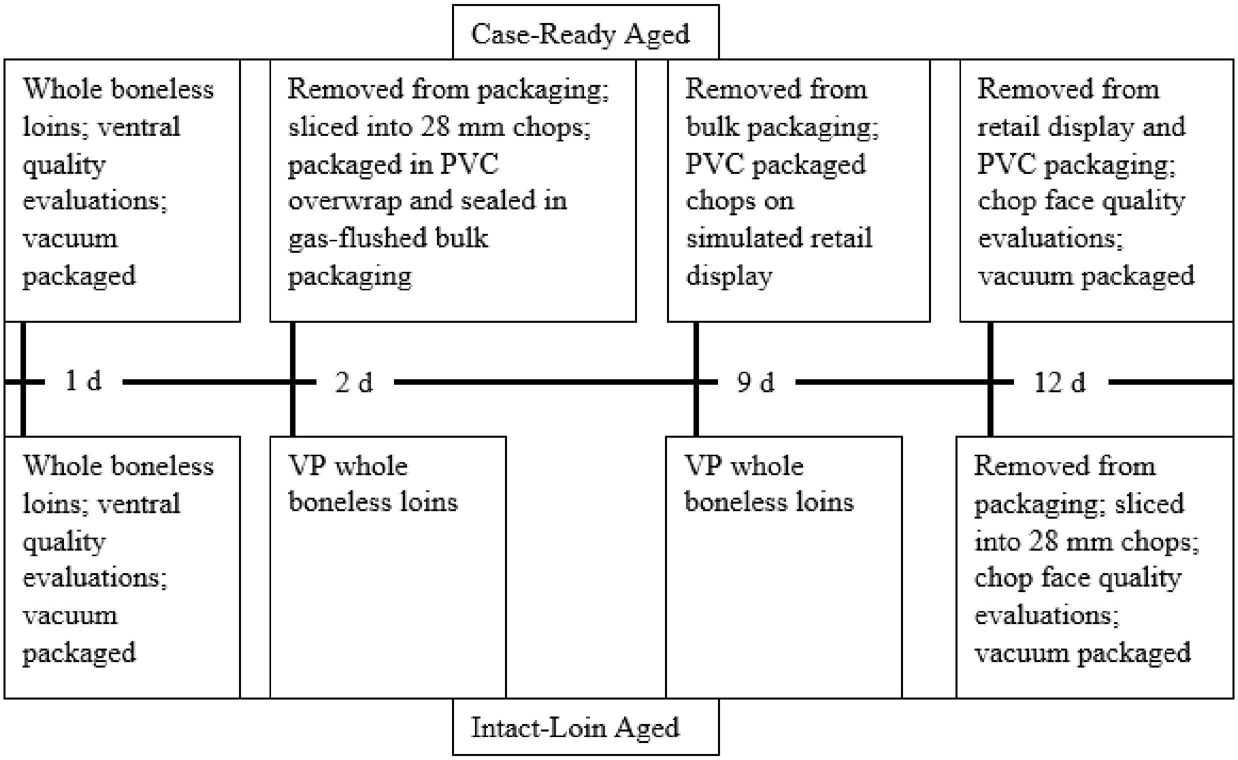

Figure 2.2. Timeline of packaging treatments

Table 2.1. Effects of aging treatment on quality parameters measured early postmortem (1 d) on the loin ventral surface and aged postmortem (12 d) on the chop face surface

Item	Intact Loin Aged	Case-ready Aged	SEM	*P*-value
Loins, n	144	144		
1 d Postmortem, Ventral surface				
Lightness[1], L*	43.34	43.82	0.52	0.11
Redness[2], a*	7.90	7.62	0.19	0.04
Yellowness[3], b*	0.62	0.64	0.12	0.83
NPPC color[4]	3.34	3.41	0.21	0.30
NPPC marbling[5]	2.16	2.10	0.08	0.44
NPPC firmness[6]	2.81	2.82	0.26	0.89
Ultimate pH[7]	5.73	5.73	0.05	0.90
Extractable lipid, %	2.39	2.32	0.16	0.53

[1]L* measures darkness to lightness (greater L* indicates a lighter color)

[2]a* measures redness (greater a* indicates a redder color)

[3]b* measures yellowness (greater b* indicates a more yellow color)

[4]NPPC color based on the 1999 standards measured in half point increments with 1 = palest; 6 = darkest.

[5]NPPC marbling based on the 1999 standards measured in half point increments where 1 = least amount of marbling; 6 = greatest amount of marbling.

[6]NPPC firmness based on the 1991 scale measured in half point increments with 1 = softest; 5 = firmest.

[7]Ultimate pH collected on the ventral surface of the whole boneless loin.

Table 2.2. Effects of packaging treatment on instrumental color measured on chop surface at 2d, 9d, and 12d postmortem.

	Case-ready Aged			Intact Loin Aged		
Item	2d postmortem[4]	9d postmortem[5]	12d postmortem[6]	12d postmortem[7]	SEM	*P*-value
Chops, n	144	144	144	144		
Lightness[1], L*	45.06[a]	55.75[b]	56.81[b]	49.99[c]	0.33	< 0.0001
Redness[2], a*	7.90[a]	8.92[b]	7.33[c]	8.18[d]	0.12	< 0.0001
Yellowness[3], b*	1.67[a]	1.90[ab]	2.54[bc]	2.66[c]	0.12	< 0.0001

[1]L* measures darkness to lightness (greater L* indicates a lighter color)
[2]a* measures redness (greater a* indicates a redder color)
[3]b* measures yellowness (greater b* indicates a more yellow color)
[4]CRA chops after slicing (2 d postmortem)
[5]CRA chops prior to simulated retail display (9 d postmortem) directly after exposure from gas flushed bulk packaging
[6]CRA chops after simulated retail display (12 d postmortem)
[7]ILA chops after slicing (12 d postmortem)

Table 2.3. Comparison of ventral loin quality traits on intact aged loins at early (1 d) and aged (12 d) postmortem[1]

	Days postmortem				*P*-value
Item	1 d	12 d	Difference	SED[2]	
Loins, n	144	144			
Lightness[3], L*	43.34	46.62	-3.29	0.23	< 0.0001
Redness[4], a*	7.90	9.02	-1.12	0.09	< 0.0001
Yellowness[5], b*	0.62	2.95	-2.33	0.09	< 0.0001
NPPC color[6]	3.34	3.35	-0.01	0.05	0.84
NPPC marbling[7]	2.16	2.18	-0.02	0.04	0.64
NPPC firmness[8]	2.81	2.37	0.44	0.08	< 0.0001
Ventral loin pH[9]	5.73	5.66	0.07	0.01	< 0.0001

[1]Early and aged postmortem quality data were compared using a paired-T test on the same loin

[2]Standard error of the difference of the mean

[3]L* measures darkness to lightness (greater L* indicates a lighter color)

[4]a* measures redness (greater a* indicates a redder color)

[5]b* measures yellowness (greater b* indicates a more yellow color)

[6]NPPC color based on the 1999 standards measured in half point increments with 1 = palest; 6 = darkest.

[7]NPPC marbling based on the 1999 standards measured in half point increments where 1 = least amount of marbling; 6 = greatest amount of marbling.

[8]NPPC firmness based on the 1991 scale measured in half point increments with 1 = softest; 5 = firmest.

[9] Ultimate pH collected on the ventral surface of the whole boneless loin

Table 2.4. Comparison of independent Fisher's r to z transformed correlation coefficients (rho) of early postmortem loin color and aged postmortem chop color

Early postmortem loin variable	Aged postmortem chop variable	Intact Loin Aged			Case-ready Aged			
			95% Confidence limit[1]			95% Confidence limit[1]		
		Rho	Lower	Upper	Rho	Lower	Upper	*P*-value[1]
Lightness[2], L*	Lightness[2], L*	0.52	0.39	0.63	0.45	0.31	0.57	0.43
Redness[3], a*	Redness[3], a*	0.63	0.11	0.41	0.61	0.11	0.41	0.76
Yellowness[4], b*	Yellowness[4], b*	0.54	0.42	0.65	0.35	0.20	0.49	0.04

[1]Confidence intervals not including zero (0) are significant correlations (P ≤ 0.05).

[2]L* measures darkness to lightness (greater L* indicates a lighter color)

[3]a* measures redness (greater a* indicates a redder color)

[4]b* measures yellowness (greater b* indicates a more yellow color)

[5]Probability value comparing correlation coefficients, using r to z transformed values, of quality traits between loins aged 12 d as either intact loin aged or case-ready aged

Table 2.5. Comparison of calculated test statistic dependent correlation coefficients (rho) from intact aged loins at early (1 d) postmortem and aged (12 d) postmortem to Warner-Bratzler shear force (WBSF) and cook loss

Ventral loin variable	1d postmortem			12d postmortem			
		95% Confidence limit[1]			95% Confidence limit[1]		
	Rho	Lower	Upper	Rho	Lower	Upper	*P*-value[2]
WBSF							
NPPC color	0.17	0.00	0.32	0.17	0.00	0.32	0.98
NPPC marbling	-0.08	-0.24	0.08	-0.15	-0.3	0.02	0.58
NPPC firmness	0.15	-0.01	0.31	-0.01	-0.18	0.15	0.15
Lightness, L*	-0.14	-0.30	0.02	-0.17	-0.32	0.00	0.83
Redness, a*	-0.11	-0.27	0.05	0.00	-0.17	0.16	0.14
Yellowness, b*	-0.01	-0.17	0.16	-0.14	-0.30	0.02	0.18
Cooking loss, %							
NPPC color	-0.12	-0.28	0.05	-0.08	-0.24	0.08	0.78
NPPC marbling	0.08	-0.08	0.24	0.06	-0.10	0.22	0.86
NPPC firmness	-0.01	-0.17	0.15	-0.08	-0.25	0.08	0.52
Lightness, L*	0.11	-0.05	0.27	0.03	-0.14	0.19	0.34
Redness, a*	0.01	-0.15	0.18	0.04	-0.13	0.20	0.81
Yellowness, b*	0.05	-0.12	0.21	0.05	-0.12	0.21	0.99

[1]Confidence intervals not including zero (0) are significant correlations ($P \leq 0.05$).

[2]Probablity value comparing correlation coefficients of meat quality traits on loins aged intact between 1 d and 12 d postmortem

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CHAPTER 3: EFFECT OF PACKAGING TYPE DURING POSTMORTEM AGING AND DEGREE OF DONENESS ON PORK CHOP SENSORY TRAITS OF LOINS SELECTED TO VARY IN COLOR AND MARBLING

Abstract

The objective was to determine the interactions between packaging type and degree of doneness on sensory traits of pork loins classified based on the newly proposed USDA quality grades. A total of 144 loins were selected from 2 groups of pigs (lean growth or meat quality production focus) to represent as much variation in visual color and marbling as possible. Selection was achieved with a VQG grading camera. The ventral surface of the loins were evaluated for loin quality traits at 1 d postmortem. At 2 d postmortem loins were sliced into 28 mm thick chops. Chop within each loin were randomly assigned to either individual vacuum packages or to individual Styrofoam trays and overwrapped in polyvinyl chloride (PVC) oxygen permeable film. Overwrapped PVC packages were then placed in bulk packages and flushed with a gas mixture that contained approximately 0.4 % carbon monoxide, 30 % carbon dioxide, and 80 % nitrogen. Vacuum-packaged chops were aged until 14 d postmortem. Chops packaged in PVC overwrap were aged until 9 d postmortem in the bulk packages, then placed on simulated retail display until 14 d postmortem. Chops from each packaging type were cooked to an internal temperature of either 63° C or 71° C for the evaluation of slice shear force (SSF) or for evaluation of tenderness, juiciness and flavor by a trained panel. Data were analyzed as split-split plot design with production focus of the pigs, proposed USDA quality grade, packaging type, and degree of doneness as fixed effects. While there were main effect differences between production focuses, there were no interactions with production focus. There were also no three-way ($P \geq 0.19$) interactions and only 1 two-way interaction among quality grade, packaging type or degree of doneness. There were no differences in sensory tenderness ($P = 0.30$), juiciness ($P =$

0.49), flavor ($P = 0.89$), SSF ($P = 0.13$), or cook loss ($P = 0.06$) among USDA quality grades. There were no differences in sensory tenderness ($P = 0.06$), juiciness ($P = 0.32$), flavor ($P = 0.74$), SSF ($P = 0.99$), or cook loss ($P = 0.12$) between chops aged in vacuum packages or PVC packages. Chops cooked to 63° C were 4.6% more tender ($P < 0.0001$), 10.1% juicier ($P < 0.0001$), and 2.9% less flavorful ($P = 0.01$) than chops cooked to 71° C. These data suggest that cooking chops to 63° C rather than 71° C was a more effective way to improve tenderness and juiciness than selecting chops of a certain quality grade or altering packaging postmortem.

Introduction

Consumers routinely rate tenderness and juiciness as primary factors that influence eating experience (Moeller et al., 2010). Additionally, they use color and marbling as indicators for tenderness and juiciness when making purchasing decisions (Brewer et al., 2001). Because of this, the Agriculture Marketing Service has proposed a USDA pork loin grading system based on the visual color and marbling of the ventral surface of a boneless pork loin (USDA, 2017). One challenge with such a grading system is that grading decisions are based on evaluations on the ventral surface of the loin at 1 d postmortem, but consumers make purchasing decisions based on the cut surface of the loin after a period of postmortem aging. Fortunately, the initial color and marbling of the ventral surface of the loin is correlated with the cut surface of chops from that loin (Lowell et al., 2017). Additionally, Wilson et al. (2017) recently reported that the combination of increasing extractable lipid and a darker surface color increased instrumental tenderness of pork chops cooked to a medium-rare degree of doneness. So, it stands to reason that a USDA grading system has the potential to sort pork loins to provide a desired eating experience based on consumer expectations.

Nearly half (48.7%) of boneless pork chops produced in the U.S. are distributed to retail establishments as case-ready chops and the remainder (51.3%) as noncase-ready (Reicks et al., 2008). It is not known if this difference in packaging affects sensory traits of boneless pork chops. However, it is readily accepted that cooking pork chops to a medium-rare degree of doneness improves sensory tenderness and juiciness compared with cooking chops to a medium degree of doneness (Moeller et al., 2010). Thus, the objective was to determine the potential interactive effects of packaging type and degree of doneness on sensory traits of pork loins selected to represent the newly proposed USDA quality grades.

Materials and Methods

Pigs were slaughtered under the supervision of the USDA Food Safety and Inspection Service at a federally inspected facility. Boneless loins were purchased from that facility and transported to the University of Illinois Meat Science Laboratory. Therefore, Institutional Animal Care and Use Committee approval was not obtained. All protocols for sensory evaluations were reviewed and approved by the University of Illinois Institutional Review Board (IRB #: 17485).

Processing Facility Data Collection

Pigs used for this study were from two separate production focus programs (lean growth and meat quality) similar to those described by Arkfeld et al. (2016). Pigs were immobilized using carbon dioxide and terminated via exsanguination. Carcasses were blast-chilled for approximately 90 min and then held in an equilibration cooler until 1 d postmortem (~22 h). At 1 d postmortem, carcasses were fabricated into primal cuts and boneless loins were further cut into boneless strap-on (longissimus costarum) center cut pork loins [NAMP # 414, PSO 3; North

American Meat Institution (NAMI), 2014]. Loins were imaged using a VQG pork loin grading camera on the ventral side of the loin immediately after boning. The VQG camera was used to select loins with variation in color (max NPPC score = 5.0, min NPPC score = 1.5) and intramuscular fat content (max NPPC marbling score = 4.0, min NPPC marbling score = 1.0). A target of 18 loins were selected from each production focus for a total of 36 loins during each loin collection period. Loins were collected on 4 separate fabrication days throughout a 4 month period for a total of 144 targeted loins. Loins were moved from the boning line to a table for early postmortem ventral evaluations. Ventral evaluations were conducted on the loin near the area of the 10^{th} rib. Instrumental CIE lightness (L*), redness (a*), and yellowness (b*) were measured using a Konica Minolta CR-400 colorimeter (D65 light source, 2˚ observer, 8 mm aperture; Minolta Camera Company, Osaka, Japan) that was calibrated with a white tile prior to evaluations (CIE, 1978). Muscle pH was measured using a MPI pH meter (Meat Probes Inc. pH-Meter, Topeka, KS) with a glass electrode probe that was calibrated prior to evaluations using pH 4 and pH 7 calibration buffers stored at 4 °C. A trained technician evaluated visual color and marbling, using National Pork Producers Council (NPPC, 1999) color and marbling standards and subjective firmness using National Pork Producers Council (NPPC, 1991) scale. Visual color was assigned using a 6 point scale (1 = pale, grayish-pink; 6 = dark, purplish-red); visual marbling was assigned using a 10 point scale (1 = 1 % intramuscular fat; 10 = 10 % intramuscular fat), and subjective firmness was assigned using a 5 point scale (1 = soft; 5 = firm). All evaluations were made in half score increments. Boneless loins were vacuum-packaged and transported in coolers with ice packs approximately 520 km to the University of Illinois Meat Science Laboratory for aging and further evaluations.

A quality grade was assigned to each loin based on the proposed USDA quality grades where a Prime grade required a NPPC visual color score of 4 or 5 and a NPPC visual marbling score of 4 or greater. To be graded Choice, a lean color score of at least 3 and a visual marbling score of at least 2 was required. To be graded Select, a lean color score of at least 2 and a visual marbling score of at least 2 was required (USDA, 2017). Any loin that did not meet the requirements for Prime, Choice, or Select was categorized as Standard.

Upon arrival at the Meat Science Laboratory, loins were removed from their vacuum sealed packaging at 2 d postmortem and sliced into 28 mm thick chops using a PUMA slicer (TREIF USA Inc., Shelton, CT). Chops were selected starting from the anterior end of the loin where the first chop (chop #1) contained the posterior end of the spinalis dorsi (Fig. 1). Chop #1 was used for WBSF determination as described in chapter 2. Chop #2 was used to quantify extractable lipid. Chops #3 - 10 were randomly assigned to either vacuum packaging or to be placed in a Styrofoam tray and overwrapped in polyvinyl chloride (PVC) oxygen permeable film. Within a packaging type, chops were randomly assigned to a cooking degree of doneness of either 63° C (medium rare) or 71° C (medium). These endpoint temperatures were chosen because in 2011 the USDA Food Safety and Inspection Service changed the recommended endpoint temperatures of whole cuts of pork from 160° F (71° C) to 145° F (63° C). This provided 4 combinations of packing type and degree of doneness with 2 chops designated for each of the 4 combinations from each loin. One of those chops was used for sensory evaluations and one of those chops was used for slice shear force determination.

Chops packaged in overwrap packages were placed in a 13.7 cm^2 tray (polystyrene Cascades Evok) on top of an absorbent pad (Ultra ZAP Soaker) and overwrapped in PVC film (O_2 transmission = 23,250 $mL \cdot m^2 \cdot d^{-1}$, 72 gauge; Resinite Packaging Films, Borden, Inc., North

Andover, MA). Each chop was standardized by trimming subcutaneous fat and accessory muscles and then weighed. Packages of PVC overwrapped chops were placed in a 35.56 cm x 50.80 cm vacuum sealable bag with all chops from the same loin in one bulk modified atmosphere package (MAP) and gas-flushed with a 600 millibars of a gas mixture (0.2 - 0.4 % carbon monoxide, 23 - 30 % carbon dioxide, and 60 - 80 % nitrogen). The bulk packages were boxed and aged in a cooler at 4° C until 9 d postmortem. At 9 d postmortem, chops were removed from boxes and bulk packaging, and placed in simulated retail display 30.50 cm under fluorescent lighting (General Electric 32 W, 122 cm fluorescent Kitchen/Bath bulb in an Utilitech 121 cm 2-light suspending fixture) in the overwrapped trays. Procedures for bulk MAP packaging and retail display followed the generally recognized as safe (GRAS) notice No. GRN 000083 MAP system for packaging fresh cuts of case ready muscle meat (FDA, 2002). Chops designated for vacuum packaging were packaged in individual packages using an Ulma TF mini rollstock packaging machine (Ulma Packaging, Guipuzkoa, Spain). Chops were vacuum sealed between a high oxygen barrier thermal forming film thermally welded to a high oxygen barrier non-forming film.

At 12 d postmortem (3 d after simulated retail display), chops designated for slice shear force analysis were evaluated for instrumental CIE lightness, redness, and yellowness with the same equipment and procedures used to evaluated the ventral surface of the intact loin at 1 d postmortem. They were then removed from their overwrap packaging and vacuum sealed for shipment to the USDA Meat Animal Research Center. Additionally, at 12 d postmortem, chops designated from the vacuum-packing treatment for slice shear force analysis were also shipped to the USDA Meat Animal Research Center.

All remaining chops were assigned for sensory panel analysis and remained in their initial packaging (VAC or PVC) until 14 d postmortem. At 14 d postmortem, chops aged in PVC overwrap packaging taken out of the original overwrap packaging and repackaged in vacuum packages. All chops (PVC and vacuum packaged) were frozen until they were used for sensory evaluation.

Proximate Analyses

Chops for proximate analysis (designated Chop #2 above and on Fig. 1) were trimmed of epimysium and other muscles and the remaining denuded longissimus chops were vacuum sealed in individual packages, boxed and placed in a freezer at -20 °C. Chops were shipped in coolers with ice packs to the USDA Meat Animal Research Center for determination of moisture and extractable lipid. Chops were tempered and diced into cubes that were approximately 5 mm × 5 mm × 5 mm. Cubes were mixed and powdered with liquid nitrogen using a waring commercial blender and micro-mini (15-37 ml) blender cups. Powdered samples were maintained at -20° C until weighed. Duplicate 1.5 g samples from each chop were weighed into pre-weighed filter bags (Ankom Technology XT4 Filter Bag). Filter bags were heat sealed (Ankom model HS), placed on a drying rack in a single layer and dried for 24 h at 102° C with a drying oven (VWR 89511-414). The filter bags were placed into a weigh tin desiccator (Ankom X49) and cooled at room temperature for 15 min and then weighed. Ether-extractable lipid was removed with an Ankom XT15 system. Samples were dried for 15 min at 102° C, returned to the weigh tin desiccator, cooled at room temperature for 15 min and then weighed. Moisture and fat percentages were calculated, agreement of duplicate samples was checked, and the average value was calculated for each loin.

Slice Shear Force

Chops for slice shear force determination were cooked on a belt grill (Magigrill model TBG-60; MagiKitch'n Inc., Quakertown, PA). Dwell time in the grill was modified to achieve a targeted internal temperature of either 63° C or 71° C. After the chops exited the belt grill, a needle thermocouple probe was inserted into the geometric center of the chop and post-cooking temperature rise was monitored with a hand-held thermometer (Cole-Parmer, Vernon Hills, IL). The maximal temperature was recorded as the final cooked internal temperature. Immediately after cooking, a 1-cm thick, 5-cm-long slice was removed from each chop parallel to the muscle fibers. The slice was acquired by first cutting across the width of the longissimus at a point approximately 2 cm from the lateral end of the muscle. Using a sample sizer, a cut was made across the longissimus parallel to the first cut at a distance 5 cm from the first cut. Using a knife that consisted of two parallel blades spaced 1 cm apart, two parallel cuts were simultaneously made through the length of the 5-cm-long steak portion at a 45° angle to the long axis of the longissimus and parallel with the muscle fibers. Each slice was sheared once with a flat, blunt-end blade using an electronic testing machine (model 4411; Instron Corp.).

Trained Sensory Panels

Sensory panel sessions consisted of six individuals that evaluated pork chop tenderness, juiciness, and pork flavor. Panelists were selected from a pool of trained students and faculty from the University of Illinois (Champaign-Urbana, IL). Panelists were trained to evaluate pork chops for tenderness, juiciness, and pork flavor. Pork tenderness was standardized by cooking one chop to an internal temperature of 60° C and a second chop to 80° C. Pork juiciness was standardized by cooking a non-enhanced chop and an enhanced chop both to an internal temperature of 68° C. Pork flavor was standardized by cooking a pork chop and 80:20 % lean:fat ground pork to an internal temperature of 71° C. Previously, sensory tenderness scores from this group of trained panelists explained 57% ($R^2 = 0.57$) of the variation in slice shear force (SSF) instrumental tenderness (Wilson et al., 2017).

Chops were assigned to sensory sessions using an incomplete randomized block schedule of chops for each sensory panel, generated using the OPTEX procedure in SAS (SAS Inst. Inc., Cary, NC). Each sensory panel session included all 4 chops (PVC/63° C, PVC/71°C, vacuum packaged/63°, vacuum packaged/71° C) from 2 loins. Each session included a set of chops from pigs from the meat quality focus and a set of chops from pigs from the lean growth focus.

Panelists evaluated samples in a breadbox-style booth with red overhead lights to mask color differences. Tenderness, juiciness, and flavor were measured on a 15-cm continuous scale anchored at 0 cm, 7.5 cm, and 15 cm where 0 = extremely tough, extremely dry, or no pork flavor and 15 = extremely tender, extremely juicy, or very intense pork flavor. Chops were removed from -20° C and placed in a 4° C cooler 24 h prior to cooking to allow for proper thawing. Chops were removed from their individual packages and weighed prior to cooking. Chops were cooked to either medium-rare degree of doneness (63° C internal temperature) or medium degree of doneness (71° C internal temperature) following National Pork Board cooking guidelines and served to panelists while still warm. Chops were cooked on a Farberware Open Hearth grill (model 455N, Walter Kidde, Bronx, NY, USA) with a copper-constantan thermocouple (Type T, Omega Engineering, Stamford, CT, USA) inserted into the geometric center of each chop to accurately monitor internal cooking temperature on a digital thermometer (model 92000-00, Barnat Co, Barrington, IL, USA). Chops were initially cooked to an initial internal temperature of either 31° C (medium-rare) or 36° C (medium) and then flipped and cooked to the final temperature. Once chops were cooked to their assigned final internal temperature, they were immediately removed, weighed, and placed in plastic serving cups to keep the chops warm until serving. Chops were then cut using a 1 cm × 1 cm sample sizer. Panelists were given three random cubes per sample. Each testing day consisted of no more than 2 sessions with 8 samples per session. Sessions were held at least 1 h apart to reduce sensory fatigue. The study consisted of 576 samples in 72 sessions on 36 different days. Panelists were recalibrated at the mid-point of the 72 sessions. Results from all panelists were averaged and the averages were used for calculation of least squares means.

Statistical Analyses

Sensory and slice shear force data were analyzed with the MIXED procedure of SAS as split-split plot design. Individual loin served as the experimental unit and the fixed effects in the model were production focus of the pigs, proposed USDA quality grade, packaging type, and degree of doneness and all possible interactions. Sensory session served as the blocking factor and was coded as a random variable. The whole plot factor of production focus and quality grade was tested with the three-way interaction of session, focus, and quality grade. The split plot was packaging type (vacuum packaging or PVC overwrap) and was tested with the four-way interaction of session, quality grade, focus, and packaging type. The split-split plot was degree of doneness (63° C or 71° C) and was tested with the five-way interaction of session, quality grade, focus, packaging type, and degree of doneness. There were no interactions among production focus and the other treatments of interest. Therefore, production focus interactive data were pooled among production focus for evaluation of the other treatments of interest. Least squares means were separated with the Probably of Difference (PDIFF) option of SAS in the Mixed procedure. Effects of USDA quality grade, packaging type, degree of doneness and all possible interactions were considered significantly different at $P < 0.05$.

Results

Early Postmortem Ventral Surface Loin Quality

There were no interactions ($P \geq 0.15$) between production focus and proposed USDA quality grade for any early postmortem ventral loin quality trait (Table 1).

Loins from lean production focused pigs (5.40 kg) were 7.1% heavier ($P < 0.01$) than loins from quality focused pigs (5.03 kg, Table 1). There were no differences in ventral pH (P = 0.20) of loins between the lean and quality production focuses. Loins from lean focused pigs were instrumentally 1.43 L* units darker (P = 0.01), 0.47 a* units less red (P = 0.05), and 0.41 b* units less yellow (P = 0.04) than loins from quality focused pigs. Visual color did not differ (P = 0.55) between production focuses. Loins from quality focused pigs (2.51%) had 0.39 percentage units greater (P = 0.04) extractable lipid compared with loins from lean focused (2.12%) pigs but visual marbling scores did not differ (P = 0.39) between production focuses (Table 1). Subjective firmness scores did not differ between loins from the lean and quality production focuses.

A total of 144 loins were used in the data analyses. Of those, 38 graded Standard (did not meet the minimum requirements for Select), 13 Select, and 92 Choice (Table 1). Only one loin met the proposed criteria for Prime and therefore, was excluded from the analyses. Instrumental L* values for loins categorized as USDA Select (46.14) were greater ($P < 0.05$) than loins categorized as USDA Choice (43.21) or Standard (44.20). Additionally, loins categorized as Standard were lighter (P < 0.05) than loins categorized as Choice (Table 1). In terms of a*, loins categorized as Choice (7.79) and Select (7.83) were redder ($P < 0.05$) than loins categorized as standard (7.16). When visually evaluated for NPPC color scores, loins categorized as Choice (3.60) were darker ($P < 0.05$) than either select (2.49) or Standard (3.27). Loins categorized as standard were darker (*P* < 0.05) than loins categorized as Select. Neither extractable lipid nor visual marbling differed (P > 0.05) between loins categorized as Select (2.77%, NPPC 2.56) or Choice (2.27%, NPPC 2.42), but both Select and Choice loins had more extractable lipid and visual marbling than Standard loins (Table 1). Subjective firmness scores did not differ (*P* > 0.05) between Standard and Select loins, but Standard loins were less firm than Choice loins (Table 1). Subjective firmness scores did not differ (*P* > 0.05) between Select and Choice loins.

Effects of Proposed USDA Quality Grade on Eating Experience

There were no three way interactions (*P* ≥ 0.19) among proposed UDSA quality grade, packaging type, and degree of doneness for any sensory or instrumental characteristics (Supplemental table 1). The only two-way interaction for any parameter was sensory tenderness between proposed USDA quality grade and packaging type for tenderness. Sensory tenderness scores of chops from loins categorized as standard and aged in vacuum packages (8.81) were less (*P* < 0.05) tender than standard chops aged in PVC packages (9.14) or chops categorized as select and aged in vacuum packages (9.23) or chops categorized as choice and aged in PVC packages (9.46). The 0.33 units difference in sensory tenderness between Standard chops packaged in vacuum packages and Standard chops packaged in PVC packages was a 3.7%. At the same time a 3.6% difference was observed between the same two parameters for SSF. A magnitude of that difference, although detected by highly trained sensory panelists, may not be detectable by consumers.

There were no differences in sensory tenderness (*P* = 0.30), juiciness (*P* = 0.49), or flavor (*P* = 0.89) among proposed USDA quality grades (Table 2). There were no differences in SSF (*P* = 0.13) or cook loss (*P* = 0.06) among proposed USDA quality grades.

Effects of Packaging Type on Eating Experience

There were no differences in sensory tenderness (*P* = 0.06), juiciness (*P* = 0.32), or flavor (*P* = 0.74) between chops aged in vacuum packages or PVC packages (Table 3). There were no differences in SSF (*P* = 0.99) or cook loss (*P* = 0.12) between chops aged in vacuum packages or PVC packages.

Effects of Degree of Doneness on Eating Experience

Chops cooked to a medium-rare (9.31) degree of doneness were rated 4.6% more tender (*P* < 0.0001) than chops cooked to a medium (8.89) degree of doneness (Table 4). Instrumentally, chops cooked to a medium-rare (10.30 kg) degree of doneness were 7.3% more tender (*P* = 0.01) than chops cooked to a medium (11.08 kg) degree of doneness. Chops cooked to a medium-rare (8.94) degree of doneness were rated 10.1% juicier (*P* < 0.0001) than chops cooked to a medium (8.08) degree of doneness. Chops cooked to a medium-rare (2.05) degree of doneness were rated 2.9% less flavorful (*P* = 0.01) than chops cooked to a medium (2.11) degree of doneness. Chops cooked to a medium-rare (11.29%) degree of doneness had 1.64 percentage units less (*P* < 0.0001) cook loss than chops cooked to a medium (12.93%) degree of doneness.

Effects of Proposed Quality Grade and Packaging Type on Eating Experience

Sensory tenderness scores of chops from loins categorized as standard and aged in vacuum (8.81) packages were less (*P* < 0.05) tender than standard chops aged in PVC packages (9.14) or chops categorized as select and aged in vacuum packages (9.23) or chops categorized as choice and aged in PVC packages (9.46, Table 2). There were no differences in sensory tenderness scores among chops categorized as select or choice regardless of packaging during aging or in chops categorized as standard and aged in PVC packages. There were no interactions between USDA quality grade and packaging type for sensory juiciness (P = 0.24), flavor (P = 0.17), slice shear force (SSF, P = 0.38), or cook loss (P = 0.93).

There were no interactions between USDA quality grade and final internal degree of doneness for sensory tenderness (P = 0.67), juiciness (P = 0.94), flavor (P = 0.41), SSF (P = 0.53), or cook loss (P = 0.06, Table 3).

There were no interactions between packaging type during aging and final internal degree of doneness for sensory tenderness (P = 0.97), juiciness (P = 0.38), flavor (P = 0.35), SSF (P = 0.32), or cook loss (P = 0.81, Table 4).

There were no differences in sensory tenderness (P = 0.30), juiciness (P = 0.49), or flavor (P = 0.89) among USDA quality grades (Table 5). There were no differences in SSF (P = 0.13) or cook loss (P = 0.06) among USDA quality grades.

There were no differences in sensory tenderness (P = 0.06), juiciness (P = 0.32), or flavor (P = 0.74) between chops aged in vacuum packages or PVC packages (Table 6). There were no differences in SSF (P = 0.99) or cook loss (P = 0.12) between chops aged in vacuum packages or PVC packages.

Chops cooked to a medium-rare (9.31) degree of doneness were rated 4.6% more tender (P < 0.0001) than chops cooked to a medium (8.89) degree of doneness (Table 7). Instrumentally, chops cooked to a medium-rare (10.30 kg) degree of doneness were 7.3% more tender (P = 0.01) than chops cooked to a medium (11.08 kg) degree of doneness. Chops cooked to a medium-rare (8.94) degree of doneness were rated 10.1% juicier (P < 0.0001) than chops cooked to a medium (8.08) degree of doneness. Chops cooked to a medium-rare (2.05) degree of doneness were rated 2.9% less flavorful ($P = 0.01$) than chops cooked to a medium (2.11) degree of doneness. Chops cooked to a medium-rare (11.29%) degree of doneness had 1.64 percentage units less ($P < 0.0001$) cook loss than chops cooked to a medium (12.93%) degree of doneness.

Discussion

It is likely that color and marbling were chosen as the traits to develop the newly proposed USDA pork quality system because these are traits usually associated with consumer purchasing decisions and eating experience (Brewer et al., 2001). Choosing these traits is logical based on previously reported pork quality research concerning color and the historical precedence the beef industry has set using marbling as part of the beef quality grades. Additionally, nearly 53% of consumers chose darker colored pork chops compared with lighter colored pork chops during a consumer preference study (Norman et al., 2003).

Increasing ultimate loin pH is correlated in darker visual color (Huff-Lonergan et al., 2002, Boler et al., 2010). Therefore, it was our hypothesis that chops categorized as choice would, by definition of the program, be darker in color and therefore have a greater ultimate pH than loins categorized as select. Likewise choice loins would be darker in color and therefore have a greater ultimate pH than standard. However, because the proposed grading system also includes visual marbling, it is possible for loins to qualify for a superior grade based on color but ultimately be categorized as a lessor grade due to a lack of marbling. That was the scenario in the current experiment where loins categorized as standard were visually and instrumentally darker than select loins due to some of the loins in the standard grade being dark enough to qualify for a choice grade, but didn’t have enough marbling to qualify for choice or select. This complicated the effects of pH, but upon closer examination proved to be quite logical. The ultimate pH of chops rated as standard were intermediate and not statistically different from Select and Choice chops. Chops rated as Choice had a greater ultimate pH than chops rated as Select. Still, based on the results of Wilson et al. (2017) and Wright et al. (2005) an attempt to develop a grading system based on color and marbling has merit. Wright et al. (2005) reported an increase in sensory scores of pork chops rated as high quality (NPPC color score of 4.01 and marbling score of 4.12) compared with chops rated as average quality (NPPC color score of 3.51 and marbling score of 2.40) or low quality (NPPC color score of 2.97 and marbling score of 1.42). Further, Wilson et al. (2017) reported a decrease in SSF in high quality chops compared with medium quality chops and from medium quality chops compared with low quality chops using a similar categorization scheme as describe by Wright et al. (2005). It should be noted that in both of the previous reports as color became darker, marbling also increased. This is in contrast to the current experiment where chops grading Select and those grading Choice had similar amounts of marbling. This highlights a complication with the proposed pork quality grades as thresholds for both color and marbling must be met to grade Choice. Therefore, it is possible to have Select loins that are equal to or even exceed Choice loins in terms of marbling but did not have a dark enough color to qualify as choice. As opposed to beef quality grades where color is only used as a marker for maturity, using both color and marbling in the pork quality grading system can be expected to produce results similar to those in the current study.

In addition to color, ultimate pH is also correlated with traits associated with water holding capacity such as purge and cook loss (Huff-Lonergan et al., 2002, Boler et al., 2010). These traits are often associated with tenderness, and increasing ultimate pH from 5.50 through greater than 5.95 increased sensory tenderness scores by over 12% (Lonergan et al., 2007).

Packaging chops in modified atmosphere packaging containing low carbon monoxide and high carbon dioxide induces greater package purge loss during aging compared with packaging chops in a vacuum package (Krause et al., 2003). It was anticipated that chops rated as choice would have a greater ultimate pH, and therefore, greater water holding capacity. Therefore, these Choice chops might better withstand packaging in a MAP bulk package followed by PVC overwrap packages. It was hypothesized that the improved water holding capacity of choice chops would be able to overcome the negative effects of the carbon monoxide on water holding capacity. If this were the case, an improvement in sensory tenderness and juiciness would be expected in choice chops packaged in PVC when compared with select or standard chops packaged in PVC. This was not the case however, and no interactions between proposed USDA quality grade and packaging type was detected for any sensory traits. Therefore, current data suggests that designating one grade of pork to one particular packaging type over another is not warranted.

Historically, as endpoint cooking temperature (degree of doneness) increases, consumers rate pork chops as less tender and less juicy (Rincker et al., 2008, Moeller et al., 2010). Both decreases in tenderness and juiciness attributed to the loss of free water and some fat during cooking. Similar to previous reports, cooking chops to a medium-rare degree of doneness resulted in greater sensory tenderness and juiciness scores when compared with chops cooked to a medium degree of doneness. It was also hypothesized that this improvement in sensory ratings of tenderness and juiciness from a reduced endpoint temperature would help overcome anticipated issues with these traits from lesser quality grades or PVC packaging. As such, interactions between degree-of-doneness and packaging type or with quality grade were anticipated. However, this was not the case. Packaging had no impact on sensory traits regardless if chops were cooked to medium-rare or a medium degree of doneness. Furthermore, the positive effects of cooking chops to a lesser degree-of-doneness was similar in standard, select, and choice chops. Therefore, in this set of pork chops, degree of doneness had a greater impact on eating experience than either USDA quality grade or packaging type.

Conclusions

In the conditions of the current experiment, it can be concluded that there were not any differences in sensory traits among the chops categorized based on the proposed USDA quality grading system or packaging type. Cooking chops to 63° C rather than 71° C was a more effective way to improve eating experience than the newly proposed USDA quality grades or differing packaging types.

Figure and Tables

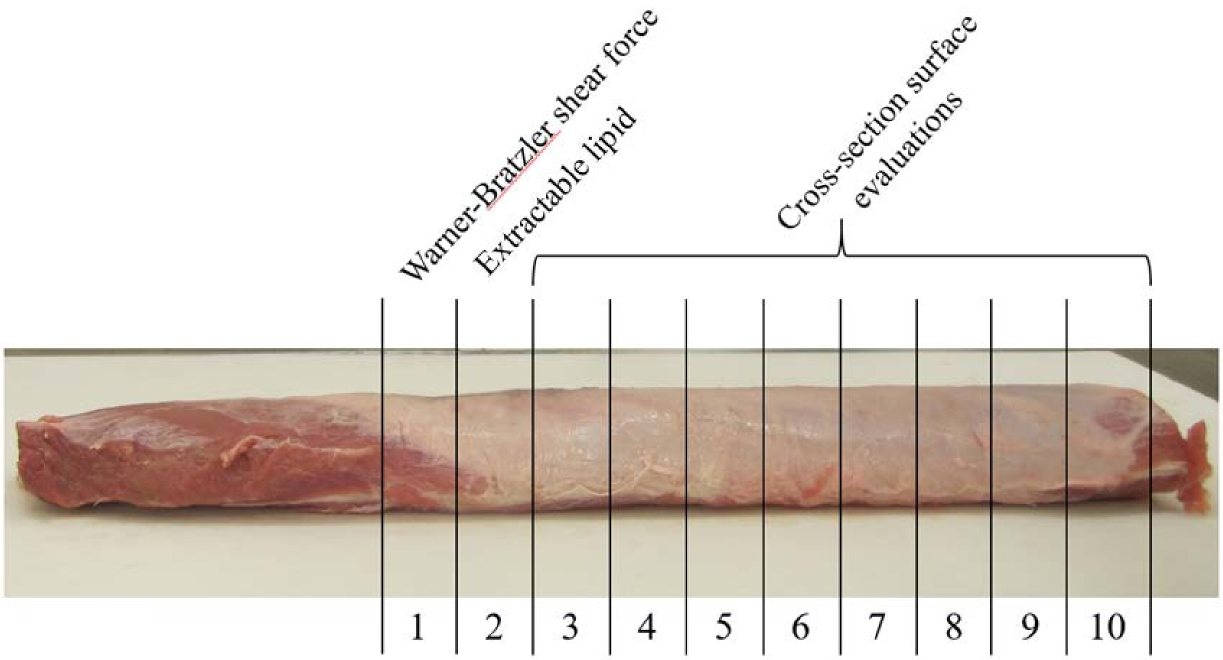

Figure 3.1. Loins sliced into 28mm thick chops were designated for different evaluations by anatomical location. Chop 1, the most anterior chop with the most posterior portion of the spinalis dorsi, was designated for Warner-Bratzler shear force (Chapter 2). Chop 2 was selected to determine extractable lipid content. Chops 3-10 were randomly assigned to instrumental and sensory evaluations. Chops were either packaged in individual vacuum-sealed packages or in PVC overwrapped trays packaged in gas-flushed bulk packages. A chop from each loin designated for each packaging type was cooked to either 63° C or 71° C. Evaluations included visual color (NPPC 1999), visual marbling (NPPC 1999), subjective firmness, and instrumental lightness, redness, and yellowness (CIE 1978). Chops from each of the 4 packaging types and degree of doneness combinations were evaluated for slice shear force or sensory tenderness, juiciness, and flavor.

Table 3.1. Lean quality estimates of the ventral surface boneless pork loins from pigs selected for lean growth or meat quality traits and
categorized based on USDA grade standards of pork carcasses.

	Production focus			USDA quality grade[1]				*P* - values		
Item	Lean	Quality	SEM	Standard	Select	Choice	SEM	Focus	USDA quality grade	Focus x quality grade
Loins, n	78	73		43	13	95				
Loin wt, kg	5.40	5.03	1.07	5.40[b]	5.19[ab]	5.07[a]	1.08	< 0.01	0.01	0.44
Ventral pH	5.69	5.72	0.05	5.72[ab]	5.65[a]	5.75[b]	0.06	0.20	0.02	0.95
Lightness[2], L*	43.80	45.23	0.51	44.20[b]	46.14[c]	43.21[a]	0.80	0.01	< 0.01	0.41
Redness[2], a*	7.36	7.83	0.20	7.16[a]	7.83[b]	7.79[b]	0.32	0.05	0.01	0.62
Yellowness[2], b*	0.46	0.87	0.20	0.41	0.95	0.64	0.29	0.04	0.15	0.15
Color[3]	3.08	3.16	0.15	3.27[b]	2.49[a]	3.60[c]	0.20	0.55	< 0.0001	0.69
Extractable lipid, %	2.12	2.51	0.23	1.61[a]	2.77[b]	2.56[b]	0.30	0.04	< 0.0001	0.78
Marbling[3]	1.95	2.03	0.07	1.28[a]	2.27[b]	2.42[b]	0.11	0.39	< 0.0001	0.73
Firmness[3]	2.62	2.76	0.28	2.46[a]	2.66[ab]	2.95[b]	0.32	0.34	< 0.01	0.63

[1]USDA quality grades are based on the newly proposed grade standards for pork carcasses where: Choice = NPPC color score of 3 and a NPPC marbling score ≥ 2, Select = NPPC color score of 2 and a NPPC marbling score ≥ 2, Standard either has a NPPC color score < 2 or a NPPC marbling score < 2.

[2]L* = measure of lightness (greater value indicates a lighter color), a* = measure of redness (greater value indicates a redder color), and b* = measure of yellowness (greater value indicates a more yellow color).

[3]NPPC color (1 = pale pink to 6 = dark purplish red), NPPC marbling (1 = 1% intramuscular lipid to 10 = ≥10% intramuscular lipid), and
NPPC firmness (1 = very soft to 5 = very firm) were based on NPPC (1991, 1999) standards.

Table 3.2. Interactive least square means of USDA quality grade and packaging type on sensory traits of boneless pork loin chops

	USDA quality grade x Packaging type							
	Standard[1]		Select[1]		Choice[1]			*P*- value
Item	Vacuum	PVC[2]	Vacuum	PVC[2]	Vacuum	PVC[2]	SEM	Quality grade x Packaging type
Chops, n	76	76	26	26	184	184		
Tenderness[3]	8.81[a]	9.14[b]	9.23[b]	8.96[ab]	9.03[ab]	9.46[b]	0.27	0.01
Juiciness[3]	8.42	8.61	8.47	8.32	8.52	8.70	0.21	0.24
Flavor[3]	2.08	2.07	2.06	2.13	2.09	2.05	0.06	0.17
Slice shear force, kg	10.85	11.25	10.37	9.88	10.86	10.93	0.53	0.38
Cook loss, %	12.76	11.97	12.42	11.68	12.28	11.56	0.33	0.93

[1]USDA quality grades are based on the newly proposed grade standards for pork carcasses where: Choice = NPPC color score of 3 and a NPPC marbling score ≥ 2, Select = NPPC color score of 2 and a NPPC marbling score ≥ 2, Standard either has a NPPC color score < 2 or a NPPC marbling score < 2.

[2]PVC = polyvinyl chloride film. Chops were place in a polystyrene tray and wrapped in PVC film. Chops were placed in a gas flushed bag and flushed to 600 millibars of a gas mixture (0.2-0.4% carbon monoxide, 23-30% carbon dioxide, and 60-80% nitrogen).

[3]Evaluated on a 15 point scale, where 0 = extremely tough, dry, or not flavorful and 15 = extremely tender, juicy, or flavorful.

Table 3.3. Interactive least square means of USDA quality grade and degree of doneness on sensory traits of boneless pork loin chops

	USDA quality grade x Degree of doneness							
	Standard[1]		Select[1]		Choice[1]			*P*- value
Item	63° C	71° C	63° C	71° C	63° C	71° C	SEM	Quality grade x Degree of doneness
Chops, n	76	76	26	26	184	184		
Tenderness[2]	9.22	8.73	9.30	8.89	9.43	9.06	0.27	0.67
Juiciness[2]	8.95	8.09	8.81	7.99	9.05	8.17	0.21	0.94
Flavor[2]	2.07	2.09	2.05	2.15	2.04	2.10	0.06	0.41
Slice shear force, kg	10.55	11.55	9.89	10.36	10.46	11.34	0.51	0.53
Cook loss, %	11.42	13.31	11.33	12.77	11.14	12.70	0.31	0.06

[1]USDA quality grades are based on the newly proposed grade standards for pork carcasses where: Choice = NPPC color score of 3 and a NPPC marbling score ≥ 2, Select = NPPC color score of 2 and a NPPC marbling score ≥ 2, Standard either has a NPPC color score < 2 or a NPPC marbling score < 2.

[2]Evaluated on a 15 point scale, where 0 = extremely tough, dry, or not flavorful and 15 = extremely tender, juicy, or flavorful.

Table 3.4. Interactive least square means of packaging type and degree of doneness on sensory traits
of boneless pork loin chops

	Packaging type x Degree of doneness					
	Vacuum		PVC[1]			*P*- value
Item	63° C	71° C	63° C	71° C	SEM	Packaging type x Degree of doneness
Chops, n	143	143	143	143		
Tenderness[2]	9.23	8.81	9.39	8.97	0.13	0.97
Juiciness[2]	8.87	8.08	9.01	8.09	0.11	0.38
Flavor[2]	2.06	2.10	2.05	2.13	0.04	0.35
Slice shear force, kg	10.76	10.63	9.84	11.54	0.46	0.32
Cook loss, %	11.48	13.49	11.10	12.37	0.26	0.81

[1]PVC = polyvinyl chloride film. Chops were place in a polystyrene tray and wrapped in PVC film. Overwrapped packages were placed in a gas flushed bag and flushed to 600 millibars of a gas mixture (0.2-0.4% carbon monoxide, 23-30% carbon dioxide, and 60-80% nitrogen).
[2]Evaluated on a 15 point scale, where 0 = extremely tough, dry, or not flavorful and 15 = extremely tender, juicy, or flavorful.

Table 3.5. Effects of USDA quality grade on trained sensory and instrumental tenderness values of boneless pork loin chops

	USDA quality grade[1]				
Item	Standard	Select	Choice	SEM	*P*-value
Chops, n	152	52	368		
Tenderness[2]	8.97	9.09	9.24	0.25	0.30
Juiciness[2]	8.52	8.40	8.61	0.19	0.49
Flavor[2]	2.08	2.10	2.07	0.05	0.89
Slice shear force[3], kg	11.05	10.12	10.90	0.43	0.13
Cook loss, %	12.36	12.05	11.92	0.27	0.06

[1]USDA quality grades are based on the newly proposed grade standards for pork carcasses where: Choice = NPPC color score of 3 and a NPPC marbling score ≥ 2, Select = NPPC color score of 2 and a NPPC marbling score ≥ 2, Standard either has a NPPC color score < 2 or a NPPC marbling score < 2.

[2]Evaluated on a 15 point scale, where 0 = extremely tough, dry, or not flavorful and 15 = extremely tender, juicy, or flavorful.

[3]Slice shear force; cooked to a final internal temperature of 63° C or 71° C and sheared at internal temperature of approximately 22° C.

Table 3.6. Effects of packaging type on trained sensory and instrumental tenderness values of boneless pork loin chops

	Packaging type			
Item	Vacuum	PVC[2]	SEM	*P*-value
Chops, n	286	286		
Tenderness[1]	9.02	9.18	0.11	0.06
Juiciness[1]	8.47	8.55	0.10	0.32
Flavor[1]	2.08	2.09	0.03	0.74
Slice shear force[3], kg	10.69	10.69	0.32	0.99
Cook loss, %	12.49	11.74	0.18	0.12

[1]Evaluated on a 15 point scale, where 0 = extremely tough, dry, or not flavorful and 15 = extremely tender, juicy, or flavorful.

[2]PVC = polyvinyl chloride film. Chops were place in a polystyrene trays and wrapped in PVC film. Chops were placed in a gas flushed bag and flushed to 600 millibars of a gas mixture (0.2-0.4% carbon monoxide, 23-30% carbon dioxide, and 60-80% nitrogen).

[3]Slice shear force; cooked to a final internal temperature of 63° C or 71° C and sheared at an internal temperature of approximately 22° C.

Table 3.7. Effects of internal degree of doneness on trained sensory and instrumental tenderness values of boneless pork loin chops

	Degree of doneness			
Item	63° C	71° C	SEM	*P*-value
Chops, n	286	286		
Tenderness[1]	9.31	8.89	0.11	< 0.0001
Juiciness[1]	8.94	8.08	0.10	< 0.0001
Flavor[1]	2.05	2.11	0.03	0.01
Slice shear force, kg	10.30	11.08	0.32	0.01
Cook loss, %	11.29	12.93	0.18	< 0.0001

[1]Evaluated on a 15 point scale, where 0 = extremely tough, dry, or not flavorful and 15 = extremely tender, juicy, or flavorful.

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