THE EFFECTS OF ULTIMATE PH AND COLOR ON SENSORY TRAITS OF PORK LOIN CHOPS COOKED TO A MEDIUM-RARE DEGREE OF DONENESS

BY

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THESIS

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ABSTRACT

It has been well-documented that both ultimate pH and instrumental color are correlated with the sensory characteristics of pork loin chops cooked to a medium (71˚C) degree of doneness. In addition, consumers use color more than any other meat quality trait to determine purchase intent. Furthermore, increasing ultimate pH positively influenced both sensory tenderness and juiciness scores when chops were cooked to 71˚C. However, in 2011, the USDA Food Safety and Inspection Service reduced the recommended final internal cooking temperature of pork chops from 71°C to 63°C (followed by a 3 min rest). The effects of ultimate pH on sensory traits of pork chops cooked to a medium-rare (63°C) degree of doneness are not known. Therefore, the objective was to determine the effects of pH and color on sensory characteristics of boneless pork loin chops cooked to an internal endpoint temperature of 63˚C. Center cut loins (296 total) from barrows and gilts, 5 different sire lines, and a range in ultimate pH of 5.36 – 6.23 were used. Loins were categorized using historical categories based on ultimate pH: >5.95, n = 22; 5.80 to 5.95, n = 75; 5.65 to 5.80, n = 102; 5.50 to 5.65, n = 91; <5.50, n= 6. Loins were then evaluated for CIE instrumental L*, a*, b*, NPPC visual color, NPPC visual marbling, and subjective firmness on 1 d postmortem. All measurements were collected on the ventral surface of the loin at the approximate location of the 10^{th} rib. Then, loins were transported to the University of Illinois Meat Science Laboratory and aged in vacuum packages at 4°C until 16 d postmortem. At 16 d postmortem, the same quality measurements were recorded and loins were sliced into 2.54 cm thick chops. Chops were then vacuum packaged and frozen until further analyses. One chop was also used to determine extractable lipid. The second chop was used to evaluate instrumental tenderness. These chops were weighed, cooked to 63°C, cooled to approximately 23°C, weighed again to determine cook loss, and then evaluated for Warner-

Bratzler shear force. Another chop was cooked to 63°C internal temperature and served warm to trained panelists to determine sensory traits. Trained sensory panels consisted of six individuals that evaluated pork chop tenderness, juiciness, and pork flavor. Panelists were selected from a pool of experienced, trained students and faculty from the University of Illinois (Champaign-Urbana, IL).Coefficients of determination (R^2) were calculated to determine the predictability of ultimate pH and instrumental color on sensory tenderness, juiciness, and flavor.

Ultimate pH explained 5% of the variation ($R^2 = 0.05$, $P < 0.001$) in trained sensory tenderness scores. However, ultimate pH was not an effective predictor of trained sensory juiciness or flavor scores as it explained less than 1% ($R^2 < 0.01$; $P = 0.10$) of the variation in panelist scores. Ultimate pH was also not predictive ($R^2 < 0.01$, $P = 0.34$) of Warner-Bratzler shear force (WBSF). Furthermore, NPPC visual color score explained less than 1% ($R^2 < 0.01$, $P = 0.83$) of the variation in sensory tenderness, juiciness, and flavor scores or WBSF and, therefore, was not an effective predictor of eating quality. In addition, instrumental L*, a*, and b* explained at most 3% of the variation in tenderness and juiciness scores. Finally, the combination of ultimate pH, instrumental L*, instrumental a* and instrumental b*accounted for 11% ($R^2 = 0.11$, $P < 0.0001$) of the variation in sensory tenderness scores, but was not at all predictive of sensory juiciness or flavor scores ($R^2 \leq 0.01$, $P \leq 0.13$). Overall, ultimate pH does not independently influence eating quality (tenderness, juiciness, and flavor) of boneless pork loin chops cooked to a medium-rare degree of doneness (63°C) unless pH is at least 5.95.

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CHAPTER 1

REVIEW OF THE LITERATURE

INTRODUCTION

Pork makes up 40.4% of the world's total per capita meat consumption, making it the most consumed meat product in the world (Pork Checkoff, 2018). In 2017, the per capita consumption of pork in the United States was 29.2 kg. (Pork Checkoff, 2018). In order to maintain and increase the demand for pork and pork products, it is necessary to provide the consumer with a satisfactory eating experience that leads to repeat purchases. Previous research has indicated that the relationship between quality expectation before purchase and quality experience after purchase determines product satisfaction and repeat purchase intent (Grunert, et al. 2004). For meat products, consumers mainly use eating quality and sensory characteristics to determine overall product satisfaction (Grunert, et al. 2004). The three primary sensory traits that define the consumer's eating experience for whole muscle meat products are tenderness, juiciness, and flavor (AMSA, 2015). Tenderness and juiciness are the most important sensory traits that determine overall eating experience (Enfält et al., 1997). Many different meat quality factors can affect these sensory traits and there is not a single quality factor that solely contributes to a positive eating experience for the consumer. However, there are some traits that are more highly correlated to both tenderness and juiciness than others. For example, ultimate pH was significantly correlated with both tenderness and juiciness when pork chops were cooked to a medium (71˚C) degree of doneness (Huff-Lonergan et al., 2002). In addition, visual color can influence both consumer purchase intent and overall eating quality (Brewer et al., 2001; Huff-Lonergan et al., 2002). Therefore, this review focuses mainly on how ultimate pH and color can affect various aspects of meat quality and important sensory characteristics.

Historically, tenderness and juiciness have primarily been evaluated on pork loin chops cooked to a medium degree of doneness (71°C). According to Huff-Lonergan et al. (2002), ultimate pH is significantly ($P < 0.0001$) correlated ($r = 0.27$; $r = 0.17$) to trained sensory panel tenderness and juiciness scores. In addition, previous research has clearly indicated that increasing ultimate pH significantly ($P < 0.001$) improves sensory tenderness and juiciness scores (Lonergan et al., 2007; Moeller et al., 2010). However, in 2011, the USDA Food Safety and Inspection Service changed the recommended endpoint temperatures of whole muscle cuts of pork from 71°C to 63°C in order to maintain food safety, but improve sensory traits. The transition from outdoor to indoor rearing in the pork industry has effectively eliminated the threat of contamination via *Trichinella sprilis*, allowing the USDA to reduce the endpoint cooking temperature. Therefore, this review will also discuss the effects of a reduced endpoint temperature on the sensory characteristics of pork loin chops.

Ultimate pH

The final pH that is attained after the termination of postmortem glycolysis is known as ultimate pH (Huff-Lonergan et al., 2002). Generally, in meat, the final ultimate pH is determined by the amount of glycogen present at the time of slaughter (Huff-Lonergan et al., 2002). In order to understand how postmortem pH decline occurs, it is important to outline the process of glycolysis and muscle contraction at both the in vivo and postmortem time points. In living muscle, the citric acid cycle produces 32 adenosine triphosphate (ATP) molecules every cycle in the mitochondria of the cell (Lawrie, 2006). This process occurs aerobically because oxygen is freely circulating the body via the blood stream. The ATP that is produced from the citric acid cycle provides all of the energy that is necessary for muscle contraction and function. However, after exsanguination, oxygen is no longer able to circulate the body. The lack of oxygen causes a shift from the primary source of ATP being from aerobic metabolism via the citric acid cycle to the primary source of ATP being from anaerobic metabolism via glycolysis. In addition, the removal of blood weakens the membranes of the muscle cells causing a rapid influx of calcium in the sarcoplasm. The excess calcium stimulates further muscle contraction through a cascade of reactions. This time, however, the product of glycolysis is not ATP, but instead, lactic acid. Without circulating blood to remove waste, the lactic acid builds up within the muscle causing the pH to decline. During the conversion from muscle to meat, the pH will fall from a neutral 7.2 to around 5.5 (Lawrie, 2006).

However, final ultimate pH can be highly variable as there are many pre- and post-slaughter factors that can affect postmortem pH decline and, subsequently, pork quality. There are several conditions related to postmortem pH decline that can negatively influence pork quality. First, an unusually rapid decline in pH after exsanguination can result in a defect known as pale, soft, and exudative (PSE) pork. Additionally, acid meat is caused by an extremely low (< 5.3) ultimate pH that results from an extended postmortem pH decline (Scheffler, et al. 2013). Both acid meat and PSE have similar characteristics and it is difficult to distinguish between the two just by visual appraisal. It has been well documented that these defects result in a significantly diminished water-holding capacity that can translate into a poor eating experience for the consumer. The denaturation of proteins within the muscle is responsible for the decrease in water-holding capacity and increase in purge loss that is common acid meat and PSE pork. In PSE pork, the ultimate pH falls to or below what is known as the isoelectric point. Once the pH meets or surpasses the isoelectric point, which is normally around 5.3, the muscle proteins become denatured and are no longer able to bind water (Scheffler, et al. 2013). Furthermore, the rapid pH decline that is associated with PSE pork causes similar protein denaturation. However, unlike acid meat, PSE pork results in a normal ultimate pH.

Factors Influencing Postmortem pH Decline

There are many pre- and post- slaughter factors that can influence the rate and extent of postmortem pH decline. First, pig genetics can significantly influence ultimate pH and meat quality. There are two specific genetic defects found in pigs that can lead to both acid meat and PSE pork. The first genetic defect is most commonly associated with the Rendement Napole (RN) gene in the Hampshire breed (Monin and Sellier, 1985). Carriers of the RN gene have elevated levels of muscle glycogen present within the muscle at the time of slaughter (Monin and Sellier, 1985). The abnormally low ultimate pH that results from the increase in muscle glycogen and extended pH decline is known as acid meat. This gene is also associated with leaner carcasses that possess reduced carcass and processing yields (Rosenvold and Andersen, 2003). For example, Le Roy et al. (2000) reported that the carcass yields of RN gene carriers were reduced by as much as 5% to 6%.

The second genetic defect is caused by a mutation of the halothane (HAL) gene. This defect causes pigs to be more susceptible to stress and have an elevated body temperature prior to slaughter. The more rapid glycolysis brought on by stress prior to slaughter allows for an increase in lactic acid present in the muscle at the time of slaughter (Rosenvold and Andersen, 2003). This results in a very rapid postmortem pH decline and, ultimately, undesirable PSE pork (Fernandez, 2002).

Furthermore, pre-slaughter stressors such as transportation, co-mingling, and handling can have a significant impact on meat quality (Cannon, 1996). Much of the stress associated with pre-slaughter handling results from the loading and unloading of animals (Cannon, 1996). Humbrecht et al., 2005 reported that both plasma cortisol and muscle lactate were significantly (P < 0.001) increased by 22 ng/mL and 13 mmol/L respectively when high stress was applied immediately prior to slaughter as compared to those where no added stressors were applied. The increase in cortisol and lactate resulted in a significant (P < 0.001) decrease in glycolytic potential by 13 units. Normally, a decrease in glycolytic potential positively influences pork quality. However, Henckel et al., 2002 reported that when stress is applied prior to stunning, pigs tended to have greater rates of energy metabolism. This high metabolic rate could continue in the muscle even in the postmortem stages, causing a rapid rate of pH decline and PSE conditions. One of the more controversial topics revolves around proper stunning methods. In 1958, the Humane Slaughter Act was approved with the goal of decreasing the suffering of livestock during slaughter. Outlined in this act are the approved stunning methods that can be used for livestock and are as follows; carbon dioxide, captive bolt, gunshot, and stunning or slaughtering with electric current (P.L. 85-765; 7 U.S.C. 1901 et seq.). The two most common methods that are employed in pork slaughter are stunning via carbon dioxide and electrical stunning. Some previous research has indicated that electrical stunning causes a greater amount of muscle activity during the stunning process and an increase in postmortem energy metabolism (Rosenvold and Andersen, 2003). As mentioned before, the increase in glycogen metabolism results in a more rapid pH decline (Rosenvold and Andersen, 2003). Channon et al. (2002) reported that pigs which were electrically stunned from head-to-brisket had a significant (P < 0.001) increase in drip loss by as much as 2% and an increase in Warner Bratzler shear force by as much as 2 kg compared to those that were head-only electrically stunned and those stunned via CO_2. However, both Channon et al. (2002) and Channon et al. (2003) reported that 24 h postmortem, pH did not differ ($P > 0.05$) between stunning methods. Furthermore, there is evidence to suggest more elevated incidence of both PSE and ecchymosis in electrically stunned pigs when compared to CO_2 stunned pigs (Rosenvold and Andersen, 2003). Velarde et al. (2001) reported a 30% increase in the instances of PSE pork in pigs that were electrically stunned when compared to pigs that were stunned via CO_2. The previous study also reported significant ($P < 0.05$) 12% increase in the instances of ecchymosis in the hams of electrically stunned pigs when compared to their CO_2 stunned contemporaries (Velarde et al., 2001). The consequences of each of these defects can be significant from a further processing and consumer appeal standpoint.

In addition, the rate of carcass chilling can also influence postmortem pH decline. Normal pH decline for pork is in the range of 6-12 h, while pH decline in beef can take as long as 18-40 h (Savell, 2005). Because pork has a more rapid pH than either beef or lamb, it is more susceptible to higher temperatures during the onset of rigor. After exsanguination, there is no blood to remove heat from the muscle system, therefore carcasses tend to have a slight increase in muscle temperature immediately after slaughter. If muscle temperature remains elevated for an extended period of time, pH decline will occur more rapidly and PSE conditions will result. Therefore, rapid chilling of pork carcasses to muscle temperatures of less than 10˚C in 12 h and then 2-4˚ C in 24 h is crucial to reducing PSE by slowing down the biochemical reactions that drive pH decline (Meisinger, 1999). There are multiple methods that can be employed to induce rapid carcass chilling. First, spray chilling uses spraying of cold water to chill carcasses using evaporative cooling, while also reducing postmortem carcass shrinkage (Savell, 2005). Although not common in the pork industry, delay chilling involves keeping the carcass out of the cooler for as much as 7 h postmortem in order to increase tenderness (Savell, 2005). Due to the more extended pH decline of beef, delay chilling is more applicable to the chilling of beef carcasses

(Savell, 2005). Martin et al. (1983) reported that tenderness was significantly ($P < 0.05$) increased as carcass cooling rates decreased. Lastly, blast chilling is perhaps the most commonly used system in the pork industry. This process involves sending carcasses through an air-cooled tunnel with temperatures ranging from -20˚C to -40˚C for 1 to 3 h (Huff-Lonergan and Page, 2000). However, chilling too rapidly to a muscle temperature of less than 14-19˚ C before rigor mortis occurs can lead to the contraction of the sarcomere known as cold-shortening (Savell et al., 2005). When this occurs, the sarcoplasmic reticulum is unable to bind calcium causing maximum muscle contraction and a decrease in sarcomere length. Hwang et al. (2004) reported that beef *longissimus* and *semitendinosus* muscles with sarcomere lengths less than 1.6 um were significantly ($P < 0.05$) less tender by as much as 60 N compared with those with a sarcomere length greater than 1.6 um when tenderness was evaluated using Warner Bratzler shear force. In some cases, an electric current is passed through the carcass prior to chilling in order to use up the extra ATP that is present in the muscle before the onset of rigor. This will prevent the extreme muscle contraction that causes cold-shortening. Most recently, Channon et al. (2018) reported that electrical stimulation significantly ($P > 0.05$) improved sensory tenderness scores by 3 units when loin chops were evaluated by a consumer panel. Furthermore, Channon et al. (2003) also reported that pork loin chop Warner-Bratzler shear force values were significantly ($P < 0.05$) decreased by as much a 2 kg when electrical stimulation was applied to the carcass before chilling. Despite these data, electrical stimulation has not been widely adopted for use in pork slaughter in the United States. Instead, it is more routinely used in beef due a less rapid postmortem pH decline when compared to pork (Channon et al., 2003). This is because electrical stimulation also increases the rate of pH decline, which has the potential to cause PSE conditions if applied to a pork carcass that is already experiencing a more rapid pH decline (Channon et al., 2003).

Ultimate pH and Water-Holding Capacity

Water makes of 75% of the total composition of lean muscle (Huff-Lonergan and Lonergan, 2005). Most of this water is in the form of free water, which is water that can flow unimpeded from the lean tissue. The other rest of the water in the muscle system comes in the form of either bound or entrapped water (Huff-Lonergan and Lonergan, 2005). Bound water is water that is closely bound to muscle proteins and has limited mobility. Conversely, entrapped water is present within the structure of the muscle but is not directly bound to a protein. The ability for muscle retain this water is crucial in determining eating quality, specifically in regards to sensory juiciness. Melody et al. (2004) reported as much as 10% reduction in total product weight due to excess purge loss in PSE pork. Both the rate of pH decline and final ultimate pH can each affect the water-holding capacity of meat (Huff-Lonergan and Lonergan, 2005). Huff-Lonergan et al. (2002) reported a significant ($P < 0.001$) relationship (r = -0.33; r = -0.28) between both 24 h and 48 h pH and drip loss percentage. Rapid postmortem pH decline causes denaturation of the sarcoplasmic proteins to the point where they can no longer bind water causing excess purge loss and PSE conditions. Furthermore, water-holding capacity can also be influenced by the extent of pH decline. At an ultimate pH of 5.3 or less, the proteins within the muscle will reach what is known as the isoelectric point (Scheffler, et al. 2013). At the isoelectric point, the proteins will no longer be able to bind water and water-holding capacity will be substantially deceased. As mentioned previously, the relationship between ultimate pH and water-holding capacity of pork can influence sensory perception of juiciness in pork loin chops. Moeller et al. (2010) reported that for every 0.20 unit increase in ultimate pH, sensory juiciness scores also increased by 0.23 units (10-point categorical line scale). Furthermore, the previous study also concluded that loins with an ultimate pH of 6.40 were 1.12 units (10-point categorical line scale) juicer when compared to those with an ultimate pH of 5.40 (Moeller et al., 2010). Furthermore, Huff-Lonergan et al. 2002 reported a significant ($P < 0.001$) albeit weak positive correlation (r = 0.17) between sensory juiciness scores and 24 h postmortem pH.

Ultimate pH and Tenderness

There is also evidence that suggests there is an increase in the amount of postmortem protein degradation that occurs at a greater ultimate pH as opposed to a lesser ultimate pH. Although there are many proteolytic enzymes that can contribute to postmortem protein degradation, calpains are the most extensively researched protease family (Kemp et al., 2010). The two main types of calpains are known as µ - and m - calpains. From a research standpoint, it can be challenging to distinguish which type is contributing to the most protein degradation because each calpain targets and cleaves the same muscular proteins, such as nebulin, titin, troponin-T, and desmin (Kemp et al., 2010). Both of these proteases are activated by calcium ions at certain concentrations (Maddock et al., 2005). The first calpain, µ - calpain, is activated within three days postmortem at fairly low levels of calcium (3-50 µM) (Kemp et al., 2010). Next, m - calpain is activated at greater calcium concentrations (400-800 µM) and tends to be more stable than µ- calpain (Kemp et al., 2010). Conversely, another protein called calpastatin acts as an inhibitor for both µ - and m - calpain. Normally, calpastatin is an unstructured protein, however, the combination of calcium and calpain binding allows calpastatin to be become an active inhibitor (Kemp et al., 2010). Calpastatin is able to bind to µ - and m - calpain at calcium concentrations of 40 µM and 250-500 µM respectively (Kemp et al., 2010). Ultimate pH can also influence the level of calpain activity. Maddock et al. (2005) reported that µ - calpains were more active an intermediate pH of 6.5 than either a pH of 6.0 or 7.5. On the other hand, m - calpains were significantly ($P < 0.05$) more active at greater pH (7.5) than at an intermediate pH (6.5) (Maddock et al., 2005). Therefore, when ultimate pH is reduced, proteolytic enzymes are not as effective in their ability to breakdown myofibrillar proteins, like titin and desmin, causing reduced tenderness. (Melody et al., 2004). Calpastatin activity can also be influenced by ultimate pH (Koohmaraie, 1992). Koohmaraie (1992) reported that a pH of 7.5, calpastatin was able to effectively inhibit 59% of µ - calpain activity, while at a pH of 5.7, calpastatin was only able to inhibit 6% of µ - calpain activity. These results align with the conclusion of Maddock et al. (2005) that µ - calpain is most active at an intermediate pH. Based on the data from the previous studies, it is clear that ultimate pH can impact the amount of postmortem protein degradation and, as a result tenderness. Moeller et al. (2010) reported a 0.22 unit (10-point categorical line scale) increase in sensory tenderness scores as ultimate pH increased from 5.60 to 5.80. Overall, sensory tenderness scores increased by 1.5 units (10-point categorical line scale) as pH increased from 5.40 to 6.40 (Moeller et al., 2010). Lonergan et al. (2007) reported similar results in that loins with a pH of 5.95 or greater were significantly ($P < 0.05$) more tender by as much as 0.5 units (5-point line scale) when compared to those with a pH of less than 5.95.

Pork Color

Consumers use color as in indicator of freshness and wholesomeness and, therefore, color influences meat purchasing decisions more than any other quality trait (Mancini and Hunt, 2005). Due the complex interactions that occur between the human eye and brain, every consumer perceives color differently (AMSA, 2012). Much like ultimate pH, there are many pre- and post-harvest factors that can impact the color of meat. However, color largely depends on the quantity and chemical state of the myoglobin that is present in the muscle. This becomes evident as we compare color across poultry, pigs, and cattle. Generally, larger animals that maintain a greater level of muscular activity tend to have an increased quantity of myoglobin within the muscle system. Myoglobin is a water-soluble protein containing eight α-helices that are linked by short nonhelical sections. There are four major chemical forms of myoglobin that are responsible for meat color. The first chemical state is called deoxymyoglobin. In this state, no ligand is present and the heme iron is ferrous (Fe^{2+}). This results in the purplish-red that is associated with either vacuum-packaged product or freshly cut meat. Once the myoglobin is exposed to oxygen through a process known as oxygenation, it becomes oxymyoglobin. Oxymyoglobin is characterized by the appearance of a bright-cherry red color and has a diatomic oxygen bound to the 6th coordination site of ferrous iron (Fe^{2+}) Conversely, the oxidation of myoglobin results in the third chemical state known as metmyoglobin. Metmyoglobin contains ferric iron (Fe^{3+}) and forms an undesirable brown color on raw meat products. In addition, metmyoglobin can form easily at oxygen concentrations as low as 1% to 2%. The last chemical form of myoglobin is carboxymyoglobin. Carboxymyoglobin forms as a result of carbon monoxide binding to the 6th coordination site of deoxymyoglobin and is characterized by a bright cherry-red color.

Humans can only detect light wavelengths that range from 390 nm to 750 nm. This range of wavelengths is known as the visual light spectrum. In order for humans to detect and interpret color, a light source must be present. When light hits the cut surface of meat it is absorbed, reflected, or scattered. Only the light wavelengths that are reflected can be detected and interpreted as color by the human eye and brain. In pork, color can be evaluated both subjectively and instrumentally. Instrumental color is commonly evaluated in a three-dimensional color space using L*, a, and b*. This color space was developed in 1976 by the

Commission Internationale de l'Eclairage and is known as the CIE L*a*b* color space. Brightness is quantified using the L* value with a more elevated L* star value indicates a lighter color that is closer to white. Furthermore, a* value represents the spectrum from green to red, while b* represents the spectrum from blue to yellow. Instrumental color can be measured with either a colorimeter or a spectrophotometer. These instruments can utilize various illuminants with some of the more common illuminants being A, C, or D_{65}. Illuminant C represents average north sky daylight (6774 K), illuminant A represents average incandescent, tungsten-filament lighting, and illuminant D_{65} represents noon daylight (6500 K). In addition, there are some F illuminants that represent the various types of fluorescent lighting and can be used for retail display studies. Another important aspect of measuring color instrumentally is the observer angle. When evaluating meat color, the most commonly used observer angles are 2° and 10°. The larger the observer angle, the more light is reflected off the sample. Aperture size should also be taken into consideration when evaluating a sample. Aperture size can range from 8 mm to 3.18 cm and it is crucial that aperture size remains constant throughout the entire experiment once it is selected. As aperture size increases, the percentage reflectance also increases. This is especially true for the red wavelengths between 600 and 700 nm. Other factors that should be taken into consideration when evaluating color instrumentally include instrument standardization, sample uniformity, and sample thickness. In order to sufficiently absorb light, samples should be at least 12 to 15 mm thick (AMSA, 2012).

Since color can be indicative of sensory characteristics, it is important to know variables, illuminant and machine affect instrumental color measurements. The use of appropriate instrument parameters will ensure an accurate measurement is recorded. Brewer et al. (2001) reported that L* values across five different porcine muscles did not vary significantly ($P > 0.05$)

between illuminants C and D_{65} when a Minolta colorimeter was used. However, a* and b* values differed by as much as 6 units between the two illuminants tested (Brewer et al., 2001). The previous study also reported that L*, a*, and b* values were significantly ($P < 0.05$) different between the Minolta colorimeter and Hunter spectrophometer (Brewer et al., 2001). However, Barkley et al. (2018) reported that differences among the same type of machine (Minolta colorimeter) accounted for 1% of the variation in L* values, less than 1% of the variation in a* values, and 23% of the variation in b* values. Based on the data above, it is crucial to standardize the type of instrument and parameters within an experiment so that accurate comparisons and predictions can be made.

A trained individual can also evaluate pork color subjectively using a visual color score. There are two important visual scales that are commonly used to evaluate fresh pork color in the United States. The first scale is the National Pork Producers Council (NPPC) visual color scale. This scale ranges from 1 to 6 where a color score of 1 = palest and a color score of 6 = darkest (NPPC, 1999). In addition, each of these scores (1 to 6) is associated with a Minolta L* value and are as follows: 1 = 61.00, 2 = 55.00, 3 = 49.00, 4 = 43.00, 5 = 37.00, 6 = 31.00 (NPPC, 1999). Note that the previously listed Minolta L* values were measured with a Minolta CR-400 Chroma meter (Minolta Camera Co., Ltd., Osaka, Japan) using a D_{65} illuminant and 2˚ observer with an 8 mm aperture. The Japanese color scale is the other commonly used visual color scale. This scale is primarily used to assess color in high quality loins destined for the Japanese export market (Ryan et al., 2010). It is similar to the NPPC color scale with a score of 1 = pale and a score of 6 = dark.

When pork loin chops are cooked to a medium degree of doneness (71˚C), both visual and subjective color can be indicative of sensory characteristics. Huff-Lonergan et al. 2002 reported a weak (r = 0.19) but significant ($P < 0.001$) correlation between instrumental color and trained sensory tenderness scores. Furthermore, Norman et al. (2003) reported that instrumental L* and b* accounted for 17% of variation in Warner-Bratzler shear force values. The previous study also concluded that consumers found chops with an NPPC visual color score of 5 and 6 to be significantly ($P < 0.05$) more juicy when compared to those with an NPPC color of 1-4 (Norman et al., 2003). However, lowering degree of doneness to 63˚ C (medium-rare) can greatly reduce influence of color on sensory characteristics. Wilson et al. (2017) reported that instrumental L* explained less than 1% of the variation in trained sensory tenderness, juiciness, and flavor scores. This could mean that some pork quality traits may not be as influential on eating quality when chops are cooked to a reduced degree of doneness.

Muscle Fiber Type and Color

There is also evidence to suggest muscle fiber type can affect color. Generally, there are four different muscle fiber types that differ in metabolic type (Lee et al., 2010). Type I fibers are ‘slow’, oxidative fibers that are more ‘red; in color due to increased myoglobin content. Type IIA fibers are ‘fast’ fibers that utilize both oxidative and glycolytic metabolism. Lastly, both type IIX and IIB are ‘fast’, glycolytic fibers are more ‘white’ in color due to decreased myoglobin content. It is not surprising that ‘red’ Type I fibers have greater myoglobin content because myoglobin binds oxygen, which is necessary for oxidative metabolism. Because Type I fibers function mainly via oxidative metabolism, they tend to have low glycogen content (Choe et al., 2008). Conversely, Type IIX and IIB muscle fibers tend to have greater glycogen content because they utilize glycolytic metabolism (Choe et al., 2008). Therefore, muscle fiber composition can have an effect on postmortem pH decline and, ultimately color. Choe et al. (2008) reported that an increase in the proportion of fast, glycolytic fibers significantly ($P <$

0.05) increased the rate of postmortem pH decline and, consequently, water-holding capacity. Therefore, excess purge loss would result in reduced myoglobin content and a paler colored loin chop.

Muscle Fiber Type and Tenderness

The relationship between muscle fiber type and sensory characteristics is a controversial one due to varying results regarding how the proportion of Type I and II fibers effects tenderness (Lee et al., 2010). Moody et al. (2008) reported that an increased number of Type I fibers has a positive effect on sensory characteristics. Maltin et al. (1998) also reported that the amount of slow, oxidative fibers was positivity correlated ($r = 0.48$; $P < 0.01$) with tenderness in beef *longissimus lumborum* muscles. Conversely, Xiong et al. (2007) and Ouali and Talmant (1990) reported that a greater number of fast Type II fibers resulted in an increase in postmortem protein degradation and, therefore, improved tenderness. This could be due to the relationship that Type II muscle fibers have with postmortem pH decline (Lee et al., 2010). As mentioned earlier, Type II muscle fibers tend to have a greater amount of glycogen that has the potential to lead to an abnormally low ultimate pH, causing a decrease in water-holding capacity and a decrease in tenderness. (Choe et al., 2008).

Endpoint Cooking Temperature

Modern pork production in the United States has changed drastically in recent years, mostly facilitated by the transition from outdoor to indoor production systems (McGlone, 2013). This change has allowed the USDA Food Safety Inspection Service to align the recommended cooking temperature of whole muscle cuts of pork with that of beef (63˚C; medium-rare). Multiple studies have evaluated the effects of lowering endpoint cooking temperature on the tenderness, juiciness, and flavor of whole muscle cuts of pork. Moeller et al. (2010) reported that cook loss decreases by as much as 3% when internal cooking temperature was reduced from 79.4 ˚C to 62.8˚C. In addition, studies by both Baublits et al. (2006) and Torley et al. (2000) reported as much as a 5% and 16% decrease in cook loss, respectively, as internal cooked temperature was decreased. This reduction in cook loss should result in a loin chop that is perceived as juicier. For example, Rinker et al. (2008) reported as much as a 3-unit increase in trained sensory tenderness and juiciness scores as internal cooked temperature decreased from 80˚C to 62˚C. Based on this evidence, it is clear that decreasing endpoint cooking has a positive influence on the important sensory characteristics of pork.

Conclusion

According to Grunert et al. (2004), consumers use important sensory characteristics, such as tenderness and juiciness, to determine overall product satisfaction and to make repeat purchase decisions. Although many meat quality attributes can contribute to enhancing eating trait, ultimate pH is the primary driving factor in pork cooked to a medium (71°C) degree of doneness. Both visual and subjective color can also contribute; however, this is also driven by ultimate pH. In addition, reducing endpoint cooking temperature from 71°C to 63°C does have the greatest positive influence both tenderness and juiciness. It has been well documented that both pH and color have a significant effect a medium degree of doneness, however, little is known about how these quality traits impact sensory characteristics when pork loin chops are cooked to 63˚C.

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CHAPTER 2

THE EFFECTS OF ULTIMATE PH AND COLOR ON SENSORY TRAITS OF PORK LOIN CHOPS COOKED TO A MEDIUM-RARE DEGREE OF DONENESS

ABSTRACT

The objective was to determine the effects of pH and color on sensory characteristics of boneless pork loin chops cooked to an internal endpoint temperature of 63˚C. Center cut loins (296 total) from barrows and gilts, 5 different sire lines, and a range in pH of 5.36 through 6.23 were used. Previously, ultimate pH was correlated with sensory characteristics of chops cooked to a medium (71°C) degree of doneness. Additionally, increasing ultimate pH improved sensory tenderness and juiciness of loin chops cooked to a medium degree of doneness. However, in 2011, the USDA Food Safety and Inspection Service reduced the recommended final internal cooking temperature of pork chops from 71°C to 63°C (followed by a 3 min rest). The effects of ultimate pH on sensory traits of pork chops cooked to a medium-rare (63°C) degree of doneness are not known. Therefore, loins were categorized using historical categories based on ultimate pH: >5.95, n = 22; 5.80 to 5.95, n = 75; 5.65 to 5.80, n = 102; 5.50 to 5.65, n = 91; <5.50, n= 6. On 1 d postmortem, loins were evaluated for CIE instrumental L*, a*, b*, visual color, marbling, and subjective firmness. Then, loins were aged in vacuum packages at 4°C until 16 d postmortem. After aging, loins were cut into 2.54 cm thick chops, vacuum-packaged and frozen until sensory or instrumental tenderness analysis. One chop was also used to determine extractable lipid. Chops were weighed, cooked to 63°C, cooled to approximately 23°C, weighed again to determine cook loss, and then evaluated for Warner-Bratzler shear force. Another chop was cooked to 63°C internal temperature and served warm to trained panelists to determine sensory traits. Coefficients of determination (R^2) were calculated to determine the predictability of ultimate pH and instrumental color on sensory tenderness, juiciness, and flavor. A one-way ANOVA and means separation test was used to determine specific differences among pH categories. Ultimate pH explained less than 5% of the variation in tenderness and less than 1% of the variation in juiciness or flavor. Further, sensory tenderness did not differ ($P > 0.05$) among pH categories, except for chops with an ultimate pH >5.95. Chops with a pH >5.95 were at least 9.1% more tender ($P < 0.05$) than chops with a pH <5.95. Visual and instrumental color were not predictive ($R^2 \leq 0.03$) of any sensory traits. Overall, pH does not influence sensory traits of pork chops cooked to medium-rare degree of doneness unless pH is at least 5.95.

INTRODUCTION

Tenderness and juiciness are important sensory traits that determine overall eating experience (Enfält et al., 1997). Ultimate pH was significantly correlated with both of these traits when pork chops were cooked to a medium (71˚C) degree of doneness (Huff-Lonergan et al., 2002). Increasing ultimate pH resulted in an increase in tenderness and juiciness scores for fresh pork loin chops cooked to 71˚C when evaluated by trained sensory panelists (Lonergan et al., 2007; Moeller et al., 2010). Visual color is also an important trait that impacts consumer purchasing intent (Brewer et al., 2001). Consumers generally prefer darker colored pork chops over lighter colored chops (Mancini and Hunt, 2005). Ultimate pH impacts the color of pork products. Darker colored chops tend to have a greater ultimate pH; whereas, lighter colored chops tend to have a lesser ultimate pH (Monin and Sellier, 1985). Further, chops with a lesser pH also have reduced water holding capacity (Huff-Lonergan et al., 2002) and tend to be less juicy. Therefore, increasing pH seems to be advantageous for both consumer purchase intent and overall eating experience.

In 2011 the USDA Food Safety and Inspection Service changed the recommended endpoint temperatures of whole muscle cuts of pork from 71°C to 63°C in order to maintain food safety, but improve sensory traits. Previous research has demonstrated that color and marbling have minimal impact the on sensory traits of pork chops cooked to 63˚C (Wilson et al., 2017). However, it is not known whether relationships between ultimate pH and sensory quality of pork chops already established in pork cooked to medium degree of doneness persists in chops cooked to a medium-rare degree of doneness. Therefore, the objective was to determine the effects of ultimate pH and color on sensory characteristics of boneless pork loin chops cooked to an internal endpoint temperature of 63˚C. Because ultimate pH tends to increase water holding capacity and improve tenderness in pork cooked a medium degree of doneness, the hypothesis was that increasing ultimate pH from 5.36 to 6.23 would improve sensory tenderness and juiciness when chops were cooked to a medium-rare degree of doneness.

MATERIALS AND METHODS

Pigs were harvested at a federally inspected facility under the supervision of the USDA Food Safety and Inspection Service. Boneless loins were purchased from that facility and transported to the University of Illinois Meat Science Laboratory (Urbana, IL). No live animal interaction occurred during this study, therefore, no Institutional Animal Care and Use Committee approval was needed.

Background

Loins from approximately 600 barrows and gilts from 5 different sire lines mated to the same F1 female line were available for selection for this experiment. Pigs were raised under the same commercial conditions and transported approximately 450 km to a federally inspected commercial abattoir. Pigs were marketed in groups of 150 over a 2 week period. Each pig was tattooed with a lot number upon arriving at the processing facility. Once at the facility, pigs were provided free access to water, but no access to feed. Pigs were immobilized via carbon dioxide and terminated by exsanguination. After evisceration, a sequential identification number was written on the shoulder of each carcass using a carcass crayon for traceability purposes.

Processing Facility Data Collection

Following commercial harvesting procedures, carcasses were blast-chilled for approximately 90 min and placed in a temperature equilibration carcass cooler for at least 16 h prior to fabrication. After chilling, carcasses were fabricated into primal cuts and loins were further fabricated into Canadian back loins (NAMP #414). Only loins from the left side were used for analysis in this study. Loins were evaluated for visual color (NPPC, 1999), visual marbling (NPPC, 1999), subjective firmness (NPPC, 1991), instrumental color, and ultimate pH immediately following fabrication with limited opportunity for oxygenation of myoglobin prior to evaluation. All measurements were evaluated on the ventral surface of the loin at approximately the area of the 10^{th} rib. Visual and subjective measurements were evaluated by a single individual. Instrumental CIE lightness (L*), redness (a*), and yellowness (b*) were measured with a Minolta CR-400 Chroma meter (Minolta Camera Co., Ltd., Osaka, Japan) using a C illuminant and 2˚ observer with an 8 mm aperture and calibrated using a white tile. Ultimate pH was measured using a Reed data logger fitted with a Hanna glass electrode (REED SD-230 Series pH/ORP Datalogger, 0.00 to 14.00 pH/0-199 mV; Hanna FC200B electrode). After 1d postmortem procedures were complete, loins were weighed, vacuum-packaged, and transported on ice at approximately 4˚C to the University of Illinois Meat Science Laboratory.

Loin Selection

A subsample of 296 (target of 300 total) loins from the original candidate loins were selected to fill a 3 × 5 matrix using 1 d postmortem ultimate pH and 1 d postmortem NPPC visual color score for trained sensory panel analysis (Table 1). There were no differences (P = 0.39) in WBSF among the 5 sire lines for the subpopulation of selected loins. Therefore, loins were pooled across sire line for all response variables. Ultimate pH categories were determined using the same categories described in Lonergan et al. (2007) and were as follows: >5.95, n= 22; 5.80 to 5.95, n= 75; 5.65 to 5.80, n= 102; 5.50 to 5.65, n= 91; <5.50, n= 6. Loins were categorized using the visual color guidelines provided by the National Pork Producers Council (1999) using half-score increments, where loins became darker with increasing color score in the following manner: 1.5 to 2.5, 3.0 to 3.5, and ≥ 4.0. There were no loins within this population that had the combination of a color score ≥ 4.0 and an ultimate pH of < 5.50 or a color score of 1.5 to 2.5 and an ultimate pH > 5.95.

Aged Loin Quality Measurements

Whole boneless loins were allowed to age in vacuum bags until 16 d postmortem at 4˚C. After the ageing period, packages were opened and loins were weighed in order to calculate purge loss. Oxygenation of the loins was allowed to occur for at least 20 min before quality evaluations took place. Final aged postmortem pH was measured on the ventral side of the longissimus dorsi muscle in the approximate location of the 10^{th} rib using a Reed data logger fitted with a Hanna glass electrode calibrated at 4˚C (REED SD-230 Series pH/ORP Datalogger, 0.00 to 14.00 pH/0-199 mV; Hanna FC200B electrode). Visual color (NPPC, 1999), visual marbling (NPPC, 1999), and subjective firmness (NPPC, 1991) were evaluated by the same individual as in data collection at the processing facility. Instrumental CIE lightness (L*), redness (a*), and yellowness (b*) were measured on the ventral side of each loin near the 10^{th} rib following the same procedure used in data collection at the processing facility. After instrumental and visual quality evaluations, loins were sliced in to 2.54 cm thick chops using a push-feed style Treif Puma slicer (Treif model 700 F; Treif, Oberlahr, Germany). The first 3 chops immediately posterior to the spinalis dorsi muscle were collected for further analysis in the following consecutive order: (1) extractable lipid and moisture content, (2) Warner-Bratzler shear force (WBSF), (3) trained sensory analysis. Chops designated for extractable lipid content were trimmed of all secondary muscles and subcutaneous fat. All chops were then vacuum packaged separately and stored at -20˚C until further analysis.

Proximate Analysis

Chops stored for analysis of moisture and extractable lipid were allowed to partially thaw, with great care taken to prevent loss of exudate such that any exudate was added to the chop and included in the homogenate. Samples were homogenized using a Cuisinart food processor (East Windsor, NJ). After homogenization, two 10-g samples from the homogenate were weighed and placed in a drying oven at 110˚C for at least 24 h. Samples were then weighed to determine moisture and washed multiple times in a mixture of chloroform and methanol for at least 24 h in the manner described by Novakofski et al. (1989). After extraction, samples were dried for at least 24 h before the lipid extracted weight was recorded.

Warner-Bratzler Shear Force

Samples designated for WBSF were allowed to thaw at 4˚C for at least 24 h prior to analysis. Chops were then individually weighed and cooked on a Farberware Open Hearth grill (model 455N; Walter Kidde, Bronx, NY) to an internal temperature of 63˚C (medium-rare degree of doneness). Chops were flipped half way through cooking when they reached an internal temperature of 31˚C. Internal temperature was monitored by using copper-constantan thermocouples (Type T, Omega Engineering, Stamford, CT, USA) placed in the geometrical center of each chop and connected to a digital scanning thermometer (model 92000-00, Barnat Co, Barrington, IL). After cooking, chops were allowed to cool to room temperature and weighed again to determine cooking loss. Four cores measuring 1.25 cm in diameter were removed from each chop. Cores were cut at an angle that was parallel to the orientation of the muscle fibers. A Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY/Stable Microsystems, Godalming, UK) with a blade speed of 3.33 mm/s and a load cell capacity of 100 kg was used to shear each sample. Warner-Bratzler shear force values from each of the four cores were averaged to yield a single shear force value for each loin.

Trained Sensory Panel

Trained sensory panels consisted of six individuals that evaluated pork chop tenderness, juiciness, and pork flavor. Panelists were selected from a pool of experienced, trained students and faculty from the University of Illinois (Champaign-Urbana, IL). Before starting these panels, panelists were trained to evaluate pork chops for tenderness, juiciness, and pork flavor using the Sensory Guidelines from the American Meat Science Association (AMSA, 2015). Pork tenderness was standardized using 3 pork chops cooked to an internal temperature of 63˚C, 71˚C, or 80˚C, respectively. Pork juiciness was standardized by cooking a non-enhanced and an enhanced chop to an internal temperature of 71˚C. Pork flavor was standardized by cooking a pork blade steak to an internal temperature of 71˚C. As a group, panelist tasted each sample in order to determine a respective anchor. For this group of trained panelists, sensory tenderness scores explained 15% (R^2 = 0.15) of the variation in WBSF instrumental tenderness. The effectiveness of the University of Illinois trained sensory panel to detect differences in tenderness was less than the 57% (R^2 = 0.57) previously reported by Wilson et al. (2017). However, this decrease in effectiveness could be explained by the lack of variation in WBSF values among pH categories (Table 2.3).

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). Panelists were seated in breadbox-style stations under red lights to mask color differences. Panelists were given apple juice and an unsalted saltine cracker between each sample to use as a palate cleanser. A 15 cm unstructured line scale was used to evaluate tenderness, juiciness, and flavor (0 = extremely tough, extremely dry, no pork flavor; 15 = extremely tender, extremely juicy, and very intense pork flavor). Chops were allowed to thaw at least 24 h prior to cooking at approximately 4°C. After thawing, chops were cooked to an internal endpoint temperature of 63°C using the same Farberware Open Hearth grills used for WBSF analysis. Internal temperature was monitored using the same copper thermocouples mentioned previously for WBSF. After a 3 min rest period, all secondary muscles and subcutaneous fat was trimmed. Chops were cut into cubes using a 1 cm × 1 cm sample sizer prior to serving. No more than 2 sensory sessions occurred per day with up to 6 samples per session. Panels were held at least an hour apart in order to reduce panelist fatigue. The study consisted of 296 samples in 50 sessions over 87 days. Results from panelists were averaged for use in data analyses.

Statistical Analyses

Loin (296 total) served as the experimental unit in this study. Summary descriptive statistics were calculated using the Means procedure in SAS. Regression analyses were performed using the REG procedure in SAS to calculate coefficients of determination (R^2) between the dependent (tenderness, juiciness, flavor, and WBSF) and independent (ultimate pH, visual color, and instrumental color) variables. Warner-Bratzler shear force was used as an independent variable in a regression analysis to validate the trained sensory panel data. Additionally, the effects of ultimate pH and visual color on sensory characteristics, WBSF, and cook loss were analyzed using the MIXED procedure in SAS as a 1-way ANOVA. A multi-variance model was fit using the repeated statement because of heterogeneous variances due to extreme differences in sample size among pH and visual color categories. Significance was determined at $P < 0.05$ for all analyses.

RESULTS

Carcass Characteristics and Loin Quality

Hot carcass weights ranged from 80.81 kg to 123.49 kg in this population of pigs. In addition, loin muscle depth was between 45.5 mm and 85.6 mm, and fat depth ranged between 15.0 mm and 39.6 mm (Table 2.2). Ultimate pH ranged from 5.36 to 6.23, NPPC visual color scores ranged from 1.5 to 4.5, and instrumental L* values ranged from 34.43 to 50.94 (Table 2.2). Visual color and marbling scores ranged from 1.5 to 4.0 and 1.0 to 5.0 respectively, while subjective firmness scores ranged from 2.0 to 4.0 (Table 2.2). Additionally, trained sensory tenderness, juiciness, and flavor scores ranged from 6.48 to 11.98, 6.22 to 11.05, and 1.70 to 3.75 respectively (Table 2.2). Furthermore, the majority of loins fell in the intermediate ultimate pH categories (5.65 to 5.95) and achieved a NPPC visual color score between 3.0 and 3.5 (Table 2.1).

Ultimate pH and Color as Predictors of Sensory Traits

Ultimate pH explained 5% of the variation ($R^2 = 0.05$, $P < 0.001$) in trained sensory tenderness scores (Table 2.5). In addition, chops from loins in the most elevated pH category (pH >5.95) were more tender ($P < 0.01$) when compared to those from the lower pH categories (Table 2.3). However, ultimate pH was not an effective predictor of trained sensory juiciness or flavor scores as it explained less than 1% ($R^2 < 0.01$; $P = 0.10$) of the variation in panelist scores (Table 2.5). Ultimate pH was also not predictive ($R^2 < 0.01$, $P = 0.34$) of WBSF.

Sensory traits, cook loss, and WBSF values did not differ among the 3 color categories (Table 2.4). In addition, NPPC visual color score explained less than 1% ($R^2 < 0.01$, $P = 0.83$) of the variation in sensory tenderness, juiciness, and flavor scores or WBSF and, therefore, was not an effective predictor of eating quality. Instrumental L* was also not ($R^2 = 0.02$, $P < 0.05$) predictive of sensory tenderness scores. Additionally, instrumental L* was not predictive of juiciness or flavor as it explained less than 1% of the variation in panelist scores (Table 2.5). Furthermore, neither tenderness nor juiciness could be predicted using instrumental a* as it explained less than 1% of the variation in panelist scores. Instrumental a* was also not predictive ($R^2 = 0.01$, $P < 0.05$) of sensory flavor scores (Table 2.5). Finally, instrumental b* explained 3% of the variation in sensory tenderness scores, but did not effectively predict ($R^2 < 0.01$) juiciness or flavor scores (Table 2.5).

The combination of ultimate pH, instrumental L*, instrumental a* and instrumental b*accounted for 11% ($R^2 = 0.11$, $P < 0.0001$) of the variation in sensory tenderness scores, but was not at all predictive of sensory juiciness or flavor scores ($R^2 \leq 0.01$, $P \leq 0.13$). Extractable lipid content was slightly predictive ($R^2 = 0.06$, $P < 0.001$) of sensory tenderness, but not of either sensory juiciness or flavor scores ($R^2 < 0.01$, $P = 0.08$) (Table 2.5). Therefore, the addition of extractable lipid to the model improved the predictability of tenderness. When extractable lipid was included along with predictor variables above, 14% ($R^2 = 0.14$, $P < 0.0001$) of the variation in sensory tenderness scores was accounted for. However, even with the addition of extractable lipid to the model, these variables are still not predictive of sensory juiciness or flavor scores ($R^2 \leq 0.01$, $P \leq 0.10$).

DISCUSSION

Previous research determined that ultimate pH is correlated with both sensory tenderness and juiciness in pork loin chops cooked to a medium degree of doneness (71˚C) (Huff-Lonergan et al., 2002). When chops were cooked to 71˚C, chops from loins with an ultimate pH above 5.95 tended to have as much as a 5% reduction in cook loss when compared to those with an ultimate pH less than 5.95 (Lonergan et al., 2007). An increase in pH also resulted in significantly greater sensory tenderness and juiciness scores (Huff-Lonergan et al., 2002; Lonergan et al., 2007; Moeller et al., 2010). Furthermore, Torley et al., (2000) reported that cook loss was affected by both internal cooking temperature and pH. In the present study, loins with a pH of greater than 5.95 were also more tender ($P < 0.01$) and had a decreased cook loss ($P = 0.04$) when compared to those with a pH less than 5.95. The relationship between pH and tenderness is likely due to the influence pH has on water-holding capacity and therefore, cook loss.

Unlike previous studies, results from this study indicate that there were no differences in sensory juiciness scores among the 5 pH categories ($P = 0.30$). The lack of variation in sensory juiciness scores are likely due to the decrease in internal cooking temperature. Reducing internal cooking temperature from 71˚C to 63˚C, has the potential to reduce both cooking time and cook loss. Moeller et al. (2010) reported that cook loss decreases by as much as 3% when internal cooking temperature was reduced from 79.4 ˚C to 62.8˚C. In addition, studies by both Baublits et al. (2006) and Torley et al. (2000) reported as much as a 5% and 16% decrease in cook loss, respectively, as internal cooked temperature was decreased. This reduction in cook loss should result in a loin chop that is perceived as juicier. As such, it is not surprising that Rinker et al. (2008) reported as much as a 3 unit increase in sensory tenderness and juiciness scores as internal cooked temperature decreased from 80˚C to 62˚C when chops were evaluated by trained panel. Therefore, the lack of differences between pH categories in the present study suggest that ultimate pH may not be an important factor in determining sensory juiciness scores when cooking to 63˚C due to minimal cooking loss of all chops.

Furthermore, in the current study, instrumental CIE lightness (L*), redness (a*), and yellowness (b*) were not predictive of overall eating quality. Previously, instrumental L* and b* explained only 2% and 3%, respectively, of the variation in tenderness scores, but less than 1% of the variation in both juiciness and flavor scores (Wilson et al, 2017; Harsh et al, 2018). Instrumental a* explained 1% of the variation in flavor scores, but less than 1% of the variation for both tenderness and juiciness. This was unexpected based on historical data that suggest darker colored chops are expected to have a more favorable eating experience due to muscle fiber type and increased myoglobin concentration (Moody et al., 1980). Moody et al. (1980) reported that carcasses with a greater number of oxidative Type I fibers can positively influence the palatability characteristics of meat. Furthermore, in pork loin chops cooked to a medium degree of doneness, visual color is significantly ($P < 0.01$) correlated to sensory tenderness scores (Huff-Lonergan et al., 2002).

In the current study, the lack of variation in sensory tenderness and juiciness scores could be due to the consistent management practices and relatively limited genetic variation in the population. Therefore, subtle differences in transport, lairage, or chilling could explain the differences in pH. However, the results indicate that these potential differences do not appear to be great enough to affect eating quality. This is unlike Lonergan et al. (2007), which reported significant differences among pH categories for both tenderness and juiciness. These differences could be due to the diverse genetic background and management practices that were utilized within the population of pigs used for the previously mentioned study. Furthermore, a study conducted by Wilson et al. (2017), which evaluated the effects of color and extractable lipid content on sensory traits of pork loin chops cooked to 63˚C, also reported that instrumental L* was poorly predictive (R^2 = 0.01; P=0.04) of sensory tenderness scores, and not at all predictive of either juiciness or flavor scores. Similar to the current study, Wilson et al. (2017) reported that extractable lipid content explained no more than 2% (R^2 = 0.02, P = 0.02) of the variation in sensory tenderness and juiciness scores. In addition, Norman et al. (2003) evaluated the effects of pork loin color on instrumental tenderness and consumer acceptance. Loins from an unknown genetic line where divided into three categories using NPPC visual color standards and were as follows: NPPC visual color scores 1 and 2, NPPC visual color scores 3 and 4, and NPPC visual color scores 5 and 6. Instrumental L* means for each of the three categories were pale = 57.00, intermediate = 50.24, and dark = 45.54. The results indicated there were no significant (P > 0.05) differences in tenderness among color categories when chops were cooked to 71˚C and evaluated using WBSF analysis. However, Norman et al. (2003) also reported that consumers rated the chops in the dark category as being significantly (P < 0.05) more juicy than those in both the intermediate and pale color categories. The lack of consistent results between these studies could also be due to internal endpoint cooking temperature as Norman et al. (2003) utilized “in-home” consumer testing. Therefore, internal endpoint temperatures may have been inconsistent and chops may have been cooked to a greater degree of doneness.

Conclusions

Based on these results, it is clear that many quality factors may impact the palatability traits of pork loin chops. Although the chops in the most elevated pH category (pH >5.95) were nearly 10% more tender, ultimate pH explained only 5% of the variation in sensory tenderness scores and less than 1% of the variation in juiciness and flavor scores. In addition, instrumental color, at most, explained 3% of the variation in tenderness scores and 1% of the variation in flavor scores, but was not an effective predictor of juiciness. In conclusion, ultimate pH does not independently influence eating quality (tenderness, juiciness, and flavor) of boneless pork loin chops cooked to a medium-rare degree of doneness unless pH is at least 5.95.

TABLES

Table 2.1 Number of chops per color-pH category combination

	Variable	pH category[1]				
		>5.95	5.80 to 5.95	5.65 to 5.80	5.50 to 5.65	<5.50
Color[2]	1.5 to 2.5	0	18	38	43	1
	3.0 to 3.5	16	53	50	45	5
	≥ 4.0	6	4	14	3	0

[1]Ultimate pH collected 1 d postmortem on the ventral side of whole boneless loins.

[2] NPPC color using the 1999 standards, half point scale where 1 = palest color; 6 = darkest color.

Table 2.2 Population summary statistics for early (1d) postmortem and aged (16d) quality parameters and sensory characteristics

Item	Observations	Mean	SD	Minimum	Maximum
Carcass characteristics					
Hot carcass wt., kg	296	101.37	6.22	80.81	123.49
Loin muscle depth, mm	296	6.57	0.64	4.55	8.56
Fat depth, mm	296	2.34	0.48	1.50	3.96
1 d fresh quality traits					
Ultimate pH[1]	296	5.73	0.14	5.36	6.23
Visual color[2]	296	2.95	0.54	1.50	4.00
Visual marbling[3]	296	2.42	0.76	1.00	5.00
Subjective firmness[4]	296	3.12	0.52	2.00	4.00
Lightness, L*[5]	296	42.08	2.87	34.43	50.94
Redness, a*[5]	296	9.08	1.69	4.50	13.20
Yellowness, b*[5]	296	0.87	1.64	-2.75	5.49
16 d aged quality traits					
Final pH[6]	296	5.70	0.13	5.46	6.25
Visual color[2]	296	3.22	0.40	2.00	5.00
Visual marbling[3]	296	2.28	0.66	1.00	4.50
Subjective firmness[4]	296	3.16	0.43	2.00	5.00
Lightness, L*[5]	296	46.62	3.35	35.56	53.43
Redness, a*[5]	296	9.27	1.15	6.19	13.07
Yellowness, b*[5]	296	4.58	1.62	-0.73	8.61
Cook loss, %[7]	296	18.89	3.72	10.80	36.74
Extractable lipid, %	296	3.43	1.10	0.99	7.69
Warner-Bratzler shear force,kg[8]	295	2.78	0.55	1.64	4.66
Sensory characteristics					
Tenderness[9]	296	9.61	0.92	6.48	11.98
Juiciness[9]	296	9.07	0.81	6.22	11.05
Flavor[9]	296	2.40	0.29	1.70	3.75

[1]Ultimate pH collected 1 d postmortem on the ventral surface of whole boneless loins.
[2]NPPC color using the 1999 standards, half point scale where 1 = visually palest; and 6 = visually darkest.
[3]NPPC marbling using the 1999 standards where 1 = visually the least marbling and 6 = visually the most marbling
[4]NPPC firmness using the 1991 standard where 1 = softest and 6 = firmest.
[5]L* measures darkness to lightness (greater L* indicates a lighter color), a* measures redness (greater a* value indicates a redder color), and b* measures yellowness (greater b* value

Table 2.2 (cont.)
indicates a more yellow color).

[6]Final pH collected 16 d postmortem on the ventral surface of whole boneless loins.
[7]Cook loss was recorded immediately prior to cooking and after cooling to an internal temperature of approximately 23˚C.
[8]Warner-Bratzler shear force was collected on chops cooked to a final internal temperature of 63˚C and sheared at an internal temperature of approximately 23˚C.
[9]Evaluated on a 15 point scale, where 0 = extremely tough, dry, or not flavorful and 15 = extremely tender, juicy, or flavorful.

Table 2.3 Effects of ultimate pH on sensory traits of pork chops cooked to a medium-rare degree of doneness[1]

Item	pH category[1]					SEM	*P*-value
	>5.95	5.80 to 5.95	5.65 to 5.80	5.50 to 5.65	<5.50		
Loins, n	22	75	102	91	6		
Sensory tenderness[2]	10.59[a]	9.67[b]	9.51[b]	9.46[b]	9.47[b]	0.29	< 0.01
Sensory juiciness[2]	9.29	9.15	9.02	9.03	8.74	0.23	0.18
Sensory flavor[2]	2.30	2.35	2.44	2.44	2.27	0.13	0.12
Cook loss, %[3]	16.14	18.09	18.54	18.58	18.87	1.13	0.08
Warner-Bratzler shear force, kg[4]	2.87	2.78	2.82	2.67	2.84	0.19	0.09

Least square means within a row lacking a common superscript are different ($P < 0.05$).

[1]Ultimate pH collected 1 d postmortem on the ventral side of whole boneless loins.

[2]Sensory scores with a greater value represent a greater degree of tenderness, juiciness, or flavor

[3]Cook loss was recorded immediately prior to cooking and after cooling to an internal temperature of approximately 23˚C.

[4]Warner-Bratzler shear force was collected on chops cooked to a final internal temperature of 63˚C and sheared at an internal temperature of approximately 23˚C.

Table 2.4 Effects of visual color on sensory traits of pork chops cooked to a medium-rare degree of doneness[1]

Item	Visual color category[1]				
	1.5 to 2.5	3.0 to 3.5	≥ 4.0	SEM	*P*-value
Loins, n	101	168	27		
Sensory tenderness[2]	9.48	9.60	9.21	0.19	0.10
Sensory juiciness[2]	9.03	9.14	8.78	0.17	0.07
Sensory flavor[2]	2.40	2.43	2.38	0.05	0.53
Cook loss, %[3]	19.08	18.93	17.99	0.96	0.53
Warner-Bratzler shear force, kg[4]	2.84	2.73	2.88	0.11	0.15

[1]NPPC color using the 1999 standards, half point scale where 1 = visually palest; and 6 = visually darkest.

[2]Sensory scores with a greater value represent a greater degree of tenderness, juiciness, or flavor

[3]Cook loss was recorded immediately prior to cooking and after cooling to an internal temperature of approximately 23˚C.

[4]Warner-Bratzler shear force was collected on chops cooked to a final internal temperature of 63˚C and sheared at an internal temperature of approximately 23˚C.

Table 2.5 Coefficient of determination (R^2) estimates between early postmortem loin ventral surface quality parameters and sensory tenderness, juiciness, and flavor

	Tenderness		Juiciness		Flavor	
Independent variable	R^2	*P* - value	R^2	*P* - value	R^2	*P* - value
Ultimate pH[1]	0.05	< 0.001	< 0.01	0.16	< 0.01	0.10
Visual color[2]	< 0.01	0.94	< 0.01	0.83	< 0.01	0.84
Lightness, L*[3]	0.02	<0.05	< 0.01	0.65	< 0.01	0.63
Redness, a*[3]	< 0.01	0.09	< 0.01	0.78	0.01	0.04
Yellowness, b*[3]	0.03	< 0.01	< 0.01	0.98	< 0.01	0.73
Warner-Bratzler shear force, kg[4]	0.15	< 0.001	< 0.01	0.43	< 0.01	0.55
Extractable lipid, %	0.06	< 0.001	< 0.01	0.29	0.01	0.08

[1]Ultimate pH collected 1 d postmortem in the ventral surface of whole boneless loins.

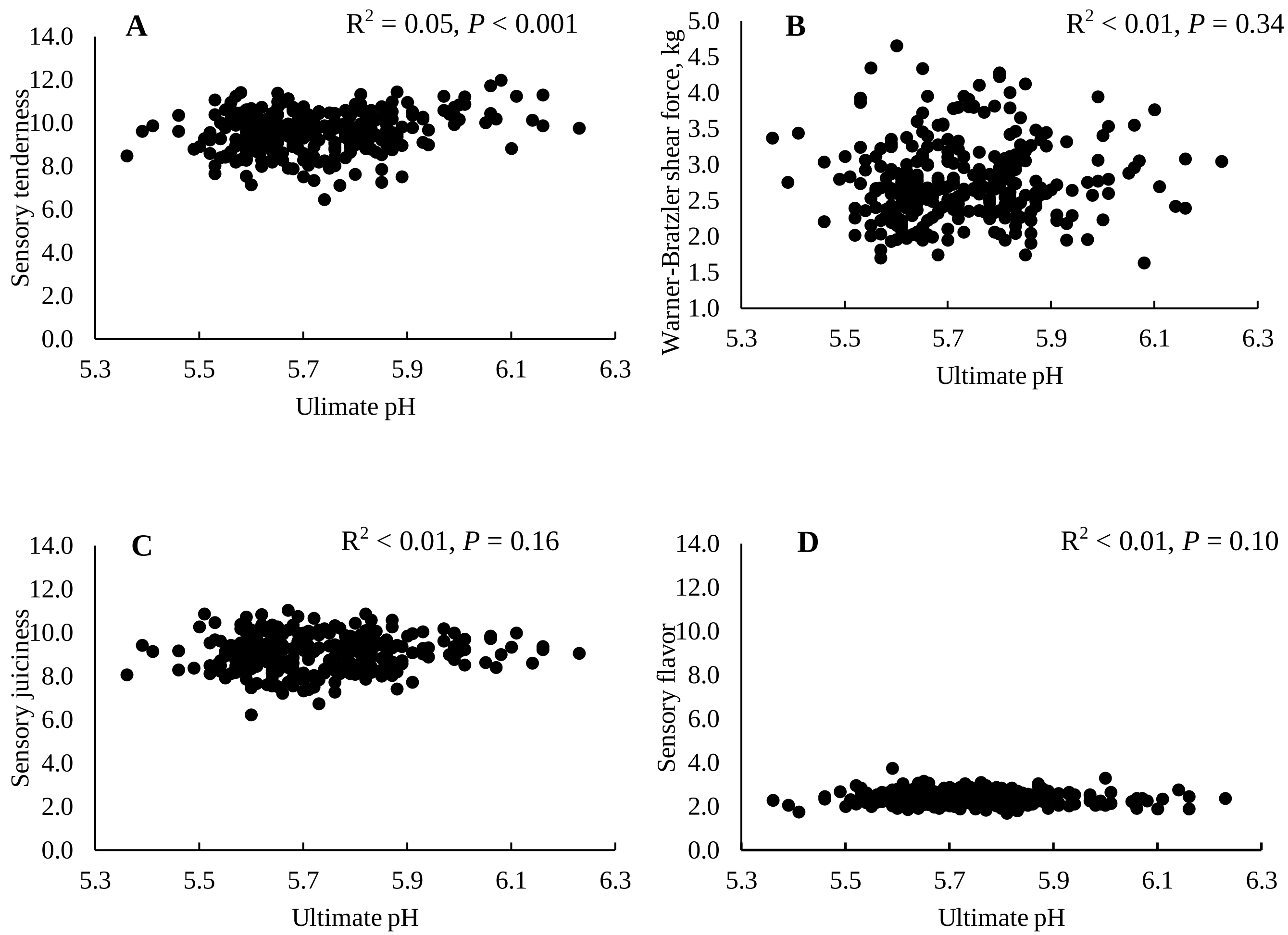
[2]NPPC color using the 1999 standards, half point scale where 1 = visually palest; and 6 = visually darkest.

[3]L* measures darkness to lightness (greater L* indicates a lighter color), a* measures redness (greater a* value indicates a redder color), and b* measures yellowness (greater b* value indicates a more yellow color).

[4]Warner-Bratzler shear force was collected on chops cooked to a final internal temperature of 63˚C and sheared at an internal temperature of approximately 23˚C.

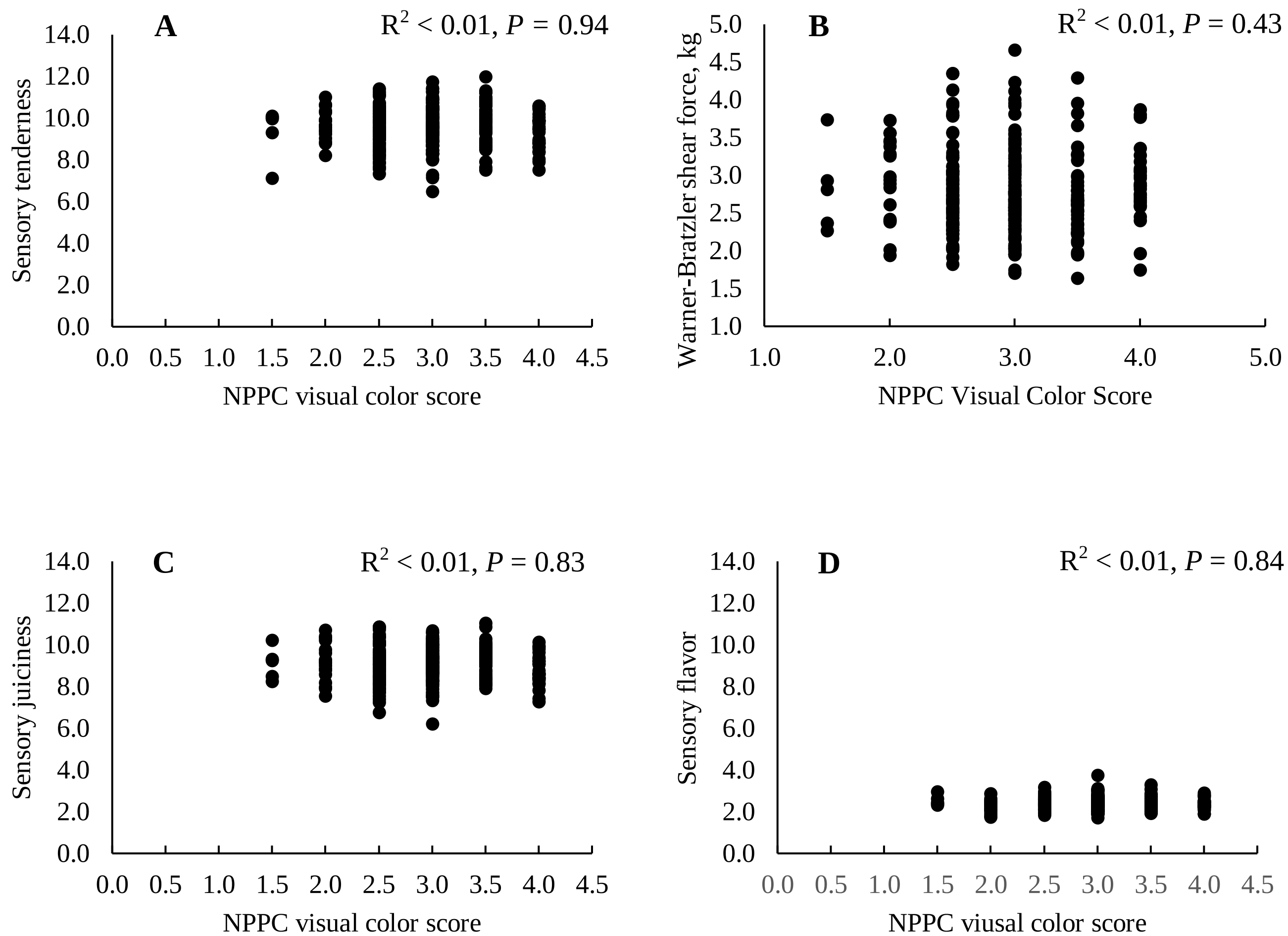
SUPPLEMENTAL FIGURES

Supplemental Figure 2.1



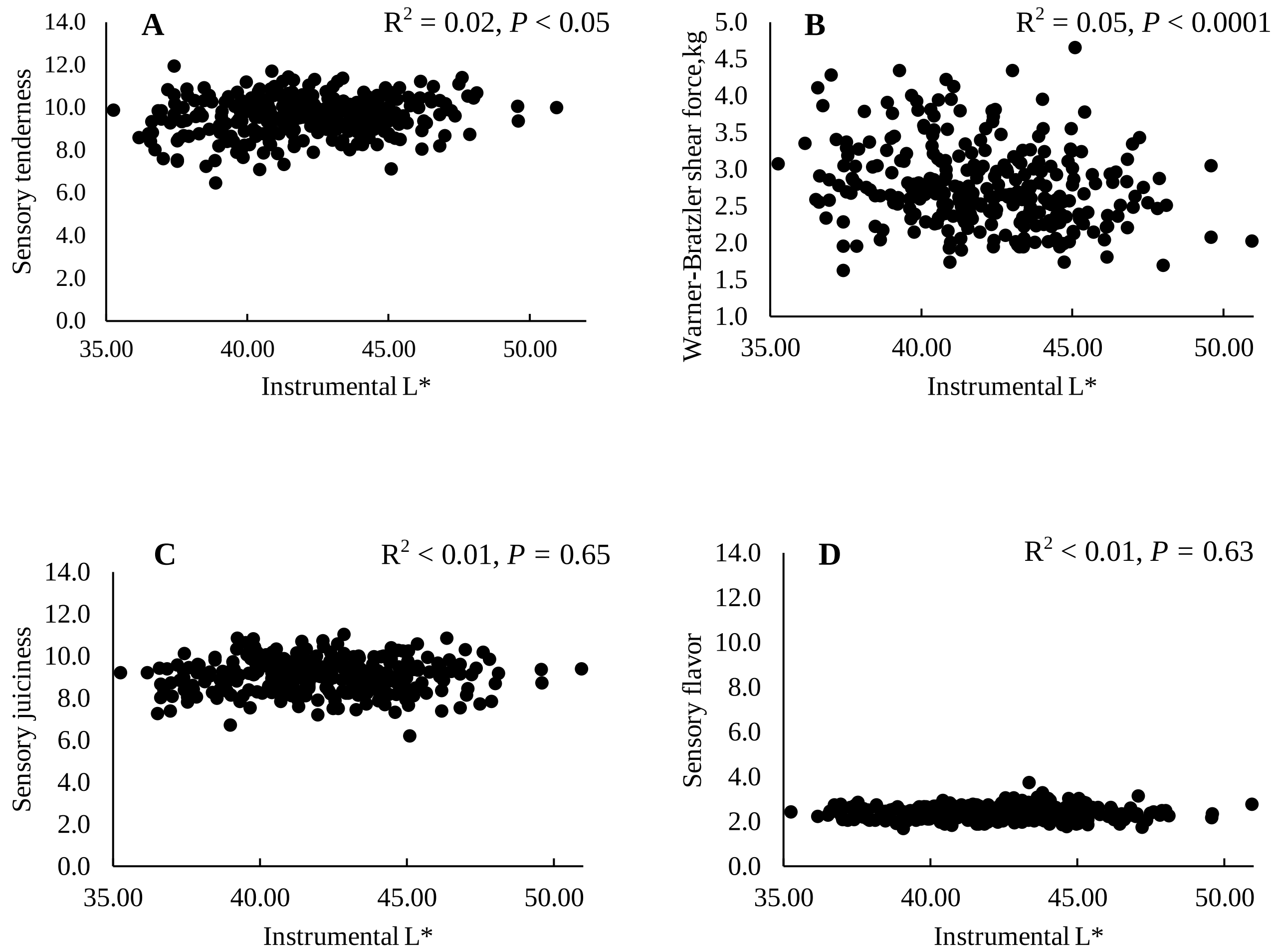
Supplemental Figure 2.1 Prediction of sensory tenderness (A), WBSF values (B), sensory juiciness scores (C), and sensory flavor scores (D) using 1 d postmortem ultimate pH collected on the ventral side of whole boneless loins.

Supplemental Figure 2.2



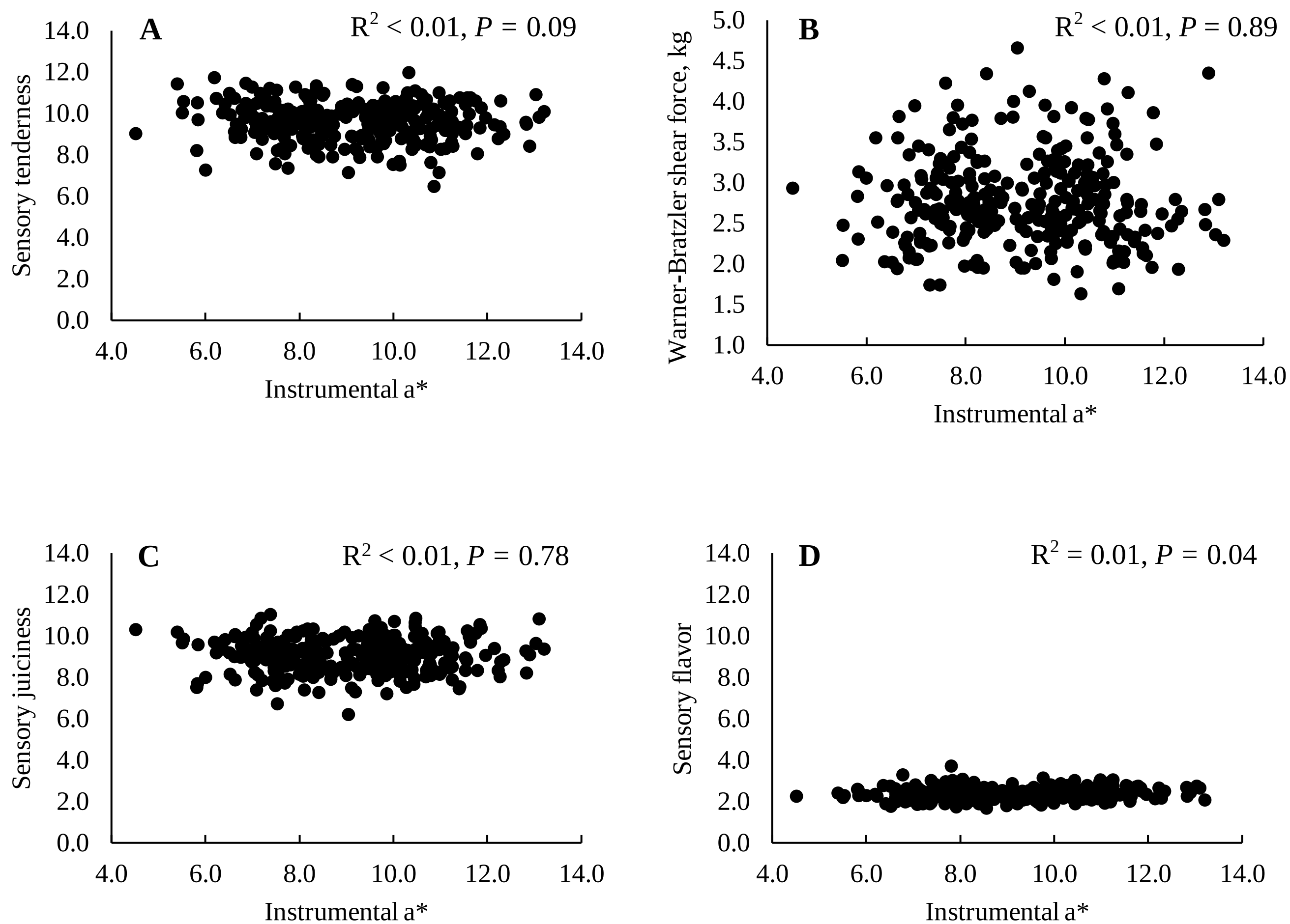
Supplemental Figure 2.2 Prediction of sensory tenderness (A), WBSF values (B), sensory juiciness scores (C), and sensory flavor scores (D) based on NPPC visual color scores using the 1999 standards, half-point scale where 1 = palest color and 6 = darkest color.

Supplemental Figure 2.3



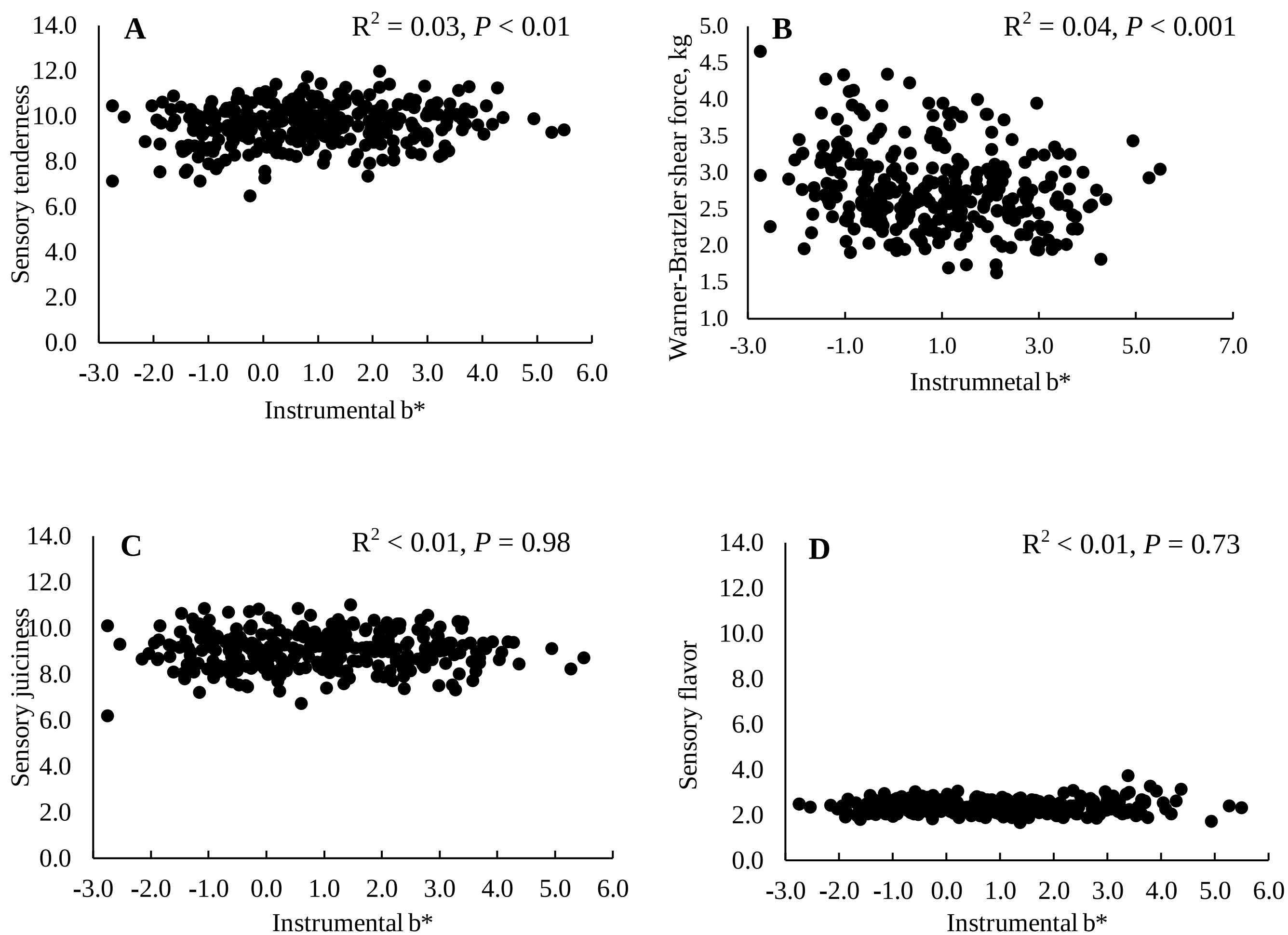
Supplemental Figure 2.3 Prediction of sensory tenderness (A), WBSF values (B), sensory juiciness scores (C), and sensory flavor scores (D) using instrumental L*. L* measures darkness to lightness (greater L* indicates a lighter color).

Supplemental Figure 2.4



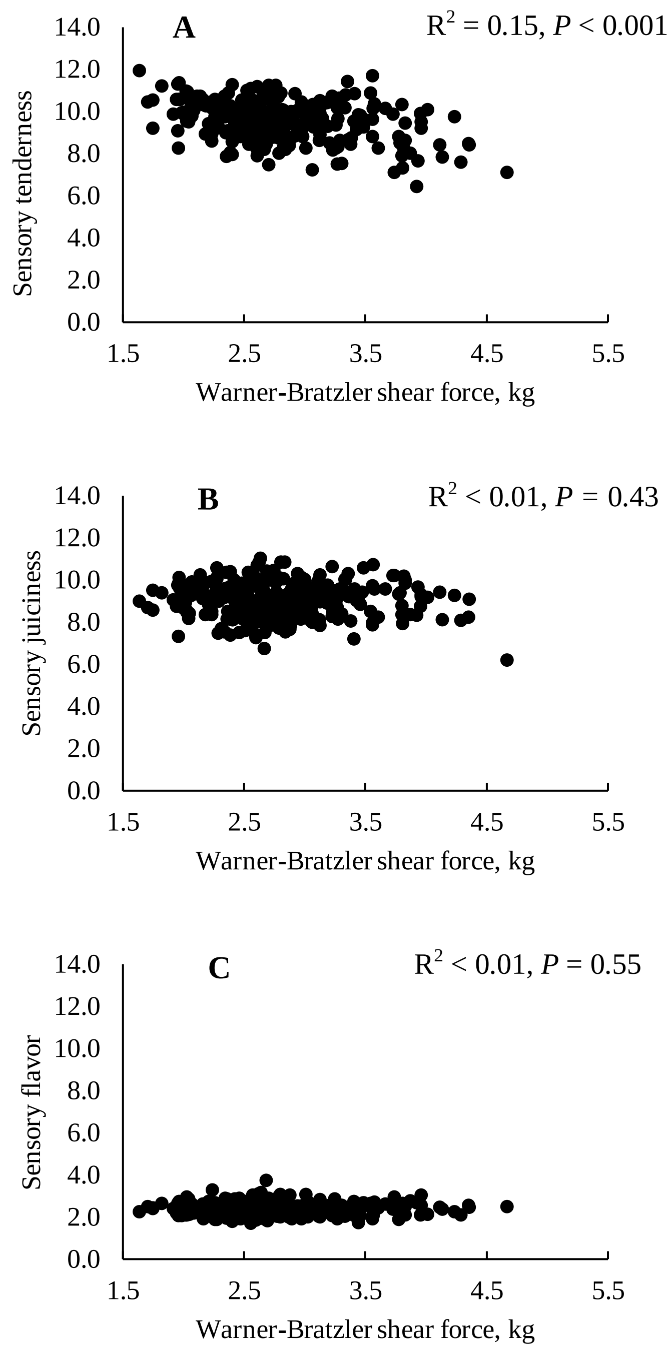
Supplemental Figure 2.4 Prediction of sensory tenderness (A), WBSF values (B), sensory juiciness scores (C), and sensory flavor scores (D) using instrumental a*. Instrumental a* measures redness (greater a* indicates a redder color).

Supplemental Figure 2.5



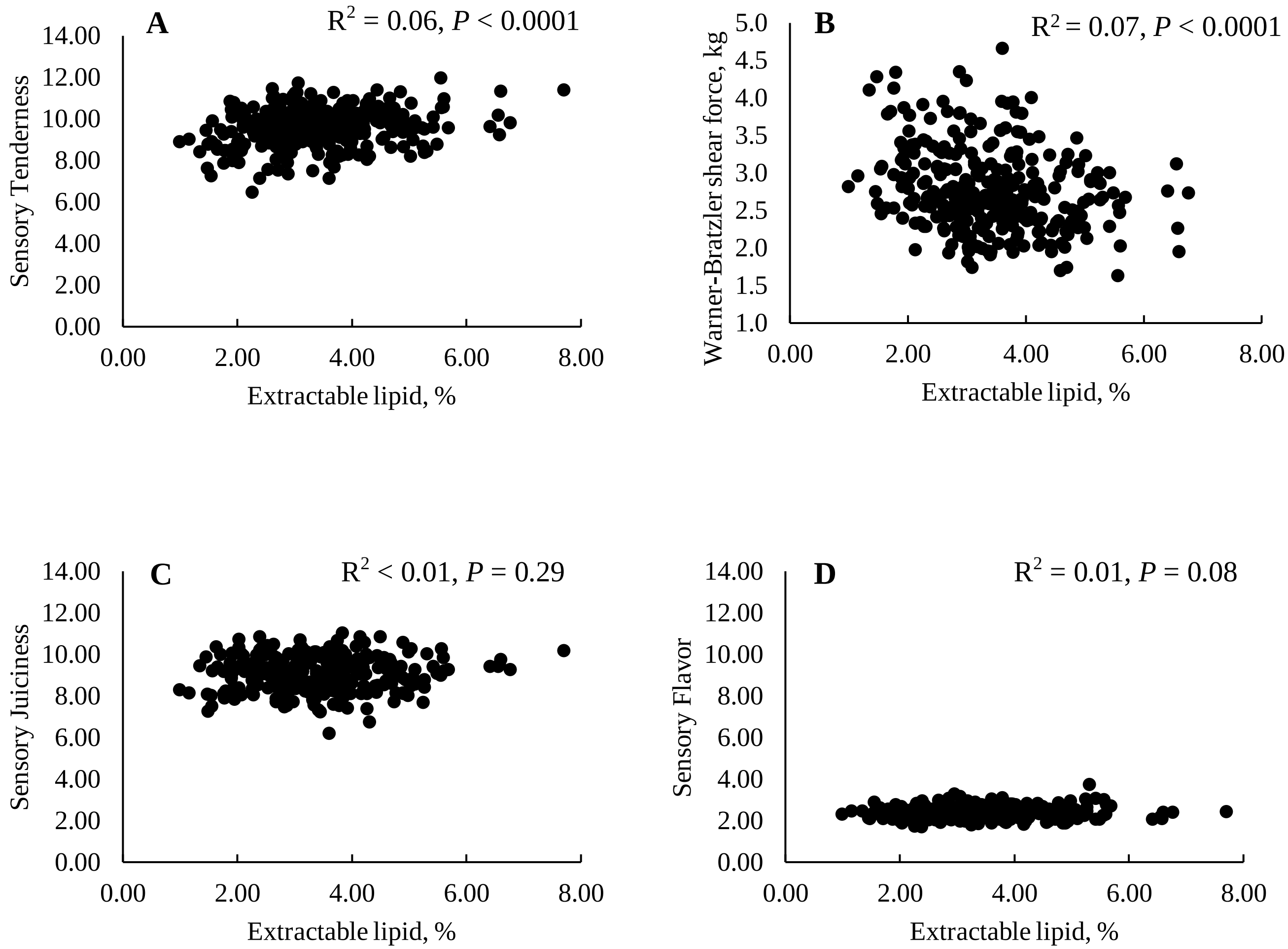
Supplemental Figure 2.5 Prediction of trained sensory tenderness (A), WBSF values (B), sensory juiciness scores (C), and sensory flavor scores (D) using instrumental b*. Instrumental b* measures yellowness (greater b* indicates a more yellow color).

Supplemental Figure 2.6



Supplemental Figure 2.6. Prediction of sensory tenderness (A), juiciness (B), and flavor (C) scores using Warner-Bratzler shear force values.

Supplemental Figure 2.7



Supplemental Figure 2.7 Prediction of sensory tenderness (A), WBSF values (B), sensory juiciness scores (C), and sensory flavor scores (D) using extractable lipid content.

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