

ESTABLISHING THE RELATIONSHIPS AMONG CARCASS CHARACTERISTICS AND
MEAT QUALITY TRAITS OF PORK

BY

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THESIS

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ABSTRACT

Barrows and gilts (N=1238) with the same genetic background, housing, and management were raised under commercial conditions and marketed when the average pig weight in a pen reached 138 kg. Pigs were slaughtered over 7 weeks in a commercial processing facility. Carcass length was measured on the left side of each carcass from the anterior of the aitch bone to the anterior of the first rib at 1-d postmortem. Carcasses were fabricated and boneless Canadian back loins (IMPS #414) were vacuum-packaged and transported to the University of Illinois Meat Science Laboratory. At the end of the 14-d aging period, loins were weighed, measured for stretched length (stretched to maximum length without distortion), compressed length (compressed to minimum length without distortion) and sliced into 2.54cm chops using a Treif Puma slicer. Complete boneless chops were counted and ends and incomplete chops were weighed. From the initial population, 286 boneless loins (NAMP #414) were further selected based on instrumental L* color and extractable lipid content resulting in a 5 x 6 factorial arrangement of treatments. Using these values, chops were also assigned a quality grade using the newly developed National Pork Board (NPB) quality grade standards. Low (n = 33) quality includes loins with color scores < 2.5 and marbling scores \leq 2.0. Medium (n = 203) quality includes color scores 2.0 through 3.5 with marbling \geq 2.5, color scores from 3.0-3.5 with marbling scores \geq 1.5, and color scores \geq 4.0 with marbling scores < 1.5. High (n = 50) quality includes color scores of > 4.0 with marbling scores \geq 2.0. Chops were assigned to sensory panel sessions in an incomplete block arrangement, cooked to a medium-rare degree-of-doneness (63 °C) and evaluated for tenderness, juiciness, and pork flavor by trained sensory panelists. Slice shear force (SSF) and cooking loss were also determined from each loin cooked to 63 °C.

Data were analyzed using the REG procedure in SAS and the effect of NPB quality grade was analyzed using the MIXED procedure in SAS as a one-way ANOVA where quality grade was considered a fixed effect. Carcass length varied from a minimum of 78.2 cm to a maximum of 96.5 cm. Boneless loin yield varied from a minimum of 13 chops to a maximum of 20 chops. Carcass length explained 15% ($P < 0.0001$) of the variation in boneless loin chop yield. Loin weight explained 33% ($P < 0.0001$) of the variation in boneless loin chop yield. Compressed loin length explained 28% ($P < 0.0001$) of the variation in boneless loin chop yield. Stretched loin length explained only 9% ($P < 0.0001$) of the variation in boneless loin chop yield. The combination of loin weight and compressed loin length was able to explain 39.3% ($P < 0.0001$; $C(p) = 12.399$) of the variation in boneless loin chop yield using a required F statistic at the SLENTY and SLSTAY level = 0.15. Instrumental L* color score ranged from 43.11 to 57.60 and extractable lipid ranged from 0.80% to 5.52%. Extractable lipid content and instrumental chop color individually accounted for a maximum of 2% ($R^2 = 0.02$) of the variation of tenderness, juiciness or pork flavor. Chops categorized as NPB high quality (SSF = 17.50 kg) were 6.5% more tender ($P \leq 0.02$) than chops categorized as medium (SSF = 18.68 kg) and 11.2% more tender than chops categorized as low quality (SSF = 19.59 kg), but medium and low quality chops did not differ in SSF. However, trained sensory panelists did not discern tenderness differences ($P = 0.13$) among NPB quality grades. Juiciness ($P = 0.43$) and flavor ($P = 0.11$) scores did not differ among NPB quality grades. Cook loss tended ($P = 0.06$) to decrease from 16.86% to 15.32% as quality grade increased.

Overall, carcass length is a poor predictor of boneless loin chop yield. However, using boneless loin parameters such as boneless loin weight and compressed loin length may be more predictive of the number of chops produced from a boneless pork loin. Further, when color or

marbling was used as a single trait, it was not predictive of sensory quality. However, using these traits in combination such as with the NPB quality grades may result in differences in sensory quality between pork loins.

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CHAPTER 1: REVIEW OF THE LITERATURE

Introduction

In the United States, of the total meat consumed per capita in 2015, approximately 22% of that was comprised of fresh or further processed pork which ranks third in the U. S. for total meat consumption behind chicken and beef (Pork Checkoff, 2016). Due to an extremely competitive protein market it is vital the pork industry continuously meets the consumer's demands in producing a high quality product that provides a satisfactory eating experience relative to the competition. The desired quality may fluctuate depending on the intended consumer, but to provide a satisfying eating experience the pork industry places emphasis on increasing the palatability of pork cuts that is defined by three primary sensory traits: tenderness, juiciness, and flavor. Sensory tenderness can be impacted by numerous factors, but of major concern is the amount of intramuscular fat (IMF) or marbling in the product. Typically, a product with a greater amount of marbling is also expected to be more tender and provide a positive eating experience (Brewer et al., 2001; Wood et al., 2004.). One explanation for this is a weakening of the cross-linkage between collagen fibers because of the infiltration of IMF content (Fortin et al., 2005). Sensory juiciness is dependent on the amount of moisture within the meat to stimulate saliva production during mastication (Ashgar and Pearson, 1980). Finally, sensory flavor is thought to derive from the combination of soluble and lipid soluble components and their degradation products such as aldehydes, alcohols, and ketones (Ashgar and Pearson, 1980; Wood et al., 1999). Taking all three palatability traits into account, the pork industry uses multiple management strategies to limit variation or more accurately predict the ultimate tenderness, juiciness, and flavor of the final product. In general, when assessing the palatability of pork, people discuss the term pork quality which is inherently a general term, because it

encompasses multiple factors; therefore, the phrase “pork quality” can have a different definition depending on what sector of swine production is involved. Moreover, there is not one definition that meat scientist have deemed appropriate to define the term pork quality. The pork quality audit published by Cannon et al., in (1996) described pork quality to be associated with terms such as freshness, wholesomeness, grade, color (appearance), eating satisfaction, and processing attributes (functionality). Despite this citation being several years old, the same holds true to today that the term “pork quality” has many factors associated with such a broad term. Therefore, instead of defining what acceptable pork quality is; the following will discuss the factors that may affect the ultimate quality of the final product and how we can control or adjust production practices to provide the highest quality product to consumers globally.

Pork quality traits are frequently influenced by both ante-mortem and postmortem factors. Therefore, the accurate prediction of ultimate pork quality is inherently very challenging. Several traits are commonly measured and used to define the ultimate quality of pork cuts. Those include but are certainly not limited to: color, intramuscular fat content, water holding capacity (WHC), and the palatability traits tenderness, juiciness, and flavor. All of the previous traits listed can be influenced by several factors which take effect immediately prior to and during the harvest process including genetics, peri-mortem handling, stunning method, and chilling method. After fabrication the type of packaging used, lighting source, and storage temperature will also play a role in the ultimate quality of the product and may also determine how long the product remains appealing to consumers.

The first factor to possibly influence pork quality would be the genetics of the pigs. Today, the commercial genetics available to producers are relatively small in number when compared to several years ago. However, these more modern genetics are very reliable in terms

of lean growth and efficiency and therefore many swine producers use similar genetics. The increased selection pressure on improving carcass merit resulting in increased lean growth and higher yielding carcasses has inadvertently led to an increased prevalence in greater variation in pork quality (Scheffler and Gerrard, 2007). Genetically, there are two mutations, halothane gene (HAL) and Rendement Napole (RN) gene, swine producers use to further limit the variation in ultimate pork quality. The HAL gene is associated with increased susceptibility to stress and elevated body temperatures upon exsanguination and pigs will have accelerated rate of postmortem glycolysis leading to a more rapid pH decline (Fernandez et al., 2002). Just as detrimental, the RN gene, associated with the Hampshire breed, causes pigs to have a greater amount of muscle glycogen; therefore, leading to an extended pH decline resulting in a lower ultimate pH (Monin and Sellier, 1985).

Regardless of genetics, the peri-mortem management and handling of pigs prior to stunning is a crucial step in the process and maybe the easiest to control. The stress placed on an animal prior to slaughter directly influences meat quality (Cannon et al., 1996). Clearly, the process of transporting any animal to a new environment and co-mingling with other animals will induce a stress response. Furthermore, the effects of lairage time and handling of pigs immediately prior to slaughter can have a major impact on pork color and drip loss. As for most aspects of life there is a delicate balance to achieve the desired result. Short lairage times (<1h) will increase drip loss and the prevalence for a lower ultimate pH consequently leading to a higher proportion of low quality carcasses (Dokmanovic et al., 2014). Conversely, the same study found that long lairage times (>20h) will result in darker colored pork and carcasses with more skin damage and bruising. With that being said, there is no perfect time range for all facilities to follow, but a lairage time range of approximately 2-4 hours with calm handling

immediately prior to stunning has shown to decrease carcass and pork quality issues while maintaining facility through-put (Berg, 2006).

When discussion begins about the proper stunning technique there is a lot of controversy. Legally, processors are required that all animals are to be rendered instantaneously insensible and remain in this state until there is complete loss of brain responsiveness due to exsanguination (Council Directive 93/199/CEE, 1993). There are several ways this result can be achieved but in pigs, the two most common commercially used methods are electrical stunning and carbon dioxide (CO₂) stunning. There are positives and negatives to both and it really just depends on what works best for the facility. Electrical stunning results in a more rapid pH decline early postmortem due the increased muscle activity (Rosenvold and Anderson, 2003). Consequently, the WHC of electrically stunned pigs is inferior to that of CO₂ stunned pigs but ultimate pH was unaffected (Channon et al., 2002). The same authors also concluded pigs stunned using CO₂ also have fewer incidences of blood splash. After stunning, exsanguination, and the evisceration process; the next step affecting pork quality is how the carcasses are chilled. There are multiple different methods used commercially including, spray chilling, blast chilling, and conventional chilling. Again, it depends on what each facility is best suited for, but there are certainly differences from a meat quality standpoint. The major concern is temperature decline as it relates to the pH of the carcass. If the internal carcass temperature remains high in combination with a rapid pH decline (<5.4), the carcass may develop into pale, soft, and exudative conditions. Likewise, if the internal carcass temperature falls too quickly (<15°C) and the pH remains high (>6.0) cold shortening may occur and lead to a tougher less palatable product. This happens when there is still ample energy within the muscle to contract and due to the extreme temperature change, excess calcium is released from the sarcoplasmic reticulum causing shortening of the

sarcomere and a tougher product. To prevent these negative pork quality results it is suggested not to chill carcasses below (5°C) while the muscle pH is greater than 6.0 (Huff-Lonerger, 2006).

Now that we have discussed several factors that can possibly affect ultimate pork quality; let's change perspective and address the process from a scientific viewpoint and describe the process in more detail. As previously stated, one of the most influential factors affecting most other quality traits is pH of the product. Further, post-rigor pH measurements are commonly used to predict several meat quality traits (Huff-Lonerger et al., 2002). In meat, pH is associated with the amount of glycogen present at the time of slaughter (Huff-Lonerger et al., 2002). Before exsanguination, the circulatory system is in an aerobic condition producing adenosine triphosphate (ATP) via the citric acid cycle. The citric acid cycle will produce 32 ATP every cycle supplying the body with ample energy. However, upon exsanguination, the loss of blood causes the circulatory system to lose the ability to regulate body heat, dispose of waste, and transport oxygen throughout the body. The depletion of oxygen supplies leads to a transition from aerobic glycolysis to anaerobic glycolysis. Therefore to produce the required ATP, the body uses anaerobic glycolysis. Glycolysis is the conversion of glucose (glycogen) to pyruvate which generates energy in the form of ATP. The challenge is glycolysis does not produce nearly as many ATP per cycle as the citric acid cycle produces. Every time a glucose molecule is converted into pyruvate, it yields 2 ATP. Consequently this causes a dramatic decrease in ATP supplies. Furthermore, the loss of blood also weakens the membrane integrity of muscle cells, therefore; allowing an excess release of calcium. This calcium influx from the sarcoplasmic reticulum stimulates muscles to contract through another series of reactions. This is important because the contraction of muscles requires additional energy in the form of ATP. Now that the

body is completely in an anaerobic condition; muscle glycogen through glycolysis, is broken down into pyruvate and further into ATP, carbon dioxide and lactic acid. Excess pyruvate is converted to lactate by lactate dehydrogenase. Aerobically, the circulatory system would remove waste such as lactate and transport it back to the liver where it is converted back into glycogen. However, anaerobically the excess lactate (lactic acid) accumulates in the muscle and causes the decline of pH post-mortem due to the lack of blood circulation (Lee et al., 2010). Eventually, the depletion of muscle glycogen stores leads to the depletion of ATP production causing muscle contractions to cease. The extent of the pH decline is primarily affected by the amount of muscle glycogen in the muscle at the time of slaughter (Lonergan et al., 2008).

During the conversion of muscle to meat, a normal pH will decline from the homeostatic level around 7.2 to approximately 5.6. There are two commonly discussed and heavily researched pork quality defects that revolve around pH decline and temperature. Pale, soft, and exudative (PSE) pork is highly undesirable within the industry due to the lack of protein functionality and poor appearance. PSE pork can occur when either the pH decline is rapid in combination with high carcass temperature or a normal temperature decline but with increased rate of glycolysis (Offer, 1991). The myofibrillar proteins become denatured, therefore; losing their ability to bind water and causing the product to reflect more light, be soft textured, and lack water holding capacity. Conversely, when the pH decline remains relatively high (approximately 6.2) dry, dark, and firm (DFD) occurs. Differently from PSE, the higher ultimate pH protects myofibrillar proteins allowing for the muscle to be darker in color, have firmer texture, and bind with more free water within the muscle system.

Post-mortem temperature decline also plays a large role in determining meat quality. As previously stated, upon exsanguination, the circulatory system no longer has the ability to

regulate the internal muscle temperature of the carcass. Immediately following exsanguination, the internal temperature of a carcass will actually for a relatively short period of time rise above that of the homeostatic body temperature of 39.2 °C. However, prolonged high carcass temperature will increase the rate of glycolysis; thus further accelerating the rate or extent of pH decline. This is especially true in swine genetically less tolerable to stress or pigs stressed prior to slaughter (Marple and Cassens, 1973). In pork especially, more rapid chilling systems have been implemented to remove heat and slow the pH decline in an attempt to reduce the incidence of PSE (Savell et al., 2005). In combination, muscle pH and temperature are the two dominate factors affecting color change (Mancini and Hunt, 2005) (Figure 1.1).

The ultimate pH of fresh meat impacts several factors one of which is the water holding capacity (WHC) of the meat. Water holding capacity is defined as the meat's ability to retain free water within the muscle system. Of the three types of water in meat/muscle [bound (0.5%), immobilized (80%), and free (10%)]; free water is the first and easiest to lose as only the capillary action holds this type of water in place. Water holding capacity and pH are directly related ($r = -0.33$, Huff-Lonergan et al., 2002; $r = -0.41$, Schwab et al., 2006; $r = -0.59$, Rinker, 2007.) because the pH influences the net charge of the proteins, therefore inadvertently affecting the ability to bind water and retain water within the muscle/meat system. The isoelectric point for proteins is approximately at a pH = 5.2. When the pH of meat is 5.2, the proteins hold no negative or positive charge therefore lacking the ability to bind to water molecules. When pH is below the isoelectric point the proteins are positively charged and conversely when the pH is above the isoelectric point the proteins are negatively charged.

Pork Color

Meat color influences meat purchasing decisions more than any other quality trait because it is always the first criterion consumers use to evaluate quality and freshness (Duan et al., 2012). With that being said, a number of pre and post-harvest factors can affect the color of the final product. Although all light rays contain color; the human eye can only detect a narrow range of 400-700 nanometer long waves. Within that range, the color red has the longest wavelength. Multiple rays harboring many different colors penetrate an object simultaneously. However, the color of the object is dependent on which rays are absorbed by pigments and which rays are reflected. Pigments are molecules which absorb light; therefore it is not visible to the human eye. Conversely, when light rays reflect off an object they produce the color we see. With that in mind, it has been determined consumers commonly use color as a purchase intent dictator and prefer pork to be a reddish-pink lean color (Brewer and McKeith. 1999).

Biologically, the color of meat is dependent on the amount or (absence of) oxygen in the surrounding atmosphere and the amount of myoglobin present within the muscle. Myoglobin is the principle protein responsible for meat color. Myoglobin has 8 α -helices surrounding a centrally located iron atom. Of the 6 available bonds to the iron atom, 4 are standardly bound to nitrogen while the 5th bond is to proximal histidine-93. The 6th and final binding space is available for reversibly binding ligands and in conjunction with the valence state of the iron atom is primarily responsible for the color of the muscle. There are four major chemical bonds dictating the color of meat (Figure 1.1). When no oxygen is present in the environment there is no ligand on the 6th binding site causing the deoxymyoglobin state. Meat will be purplish-red in color and this is typically associated with vacuum packaged product. Further, in this state the centrally located iron atom is in the Ferrous state (Fe^{2+}). The centrally located iron atom can either gain an electron (be reduced) therefore being in the Ferric state (Fe^{3+}) or lose an electron (be oxidized)

and shift back to the ferrous state. When exposed to oxygen, oxygenation will occur which is commonly referred to as “blooming” within the meat industry. Given enough time (15-30min), the oxygen tension will be great enough for meat to turn a more desirable (reddish-pink for pork) color on the surface and transition into the oxymyoglobin state. In the oxymyoglobin state, the valence state of the centrally located iron has not changed from the ferrous form as it was in the deoxymyoglobin state, but now a diatomic oxygen molecule is bound at the 6th ligand binding site. As oxygen pressure continues to increase, oxymyoglobin will penetrate further beneath the surface. The extent and pace of oxymyoglobin penetration is dependent on many factors including; pH, meat and environment temperature, and any competing sources for oxygen such as mitochondria. When the partial pressure of oxygen is greater than the atmosphere it will facilitate a thicker oxymyoglobin layer on and just below the meat’s surface (AMSA, 2012). Of the 3 primary color states; the most unappealing and financially detrimental color state for the retail market is when meat is in the metmyoglobin state and becomes brown in color. This occurs as the oxygen consumption continues to increase or oxygen partial pressure decreases and the valence state of iron atom is oxidized or shifts from ferrous to ferric due to the loss of an electron. Metmyoglobin formation actually begins below the meat’s surface and as the concentration of metmyoglobin increases the surface will begin to turn brown. The formation of metmyoglobin under aerobic conditions is a result of the formation of oxygen free radicals from the diatomic oxygen interacting with free metal ions such as iron and copper. As free radical production increases, the shift from oxymyoglobin to metmyoglobin will increase.

Color can be measured either subjectively or instrumentally. Subjective measurements are done so using standard grading cards published by scientist within their respective markets. There are several subjective color grading scales used world-wide including but not limited to:

National Pork Producers Council (NPPC, 1999), Japanese pork color standards, and Australian pork color standards. Depending on the intended export market; color preference can vary greatly from consumers preferring darker colored pork chops to lighter colored pork chops (Cho et al, 2007; Chen et al, 2010; Ngapo et al, 2010). The use of scientifically accepted grading cards allows the use of a common scale among institutions and industry alike. Unfortunately, not everyone is calibrated to the same degree so directly comparing results is challenging. Subjective color scores using the NPPC, (1999) scale can range from 1 being the visually palest colored to 6 being visually the darkest colored. This range corresponds to a Minolta L* range of 61.00 being the palest colored to 31.00 being the darkest colored. The subjective color scores are 6 – L* units apart (NPPC 2 = 55.00; NPPC 3 = 49.00). However, the average untrained consumer can distinguish between 3 – L* units and therefore it is common for institutions to record data in half score increments (Zhu and Brewer. 1999). Instrumental measurements include using either a colorimeter or photo spectrometer. Instruments such as a Minolta Colorimeter measure color using the Commission Internationale de l'Eclairage (CIE; L*, a*, and b*). The grey band (L*) measures lightness or darkness of an object and ranges from 0 being black to 100 being white. Red band (a*) measures red and green bands with -60.00 being green and +60.00 being red. Lastly, the yellow band (b*) measures yellow and blue bands with -60.00 being blue and +60.00 being yellow. Other parameters associated with using instrumental color measurements that are often over looked but should be considered are the aperture size, degree of observer and illuminant source. There are two commonly used observer degrees (2^0 and 10^0) that can be used to take light measurements based on the sample of interest. The larger the degree of observer the more light is reflected off the sample. Aperture size is perhaps one of the most overlooked but most vital parameters used to collect color. Aperture sizes range from 8mm to 3.18mm in size.

The size of aperture used is dependent on the size of the sample of interest. As the size of aperture decreases, the percentage of reflectance decreases as well, particularly with red wavelengths. When comparing data, this is important to consider when using wavelength ratios (630/580nm ratio) as the size of the aperture may influence the reflectance at those wavelengths. Lastly, the illuminant source is the parameter mostly considered when conducting or comparing research. There are several different illuminants commonly used and the decision is dependent primarily on the main objectives of the experiment. Illuminants such as C (average north sky daylight, 6774 K) and D₆₅ (noon daylight, 6500 K) are commonly used when measuring meat products. Illuminant A (average incandescent, tungsten-filament lighting, 2857 K) places more emphasis on red wavelengths and should be considered when the detection of redness differences is important. Likewise, illuminant F (fluorescent) is common in shelf life studies where fluorescent lighting is used in display cases.

Within pork, lightness values (L^*) can vary greatly from animal to animal (Arkfeld et al., 2016). With that being said, it is vital for producers and packers to limit variation both on live basis and whole carcass basis through the use of proper handling and processing techniques as described above. However, there are still other avenues used to further limit color variation in the food service sector. Those include the type of packaging used and the lighting source at which products are displayed under. There are several different types of packaging used commercially such as; vacuum packaging, PVC overwrap film, and a multitude of different gas mixtures used in modified atmosphere (MAP) packaging. An increase in shelf life of MAP packages is achieved through the use of carbon dioxide gas in the headspace of the package. Using carbon dioxide gas at a percentage of (20-30%) will increase shelf life through bacteria growth inhibition without causing discoloration of the product (Krause et al., 2003). The same authors

concluded gas mixtures containing low levels (< 0.5%) of carbon monoxide will increase color stability and shelf life over that of over-wrap packages. Regardless of the type of packaging there are ingredients available to inhibit the conversion of oxymyoglobin to metmyoglobin. The use of metal chelating antioxidants (citrate, phosphates, etc) or free radical scavenging antioxidants such as BHT, BHA, vitamin E, and plant extracts are commonly used in conjunction with different packing types to limit discoloration. As stated earlier, the mechanism behind these antioxidants is to bind to free metals within the muscle system; therefore, preventing them from binding to free oxygen molecules and limiting the conversion of oxymyoglobin to metmyoglobin.

Intramuscular Fat (Marbling)

Along with the color of pork loins influencing purchasing decisions, the amount of marbling or intramuscular fat (IMF) content is another factor consumers regularly use to assess the value and quality of the product (Levy and Hanna, 1994; Brewer et al., 2001). Historically, there has been a vast amount of resources invested to determine if marbling content actually has a positive or negative influence on the consumers' perception of the quality of pork. Several studies have been conducted examining the effects marbling content has on the palatability of pork loin chops and if consumers have a preference for the amount of marbling content. When examining the factors effecting purchase intent; chops containing high levels of IMF (3.46%) had the lowest overall acceptability scores over chops containing low and medium IMF levels (1.05% and 2.33%, respectively) by consumers (Brewer et al., 2001). Authors attributed the disparity to consumers' health concerns associated with increased fat content even though the highly marbled chops were rated higher for juiciness, tenderness, and overall flavor upon a cooked evaluation. Another study using a trained sensory panel concluded chops with high levels of IMF content (3.56%) received higher sensory scores for both tenderness and juiciness over

chops containing low IMF content (1.96%) while the medium IMF content chops (2.50%) were intermediate (Cannata et al., 2010). On the other hand, studies conducting consumer sensory panels over a wide range of IMF levels (1.5 % through 5.5 %) found no differences between sensory tenderness, juiciness, or flavor across all IMF levels (Rincker et al., 2008). The results are clearly conflicting, but some of this may be due to differences in genetics, post-mortem handling, and sensitively differences between trained and consumer panels.

With all this disparity in mind, let's discuss how producers can influence the amount of marbling content that is deposited within the *longissimus dorsi* muscle specifically. Marbling or IMF is deposited within the perimysium in the muscle system (Nishimura, 2010). Therefore, because pigs lack the ability to alter the fatty acid profile contained within the diet; it is possible to manipulate the type of fatty acids deposited during the growth phrase. Commercially, pigs are fed a heavily concentrated diet that is primarily made up of polyunsaturated fatty acids (PUFA) such as Linoleic acid (18:2n-6) and α -Linolenic acid (18:3n-3) (Wood et al., 2008). This leads to a more PUFA profile in muscle and a softer textured intramuscular fat compared to beef and sheep. It has been illustrated that feeding diets to pigs higher in saturated fats leads to an increase in IMF content (Olivares et al., 2009; Souza et al., 2003). However, both authors stated genotype played a greater role in IMF deposition than the diet effect. In addition to adjusting fat sources; another possibility is restricting the Vitamin A amount in the diet to increase IMF deposition. By limiting the Vitamin A content, the amount of retinoic acid is also limited. It is proposed that retinoic acid, which is a derivative of Vitamin A, regulates adipogenesis. Therefore by limiting retinoic acid production, fat deposition will increase and IMF levels will increase as well (Dalke et al., 1992). Although the effects were marginal, Souza et al., (2003) illustrated a statistically lower amount of IMF content in pigs fed the limited Vitamin A diet (2.0%) compared to the

control diet (1.3%). Other authors suggest feeding a lysine deficient diet during the last weeks of the finishing phase will result in an increased IMF content (Cisneros et al., 2000). Manipulating the protein to digestible energy (P: DE) ratio will cause a decrease in protein deposition while maintaining the fat deposition, therefore; increasing overall fatness and IMF levels (Castell et al., 1994). Formulating a protein deficient diet during the finisher period (90-126 kg live weight) increased IMF from 2.9-3.5% compared with the control diet (Witte et al., 2000). Additionally, reducing the P: DE ratio by 15% and 30% during 10-18 weeks of age resulted in an increased IMF level of 1.9% and 2.7% respectively, compared with pigs fed the control diet 1.3% (Souza et al., 2003). There are a multitude of different fat sources available to feed as well, however, the literature has mixed results on concentrations and the marginal benefits in IMF increases are minimal. It is commonly known feed constituents the majority of a pork producers cost. Therefore, increasing diet costs due to more saturated fats is often financially not profitable and adjusting diets may have negative effects on growth performance.

Another approach producers can use to increase the IMF level is through genetics. There are several swine breeds producers can use in combination with each other to achieve the desired economic traits such as growth performance and feed efficiency, but without sacrificing carcass quality. There are some breeds of swine (Duroc and Berkshire) used to increase the marbling content in attempt to increase the eating quality (Suzuki et al., 2003). In general, the Berkshire breed has superior meat quality; however, they suffer in growth and feed efficiency traits. Studies examining the effects of the Duroc and Berkshire breeds compared to crossbred lines found Duroc and Berkshire sired pigs to have greater marbling fat and this was associated with higher tenderness and juiciness scores in the longissimus dorsi muscle (Wood et al., 2004). Of all the purebred breeds and crossbred programs studied throughout history, it is common consensus

the Duroc breed has the best combination of economically important traits and good meat quality traits (Meisinger, 2002). When implemented in crossbreeding-programs, the Duroc breed will increase IMF levels in lean lines of pigs (Ellis et al., 1996). When compared to a Pietrain x Large White cross, Duroc sired pigs had similar backfat levels but, increased intramuscular fat content (3.4% vs 2.7%) and were instrumentally more tender (Latorre et al., 2003). Other studies have yielded similar results when comparing Duroc sired lines to terminal sired lines (Lonergan et al., 2001; D'Souza and Mullin, 2002). Furthermore, when discussing other commonly used breeds of swine; breeds such as Spots, Poland China and Yorkshires are classified as having average pork quality and the Landrace and Hampshire (RN-) breeds have the poorest meat quality (Meisinger, 2002). From a research standpoint, it is imperative to understand the genetic source used in studies when comparing meat quality and eating quality results. Studies incorporating the Duroc breed have typically yielded positive results between marbling and palatability due to the strong positive influence the Duroc breed can have on meat quality (Rincker et al., 2008).

Endpoint Cooking Temperature

Historically, it has been recommended to cook pork to an internal temperature of (71 °C) to prevent the possibility of contracting the pathogen *Trichinella spiralis*. This pathogen is transmitted from swine to humans when meat is not properly cooked. This pathogen is effectively inactivated by cooking pork to thorough internal temperature of 60 °C (140 °F) for a minimum of 1 minute (9 CFR 318.10). However, due to the advances in pork production practices within the United States and a drastic change in how pigs are raised the threat of contracting *Trichinella spiralis* has diminished substantially. This in combination with studies showing an increase in sensory tenderness and juiciness scores when pork is cooked to a lower degree-of-doneness (Moeller et al., 2010; Rincker et al., 2008) has prompted the National Pork Board in 2011 to decrease the recommended cooked temperature for pork from medium (71 °C)

to medium-rare (63 °C). Trained sensory panelists rated samples 9% more tender when cooked to a medium-rare degree-of-doneness (tenderness = 8.56) over medium degree-of-doneness (tenderness = 7.76) (Rincker et al., 2008). The same study also concluded chops to be 14% juicier when cooked to a lower degree-of-doneness. Furthermore, others have reported similar results cooking pork chops to a lower degree-of-doneness (62.8 °C) rather than (73.9 °C). Trained panelists rated chops significantly ($P < 0.001$) more tender and juicy (2% and 12%, respectively) (Moeller et al., 2010). Therefore, with the increase in eating quality of pork when cooked to a lower degree-of-doneness and the drastically minimized risk of contracting *Trichinella spiralis* it makes sense to reexamine if the color and marbling content of pork chops has an effect on the newly revised cooking guidelines published by the National Pork Board. This study is the first reported literature to test that response using a trained panel.

Carcass Length and Boneless Loin Chop Yield

The visual appearance (color and marbling) of pork is certainly a factor consumers use to influence purchasing decisions. As just discussed, there have been decades of research focused on improving or enhancing the color and marbling content of pork and pork loins specifically. However, not all pork is of high quality and therefore, regardless of quality, the yield of saleable chops from all loins is perhaps more directly related to the packer and food service sector's bottom line. The visual meat quality of pork can vary greatly, but all aspects of production are affected and more directly related to the yield of saleable product. Despite this, boneless pork chop yield has not been studied near as intensely as pork loin quality. Historically, whole carcass parameters such as carcass length, subjective muscle scores, and percent lean have all been studied and rightfully so to establish whole carcass based premium programs. Pork carcass length is moderately heritable (estimate = 0.62, Lo et al., 1992) and linearly increased with heavier carcass weights (Cisneros et al., 1995). Furthermore, a study by Trew et al., (1987)

concluded carcass length was significantly correlated with lean percentage ($r = 0.49$; $P < 0.01$). Economically, there are incentives to increase the yield of boneless pork chops from a boneless pork loin. Recently, the retail price of boneless pork chops increased approximately 17% from \$7.92/kg in 2006 to \$9.56/kg in 2015 (Bureau of Labor Statistics, 2015). At the same time, the price of carcasses only increased 6% (Schulz, 2016). Further, 30% of pork is consumed as bone-in or boneless pork chops (USDA, 2005). Therefore, if longer carcasses produce more boneless loin chops, it stands to reason that longer carcasses would generate more revenue.

However, there are inherent challenges to measuring carcass length due to the removal of the backbone which provides a rigid structure that a boneless pork loin lacks. Thus, measuring other boneless loin parameters that can be relatively easily measured in a fast pace commercial environment is necessary. Other boneless loin parameters including: boneless loin weight, stretched loin length, and compressed loin length were also measured and may be more predictive of the number of boneless loin chops derived from a boneless pork loin. If these parameters are more predictive, they may be valuable to packers and food service sector marketing boneless loin chops. Previously, there is no published literature establishing if boneless loin parameters are predictive on the number of boneless loin chops produced by a boneless pork loin.

Overall, we conducted two experiments examining the eating quality and factors' influencing the yield of boneless pork chops from a boneless pork loin. The first was using carcass and loin parameters to determine the predictive ability of the number of boneless pork loin chops produced by a pork loin. The second was if instrumental color and marbling content in fact do affect the eating quality of a pork loin when cooked to a medium-rare degree-of-doneness. The first study takes an older concept but incorporates the use of more modern

equipment and technology. Plus, measuring other boneless loin parameters in combination with carcass length now provides more insight into where the variation exists and how to possibly control for it. The second project bridges the gap between studies using genetics predisposed to pork with good eating quality and common commercial genetics while being raised and managed in a heavily controlled commercial environment. This work is the first reported to examine the effect of both color and extractible lipid content in such an extensively controlled population of pigs large enough in size to have commercially relevant wide ranges. Perhaps more importantly is the effect of grouping chops based on the newly revised National Pork Board quality based system. Determining the effects of the new grading system on palatability traits allows for the opportunity to understand what color and extractible lipid combinations actually do provide a more satisfying eating experience and will ultimately prompt repeat purchases of pork in this extremely competitive protein market.

Figure

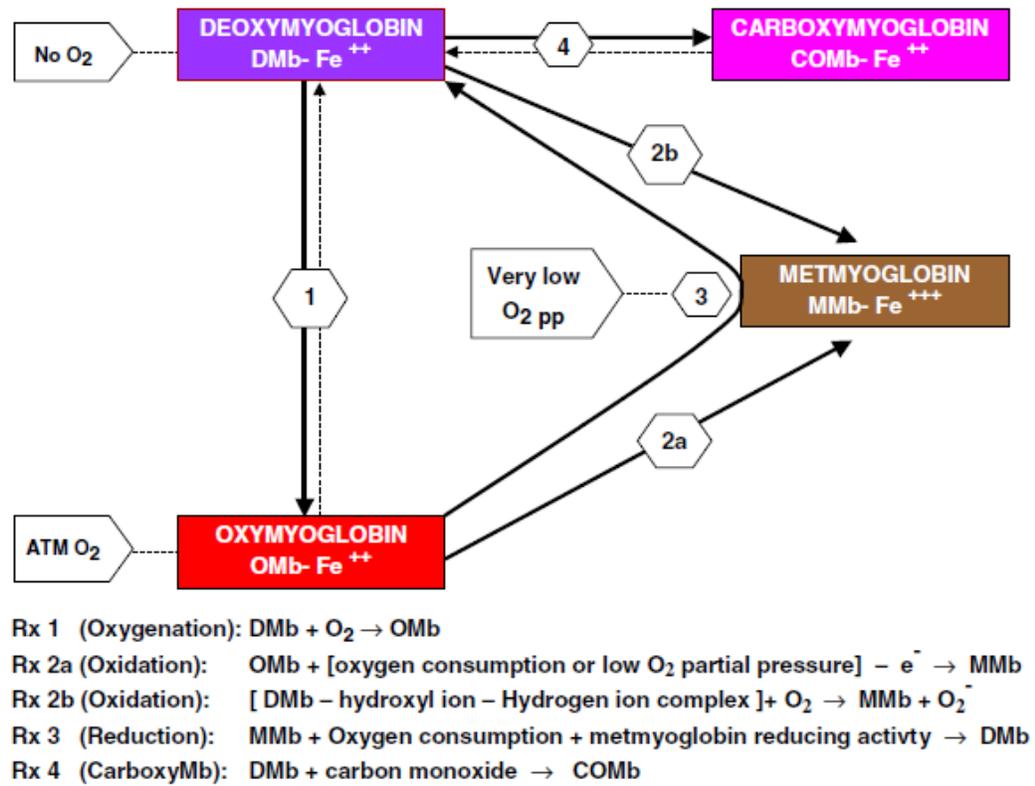


Figure 1.1 Visible myoglobin redox interconversions on the surface of meat.¹

¹ Adapted from Mancini and Hunt, 2005

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CHAPTER 2

PREDICTING PORK LOIN CHOP YIELD USING CARCASS AND LOIN CHARACTERISTICS

Abstract

The objective was to determine the predictive ability of carcass length for the number of equal-thickness chops obtained from a boneless pork loin. Longer pork carcasses are assumed to yield longer loins and therefore an increased number of chops. Loins were collected from pigs (1238 total) raised under commercial conditions and marketed when the mean pig weight in a pen reached 138 kg. Pigs were slaughtered over 7-wk in a commercial facility. Carcass length was measured at 1-d postmortem on the left side of each carcass from the anterior edge of the symphysis pubis bone to the anterior edge of the first rib. Carcasses were fabricated, and boneless loins (NAMP #414) were vacuum-packaged and transported to the University of Illinois Meat Science Laboratory. Loins were stored at 4 °C for 14-d. At the end of the aging period, loins were weighed, measured for stretched length (stretched to maximum length without distortion), compressed length (compressed to minimum length without distortion) and sliced into 2.54 cm thick chops. Boneless chops were counted and weighed. Carcass length ranged from a minimum of 78.2 cm to a maximum of 96.5 cm and the number of boneless chops ranged from a minimum of 13 to a maximum of 20 chops. Data were analyzed using the regression procedure of SAS. The dependent variable was the number of boneless chops. Coefficient of determination (R^2) was calculated for carcass length, boneless loin weight, compressed loin length, and stretched loin length. Carcass length explained 15% ($P<0.0001$) of the variation in the number of loin chops. Loin weight explained 33% ($P<0.0001$) of the variation in the number of loin chops. Compressed loin length and stretched loin length explained 28% and 8% ($P<0.0001$) of the variation in the number of loin chops, respectively. Multiple linear regression

was used to determine a predictive equation for the number of loin chops using the stepwise selection option of all independent variables. The combination of boneless loin weight, compressed loin length, 10th rib carcass fat depth, and carcass length explained 45% of the variation ($P < 0.0001$; $C(p) = 16.76$) in the number of loin chops using a required F statistic at the SLENTY and SLSTAY level = 0.15. Overall, carcass length is a poor predictor of the number of equal-thickness loin chops that can be derived from a boneless pork loin.

Introduction

Pork carcass length is heritable (estimate = 0.62, Lo et al., 1992), and linearly increased with heavier carcasses (Cisneros et al., 1995). Further, carcass length was correlated ($r = 0.49$; $P < 0.01$) with estimated lean percentage of pigs (Trew et al., 1987). However, removing the backbone increased error associated with measuring carcass length of all carcasses (Braude et al., 1957). Recently, the retail price of boneless pork chops increased approximately 17% from \$7.92/kg in 2006 to \$9.56/kg in 2015 (Bureau of Labor Statistics, 2015). At the same time, the price of carcasses only increased 6% (Schulz, 2016). Further, 30% of pork is consumed as bone-in or boneless pork chops (USDA, 2005). Therefore, if longer carcasses produce more boneless loin chops, it stands to reason that longer carcasses would generate more revenue. However, without the backbone and after the resolution of rigor mortis, a boneless intact pork loin can be distorted and therefore, carcass length may not truly reflect loin length. Still, measuring boneless loin parameters such as compressed and stretched loin length may be more predictive of the number of boneless chops. Given that carcass length was actually based on the fixed length of the skeleton and not the variable length of muscle, the hypothesis was carcass length would not be predictive of loin chops obtained from a boneless loin, but other carcass or loin characteristics may be.

If boneless loin parameters such as boneless loin weight, stretched length, and compressed length are predictive of the number of boneless chops, they may be valuable to packers. Even so, predictive ability estimates of carcass length, boneless loin weight, stretched loin length, and compressed loin length on the number of loin chops have not been determined. Therefore, the objective was to use linear regression to determine which carcass and boneless loin traits were the most predictive of the number of loin chops derived from a boneless loin.

Materials and Methods

Pigs were slaughtered under the inspection of the USDA food safety inspection service at a federally inspected facility. Boneless loins were purchased from that facility and transported to the University of Illinois Meat Science Laboratory (Urbana, IL). Therefore, Institutional Animal Care and Use Committee approval was not obtained.

Experimental Design and Processing Facility Data Collection

Loins were obtained from both barrows and gilts (1,238 total) from a single genetic line and were raised and slaughtered under commercial conditions. Pigs were housed in single sex pens with 20 pigs per pen. Five pigs from each pen were selected for evaluation. The 5 selected pigs represented a pig with an ending BW closest to the pen average BW, a pig with a BW 1 SD above and a pig with a BW 1 SD below the average BW of the pen, and a pig with a BW 2 SD above and a pig with a BW 2 SD below the average BW of the pen. Pigs were slaughtered over 7-wk as the average BW of each pen reached 138 kg. Transportation distance was approximately 277 km and pigs were held overnight with no access to food but free access to water prior to slaughter. Pigs were immobilized via carbon dioxide stunning and terminated via exsanguination. Following commercial slaughtering procedures, HCW was measured along with fat depth, and loin depth using a Fat-O-Meater probe (SFK Technology A/S; Herlev, Denmark) at approximately the 10th rib location and estimated carcass lean was calculated using the

facility's proprietary equation. Carcasses were blast-chilled for approximately 90 min. After exiting blast-chill, carcasses with minimal harvest trim and complete carcass characteristic estimates were identified and placed in a temperature equilibration cooler. After an equilibration period of approximately 1 h, carcasses were identified with a slaughter sequence on the vertebral column of the loin. Carcass length was measured on the left side of each carcass from the anterior edge of the symphysis pubis bone to the anterior edge of the first rib. Carcasses were fabricated at approximately 22 h postmortem into primal pieces. Loins were separated from the shoulder between the second and third ribs and separated from the ham 2.79 to 3.81 cm anterior to symphysis pubis bone. Loins were further fabricated into boneless Canadian back loins (NAMP #414), vacuum-packaged, and transported to the University of Illinois Meat Science Laboratory for further evaluation.

Boneless Loin Chop Determination

Loins were aged for 14-d at 4⁰ C, after which they were removed from their packaging and weighed to determine boneless loin weight. Stretched loin length (stretched to maximum length without distortion, lack of distortion was subjectively determined) and compressed loin length (compressed to minimum length without distortion) was measured by hand using a tape measure (Prym Consumer USA, Spartanburg, SC) on each loin prior to slicing to the nearest 0.5 cm. Then, loins were sliced into 2.54 cm thick chops using a push-feed style Treif Puma slicer (Treif model 700 F, Oberlahr, Germany). Ends and incomplete chops (chops from the blade end that were distorted during slicing and any chops not 2.54 cm thick) were assessed and weighed. Complete 2.54 cm thick boneless chops were counted. Chop yield was calculated: [(Boneless loin weight, kg – Ends and pieces, kg) / Boneless loin weight, kg] x 100. Total chop weight per loin was calculated as: (boneless loin weight, kg – ends and pieces weight, kg). Total chop weight per loin was used to calculate the breakeven price of each loin. Breakeven price was

calculated as: [(boneless loin weight, kg x boneless center cut loin, strap-off price (\$1.34/lb converted to \$2.95/kg, USDA AMS, 2015) – (ends and pieces weight, kg x 72 trim, combo price (\$0.82/lb converted to \$1.81/kg, USDA AMS, 2015))]. Revenue from total chops per loin was calculated as: (total chop weight per loin, kg x \$9.66/kg (converted from \$4.39/lb, Bureau of Labor Statistics, 2015)).

Statistical Analyses

Because carcass length was a function of the individual pig, loin served as the experimental unit for each set of analyses. Population summary statistics were calculated with the Means procedure of SAS (v.9.3, SAS Institute Inc., Cary, NC). Pearson correlation coefficients among independent variables were calculated using the CORR procedure of SAS. Correlations were considered significant at $P < 0.001$. Other data were analyzed using the REG procedure in SAS. The dependent variables were the number of chops produced from a boneless loin or chop yield. Coefficients of determination (R^2) were calculated for following independent variables: carcass length, HCW, compressed loin length, stretched loin length, loin depth, and boneless loin weight. A linear regression equation was developed using the independent candidate variables to predict the number of loin chops derived from a boneless loin. An initial regression model included each of the 6 independent variables as well as 10th rib carcass fat depth. Multicollinearity among independent variables was assessed using a variance inflation factor (**VIF**) statistic. However, no parameters exceeded VIF values of 4, therefore, all independent variables remained as candidate variables for selection in the model. Influence of individual observations on the estimated dependent variable was determined using the difference of fit (DFITTS) statistic. Observations were considered to have excessive influence on the estimation of the regression parameters when $DFITTS \geq 2[(p/n)^{1/2}]$, where p = was the number

of parameters considered and n is the total number of observations. In the present study, 7 variables were considered and 1,238 observations were used. Twenty observations met this criterion and were removed from the data set. Using the stepwise selection method, independent variables were required to have a significant F statistic at the SLENTRY and SLSTAY level = 0.15 to be included and remain in the final model.

Results and Discussion

Carcass Characteristics

Population summary statistics including mean, minimum observation, maximum observation, and CV were presented in Table 2.1. The mean hot carcass weight of pigs from this trial was 103.6 kg. The selection strategy implemented resulted in wide variation in HCW as it ranged from 75.0 kg to 131.0 kg with a CV of 9.76. Moreover, neither fat thickness nor LM depth was controlled; therefore, the selection criteria resulted in calculated CV estimates of 22.40 for BF depth and 10.84 for LM depth. However, carcass length (CV = 3.64) was relatively less variable than other carcass compositions traits. Other studies that slaughtered pigs over wide ranges in ending BW reported similar CV estimates. Carcasses with an average length of $77.44 \pm$ had the same chilled carcass weight CV (12.22) and length CV (4.47) regardless of fat thickness category ((2.29-3.28 cm, 3.30-4.29 cm and 4.32-5.33 cm), Edwards et al., 1981). Likewise, CV estimates of 4.45 for carcass length and 12.67 for chilled side weight in a population of pigs that ranged in chilled side weight of 32.78 ± 4.15 kg (Cross et al., 1975). Differences in CV estimates between BW and carcass weight can be easily explained because carcass length is indicative of bone growth and reflects the overall size of the skeleton. Further, pigs attain a large proportion of skeletal size before reaching mature BW (Gerrard and Grant, 2003). Because of this, measurements that have evaluated skeletal growth (carcass length) as a proportion of BW, decrease as the animal gets heavier (Gerrard and Grant, 2003). Over 40 years ago chilled carcass

weights were approximately 68.3 kg and carcass length was approximately 76.5 cm (Pearson et al., 1970). Carcasses in this study averaged 103.6 kg and were 86.8 cm long (Table 2.1). This demonstrates 41.1% increase in HCW, but only a 12.6% increase in carcass length.

Even so, in this population of carcasses, carcass length was correlated ($r = 0.71$) with HCW (Table 2.2). This supported historically accepted growth curves (Moulton et al., 1922) where the skeleton, indicated by carcass length, was the first to plateau while muscle and fat deposition continued to increase in relative proportions. Other correlations among independent variables demonstrated logical allometric growth relationships as most carcass traits were all positively correlated ($P < 0.001$) with each other (Table 2.2). As expected, as HCW increased, loin depth increased ($r = 0.41$), loins became heavier ($r = 0.64$), and longer (stretched loin length $r = 0.41$; compressed loin length $r = 0.45$). Also, as HCW increased fat depth increased ($r = 0.30$). Previously, Edwards et al. (1981) correlated chilled carcass weight with BF thickness over increasing fat depth ranges (2.29 to 3.28cm, $r = 0.28$; 3.30 to 4.29 cm, $r = 0.31$), which indicated a stronger relationship with fat thickness as carcasses got heavier. To validate our hypothesis, as carcasses became longer, loins became longer (stretched loin length $r = 0.54$; compressed loin length $r = 0.40$). Moreover, carcass length was more correlated ($r = 0.67$) in carcasses with fat thickness ranging from 4.43 cm to 5.33cm than in leaner carcasses ($r = 0.46$) that ranged in fat thickness from 2.29 cm to 3.38 cm (Edwards et al., 1981). In the present study, boneless loin weight ($r = 0.52$) was more correlated to carcass length than LM depth ($r = 0.25$) even though both relationships were statistically significant ($P \leq 0.001$, Table 2.2). This may be due to changes in the geometric shape in the longissimus muscle as pigs continue to add lean muscle therefore causing an underestimation of the actual LMA (Lowe et al., 2010). Though LM depth is an estimator of LMA; it only accounts for one dimension (depth) and not for muscle

width or length. On the other hand, boneless loin weight likely served as a proxy for true dimensional muscle size. Carcass length was historically correlated to backfat depth ($r = 0.67$; Edwards et al., 1981). However, carcass length was not correlated ($r = -0.02$; $P = 0.58$) with fat depth in the present study carcasses (Table 2.2). The same lack of correlation ($r = 0.06$) was reported when evaluating the relationship between carcass length and carcass value (Pearson et al., 1970).

Still, other carcass traits were related to each other. Loin depth was negatively correlated with fat depth ($r = -0.13$). This is similar to Holland and Hazel (1958) who reported an inverse correlation ($r = -0.30$) between LMA and backfat thickness. In this population of carcasses, larger loins (greater LM depth) was also correlated with heavier boneless loin weight ($r = 0.47$) and longer loins (stretched loin length $r = 0.14$; compressed loin length $r = 0.23$). Boneless loin weight was correlated with stretched loin length ($r = 0.40$) and compressed loin length ($r = 0.57$). Although not as strong as expected, compressed loin length was correlated with ($r = 0.47$) stretched loin length.

Coefficients of Determination for Boneless Pork Loin Chop Number

As stated in the introduction, the increase in boneless loin chop price relative to the increase in pork carcass price offers potential for increased revenue from longer pork carcasses compared with shorter carcasses if in fact a greater number of boneless loin chops can be cut from loins of longer carcasses. More importantly, measuring carcass length is a non-invasive measurement that can be done quickly at a processing facility and may provide a sorting tool for packers. Unfortunately, carcass length only explained a small portion ($R^2 = 0.15$) of the variation for the number of boneless loin chops produced from a Canadian back loin (Fig. 2.1). This coefficient of determination aligned with previous studies that used carcass length to predict carcass value where carcass length accounted for less than 10% of the variation in lean cutting

yields (Cross et al., 1975) and less than 13% of variation in percentage of total lean (Edwards et al., 1981). Hot carcass weight explained 24% ($R^2 = 0.24$) of the variation in the number of chops derived from a boneless loin (Fig. 2.2). Historically, HCW along with BF depth and LM depth have been used to determine the composition of a pork carcass (Johnson et al., 2004). However, in the present study a high coefficient of determination was classified as an $R^2 > 0.60$; therefore, under these parameters carcass weight was a poor predictor of the number and yield of boneless chops.

The length of a boneless loin can vary, due to the absence of bone to stabilize the muscle. However, the amount of external fat remaining on a boneless loin can affect its ability to compress (Braude et al., 1957). Therefore, determining the minimum length and maximum length of each loin was necessary. The average compressed length was 51.5 cm and the average stretched length was 63.5 cm (Table 2.1). This equates to an average 18% difference between compressed and stretched lengths for each loin. Compressed loin length was a better predictor ($R^2 = 0.28$) of the number of boneless chops that can be cut from a loin than stretched loin length ($R^2 = 0.08$, Fig. 2.3 and 2.4 respectively). Based on mechanism of the push-feed style slicer used, it is logical that compressed loin length was a better predictor than stretched length as the loins were likely “semi-compressed” as they were sliced. Loin depth explained only 3% ($R^2 = 0.03$) of the variation in the number of boneless loin chops from a boneless loin (Fig. 2.5). This is not surprising, because geometrically depth may not be a good predictor of length. From anterior to posterior, LEA, loin width, loin depth, and fat depth all increase, however; the depth: width ratio decreases indicating the loin becomes flatter more posterior (Lowe et al., 2010). However, boneless loin weight explained 33% ($R^2 = 0.33$) of the variation in the number of boneless loin chops derived from a boneless loin (Fig. 2.6). Studies conducted in the 1970’s and 80’s intended

to use carcass length as an indicator of carcass value because longer carcasses were perceived to be leaner (Braude et al., 1957). Moreover, carcass length will increase with age but, if expressed relative to live or carcass weight this percentage decreases as the animal gets older (Gerrard and Grant, 2003).

Even though the number of chops is important the weight of chops (yield) was also evaluated. Carcass length explained an even lesser portion of the variation in chop yield ($R^2 = 0.01$, Fig. 2.7). This trend in lack of predictive ability of chop yield using other carcass and loin measurements continued as HCW explained 5% ($R^2 = 0.05$) of the variation in chop yield. Both boneless loin weight and compressed loin length explained 6% ($R^2 = 0.06$) of the variation in chop yield separately. Stretched loin length and loin depth only explained 1% ($R^2 = 0.01$) of the variation in chop yield separately. Not surprisingly, the weight of the ends and pieces explained the greatest amount of variation in chop yield ($R^2 = 0.60$, Fig. 2.8). From an economic standpoint, carcass length explained a slightly greater portion of the variation in revenue of total chops per loin compared with chop yield ($R^2 = 0.25$, Fig. 2.9). Additionally, HCW explained a greater portion of the variation in revenue of total chops per loin compared to carcass length ($R^2 = 0.40$, Fig. 2.10). This confirms using weight parameters such as HCW instead of carcass length is a better estimator of the number of chops derived from a boneless pork loin and therefore equating to potentially greater revenue from the additional chops. Heavier and longer carcasses do have a greater revenue return; however, carcass weight is a much better predictor than length of the carcass.

Stepwise Regression Model

Carcass length has been used to predict cutability and value. Carcass length was used to predict cutability of the lean cuts (bone-in trimmed ham, loin, picnic shoulder, and Boston butt, but ultimately was a poor predictor ($R^2 = 0.18$) of cutability (Cross et al., 1975). Prior to that,

Pearson et al., (1970) attempted to formulate equations to predict whole carcass value systems but concluded adding carcass length into the stepwise model increased the explanatory power by only 4% in combination with HCW, BF thickness, and LMA. Despite this, there may still be utility in using carcass length to determine the number of chops that can be cut from a boneless loin. Approximately 45% of the variation in the number of boneless loin chops derived from a boneless loin can be accounted for with the following equation: $3.53 + (\text{loin weight, kg} * 0.372) + (\text{compressed loin length, cm} * 0.113) + (\text{BF depth, mm} * 0.050) + (\text{carcass length, cm} * 0.034)$. Carcass length entered the model 4th with a partial $R^2 = 0.005$ (Table 2.3). The additional marginal R^2 value of adding carcass length into the model was minimal and only increased the model R^2 from 0.441 to 0.446. This is evident by the conceptual predictive criterion (Cp) for adding carcass length $Cp=16.76$. As the Cp approaches the number of parameters it is indicative of a more unbiased model.

In addition to chop number, a stepwise regression model for breakeven price (Table 2.4) and chop yield from each loin (Table 2.5) was established. When determining a stepwise regression equation for breakeven price, 49.5% of the variation in breakeven price was accounted for with the following equation: $-14.827 + (\text{hot carcass weight, kg} * 0.1246) + (\text{percent lean} * 0.2505)$. With a SLENTY and SLSTAY level = 0.15 carcass length failed to enter the model for predicting the breakeven price of boneless pork chops from a boneless pork loin. This reaffirms the lack of predictability of carcass length on economic value of a boneless pork loin. For chop yield, 5.4% of the variation was accounted for with the following equation: $85.236 + (\text{hot carcass weight, kg} * 0.0717) + (\text{Percent lean} * 0.0713) - (\text{carcass length, cm} * 0.0796)$. Carcass length entered the model 2nd with a partial model $R^2 = 0.0038$. The additional marginal

utility of adding carcass length into the model was minimal and only increased the model R^2 from 0.0465 to 0.0503.

Conclusions

These data indicate carcass length is a poor predictor for the number of boneless loin chops yielded from a boneless pork loin and for the associated breakeven cost of each boneless loin. Carcass length only explained approximately 15% of the variation in the number of boneless chops produced by a boneless pork loin. Furthermore, the marginal model R^2 utility of adding carcass length to the stepwise regression model was minimal and contributed less than an additional 0.05 units of predictive ability (R^2) when loin weight, loin length, and carcass BF depth are also known. Additionally, when predicting chop yield, the same minimal marginal utility of adding carcass length in the model was calculated and for breakeven price of each loin, carcass length did not enter the stepwise model. However, for those markets capturing revenue from chop number rather than chop weight, measuring loin weight, compressed loin length, and BF depth can account for approximately 45% of the variation in the number of chops produced from a boneless pork loin. Therefore, although carcass length is a poor predictor of the number of chops from a boneless loin; the use of loin weight, compressed loin length, and BF depth may aid in predicting the number of chops that can be cut from a boneless loin.

Figures

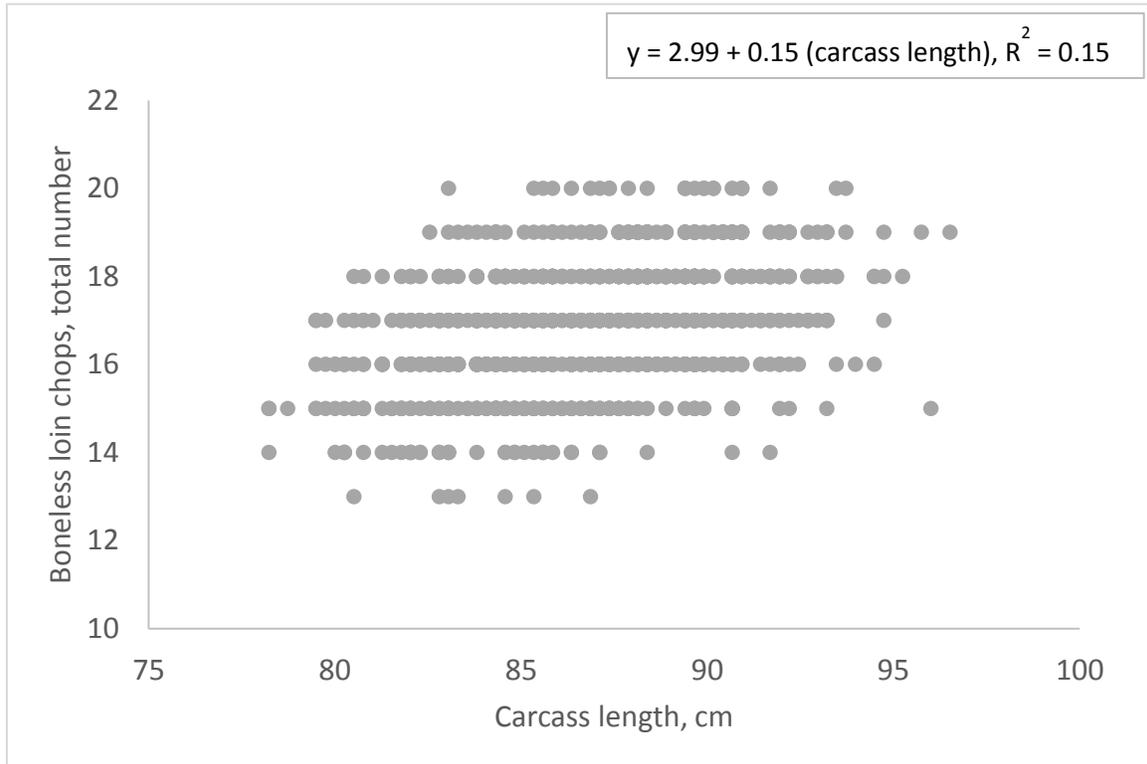


Figure 2.1. Prediction of the number of boneless pork loin chops using carcass length as the independent variable.

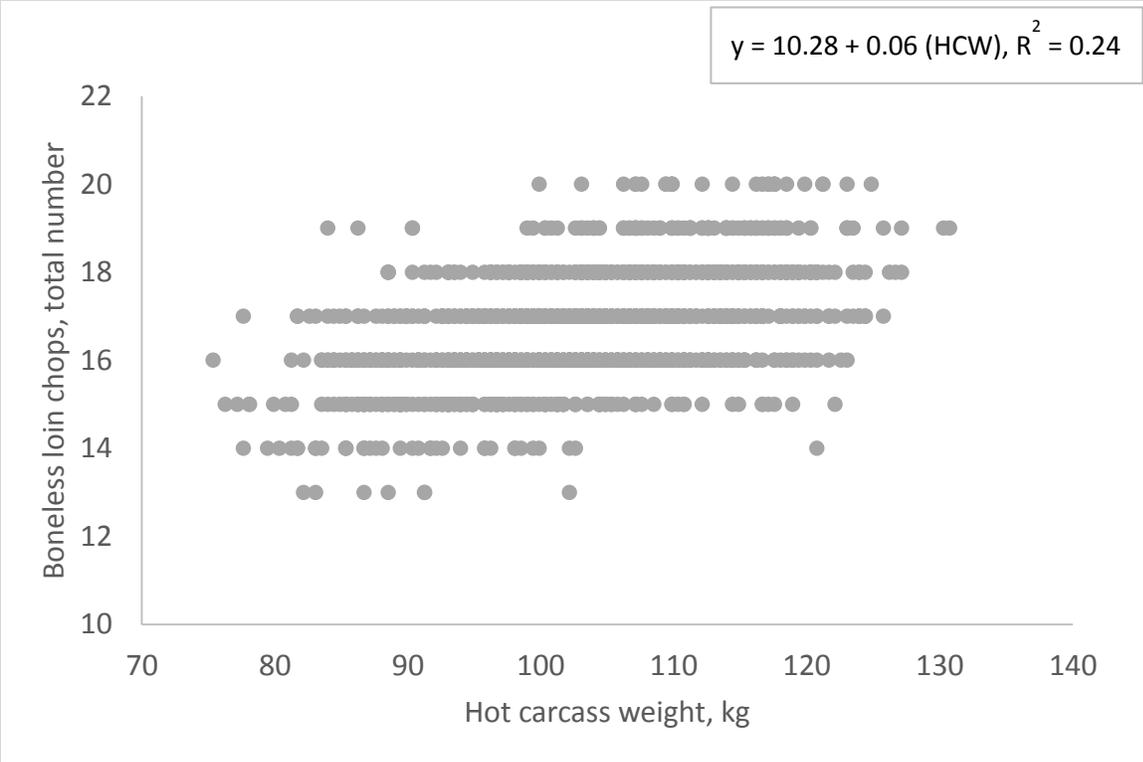


Figure 2.2. Prediction of the number of boneless pork loin chops using hot carcass weight as the independent variable.

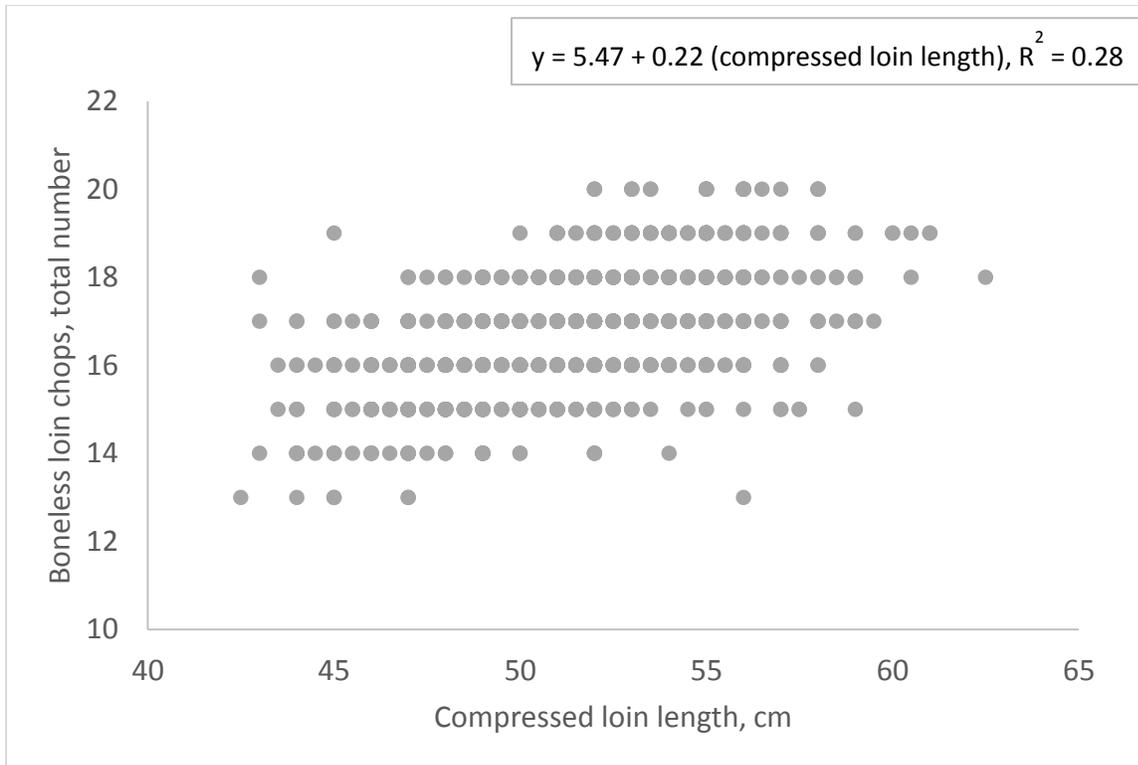


Figure 2.3. Prediction of the number of boneless pork loin chops using boneless compressed loin length as the independent variable. Boneless loins (North American Meat Processors, NAMP #414) were compressed to a minimum length without distortion.

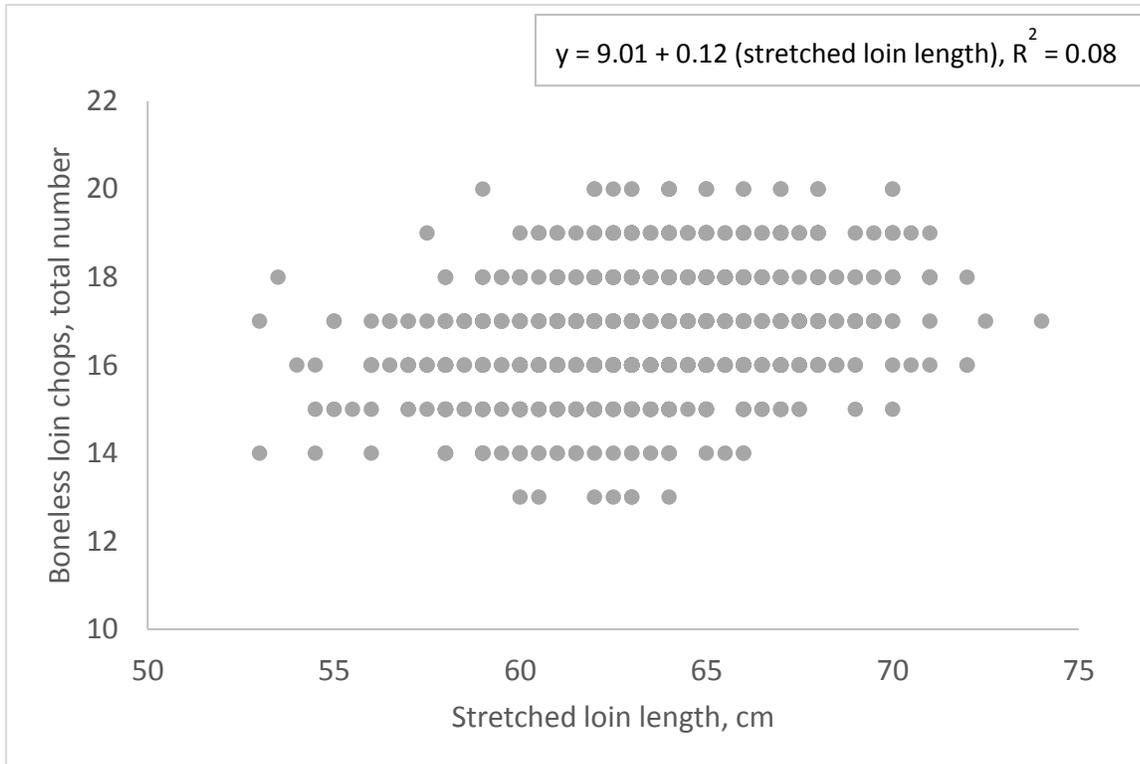


Figure 2.4. Prediction of the number of boneless pork loin chops using boneless stretched loin length as the independent variable. Boneless loins (North American Meat Processors, NAMP #414) were stretched to maximum length without distortion.

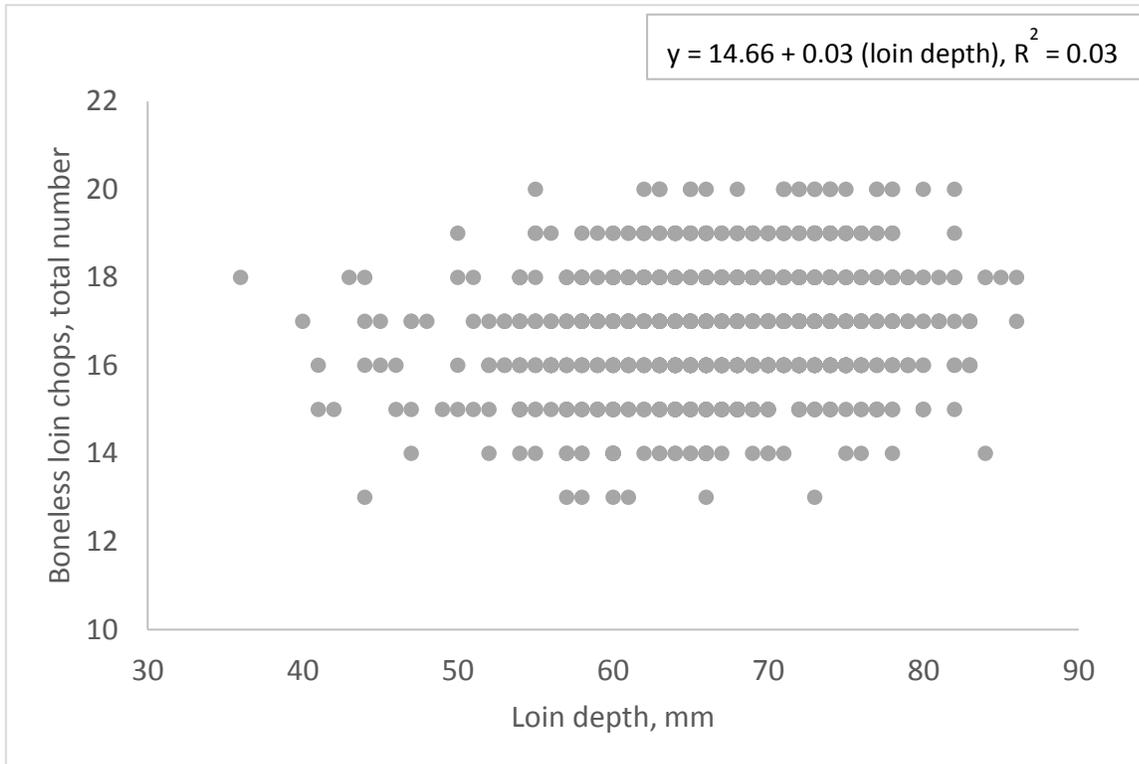


Figure 2.5. Prediction of the number of boneless pork loin chops using boneless loin depth as the independent variable. Loin depth was determined using a Fat-O-Meater at approximately the area of the 10th rib.

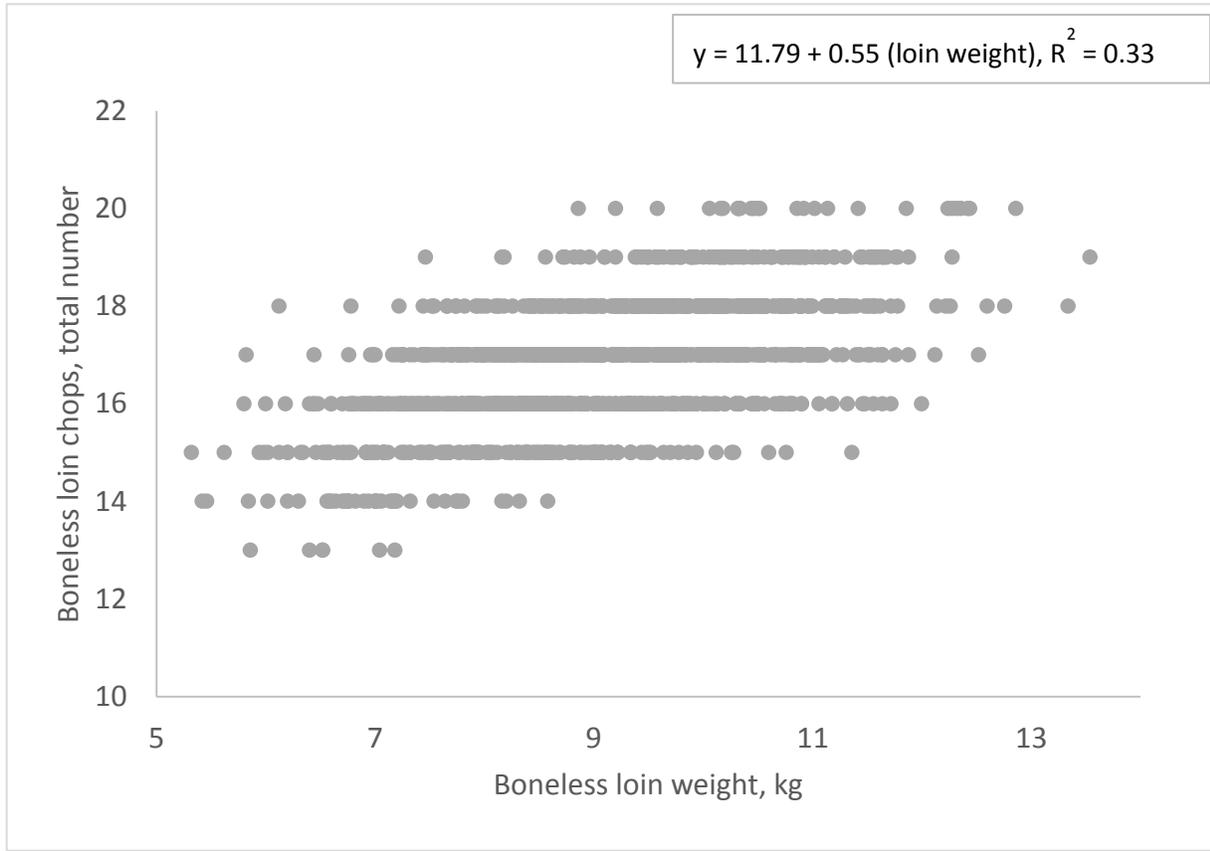


Figure 2.6. Prediction of the number of boneless pork loin chops using boneless loin weight as the independent variable.

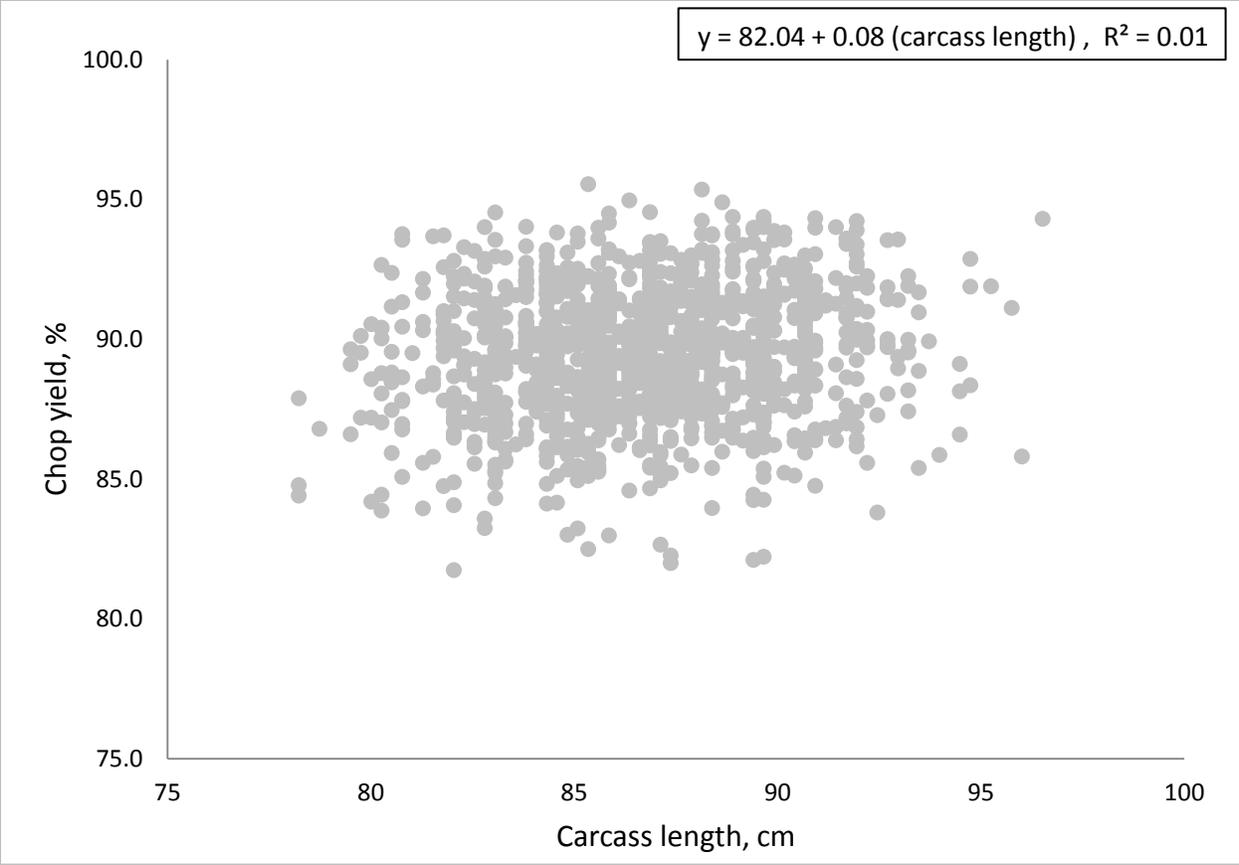


Figure 2.7. Prediction of chop yield using carcass length as the independent variable.

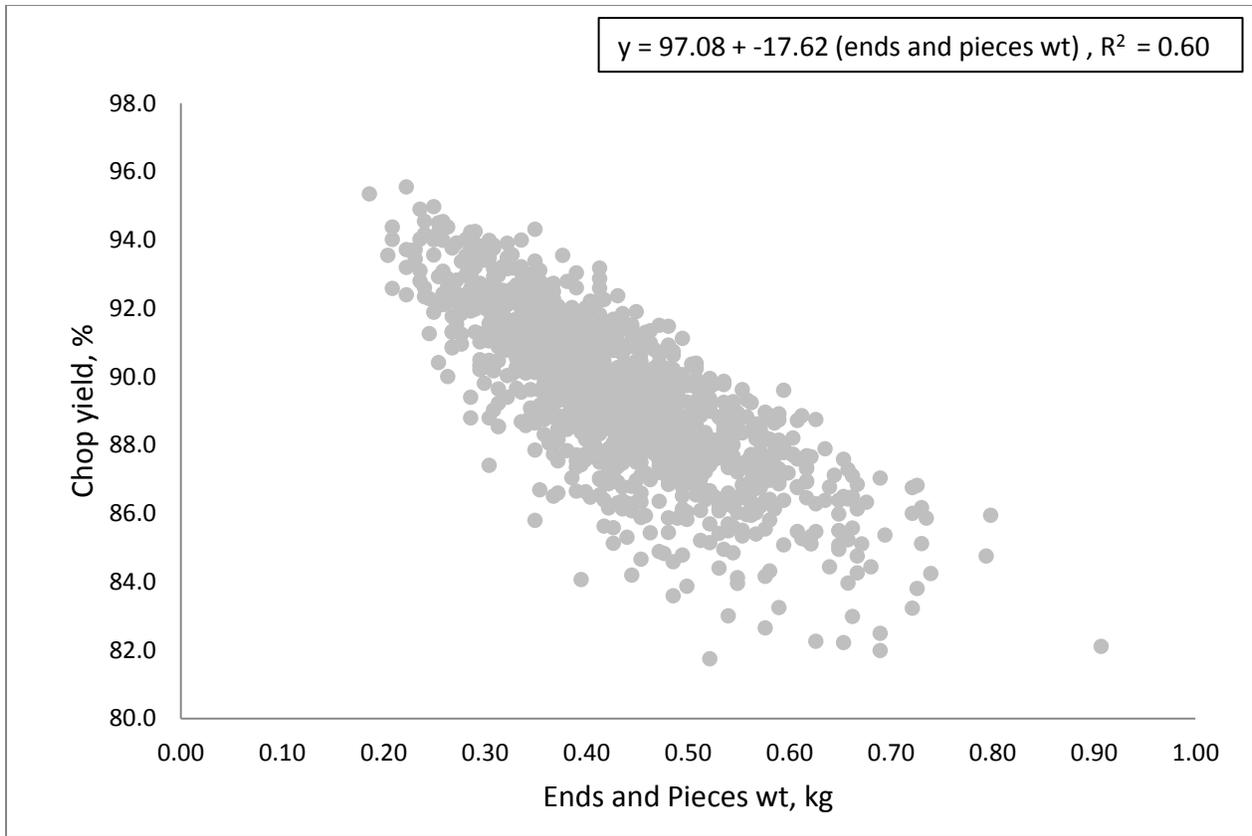


Figure 2.8. Prediction of chop yield using ends and pieces weight as the independent variable.

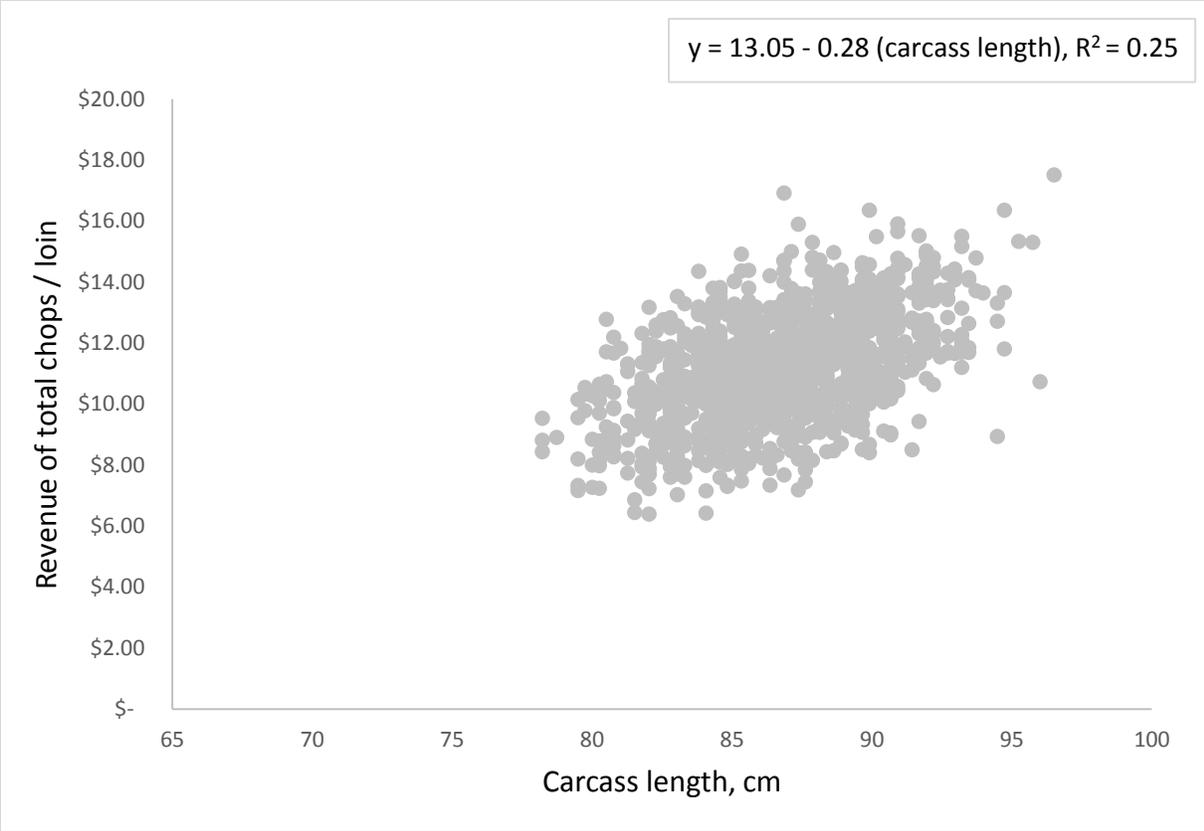


Figure 2.9. Prediction of revenue from total chops per loin using carcass length as the independent variable.

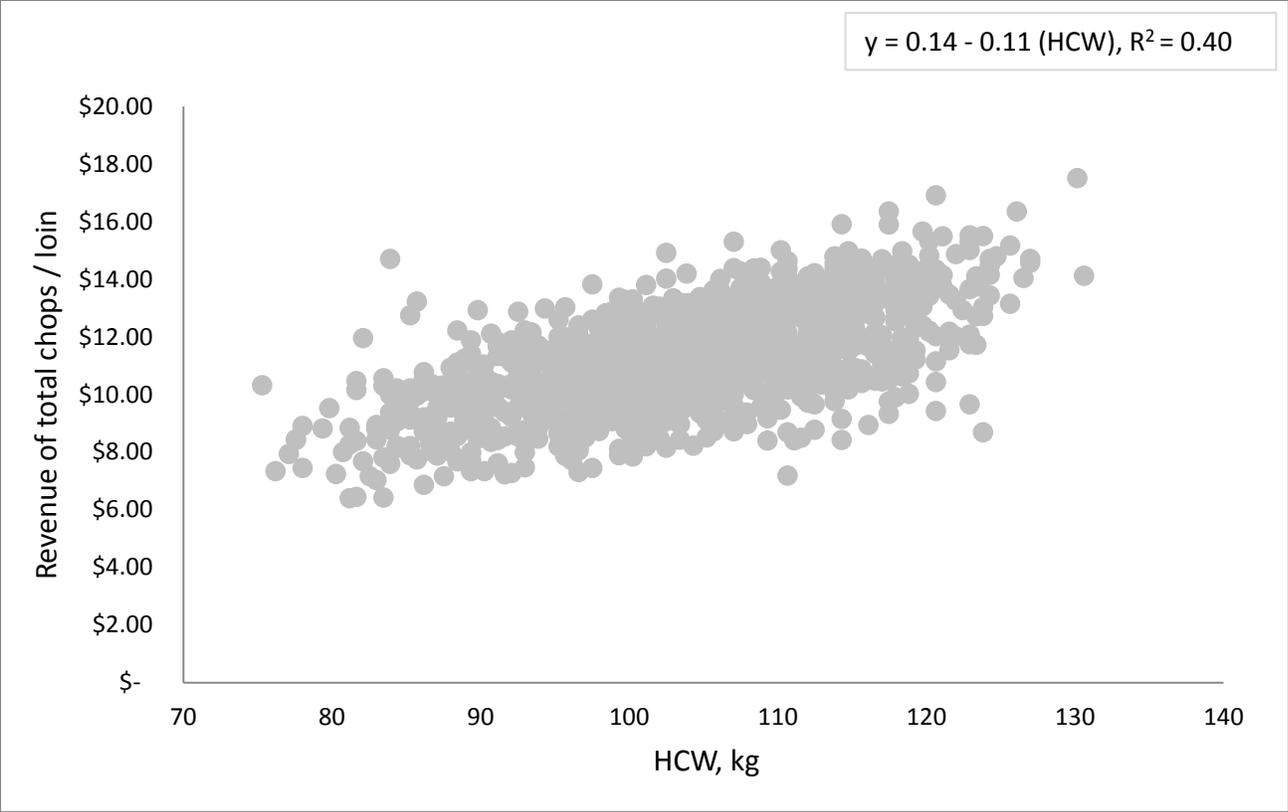


Figure 2.10. Prediction of revenue from total chops per loin using hot carcass weight as the independent variable.

Tables

Table 2.1. Population summary statistics of carcass and loin characteristics

Item	N	Mean	Minimum	Maximum	CV, %
HCW, kg	1235	103.6	75.0	131.0	9.76
Fat depth, mm	1234	22	11	51	22.40
Loin depth, mm	1234	67	36	86	10.84
Boneless loin weight, kg	1232	4.1	2.4	6.1	14.95
Carcass length, cm	1238	86.8	78.2	96.5	3.64
Stretched loin length, cm	1235	63.5	53.0	74.0	4.86
Compressed loin length, cm	1237	51.5	42.5	62.5	6.16
End and pieces weight, kg	1235	0.43	0.19	0.91	24.20
Chops, #	1238	17	13	20	7.82
Chop yield, % ¹	1236	89.5	81.8	96.0	2.64

¹Chop yield was calculated as: [(Boneless loin weight, kg – Ends and pieces, kg) / Boneless loin weight, kg] x 100

Table 2.2. Pearson correlation coefficients (r) of carcass and loin characteristics

	Hot carcass weight	Loin depth	Fat depth	Boneless loin weight	Stretched loin length	Compressed loin length
Loin depth	0.41*					
Fat depth	0.30*	-0.13*				
Boneless loin weight	0.64*	0.47*	-0.06			
Stretched loin length	0.41*	0.14*	-0.10	0.40*		
Compressed loin length	0.45*	0.23*	0.08	0.57*	0.47*	
Carcass length	0.71*	0.25*	-0.02	0.52*	0.54*	0.40*

* $P \leq 0.001$

Table 2.3. Summary of stepwise selection of independent variables using the regression procedure of SAS to predict the number of 2.54 cm thick chops derived from a boneless loin

Step	Variable entered	Variable removed	No. of variables included	Partial R ²	Model R ²	C(p)	F value	Pr > F
1	Boneless loin weight		1	0.336	0.336	253.84	615.78	< 0.0001
2	Compressed loin length	None	2	0.070	0.406	101.92	142.34	< 0.0001
3	Fat depth	None	3	0.035	0.441	25.82	76.73	< 0.0001
4	Carcass length	None	4	0.005	0.446	16.76	10.95	< 0.0001
5	Loin depth	None	5	0.004	0.450	9.02	9.72	< 0.0001
6	Hot carcass weight	None	6	0.001	0.452	7.85	3.17	< 0.0001

Table 2.4. Summary of stepwise selection of independent variables using the regression procedure of SAS to predict the breakeven price of a boneless loin¹

Step	Variable entered	Variable removed	No. of variables included	Partial R ²	Model R ²	C(p)	F value	Pr > F
1	Hot carcass weight		1	0.4031	0.4031	222.589	852.36	< 0.0001
2	Percent lean	None	2	0.0922	0.4954	1.6261	223.21	< 0.0001

¹Breakeven price was calculated as: [(boneless loin weight, kg x boneless center cut loin, strap-off price) – (ends and pieces weight, kg x 72 trim, combo)]

Table 2.5. Summary of stepwise selection of independent variables using the regression procedure of SAS to predict chop yield of a boneless loin¹

Step	Variable entered	Variable removed	No. of variables included	Partial R ²	Model R ²	C(p)	F value	Pr > F
1	Hot carcass weight		1	0.0465	0.0465	8.18	57.73	< 0.0001
2	Carcass length	None	2	0.0038	0.0503	5.41	4.75	0.0294
3	Percent lean	None	3	0.0039	0.0542	2.5	4.93	0.0266

¹Chop yield was calculated as: [(Boneless loin weight, kg – Ends and pieces, kg) / Boneless loin weight, kg] x 100

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CHAPTER 3

THE EFFECTS OF INSTRUMENTAL COLOR AND EXTRACTABLE LIPID CONTENT ON SENSORY CHARACTERISTICS OF PORK LOIN CHOPS COOKED TO A MEDIUM-RARE DEGREE-OF-DONENESS

Abstract

Approximately 300 boneless loins (NAMP #414) were selected from a group of pigs with the same genetic background, housing, and management, cut into 2.54 cm chops and aged 14-d postmortem. Instrumental L* color scores of the chops ranged from 57.60 (light) to 43.11 (dark) and extractable lipid ranged from 0.80% to 5.52%. Using these values, chops were assigned to NPPC color and marbling scores resulting in a 5 color x 6 marbling factorial arrangement of treatments. Chops were also assigned a quality grade using the newly developed National Pork Board (NPB) quality grade standards. Low quality (n = 56) included loins with color scores < 1.5 regardless of color or loins with color scores of ≤ 2.5 with marbling scores of ≤ 2.0 . Medium quality (n = 180) included loins with color scores of 2.0 through 3.5 and marbling ≥ 2.5 or loins with color scores of 3.0 through 3.5 and marbling scores ≥ 2.0 . High quality (n = 50) included color scores of > 4.0 with marbling scores ≥ 2.0 . Chops were assigned to sensory panel sessions in an incomplete block arrangement, cooked to a medium-rare degree-of-doneness (63 °C), and evaluated for tenderness, juiciness, and pork flavor by trained sensory panelists. Slice shear force (SSF) and cooking loss were also determined from each loin cooked to 63 °C. Data were analyzed using the MIXED procedure in SAS as a one-way ANOVA where quality grade was considered a fixed effect and using the REG procedure in SAS. Extractable lipid content and instrumental chop color individually accounted for a maximum of 2% ($R^2 \leq 0.02$) of the variation of tenderness, juiciness or pork flavor. Chops categorized as NPB high quality (SSF = 17.50 kg) were 6.5% more tender ($P \leq 0.02$) than chops categorized as medium (SSF = 18.56 kg)

and 11.2% more tender than chops categorized as low quality (SSF = 19.60 kg), and chops categorized as medium were 5.6% more tender ($P = 0.04$) than chops categorized as low quality. However, trained sensory panelists did not discern tenderness differences ($P = 0.09$) among NPB quality grades. Low and medium quality chops were more flavorful ($P < 0.01$) than high quality chops. Juiciness scores did not differ ($P = 0.48$) among NPB quality grades. Cook loss tended ($P = 0.06$) to decrease from 16.57% to 15.32% as quality grade increased. When color or marbling was used as a single trait, it was not predictive of sensory quality. However, using these traits in combination such as with the NPB quality grades may result in differences in sensory quality between pork loins.

Introduction

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 required.

Animals

Canadian back loins (NAMP #414) from 1,238 carcasses were sourced from a single genetic line of pigs that were raised and slaughtered under commercial conditions. Pigs were housed in single sex pens with 20 pigs per pen. Pigs were marketed over 7-wk as the average BW of each pen reached 138 kg. Transportation distance was approximately 277 km, and pigs were held overnight with free access to water but no access to feed prior to slaughter. Pigs were immobilized via carbon dioxide stunning and terminated via exsanguination.

Processing Facility Data Collection

Following commercial harvesting procedures, carcasses were blast-chilled for approximately 90 minutes. Carcasses were fabricated approximately 22 h postmortem into

primal pieces and loins were further fabricated into boneless Canadian back loins. Boneless loins were then vacuum packaged and transported to the University of Illinois Meat Science Laboratory for further evaluation.

Boneless Loin Chop Quality Measurements

Loins were aged for 14-d postmortem under refrigeration at 4 °C as whole boneless loins. At the end of the aging period, loins were removed from packaging, weighed, pH was collected, and mechanically sliced into 2.54 cm thick chops as described by Wilson et al., (2016). Ultimate pH was measured on the ventral side of longissimus dorsi muscle using a handheld MPI pH meter fitted with a glass electrode (MPI pH-Meter, Topeka, KS, USA; 2-point calibration; pH 4 and 7). After slicing, whole muscle boneless loins were cut into chops, a minimum of 30 minutes was allowed for oxygenation of myoglobin before any subjective color and marbling or instrumental color measurements were collected. Subjective color and marbling, instrumental color, proximate composition, ultimate pH, drip loss, cook loss, and slice shear force were conducted by trained University of Illinois personnel. Consecutive 2.54 cm chops immediately posterior to the spinalis dorsi were used for evaluation in the following order: (1) proximate analysis/drip loss, (2) trained sensory analysis, (3) slice shear force. Subjective color and marbling scores (NPPC, 1999), were evaluated by a single individual in half score increments on chop 1. Instrumental CIE L* (lightness), a* (redness), and b* (yellowness; CIE 1978) were collected on chop 1 with a Minolta CR-400 Chroma meter (Minolta Camera Co., Ltd., Osaka, Japan) using a C illuminant, 0° observer with an aperture size of 8 mm and calibrated using a white tile. Chops designated for slice shear force and trained sensory panel evaluation were individually vacuum packaged and frozen until further evaluation. At the completion of the 24 h drip loss time, chops were individually packaged and frozen for proximate analysis at a later date.

Proximate Analyses

Chops were prepared for proximate analysis by trimming chops free of all subcutaneous fat and secondary muscles before homogenizing in a Cuisinart (East Windsor, NJ) food processor. Moisture and extractable lipid content were then quantified using a chloroform-methanol solvent as described by Novakofski et al. (1989). Briefly, 10 g samples were weighed in duplicate and placed in a drying oven at 110 °C for at least 24 hours. After drying, samples were weighed to quantify moisture loss and lipid was extracted using an azeotropic mixture of chloroform and methanol (87:13). Samples were placed back in the drying oven for at least an additional 24 h before collecting a lipid extracted weight. Percent moisture and extractable lipid were determined by the difference between initial weight, dried weight, and extracted weight.

Slice Shear Force

The 2.54 cm thick chops were removed from the freezer where they had been stored at -40 °C at least 24 h prior to analysis and allowed to thaw thoroughly. Secondary muscles and excess subcutaneous fat were trimmed. Chops were cooked on a Farberware Open Hearth grill (model 455N, Walter Kidde, Bronx, NY, USA). Chops were cooked on one side to an internal temperature of 31.5 °C, flipped, and then cooked until they reached an internal temperature of 63 °C. Internal temperature was monitored 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, USA). Immediately after reaching 63 °C internal temperature, chops were removed from the grill. Chops were cooled to approximately 22 °C before slicing. A 1-cm thick, 5-cm long slice was then cut from each chop parallel to the muscle fibers. The slice was acquired by first cutting across the width of the chop on the dorsal end and then making a cut approximately 2-cm from the lateral end of the chop. Using a sample sizer, a cut was made across the longissimus muscle

parallel to the length of first cut 5-cm from the lateral end. Using a knife that contained two parallel blades spaced 1-cm apart, two parallel cuts were made simultaneously through the length of the 5-cm long slice at a 45° angle to the long axis of the longissimus and parallel with the muscle fibers (Shackelford et al., 2004). Each sample was sliced using a flat blunt-end blade attached to a Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY, USA / Stable Microsystems, Godalming, UK) with a blade speed of 8.33 mm/sec and a load cell capacity of 100 kg. A single slice shear force (SSF) value was reported for each chop using a single slice. Cook loss was recorded and calculated as [(weight of raw chop, g – weight of cooked chop, g) / weight of raw chop, g].

Chop Selection

A sub-sample of approximately 300 loins were selected from the original 1,238 using aged (14-d postmortem) evaluations to fill a 5 x 6 factorial arrangement based on instrumental L* and extractable lipid for trained sensory panel analyses (Fig. 3.1). Because extractable lipid was precise and accurate it, rather than subjective marbling score, was used for the selection of chops used for sensory analyses. Likewise, because instrumental L* was precise and accurate it, rather than subjective color scores was used for the selection of chops used in sensory analysis. Instrumental L* color scores of the subsample population ranged from 57.60 (light) to 43.11 (dark) and extractable lipid ranged from 0.80% to 5.52%. The 5 color categories (2.0, 2.5, 3.0, 3.5, and 4.0) were classified in half score increments using the guidelines declared by (NPPC, 1999) where chops become visually darker with increasing color score. Chops were categorized by the instrumental L* value from the cross sectional surface of the loin chop. For example, as stated by (NPPC, 1999) a color score 3.0 would be an L* range of 49.00 to 51.99 and a color score 3.5 would be an L* range of 46.00 to 48.99. Therefore, making the printed L* value on the NPPC guidelines card the average L* value within each whole color score and not the high or

low value. An $L^* = 49.00$ would be visually the darkest colored chop within the color score 3 range and likewise an $L^* = 51.99$ would be visually the lightest colored chop within the color score 3 range. The 6 marbling categories (<1.5, 2.0, 2.5, 3.0, 3.5, and >4.0) were classified in half score increments and based on the proximate analysis results from each chop. For example, marbling category 3.0 encompassed all chops with an extractable lipid range of 2.51 to 3.00 and so on for the remaining marbling categories. A target of 10 chops per color/marbling combination were sought, but there were 3 color and marbling treatment combinations (Color/Marbling: 2.0: < 1.5, 2.0: 2.0, 4.0: <1.5) that did not have enough available chops. Because chops with some color and marbling combinations were not available, 286 loins (chops) were ultimately selected resulting in 10 replications of most color and marbling combinations (Fig. 3.1). For treatment combinations where there were more than 10 possible chops, chops were randomly selected using the following criteria. The respective color and marbling range for each color and marbling combination was divided into thirds where one chop was then randomly selected from each of the 9 quadrants (3 color quadrants x 3 marbling quadrants) making up the entire range and the 10th chop was the chop closest to the mean for both the color and marbling value within each color and marbling combination range. Upon completing the 5 x 6 factorial arrangement, chops were then further categorized into one of three quality groups based on quality grades proposed by the National Pork Board. Low quality included loins with marbling scores ≤ 1.5 regardless of color or chops with color scores of ≤ 2.5 with marbling scores of ≤ 2.0 . Medium quality included chops with color scores of 2.0 through 3.5 and marbling ≥ 2.5 or chops with color scores of 3.0 through 3.5 and marbling scores ≥ 2.0 . High quality included color scores of ≥ 4.0 with marbling scores ≥ 2.0 (Personal communication with the National Pork Board). Aged 14-d quality measurement of this sub-population summary statistics including

mean, minimum observation, maximum observation, and standard deviation are presented in Table 1. Full population pork quality summary statistics are available in Wilson et al. 2016.

Trained Sensory Panels

A 6 member panel was selected from a pool of experienced, trained panelists at the University of Illinois. Panelists were trained for tenderness, juiciness, and pork flavor. Tenderness and juiciness training was completed by cooking several different pork chops (enhanced and not enhanced) to different degrees of doneness (63 °C - medium-rare, 71 °C - medium, and 80 °C - well-done) and as a collective group, panelists sampled chops to determine a respective anchor. Sensory tenderness validation for the effectiveness of the panel to determine differences in tenderness was completed using pork chops with a slice shear force range of 9 kg through 30 kg. Average panelist tenderness scores explained 57% of the variation in slice shear force ($R^2 = 0.57$) tenderness. The effectiveness of the University of Illinois sensory panel to detect tenderness differences was similar to Shackelford et al., (2004) where the coefficient of determination for sensory tenderness was $R^2 = 0.52$ using a slice shear force range of 10.6 kg through 36.8 kg. Pork flavor was standardized using methods described by Chu, (2015) using 80% lean: 20% fat ground pork and a pork chop. Trained sensory panel analyses for tenderness, juiciness, and flavor were evaluated in a partially balanced incomplete block design. Chops were assigned to sensory sessions using an incomplete randomized block schedule of chops for each sensory panel and this was generated using the OPTEX procedure in SAS where a treatment assignment efficiency of 99.7% was achieved using the randomization seed #73462. Chops were thawed approximately 24 h prior to each panel evaluation by placing the vacuum packaged chops in a refrigerator at approximately 4 °C. Panelists were placed in individual, breadbox-style booths with red lights to mask color differences between samples. Tenderness, juiciness, and flavor were measured on a 15-cm anchored scale (0 = extremely tough, extremely dry, or no pork

flavor and 15 = extremely tender, extremely juicy, or very intense pork flavor). Each panelist received unsalted saltine crackers and water for palate cleansing between samples. To follow the recent cooking guidelines published by the National Pork Board, all chops were cooked to a medium-rare degree-of-doneness (63 °C) with a 3 min rest after reaching the final internal temperature using the same Farberware grills used for SSF. During cooking, internal temperature was monitored using copper-constantan thermocouples placed in the geometric center of the chops. At the conclusion of the 3 minute rest period, subcutaneous fat and ends were removed from each chop and the remaining portion was cut using a sample sizer into approximately 1 cm cubes that did not contain visible connective tissue. Panelists were each given 3 cubes per sample on a paper plate. Each testing day consisted of 2 sessions with at most 6 samples per session. The study consisted of 27 d and 286 samples. Sessions were held at least 1 h apart to reduce sensory fatigue. Results from all 6 panelists were averaged for use in data analyses.

Statistical Analyses

Chop (N = 286) served as the experimental unit for all dependent variables. Summary data for descriptive statistics were generated using the Means procedure in SAS. Regression analyses were performed using the REG procedure in SAS to calculate coefficients of determination between the dependent variables and independent variables. The dependent variables were the sensory properties of tenderness, juiciness, and flavor and the independent variables were extractable lipid percentage and instrumental loin chop color. The effects of National Pork Board quality grade on sensory properties, SSF, and cook loss were analyzed using the MIXED procedure in SAS as a one-way ANOVA where quality grade was considered a fixed effect. Session was included in the model as a random variable for all three sensory characteristic traits. Assumptions of ANOVA were tested with the Levene's test and Brown-

Forsythe test for homogeneity of variances. Normality of the residuals was tested using the UNIVARIATE procedure of SAS. Significance was determined at $P < 0.05$ for all analyses.

Results

Loin Quality

Loins selected for this study were from a commercial genetic line of pigs raised in a commercial setting, where diet, management practices, and slaughter facility, were all the same. This population of pigs was a commercially representative population with a NPPC subjective color range from 1.5 through 5.5, pH range of 5.43 through 6.04, and an extractable lipid range of 0.80% through 5.52% (Table 3.1).

Color and Marbling as Predictors of Sensory Traits

Neither extractable lipid nor instrumental color influenced trained sensory tenderness scores (Fig. 3.2). Extractable lipid explained less than 1% of the variation in sensory tenderness and instrumental L* explained 1% of the variation in sensory tenderness of boneless pork chops. Neither extractable lipid nor instrumental color influenced trained sensory juiciness scores (Fig. 3.3). Extractable lipid percentage explained 2% of the variation in sensory juiciness and instrumental L* explained less than 1% of the variation in sensory juiciness of boneless pork chops. Lastly, neither extractable lipid nor instrumental color influenced trained sensory flavor scores (Fig. 3.4). Extractable lipid percentage explained 1% of the variation for sensory flavor and instrumental L* explained less than 1% of the variation in sensory flavor scores of boneless pork chops. Based on these data, extractable lipid and instrumental L* color when used as single variables were poor predictors for trained sensory tenderness, juiciness, and flavor of boneless pork loin chops cooked to a medium-rare degree-of-doneness and explained at most 2% of the variation for eating quality traits.

National Pork Board Quality Grade

Sensory tenderness and juiciness did not differ ($P \geq 0.09$) among National Pork Board quality grades (Table 3.2). Chops categorized as low and medium quality were rated more flavorful ($P < 0.01$) than high quality chops. However the magnitude of difference was minimal. Chops categorized as NPB high quality (SSF = 17.50 kg) were 6.5% more tender ($P = 0.03$) than chops categorized as medium quality (SSF = 18.56 kg) and were 11.2% more tender ($P < 0.01$) than chops categorized as low quality (SSF = 19.60 kg) and medium quality chops were 5.6% more tender ($P = 0.04$) than low quality chops. Cook loss tended ($P = 0.06$) to decrease from 16.57% to 15.32% as quality grade increased. Therefore, though when used as a single variable instrumental L* color and extractable lipid content were not predictive of eating quality, but when used in combination differences in sensory quality between boneless pork loins may exist.

Discussion

Fresh color and marbling are used by consumers as indicators for tenderness and juiciness (Wood et al., 2004; Lonergan et al., 2007). Consumers use the amount of marbling as a primary characteristic driving purchase intent of fresh pork (Brewer et al., 2001; Fernandez et al., 1999). Later, Mancini and Hunt, (2005) concluded color influences meat purchasing decisions more than any other quality trait. Thus, the NPB developed a pork loin quality grade system based on both visual color and marbling. This study examined the effects of both instrumental color and extractable lipid content on sensory qualities of boneless pork loins cooked to a medium-rare degree-of-doneness.

Extractable lipid content independently only explained no more than 2% of the variation in sensory tenderness, juiciness, or flavor when cooked to a medium-rare degree-of-doneness. Multiple studies have evaluated influencers of sensory characteristics of boneless pork chops by controlling factors such as genetics, muscle pH, color variation, marbling, or endpoint cooking

temperatures. In 2008, Rincker et al., (2008) evaluated the effects of extractable lipid ranging from 0.76% through 8.09% on eating quality of boneless pork chops cooked to 62 °C, 71 °C, or 80 °C in a population where genetics were not controlled. Extractable lipid content had no influence on eating quality as lipid content was unable to explain no more than 13% of the variation in tenderness, juiciness, or flavor. Another study using commercially purchased loins (unknown pig background), grouped loins into extractable lipid categories of low (< 1%), medium (2 through 2.5%), and high (3 through 3.5%) extractable lipid content and concluded that consumers rated chops cooked to a medium degree-of-doneness in the high extractable lipid group to be 24% more tender ($P < 0.05$) than chops in the low extractable lipid category while chops in the medium extractable lipid category were not different ($P > 0.05$) from either the low or high extractable lipid categories (Brewer et al., 2001). Additionally, when those consumers were asked to prepare chops at home for evaluation, chops in the high extractable lipid category were still rated 7% tenderer ($P < 0.05$) than chops in the low extractable lipid category (Brewer et al., 2001). Later, Cannata et al. (2010) sorted loins into bins of low extractable lipid (1.96%), medium (2.50%), and high (3.56%) extractable lipid and at the same time kept instrumental L* constant across categories, reported when cooking chops to 72 °C, trained panelist scored chops in both the high and medium extractable lipid bins as (27% and 19%), respectively, more tender ($P \leq 0.01$) than chops in the low extractable lipid bin. In another study using Duroc x Landrace crossbred pigs where , instrumental L* and ultimate pH were both controlled, researchers concluded, tenderness ratings of pork chops were similar ($P > 0.05$) across extractable lipid ranges of < 1.5% to > 3.5% when evaluated by trained panelist (Fernandez et al., 1999). Moreover, another study specifically evaluating the effects of the Duroc breed on eating experience concluded no differences ($P > 0.05$) in consumer panel tenderness ratings regardless

of extractable lipid content (Channon et al., 2004). Therefore, regardless what variable is controlled, the present results align with historical data concluding extractable lipid content is a poor predictor for sensory quality.

Similarly, lack of differences in tenderness ratings due to increasing marbling scores has also been reported in beef. Even so, beef steaks cooked to a medium degree-of-doneness with Trace amounts of marbling were instrumentally tougher ($P < 0.05$) than steaks with Slight marbling and Slight marbling steaks were instrumentally tougher ($P < 0.05$) than steaks with Small or greater amount of marbling (Wheeler et al., 1994). However, when marbling content in beef steaks exceeded Small, no differences ($P > 0.05$) were reported for either instrumental tenderness or trained sensory tenderness when cooked to a (70 °C). Further, the retail beef study by Savell et al., (1987), concluded when steaks were cooked to a medium degree-of-doneness, instrumental tenderness did not differ ($P > 0.05$) between steaks of Small marbling or greater. In general, it does not appear that marbling affects tenderness of pork and beef cuts regardless of final cooking degree-of-doneness. In the current study, genetics, color, and endpoint cooking temperature were all controlled and extractable lipid content independently only explained at most 2% of the variation in any sensory trait.

In the present study, instrumental L^* color was able to independently explain at most 1% of the variation in any sensory quality trait. Data in the current study agree with historical literature, that when examined independently, instrumental color does not influence eating quality of boneless pork chops. Regardless, color is another key parameter in sorting pork loins into quality categories. When grouping loins by instrumental L^* into three categories pale ($L^* = 57.00$), intermediate ($L^* = 50.24$), and dark ($L^* = 45.54$) consumer panelist rated chops in the darkest color category no different ($P > 0.05$) in sensory tenderness as chops in the palest colored

category (Norman et al., 2003). However, chops in the darker colored category were rated 8% juicier ($P < 0.05$) by consumer panelists than chops in the pale colored category (Norman et al., 2003). Beef studies evaluating the effect of color on tenderness have reported both instrumental SSF tenderness ($r = -0.36$; $P < 0.05$) and sensory tenderness ratings ($r = 0.34$; $P < 0.05$) to be positively correlated with instrumental L^* color measurements in beef longissimus steaks when cooked to medium degree-of-doneness ($70\text{ }^{\circ}\text{C}$) (Wulf et al., 1997). Additionally, ultimate pH can be a surrogate for pork color as instrumental L^* readings and subjective color scores have been historically correlated. A study by Huff-Lonergan et al., (2002) reported 48 h pH to be correlated ($P < 0.01$) with Hunter L^* ($r = -0.27$) and further concluded 48 h Hunter L^* to be correlated ($r = -0.69$; $P < 0.01$) with subjective color scores of boneless pork loins. Later, in 21-d aged boneless pork loins, pH was correlated ($P < 0.05$) with Minolta L^* ($r = -0.53$) and Minolta L^* was correlated ($P < 0.05$) with subjective color scores ($r = -0.51$; Boler et al., 2009). In the same study, 21-d aged boneless loins categorized as low pH (≤ 5.44) were paler ($P < 0.05$) colored (NPPC = 2.3) than loins categorized as high pH (≥ 6.05) NPPC = 4.1 (Boler et al., 2009). Loins with similar average pH of the present study ($\bar{x} = 5.68$; Table 3.1) were less tender ($P < 0.05$) than loins with a pH greater than 5.80 but, were more tender ($P < 0.05$) than loins with pH less than 5.65 (Lonergan et al., 2007). Therefore, as concluded in the present study, when controlling for genetics, marbling, and endpoint cooking temperature; color is a poor indicator of sensory quality in boneless pork loin chops.

Tenderness can be influenced by degree-of-doneness in both pork and beef. In pork, cooking boneless pork loin chops to a medium-rare degree-of-doneness resulted in a 9% increase in tenderness ($P < 0.05$) compared to medium degree-of-doneness (Rincker et al., 2008). Furthermore, sensory juiciness ratings were positively influenced by 12% when cooking

boneless pork loin chops to 63 °C compared with 71 °C in a trained panel (Moeller et al., 2010). It has also been concluded in beef studies cooking steaks to a medium-rare degree-of-doneness will result in instrumentally more tender steaks ($P < 0.05$) than cooking to medium or medium-well across multiple different cookery methods (Yancey et al., 2016). Nonetheless, when cooking pork to 63 °C as done in the present study, sensory quality of boneless pork chops was not independently impacted by either color or marbling.

Results of the newly revised NPB quality grade system suggest selecting boneless pork loins on both instrumental L* color and extractable lipid content may improve instrumental tenderness. Even so, trained panelists were not able to discern differences in sensory tenderness values among quality grades. So, even though instrumental tenderness may differ among quality grades, the magnitude of difference was not great enough for the trained panel to detect differences. This agrees with Wright et al., (2005) where chops were binned into three quality grade categories using NPPC (1999) subjective color and marbling measurements with wider ranges of both instrumental L* color (range: 26.50 through 74.90) and marbling scores (range: 1 through 6). Their designated quality grades were: low quality chops (color: ≤ 1.0 or marbling: ≤ 1.0), average quality chops (color: 1.5 through 2.5 or marbling: 1.5 through 3.5) and high quality chops were (color: ≥ 3.0 or marbling: ≥ 4.0) (Wright et al., 2005). Similar to results from the current study, Wright et al. (2005) who cooked chops to a medium degree-of-doneness (70 °C) reported that instrumental tenderness of chops in the high quality group were 10% more tender than chops in the low quality group ($P < 0.05$). At the same time, chops in the average quality group were no different ($P > 0.05$) for instrumental tenderness compared with both the high and low quality chops. Also, similar to results of the current study, Wright et al., (2005) reported no differences ($P > 0.05$) in sensory panel tenderness. Unlike the present study however, chops in

the high quality group were scored 4% more juicy ($P < 0.05$) than chops in the average quality group and 5% more juicy ($P < 0.05$) than chops in the low quality group (Wright et al., 2005). Therefore, based on results reported by Wright et al. (2005) and data from the current study, instrumental tenderness may be improved in loins that are concurrently darker and contain a greater percentage of extractable lipid compared with loins that are less dark or have less extractable lipid, but those differences are not detectible by trained sensory panelists regardless of final cooking degree-of-doneness.

Conclusions

Color and marbling did not independently influence eating quality (tenderness, juiciness, and flavor) of boneless pork loin chops when cooked to a medium-rare degree-of-doneness. Color and extractable lipid at most explained 2% of the variation for any palatability trait. However, when used together as part of the newly developed NPB quality grading classification system, chops did become more tender when cooked to a medium-rare degree of doneness as extractable lipid content increased and instrumental chop color got darker. When color or marbling was used as a single trait, it was not predictive of sensory quality. However, using these traits in combination such as with the NPB quality grades may result in differences in sensory quality between pork loins.

Figures

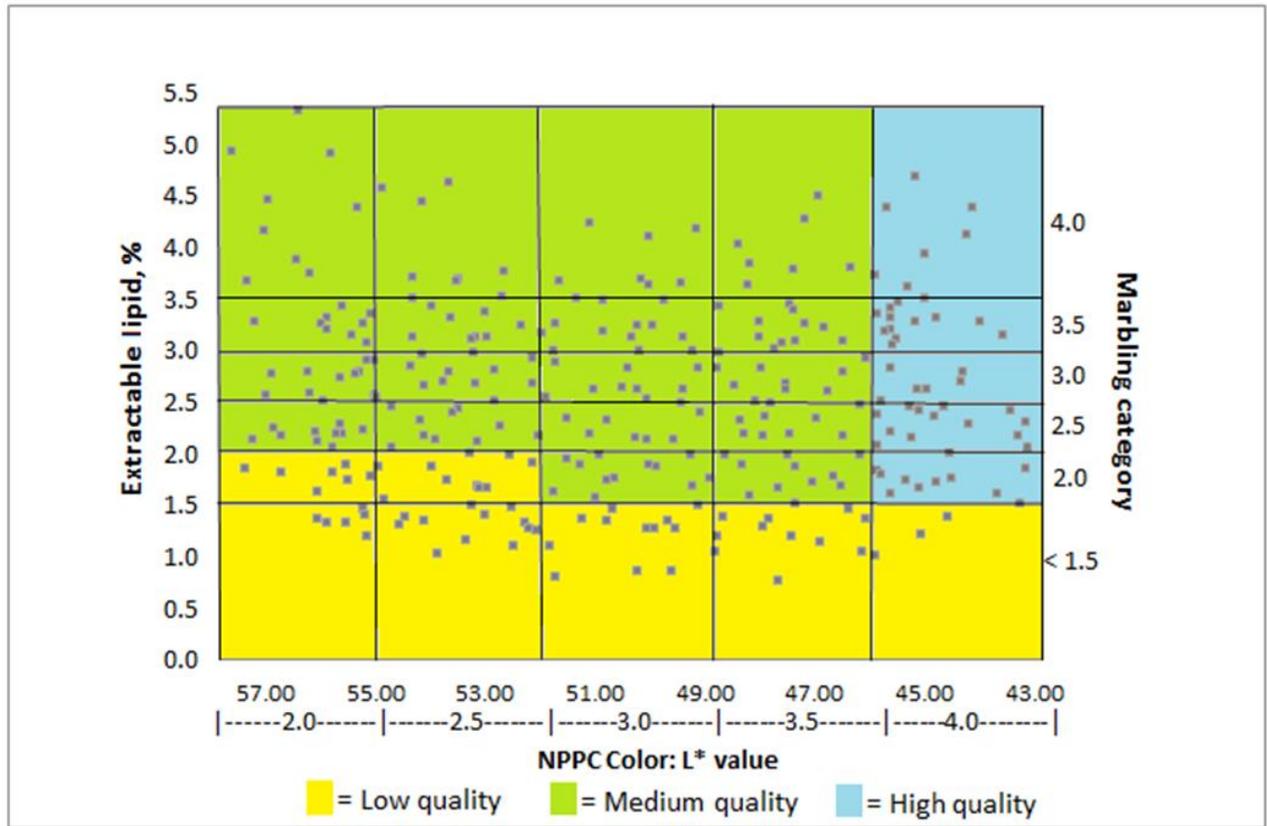


Figure 3.1. Matrix displaying instrumental color and extractable lipid combinations of boneless pork chops used in trained sensory evaluations. Proposed NPB Quality Grades = [(Low: marbling ≤ 1.5 regardless of color or color ≤ 2.5 with marbling ≤ 2.0), (Medium: color 2.0 through 3.5 and marbling ≥ 2.5 or color 3.0 through 3.5 and marbling ≥ 2.0), (High: color ≥ 4.0 with marbling ≥ 2.0)].

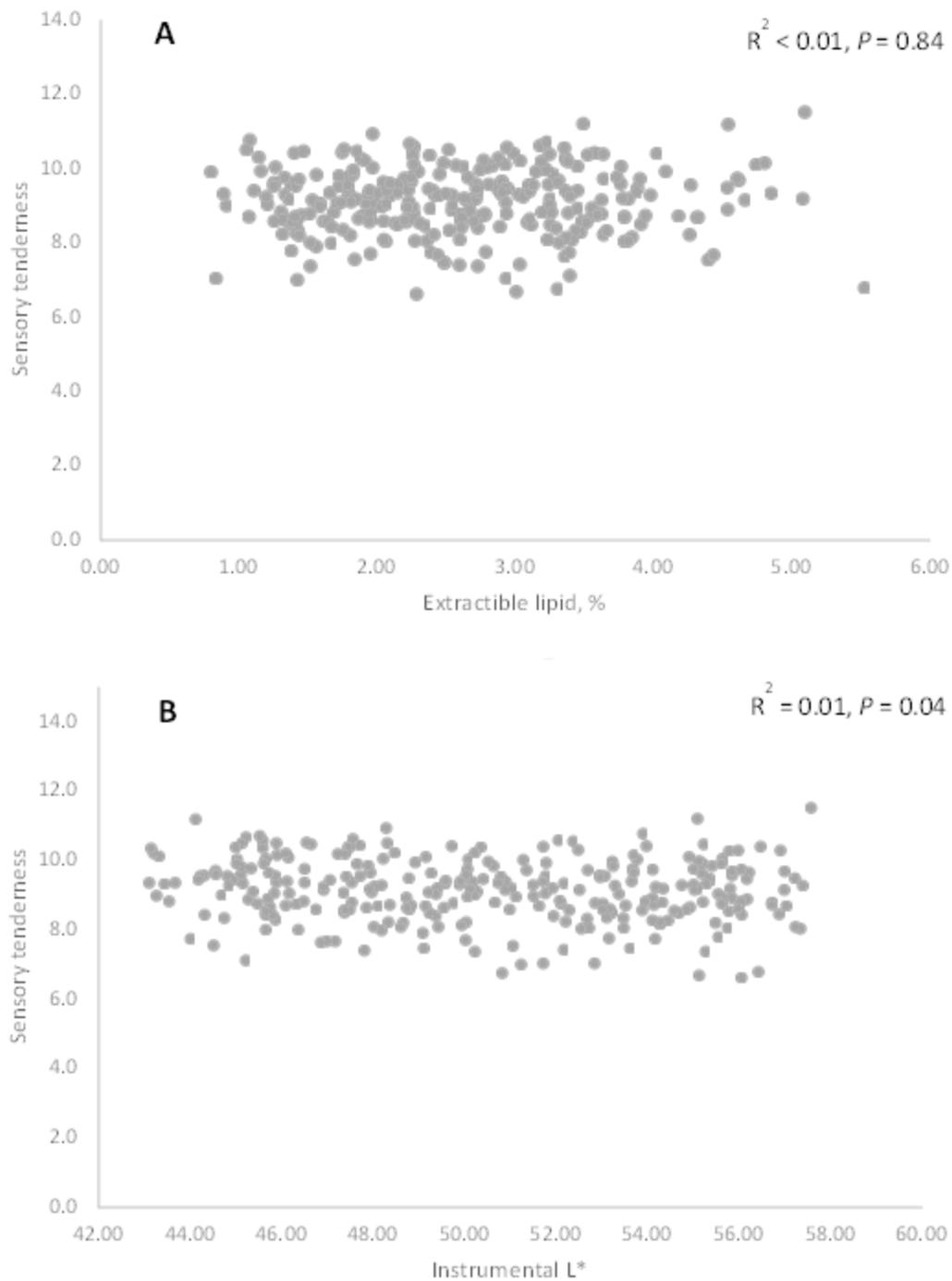


Figure 3.2. Prediction of trained sensory tenderness score using extractable lipid percentage (a) or instrumental L* based NPPC color score (b) as the independent variable. L* measures darkness to lightness (greater L* indicates a lighter color). Sensory attributes evaluated on a 15 point scale, where 0 = extremely tough, dry, or not flavorful and 15 = extremely tender, juicy, or flavorful.

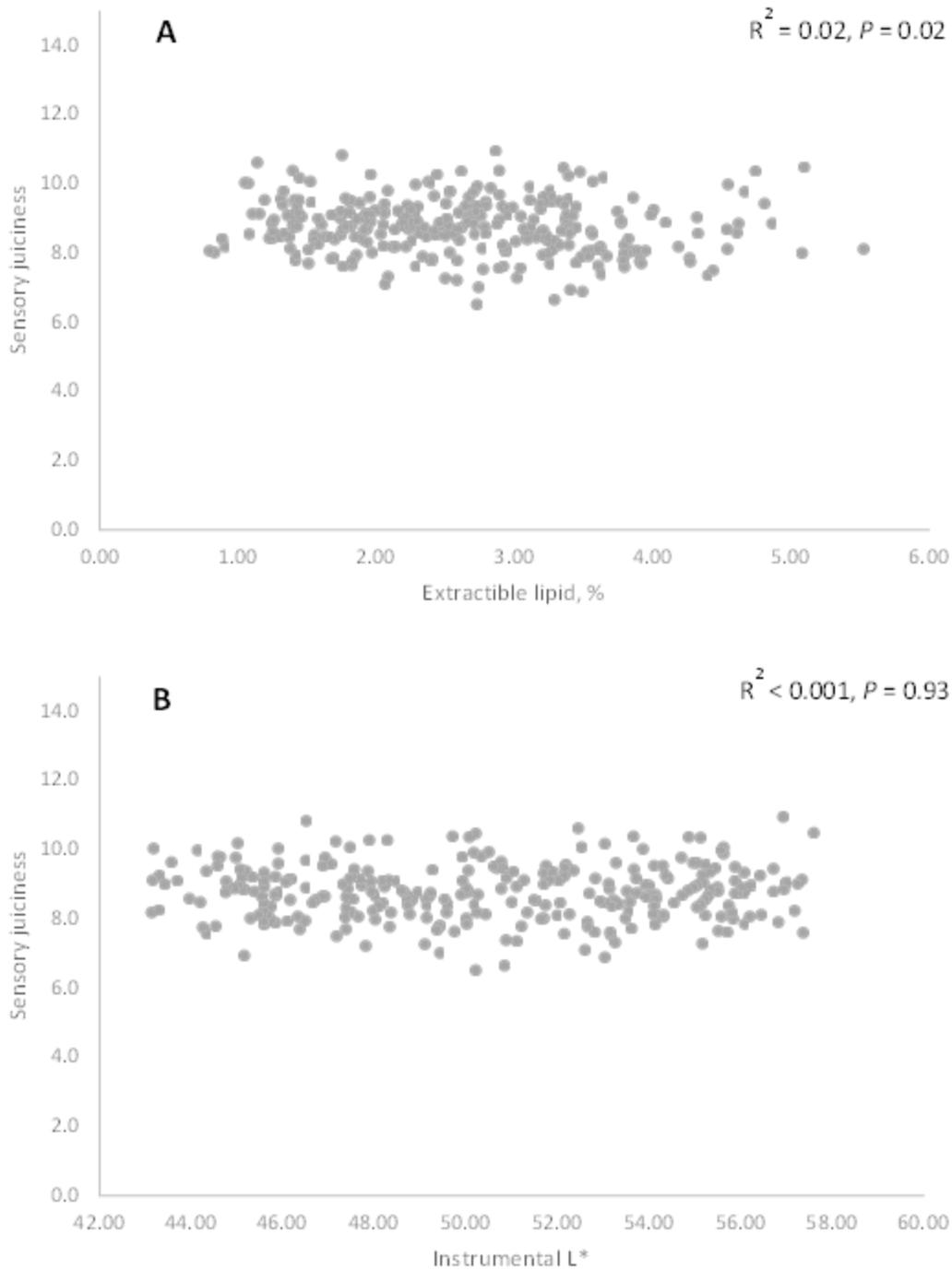


Figure 3.3. Prediction of trained sensory juiciness score using extractable lipid percentage (a) or instrumental L* based NPPC color score (b) as the independent variable. L* measures darkness to lightness (greater L* indicates a lighter color). Sensory attributes evaluated on a 15 point scale, where 0 = extremely tough, dry, or not flavorful and 15 = extremely tender, juicy, or flavorful.

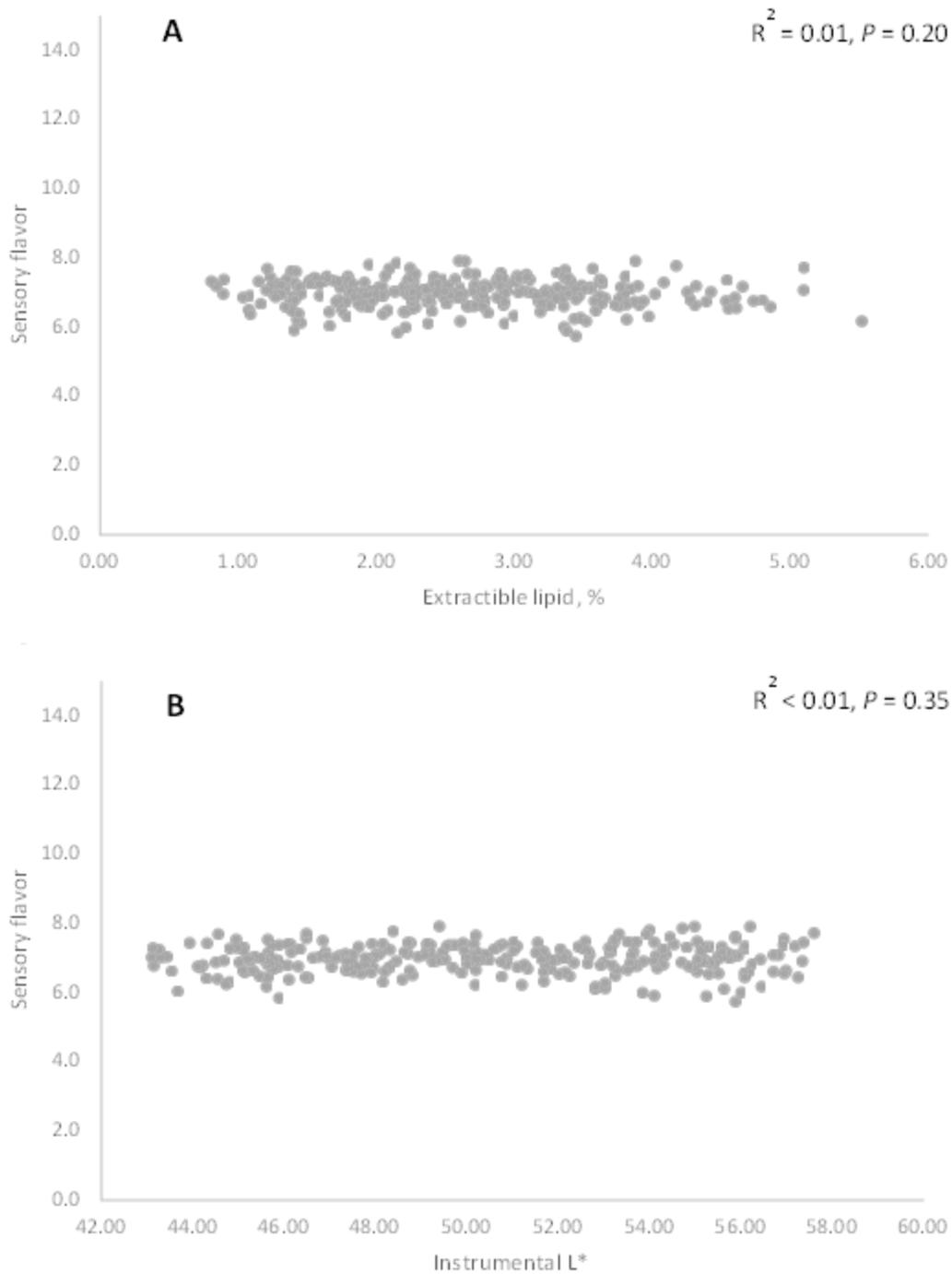


Figure 3.4. Prediction of trained sensory flavor score using extractable lipid percentage (a) or instrumental L* based NPPC color score (b) as the independent variable. L* measures darkness to lightness (greater L* indicates a lighter color). Sensory attributes evaluated on a 15 point scale, where 0 = extremely tough, dry, or not flavorful and 15 = extremely tender, juicy, or flavorful.

Tables

Table 3.1. Population summary statistics of boneless pork loin chop quality

Item	N	Mean	SD	Minimum	Maximum
NPPC color ¹ , 1 to 6	286	3.05	0.56	1.50	5.50
NPPC marbling ² , 1 to 6	286	2.15	0.84	1.00	5.00
NPPC firmness ³ , 1 to 3	286	2.02	0.70	1.00	3.00
Ultimate pH ⁴	286	5.68	0.11	5.43	6.04
Minolta L* ⁵	286	50.45	3.96	43.11	57.60
Minolta a* ⁵	286	9.34	1.17	6.48	13.41
Minolta b* ⁵	286	-0.28	1.07	-3.30	4.60
Cook loss ⁶ , %	284	16.46	3.78	8.22	28.48
Extractable lipid, %	285	2.62	0.94	0.80	5.52
Slice shear force ⁷ ,kg	283	18.57	3.26	11.42	31.38

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

²NPPC marbling using the 1999 standards where 1 = visually the least amount of marbling; and 6 = visually the most amount of marbling.

³NPPC firmness using the 1991 standards where 1 = softest and 6 = firmest.

⁴Ultimate pH collected 14 d postmortem on the ventral side of whole boneless loins.

⁵L* measures darkness to lightness (greater L* indicates a lighter color); a* measures redness (greater a* value indicates a redder color); b* measures yellowness (greater b* value indicates a more yellow color).

⁶Cook loss, % was recorded immediately prior to cooking and following the completion of a 1 minute rest period after chops reached 63 °C.

⁷Slice shear force, kg was collected on chops cooked to a final internal temperature of 63 °C and sheared at an internal temperature of approximately 22 °C.

Table 3.2. Trained sensory panel effects of eating characteristics of boneless pork chops based on the National Pork Board (NPB) quality grade system¹

Item	NPB Quality Grade ¹			SEM	P values
	Low	Medium	High		
Chops, n	33	203	50		
Tenderness ²	9.04	9.10	9.36	0.20	0.13
Juiciness ²	8.94	8.75	8.80	0.14	0.43
Flavor ²	7.09	6.98	6.90	0.07	0.11
Slice Shear Force ³ , kg	19.59 ^a	18.68 ^a	17.50 ^b	0.57	0.01
Cook loss ⁴ , %	16.86	16.68	15.32	0.66	0.06

¹NPB Quality Grade = [(Low: color < 2.5 and marbling ≤ 2.0), (Medium: color 2.0 through 3.5 and marbling ≥ 2.5 or color: 3.0 through 3.5 and marbling: ≤ 2.0 or color ≥ 4.0 and marbling: < 1.5), (High; color 4.0 through 5.0 and marbling ≥ 2.0)].

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

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

⁴Cook loss was recorded immediately prior to cooking and following the completion of a 1 minute rest period after chops reached the desired internal temperature.

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