

**Title:** National Pork Retail Benchmarking Study - NPB # 14-262

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### Industry Summary:

The primary objective of this project was to benchmark fresh pork quality at the retail store level. A great deal of variation in pork quality exists in the retail marketplace, leaving consumers with a broad variety of pork quality characteristics, packaging types, and price levels. Specifically this project gathered pork quality baseline values in the fresh pork retail case.

Nationally, 133 retailers in 29 cities were selected for sampling using a novel selection model. Center-cut loin chops were observed in-store, in package, to obtain subjective color and marbling (n=3795). Enhanced and non-enhanced center-cut loin chops, sirloin chops, and blade steaks of each brand were purchased for measurements of pH, Minolta color (L\*, a\*, and b\*), and tenderness (WBSF).

Key points/excerpts are as follows.

- Center-cut loin chop packages were selected to account for each representative brand and enhancement type available to consumers nationwide.
- Center-cut loin chop packages were selected from the self-serve case to represent different loins and evaluated for subjective measurements of color (NPB 1-6, 2011; NPB 1-6, 2011; n=3795)
- Results indicate a large amount of variation exists in the pork meat case.

**Keywords:** Benchmark; Consumer; Meat; Pork Quality; Retail Store

### Scientific Abstract:

The objective of this study was to quantify pork quality attributes in the retail meat case nationwide. 133 retail supermarkets, representing 29 cities were visited. Center-cut loin chops (CCLC) (n=3795) were analyzed in-store for subjective color and marbling (2.85 and 2.30, respectively). Means for enhanced (EN) and non-enhanced (NON) CCLC were: L\* (54.46 vs. 55.99;  $P < 0.0001$ ), pH (6.00 vs. 5.74;  $P < 0.0001$ ), and Warner-Bratzler Shear Force (WBSF) (20.43 vs. 25.99 N;  $P < 0.0001$ ). Mean EN and NON sirloin chop values were: L\* (53.74 vs. 52.51;  $P = 0.20$ ), pH (6.00 vs. 5.89;  $P = 0.04$ ), and WBSF (16.18 vs. 22.92 N;  $P < 0.0001$ ). Mean EN and NON blade steak values were L\* (45.81 vs. 45.96;  $P = 0.82$ ), pH (6.42 vs. 6.28;  $P = 0.04$ ), WBSF (15.74 vs. 19.42 N;  $P = 0.0005$ ). Results indicate a large amount of variation exists in the pork meat case.

These research results were submitted in fulfillment of checkoff-funded research projects. This report is published directly as submitted by the project's principal investigator. This report has not been peer-reviewed.

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## **Introduction:**

Fresh pork color, pH, water-holding capacity, marbling, tenderness and enhancement type constitute attributes associated with pork quality. One parameter alone cannot define pork quality and numerous factors can impact variation. However, the end goal for all segments of the pork industry is to provide consumers with wholesome pork products. Consumers individually use a variety of factors to determine the quality of pork. Physical factors include color, marbling, subcutaneous fat, and the amount of exudation in package, type of packaging, if the product is bone-in or boneless, firmness and odor. While sensory factors include tenderness, juiciness and flavor of the meat once cooked, where consumers judgement is unique to every individual (Jeremiah, 2001). Mancini and Hunt (2005) described there is a complexity regarding the appearance of meat to due animal genetics, ante- and post-mortem conditions, fundamental muscle chemistry, as well as other factors associated with meat processing like packaging, distribution, storage, display and final preparation for consumption. Purchasing decisions are more commonly impacted by the products appearance compared to any other quality factor (Tapp, 2011). Appearance has a great influence on how meat, including pork is valued by the customer (Fortomaris et al., 2006). Consumers have trouble evaluating pork quality, resulting in uncertainty (Grunert et al., 2004) due to being misinformed on quality attributes and their lack of confidence (Papanagiotou et al., 2013). Predicting these pork quality traits are difficult to measure since there are many factors which are complex, particularly when endeavoring to improve pork quality (Huff- Lonergan et al. 2002).

Pork quality is important to study for the entire swine industry especially in meeting the National Pork Board (2014) Specific/single outcome, Measureable, Achievable, Relevant/realistic and Time bound (SMART) objectives. Specifically for pork quality, the SMART objectives consists of three main goals; “build customer trust, drive sustainable production and grow consumer demand. Under growing consumer demand, a more detailed goal is to by 2020, reduce the percentage of pork loin chops scoring below the National Pork Board color 3 by 10 percentage points as compared to the 2012 retail baseline study (55 percent reduced to 45 percent)”. Therefore, benchmarking pork quality is imperative to distinguish what type of pork the industry is actually providing consumers.

## **Pork Color**

Myoglobin, a heme protein is the pigment of muscle is what gives meat its red color. Myoglobin constitutes 80 to 90 percent of the total pigment (Hedrick et al., 1989). When myoglobin is denatured, the color strength is reduced (Lonergan, 2008). Myoglobin is a water soluble protein that undergoes three chemical states which are associated to the amount of oxygen present or depletion of; Deoxymyoglobin, Oxymyoglobin and Metmyoglobin. The oxidation of the central iron atom in myoglobin decipher the concentration. Deoxymyoglobin causes the meat to turn purple once exposed to oxygen. Once given a bloom time of 10 to 15 minutes the chemical state switches to oxymyoglobin turning to red and finally, brown when at the metmyoglobin stage. The shift of purple to red is a result of myoglobin absorption of oxygen (Brewer et al. 2006). Thus, there is the ability to control the color of meat based on the environment it is exposed to, packaged or stored.

The consistency of fresh pork color in the pork retail self-service display case can influence the consumer’s decision to purchase the pork product. Color is the most important characteristic consumers deliberate when buying pork (Tan et al. 2000; Barbut, 2001; Font-i-Farinois et al. 2012). Typically, consumers will buy pork that is darker versus lighter in color (Brewer & McKeith, 1999; Norman et al., 2003). Consumers evaluate the ‘value’ or quality of pork from their individual expectations of the product and past experience (Brewer, 2001). Color evaluation is the first impression a consumer perceives of the pork (Troy & Kerry, 2010). Therefore, in the purchasing decision, if a consumer is dissatisfied with a poor eating

experience from pork, they have the option to switch to another meat source available (i.e. chicken or beef). Consumers prefer pork that is lean, has a consistent color and little amount of water on the surface (Mabry & Bass, 1998) because they use discoloration as a display of being fresher (Mancini & Hunt, 2005). This agrees with the findings from Buege et al. (2003) that consumers avoid pork that appears to have unusual and variable lean color and excessive amount of purge in the package. Therefore, it's imperative to quantify pork color.

Fresh pork color can be appraised and quantified through a multitude of subjective and instrumental measurements. Subjectively color is measured by an experienced grader using the National Pork Board Color Standards (NPB, 2011). The scale ranges from one to six. A color score of one appears pale, grayish pink to white in its appearance. While a color score of six appears dark, purplish. Wright et al. (2005) determined an average mean color score of boneless loin chops was 3.52. Newman (2012) reported a mean color score in center-cut loin chops of 3.12. Moeller et al. (2010a) reported a subjective color score of 3.13. Whereas, Brewer (2001) reported higher marbled chops were lighter pink in color (2.42) than low and medium marbled chops due to the mixture of white from the marbling and pink color from myoglobin causing more reflection on the surface when observed for coloring. Suggesting, over the years, subjective color has decreased. Subjectively there is also the Japanese standard color model, but is not commonly used in the United States for subjective pork color evaluation. Many pork processors visually inspect color on the processing line to sort various pork retail cuts to sell domestically or to export markets (Forrest, 1998). On March 4<sup>th</sup>, 2011, the National Pork Board eliminated the previous industries slogan which was advertised for over 23 years, and recognized as the fifth most popular slogan in the United States (NPB, 2000), beginning in March 2<sup>nd</sup>, 1987 as, "Pork: The Other White Meat", with a more respectable slogan of "Pork: Be Inspired". Therefore, by changing the slogan in 2011 was applicable to better educate consumers that selecting pork with a reddish to pink color will enhance the palability of the pork.

Pork color can also be evaluated instrumentally. By instrumentally measuring fresh pork color, it eliminates human error by being more accurate and is less time consuming. Instrumental color can be assessed using a spectrophotometer or colorimeter. There are two commercially available colorimeters available; Hunterlab or Minolta Colorimeter. These instrumental devices measure the amount of light reflected from the pork muscle. Additional free water on the surface causes more light reflectance, resulting in lighter pork. Light can either be absorbed, reflected or scattered on the cut surface of meat (Hughes et al., 2014). It measures CIE L\*, a\* and b\* color space values. In meat research, CIE is most commonly used. L\* measures the lightness to darkness (100 = white; 0 = black). Minolta a\* measures the redness to greenness. A more positive a\* measures red, a more negative a\* measures green. Brewer and McKeith (1999) reported a normal a\* value is  $11.04 \pm 0.4$ . Minolta b\* measures the yellowness to blueness. A more positive b\* measures yellow and a more negative b\* measures blue. Brewer & McKeith (1999) reported a normal L\* value is 51.5. Brewer et al. (2001), concluded L\* was not prejudiced by bloom time, resulting it is the best indicator to determine if a carcass is predisposed to becoming pale, soft, and exudative (PSE) or dark, firm, and dry (DFD) pork. Hunter L\* and Minolta L\* values are not affected by bloom time, but decrease with pH (Brewer et al., 2006). Furthermore, Brewer et al., (2001) reported Minolta L\* score should range from 38 to 55. PIC (2003) reported preferred Minolta L\* scores range from 42 to 46. As Minolta L\* values decrease, subjective color increases and vice versa, as Minolta L\* increases, subjective color increases. According to the NPB (2011), an L\* value of 53 represents a subjective color score of 3.

The National Pork Board has established pork quality standards in which it describes three types of pork quality; red, firm and non-exudative (RFN), pale, soft and exudative and dark, firm, dry. The quality standards define fresh pork's color, texture and meat's ability to bind water.

Ideally, the pork industry would prefer to provide consumers with red, firm and non-exudative pork, as it describes the quality of the pork as having a reddish-pink color, firm in its texture displaying no exudation on the cut surface or in package. These characteristics of RFN pork are due to the fact that the carcass has an optimal pH value since proteins like myoglobin are not denatured in the process of the conversion of muscle to meat. It provides a more reddish-pink color since more myoglobin is present in the muscle causing a more firm texture as the muscle fibers are more evenly spaced and contractile proteins do not bind an excessive amount of water.

Abnormalities in pork quality include PSE and DFD pork. PSE pork is not desirable to consumers therefore contributes a large loss to the pork industry. Kauffman et al. (1992) reported in the U.S. 16% of carcasses were PSE, while Cannon et al. (1996) reported 10.2% of carcasses are PSE. Yet, according to Stetzer and McKeith (2003) approximately 15.5% of the pork produced in the United States in 2003 had the characteristics of PSE like pork. PSE occurs when the process of glycolysis occurs at a rapid rate, resulting in a rapid pH decline, lower processing yields, increased cook loss percentage and reduces juiciness (Hedrick et al., 1989). As the name PSE implies, the color appearance displays pale or white lean color, typically having a subjective color score equal to or less than 1.0. Consumers distinguish pork color that appears very light (Brewer & McKeith, 1999). PSE pork is also more prone to display discoloration of green and grey color (Buege, 2003). Furthermore, it is characterized the texture as very soft, because it doesn't hold its shape due to the unfolding of two proteins actin and myosin. As heat is added in the muscle from the carcass, it effects the weak interactions of the proteins. Primarily on the hydrogen bonds, resulting in the proteins from going to a folded to unfolded state due to the high degree of conformational entropy and relatively high free energy not allowing the proteins to accurately bind to water. Thus, causing an excess amount of exudative on the cut surface and in the pork package. Due to the poor water-holding capacity, once cooked it loses additional water, therefore from a palatability standpoint is tough and dry.

Every aspect a pig encounters throughout their lifetime can influence the consistency and quality of pork. Therefore, producers have 50% of the influence as well as packers have 50% of an impact on the quality of pork (Grandin, 2000). Producers have the influence of selecting the genetics, nutrition, pre-slaughter handling and transportation that affects the quality of pork. Packers can impact the quality of an animal's carcass based on on-site handling, time in lairage, method of slaughter, time required to exsanguinate, and chilling rate. Various factors that influence the individual animal throughout an animal's lifetime can impact the quality of the carcass in terms of converting muscle to meat. These factors are crucial to provide RFN pork rather than PSE or DFD pork. First, before a market animal is even born, the producer must consider selecting for genetic economical traits which encompass breed, heritability, and specific genes associated with certain terminal and maternal lines. One particular autosomal recessive gene found in the pig genome that impacts pork quality, but more specifically a contributor to PSE meat is the Halothane Gene (HAL), or also referred to as porcine stress syndrome (PSS). The HAL gene accounts for 25-35% of PSE carcasses (Allison, Johnson & Doumit, 2005). The muscles cannot regulate the abundant amount of Ca<sup>2+</sup> concentrations in the sarcoplasmic reticulum and other calcium channels being released (Bowker et al., 2000; Scheffler & Gerrard, 2007), resulting in an accumulation of lactic acid. One benefit to the HAL gene is the increased muscle lean. Yet, Norman (2002) reported producing lean pork can lead to PSE carcasses. The Rendement Napole (RN<sup>-</sup>) gene is another genetic gene typically found in Hampshire swine (Miller, 2001) that negatively impacts numerous pork quality traits. Carr et al. (2014) reported RN<sup>-</sup> gene pigs significantly had

greater glycolytic potential values, higher drip loss percentage, higher  $a^*$  values and lower pH values than LM samples from non-carrier pigs.

Biochemically, prior to slaughter how swine are handled can impact the quality of pork as it is converted from muscle to meat. It is well known that porcine are susceptible to stress. Thus, the amount of stress a pig experiences, mostly acute stress can influence a pig to produce a PSE carcass. Varying situations to cause the acute stress can range from co-mingling pigs, use of a hot shot on sensitive areas, ground surface, different lighting, moving pigs in large crowds (Norman, 2002) with unfamiliar animals down narrow alleyways, or traveling up steep trailer ramps, use of a hot shot on sensitive body parts or even being exposed to loud or unknown noises. As the animal becomes increasingly stressed, they respond with the fight or flight mechanism. First, there is an endocrine response from the sympathetic nervous system that releases adrenaline (cortisol) from the ACTH in the brain signaling the body to mobilize energy. As the animal becomes increasingly stressed, their body requires more adenosine triphosphate (ATP) or adenosine di phosphate (ADP)/creatine phosphate (CP) to contract muscles. The ATP is fueled by carbohydrates. When oxygen is present, ATP is converted from glucose to the polysaccharide, glycogen, which is a 20+ sugar unit and produces lactate in the muscle which travels through the blood stream into the liver where it is eventually extracted. In addition to this conversion, free inorganic phosphates and ADP convert to ATP in the muscle. Yet, once the animal is rendered unconscious and exsanguinated, the blood flow stops. Therefore, the remaining glycogen is going too continually produce an accumulation of lactic acid in the muscle, resulting in a prompt pH drop until glycogen or ATP stop functioning. Rapid glycolysis also generates significant amounts of heat, which increases the carcass temperature (Du & McCormick, 2009). In conjunction with a rapidly declining pH and high carcass temperature, this results in denaturing of the proteins, especially myosin. During postmortem, the body temperature decreases which decreases the amount of lactic acid and enzymes present causing a more acidic pH level. Yet, with high stress, the increased amount of lactic acid built up in the muscle fibers causes the pH to decline more rapidly. As the accelerated rate of decline in pH occurs to reach its isometric point of 5.1, along with a high carcass temperature that is closer to living body temperature, causes denaturing in protein and ultimately ensuing in PSE pork as proteins myosin and actin don't absorb the light but reflect it, resulting in a more pale product.

Processors additionally have impact on pork quality, including their animal handling techniques, harvest method (i.e. electrical stunning or CO<sub>2</sub> gas), time in lairage, and chilling rates to name a few. Grandin (1994) reported a time period of 2-4 hours pigs should be kept in lairage before harvested to recover from any stress experienced prior to slaughter. Lesiow and Xiong (2013) reported delaying carcass chilling can lead to PSE carcasses. However, another method at the processing facility utilized in the industry by some packers is blast chilling carcasses to reduce the amount of PSE carcasses present.

Contrary of PSE pork, there is Dark, Firm, Dry (DFD) pork. It is similarly related to dark cutter in beef. Dark color is often associated with lack of freshness (Hedrick et al., 1989). DFD is caused by chronic stress that ranges from minutes to hours, as opposed to acute stress in PSE pork. The long term stress contributes to events like extended transport of pigs. Gajana et al. (2013) reported that higher risk incidences of PSE pork occurred when pigs were transported during the autumn season, with transportation time >1 hour 30 minutes and space allowance increased from 0.4 m<sup>2</sup> per 100 kg. Additionally, prior to slaughter, due to long term stress, the muscle glycogen is depleted. PSE causes a more acidic pH, while DFD pork has a more basic pH, since there is a lower amount of acidic production. Since pH declines at a slower rate, proteins are not denatured, but bind more free water, resulting in a greater WHC and ultimately a darker,

firmer product (Miller, 2001). Plus, due to the higher pH value postmortem, typically DFD pork has a shorter shelf life in the retail meat case that causes more bacterial growth and resulting in consumers avoiding this product.

### **Pork pH and Water-Holding Capacity**

The rate at which pH declines can greatly affect the quality of meat. pH is defined as the negative logarithmic of hydrogen ion concentration, also referred to as the acid-base relationship.  $\text{pH} = -\log [\text{H}^+]$ . pH is measured on a scale of 1 to 14. A neutral pH, and the pH of living tissue is 7.0. A pH value above 7.0 is basic, while a pH value below 7.0 is acidic. During the conversion of muscle to meat, pH is typically measured in plant in two increments. Initial pH is measured 30 minutes to 1 hour post-mortem once the onset of rigor mortis is completed, followed by ultimate pH which is measured 24 hours post-mortem. However, for research purposes, it is difficult to collect pH values due to the high line speed at packing facilities (Meisinger, 2008). The rate at which glycolysis occurs can impact the pH of a pork carcass. The amount of glycogen present in the muscle after exsanguination is broken down and directly correlated to the amount of lactic acid it converts to (Lonergan, 2008). Thus, the more glycogen in the muscle, results in a lower ultimate pH (Lonergan, 2008). Prior to slaughter the pH of living muscle is 7.0. Forrest (1998), reported measuring pH 45 minutes postharvest is a more proven method to detecting PSE pork early on. O'Neill et al. (2003) reported an initial pH 45 minutes postmortem < 5.7-6.0 results in PSE carcasses. A low ultimate pH reflects more light causing a lower subjective and instrumental color score, because the light is not absorbed (Huff-Lonergan et al., 2002). PIC (2003) reported PSE pork has an initial pH below 5.8, and an ultimate pH below 5.5, and ideal ranges for initial pH should range from 6.7 to 6.3 and ultimate pH to be 6.1 to 5.7. But, Forrest (1998), reported 99% of pork will be PSE like pork if the ultimate pH is 5.5 or lower. Bidner et al. (2004) indicated 57.4% of loins had an ultimate pH between 5.4 and 6.1. Moeller et al. (2010) reported an ultimate pH near 5.40 reduced consumer's satisfaction, while a pH up to 6.40 increases the amount of juiciness, tenderness and flavor factors. Furthermore, a study by (Aberle et al., 2001) showed that ultimate pH is related to water holding capacity. A higher pH holds more free water, to increase cook yield. Proteins are responsible for binding water (Lonergan, 2008) which influences meats texture and color. Two major proteins, actin and myosin, within the muscle are denatured and lose their secondary and tertiary protein structure during post-mortem as the carcass is cooling and pH drops. At a pH of 5.1, the proteins have no net charge (Lonergan, 2008). Yet, Huff-Lonergan & Lonergan (2005) reported when the proteins reach the isoelectric point (pI) of 5.4 it signifies when the negative and positive charges are equal to one another, causing an increase in the water holding capacity of raw meat. Once water binds to proteins with zero net charge, the amount of water attracted to muscle proteins decrease. Aberle et al. (2001) showed that ultimate pH is related to water holding capacity once the pH reaches its isoelectric point of contractile proteins actin and myosin. The amount of water pork muscles retain is defined as water-holding capacity (WHC). The amount of water-holding capacity a pork muscle has can be measured by its amount of drip loss, purge loss or cook loss. About 75% of water is in post-rigor muscle (Hughes et al., 2014). PIC (2003) reported above 5% drip loss and above 35% cook loss and greater than 3% purge in whole loin packages designates a pork quality problem. Huff-Lonergan et al. (2002) reported a higher ultimate pH results in darker color and reduced drip loss. Vice versa, a lower ultimate pH will result in more exudation, causing more light to be reflected, instead of absorbed. In general, consumers believe the water loss on the bottom of pork packages to be blood due to its red appearance and have a tendency to avoid these products exhibiting an excessive amount of exudation.

## **Pork Marbling**

The intramuscular fat within the muscle fibers of meat is considered marbling. Intramuscular fat is measured chemically, while subjective marbling is measured by an experienced grader (Jeremiah, 2001) using the National Pork Board Marbling Standards (NPB, 2011). Which consists of a range of one to ten to signify the minimum percentage degree for each score. A marbling score of one is practically devoid of intramuscular fat, while a ten has an abundant amount of marbling on the loin chop surface. The experienced grader evaluates the amount of fat deposited based on the number, size and shape.

The amount of marbling present may be influenced by the amount of connective tissue, genetics, sex, age, or even type or time amount the pigs are on a certain phase feeding ration. Collagen and elastin are the proteins components in connective tissue (Monin, 1998). There is currently a tendency in the swine industry to select swine genetics the produce more efficient swine that are leaner and more expressively muscled. Huff-Lonergan et al. (2002) reported hogs that have a higher percent lean harvest carcasses exhibiting less marbling in pork chops as compared to hogs that harvest carcasses with more 10<sup>th</sup> rib backfat. Additionally, gilts tend to have a higher percent lean than barrows. Various studies have proven that marbling is associated with juiciness and flavor, but not correlated with tenderness, because the research is not consistent. However, this disagrees with De Vol et al., (1998) that IMF and tenderness are correlated ( $r=0.34$ ) when evaluated by a trained taste panel because lower IMF levels resulted in tougher meat. Cannanta et al. (2012) reported when IMF was 2.5% or greater tenderness and juiciness increased. Similarly, Fernandez et al. (1999a) reported when IMF values reached 2.5 % juiciness and flavor was enhanced. As well, Brewer et al. (2001) reported chops with 3 to 5 % IMF were more juicy, tender and flavorful than lower marbled chops that had 1 to 1.5 % IMF, although consumers accepted purchasing lower marbled chops Furthermore, Font-i-Farinos et al. (2012) recommended 2.2-3.4 % minimum of IMF improves eating satisfactoriness. Papanagiotou et al. (2013) reported marbling is the most important factor to consumers. The majority of U.S. pork is exported to countries such as Japan, who demand high marbling. Yet controversy, in a study conducted by (Rincker, 2008) on intramuscular fat content in pork loin chops, concluded that nearly 50 % of the consumers in a sensory panel selected pork loin chops in a display case with the least amount of marbling, but said they would purchase pork that is leaner. These findings support Jeremiah (2001) stating that consumers request a small amount of visual IMF, while still having an acceptable eating experience. Therefore, in the different swine industry segments, especially producer decisions need to be made because one factor is going to have an antagonist effect on the other (i.e. percent lean and backfat). (Moeller et al., 2010) suggested IMF levels of 5-6% would improve pork flavor, but contribute very little or have no influence on consumer's perceptions of juiciness or tenderness attributes. Breed has an effect on the amount of marbling present on loin chops. Berkshire display the most amount of marbling (Brewer et al., 2002) due to breeders selecting for lower percent lean or niche markets. The intermingling fat may influence consumer's purchasing decisions if concerned about their caloric or cholesterol intake. However, Jones et al. (1992) reported a 100gm sample displaying a small degree of marbling contains 69 calories, while a sample with a slight degree of marbling contains 63 calories, concluding increased marbling does not impact the amount of calories. Brewer (2001) reported low and medium marbled chops were more accepting than highly marbled chops as well as for consumers purchase intent. Fernandez et al. (1999) reported that as the amount of intramuscular fat increased, consumers responses decreased for positive answers in response of willingness to eat. From the same study, as intramuscular fat increased to up 3.5%, consumer's responses for texture and taste were more satisfactory. Yet, from the second experiment in the study, intramuscular fat levels were unaffected when loin

chops were trimmed of external fat. These findings also agree with Wright et al. (2005) where consumers purchase intent increased with more highly marbled pork, resulting in the pork to be more tender, juicy and flavorful.

### **Pork Tenderness**

In general, consumers consider tenderness to be the most influential factor associated to the palability of pork (Koohmaraie, 1996; Koohmaraie et al., 2002; Koohmaraie et al., 2006). Tenderness deals with the skeletal muscle structure and biochemistry of muscle. Measuring pork tenderness via trained sensory panels, or consumer panels is time consuming and costly, so instrumentally measuring tenderness is a more accurate way to quantify tenderness. There are a variety of ways to instrumentally measure pork tenderness, which includes the Warner-Bratzler Shear Force (WBSF), slice shear force (SSF), or the star probe method. The WBSF method was established in 1932, and is the most accepting methodology to quantify tenderness in the meat industry. The device has yet to be modified from the original version. Recently, the SSF method was developed (Shackelford et al., 1999b) as another method to determine tenderness in meat. Shackelford et al. (2004a) compared SSF and WBSF in pork loins and determined SSF had a higher CV (32%), then WBSF (19%) to determine pork tenderness in the *Longissimus* muscle. The WBSF method measures the force necessary to shear through a cored piece of meat parallel to the muscle fibers of cooked meat against a dull blade. A lower shear force value represents more tender pork, whereas a higher shear force value represents a more tough pork product. The method is designed to mimic a consumer biting down on a piece of pork. Moeller et al. (2010b) reported trained sensory panelists favored pork with a WBSF value less than 24.5 N but could determine the difference in tenderness for every 4.9 N increase above 24.5 N and therefore the panelists acceptability decreased by 4 %. Norman et al. (2003) reported trained panelists had a more tender and juicy product when evaluating darker colored pork compared to lighter colored pork. Wheeler et al. (1994) reported the orientation of the core to the muscle fibers and cooking method conditions significantly influenced the shear force values reported. As well, Wheeler et al. (1996) determined after 5 cores in steaks, there was little difference in WBSF values.

Meat tenderness is determined by the amount of connective tissue, IMF content and myofibrillar structure (Laack, Stevens, & Stalder, 2001). Intrinsic factors that influence pork tenderness include sarcomere length, age of the animal, the amount of connective tissue (perimysium), marbling content, and location of muscle. The shorter the sarcomere length, the more tough meat is due to the amount of myofibrillar spacing between actin and myosin (Hughes et al., 2014). Additionally, the increased spacing between the sarcomere results in more moisture loss and ultimately once pork is cooked will have negative sensory characteristics because the pork tastes drier. Wheeler et al. (2000) evaluated 5 pork muscles (*Semitendinosus*, *Triceps brachii*, *Longissimus*, *Semimembranosus*, and *Biceps femoris*) to determine the differences in tenderness based on sarcomere length and the amount of collagen and desmin present. The results indicated the various muscles obtained various tenderness values and tenderness and connective tissue are highly correlated (Wheeler et al., 2000). From the perspective of a pig carcass, there are muscles of locomotion, as well as muscles of posture. The muscles of locomotion include the picnic shoulder, Boston butt and ham, which are more commonly used for movement. These muscles tend to be more glycolytic and used for strength, therefore tend to be less tender. While the muscles of posture include the loin, do less work so as a result, tend to be more tender. van Laack, Stevens & Stalder (2001) found among three breeds of swine Hampshire, Berkshire and Duroc, Duroc was the only breed with IMF and WBSF correlated, suggesting the relationship is due to genotypes.

## **Enhancement Type**

The pork industry has implemented the use of enhancement, or the addition of non-meat ingredients to fresh pork primals and subprimals in a water-based solution, to improve the juiciness, tenderness and flavor of pork and as a degree of doneness increases, enhancement has been shown to have a protective effect on pork palability (Moeller et al., 2009). Over the last 10 years, non-enhanced pork represents 55.1 % and enhanced pork represents 44.9 % of fresh pork at the retail level (Reicks et al., 2008). Reicks et al. (2008) also noted compared to any other protein, pork significantly ( $P < 0.001$ ) represents the largest amount of enhanced product in the retail meat case. A snapshot of today's retail meat case, (2010) reported since 2004 to 2010, enhanced pork available to consumers decreased by 6 %. The trend for marketing non-enhanced pork is expected to increase due to potential health concerns associated with eating pork products enhanced with sodium and phosphate (McEwen & Mandell, 2011). Advantages to enhancing pork include improving ultimate pH (Sheard et al., 1999), pork color, increasing water-holding capacity tenderness and juiciness (Miller, 2002), and the shelf life of pork as it reduces the browning of the meat while stored. Wright et al. (2005) determined enhanced boneless pork loin chops were darker in color with a mean color score of 3.59 as compared to non-enhanced boneless pork loins having a mean color score of 3.46. Phosphates increase the water-holding capacity of meat (Hedrick et al., 1989). Lonergan (2008) reported that adding salt, another non-meat ingredient to the myofibrillar proteins in muscle increases water-holding capacity. Furthermore, Sheard et al. (1999) reported adding 0.25-0.5 grams of polyphosphate per 100 gram of pork steaks improves tenderness and juiciness. These results agree with Prestat et al. (2002) that enhancing pork increases tenderness, juiciness, and flavor. Brewer et al. (2002) recommended adding 6-12 % of solution improves pork quality. The USDA/FSIS requires labeling regulations on packages describing the percent of enhanced solution added to the product. Disadvantages to enhancing pork include the formation of enhancement striping which visually causes light and dark stripes on the cut surface from the injection of non-meat ingredients. Gooding et al. (2009) reported enhanced longissimus samples significantly ( $P < 0.05$ ) had higher incidences of striping for various experiments conducted using different brines, brine concentrations, brine temperature enhancement pressure, and enhancement level. Furthermore, enhancement striping occurs immediately, and is difficult to eliminate and a permanent problem (Gooding et al., 2009). Carr et al. (2014) determined eliminating pork quality problems associated with the Rendement Napole gene did not improve after enhancing pork loins. Additionally, consumers are aware of the added sodium in enhanced product versus non-enhanced product. Therefore, marketing non-enhanced pork will potentially increase due to health concerns related with eating pork products enhanced with various solutions. Resurreccion (2003) reported consumers believe high-fat and high-protein meat will increase their incidences of developing health problems (i.e. high blood pressure, cancer, heart disease). Williams et al. (2011) reported sodium content of enhanced pork is 2.5 to 5.2 times greater than non-enhanced pork in fresh pork tenderloin, shoulder blade, and top loin cuts.

## **Consumer Preference**

Over the years, there have been many studies conducted to determine what consumers prefer in their pork product, as well as their intent to buy. The National Pork Board conducted a pork purchasing study (NPB, 2012) where they determined consumers add pork to their shopping list as a result of a request, sale or advertisement (in-store, media, marketing, mail) and are particular about where they purchase their pork compared to other protein sources. Brewer et al. (2001b) determined consumers will purchase leaner pork,

but want pork that is higher marbled to increase sensory characteristics. Ngapo et al. (2007) reported across different countries, women preferred leaner pork than men. ISU educated a consumer panel the difference between pork that was categorized as high pH, low pH and Berkshire pork based on their appearances. Consumers accepted pork that had a higher pH, followed by Berkshire pork and lastly lower pH pork that was rated on a scale 1-9 for tenderness, juiciness and flavor (McMullen, 2005). Aaslyng et al. (2006) concluded in terms of pork quality attributes, pork color was the only parameter that male and female consumers had different opinions on. Males were not influenced by pork color, whereas, females preferred pork color to be more light or grey in color. The National Pork Board classifies “pork champions” as men and women who are principally medium to heavy fresh pork users.

Consumers over cook pork (Detienne & Wicker, 1999). Therefore, Moeller et al. (2010a; 2010b) conducted two tests determining pork quality on different end-point cooked temperatures for consumers and trained panelists to determine what type of pork consumers accept, want and prefer. The authors reported WBSF and pH greatly are important to the palatability. Consumer’s desired pork loins cooked to lower end-point temperature, had a greater ultimate pH and IMF values which positively impacted palatability of the loins. However, IMF did not influence the consumer’s perception of tenderness, juiciness or flavor of the pork (Moeller et al., 2010a; Rincker et al., 2008). By benchmarking what consumers want, based on their preference of lower end-point cooked temperatures, and food safety regulations in May 2011, the USDA/FSIS changed the recommended end-point cooking temperatures of whole cuts of pork of 160°F to 145°F (USDA, 2013) to provide and educate consumers that cooking pork with a lower internal temperature will improve their pork eating experience.

### **Benchmarking Pork Quality**

A variety of benchmarking studies have been conducted relevant to pork quality. In response to the Pork Chain Quality Survey Audit, pork quality attributes were ranked at slaughter to benchmark various pork quality defects. Pearson et al. (2005a) first examined how PSE pork in bone-in and boneless hams influenced the quality. Person et al. (2005b) researched benchmarking value in the pork supply chain, first on processing characteristics and consumer evaluations of pork bellies of different thicknesses when manufactured into bacon due to the rapid growth of bacon sales in the 90’s. Subjectively, pork bellies were organized into three distinct thickness groups, thin, average and thick. 96 bellies were assigned to each group, where the bellies were first skinned to determine yield, injected with a curing solution, cooled, and then sliced into bacon with specific dimensions and musculature. It was concluded, that although the larger yields associated with a thick belly were beneficial to the packer, and the consumer response was unfavorable due to an ample amount of fatness. Inversely, the thin to average cuts had reduced yields, however were more appealing to consumers palatability.

The National Meat Case Study was first conducted in 2002, 2004 (Reicks et al., 2008), 2007 and then in 2010 (A snapshot of today’s retail meat case, 2010). The 2004 benchmarking study focused on the various labeling information, brands, and packaging types and the trends associated for all meat sources consumers were being offered in the retail meat case. Following, in 2010 the 2010 National Meat Case Study was conducted to compare changes evident in the meat case. No product was bought in either of the studies. A few major evident differences were the availability of store brands tripled, increased package information regarding cooking recommendations (34 % vs. 39%), and increased case-ready packages (in pork, 50% vs. 58 %) (A snapshot of today’s retail meat case, 2010). Each year of benchmarking the meat case, pork ranked third every year, 2002 (21 %), 2004 (22 %), 2007 (21 %), and 2010 (20 %) in available linear feet in the self-serve meat case, indicating over the years the linear footage of pork has decreased. Benchmarking in the retail meat case is essential to understand and more effectively meet consumer’s demands.

Wright et al. (2005) also benchmarked value in the pork supply chain but in the characterization of US pork in the retail marketplace on both processed and fresh meat. There is a great deal of variation in pork quality values, specifically 12.5 % of pork loin chops in the retail marketplace are quantified as low quality (Wright et al., 2005).

The most recent benchmarking study in 2012 (Newman, 2012) conducted a national benchmarking pork quality retail study to quantify pork quality to determine what consumers are being offered at the retail level. From the 117 retail stores visited, the author reported an average subjective color score of 3.12, subjective marbling score of 2.48, Minolta L\* of 55.30, Minolta a\* of 5.89, Minolta b\* of 3.73, pH value of 5.86, and WBSF value of 23.39 N in center-cut loin chops, and in sirloin chops Minolta L\* of 51.92, Minolta a\* of 19.50, Minolta b\* of 10.06, pH value of 5.88, and WBSF value of 18.71 N, and in blade steaks Minolta L\* of 45.27, Minolta a\* of 19.70, Minolta b\* of 8.13, pH value of 6.22, and WBSF value of 17.12 N (Newman, 2012). The results indicate that there is a lot of variation in the retail meat case. In the United States there is currently not a ‘pork grading’ system established based upon pork quality attributes. However due to the variety of variation in the retail meat case, the future of the pork industry could develop such a system.

### **Objectives:**

**The primary objective of this project is to benchmark fresh pork quality at the retail store level.** A great deal of variation in pork quality exists in the retail marketplace, leaving consumers with a broad variety of pork quality characteristics, packaging types, and price levels.

The specific objectives of the study are outlined below:

- Use a novel method for determining retail locations nationwide utilizing retail store information from Progressive Grocer’s 2011 Marketing Guidebook (Stagnito Media, 2011) in combination with census data from the major United States metropolitan market areas.
- Gather price, package, and pork quality baseline values on fresh pork in the retail case. Information on all fresh whole-muscle pork products in the meat case will be evaluated. Fresh pork loin chops (center-cut), sirloin chop or roast, and blade steak or roast will be purchased for further analysis of quality. A cross-section of price for products that compete against pork (beef, poultry) will be evaluated at time of collection.
- Information collected will be utilized by retailers, processors, and other industry stakeholders to identify areas of challenge and needed improvement in order to provide consumers with consistent, safe, high quality pork products.

Additionally, relating the aforementioned attributes with consumer perception and purchase intent will provide the pork industry greater understanding of how these factors impact purchase of pork

### **Materials & Methods:**

#### **NATIONAL PORK RETAIL BENCHMARKING STUDY: CENTER-CUT LOIN CHOP, SIRLOIN CHOP, AND BLADE STEAK ANALYSIS**

##### **Retail Store Selection and Sampling**

North Dakota State University, The Ohio State University, and The University of Florida collaborated to benchmark pork quality from the top 3 major retailers and supermarkets according to the

2013 Progressive Grocer Marketing Guidebook (Stagnito Media, 2013). The Progressive Grocer Marketing Guidebook did not include club stores, however for the purpose of this study, club stores were included in the model. Cities sampled were identified (Table. 1) from 7 different market regions. Retail stores within each city were selected based on the following criteria 1) Geographic population distribution and major retailers, both national and regional. 2) Top 3 retail supermarkets in each city. 3) Retail stores where middle class income consumers most frequently purchase pork. One hundred and thirty-three retail supermarkets, representing 29 cities from across 23 states were selected for the study (Table 2). From each University there was a principal investigator assisted by a trained group of meat science graduate students. Three months prior to data collection, each principal investigator and the National Pork Board Retail Marketing Team met in Chicago, Illinois for a training session to plan, organize and discuss the data collection process, determine which specific stores and store locations within market regions would be visited for the study. Boneless and bone-in center-cut loin chop, sirloin chop and blade steak samples were collected between January 2015 and April 2015 to eliminate any holiday or seasonal merchandizing variation. Retail supermarkets were visited between the hours of 9 A.M. and 5 P.M. In-store data collection parameters included 1.) Store Information- date store was visited; store name and store identification number; address; state; zip; investigators; time store entered; time collection ended; linear footage in full and self-serve meat case for coffin, tiers and number of tiers; promotional items present for any pork, beef, poultry, other or none; stand up displays present for any pork, beef, poultry, other or none; cooking brochures for any pork, beef, poultry, other or none; coupons for any pork, beef, poultry, other or none; type of lighting (white LED, pink LED, or Florescent); three light (lumens) for tired and coffin display cases; compliance with pork nomenclature 2.) Self-Serve Pork Case Assessment: brand/packer; specific item description (nomenclature); cut (loin, sirloin, blade); bone-in or boneless; chop or roast; number of packages available; number of pieces per package; packaging type (modified atmosphere packaging, vacuum packaging, overwrap packaging); establishment number, product thickness (1,2,3); original price per pound; product label claims; recipe (sticker, price label, none); temperature recommendation (sticker, price label, none); temperature; sell-by-date; packed-on date, enhanced (yes or no); enhancement percent 3.) Package Quality Assessment: brand; packer; cut (loin, sirloin, blade); bone-in or boneless; package #; chop letter; color score (1-6); marbling (0-10); sell-by-date; blood splash; bruised; bone dust; purchased. Only center-cut loin chop (n= 3795) packages were randomly selected from the retail self-serve meat case and assessed under store lighting by an experienced grader for subjective color (NPB 1-6, 2011), and subjective marbling (NPB 1-10, 2011) and any pork quality defects including blood splash; bruised; bone dust.

**Table 1. Identification of cities included in retail store sampling by region.**

	Region <sup>1</sup>						
	EC	MA	NE	PA	SE	SW	WC
Cities	Columbus	New York City	Boston	Los Angeles	Atlanta	Dallas	Chicago
	Detroit	Philadelphia	Hartford	Phoenix	Charlotte	Houston	Denver
	Indianapolis			Portland	Memphis	San Antonio	Des Moines
	Pittsburgh			Salt Lake City	Miami		Kansas City
				San Francisco	Tampa		Milwaukee
				Seattle			Minneapolis
							St. Louis

<sup>1</sup> EC = East Central; MA = Mid-Atlantic; NE = New England; PA = Pacific; SE = Southeast; SW = Southwest; WC = West Central

**Table 2. Center-cut loin chop, sirloin chop, and blade steak demographics by region across the United States.**

	Region <sup>1</sup>							National
	EC	MA	NE	PA	SE	SW	WC	
<b><i>Center-Cut Loin Chops</i></b>								
Cities included	4	2	2	6	5	2	7	28
Market areas included								
Stores assessed	19	12	12	29	22	11	38	143
Brands assessed	8	10	11	18	14	9	14	84
<b>Packages Observed<sup>2</sup></b>								
Enhanced	76	23	10	90	47	31	150	427
Non-enhanced	150	112	116	216	139	76	219	1,028
<b>Packages Purchased<sup>3</sup></b>								
Enhanced	76	23	10	90	47	31	150	427
Non-enhanced	150	115	93	217	178	76	251	1,080
<b><i>Sirloin Chops</i></b>								
Cities included	1	1	2	6	4	1	5	20
Market areas included								
Stores assessed	2	1	7	16	8	5	12	51
Brands assessed	1	1	5	9	5	3	7	31
<b>Packages Purchased<sup>3</sup></b>								
Enhanced	11	0	6	25	0	2	34	78
Non-enhanced	0	3	26	53	40	8	25	155
<b><i>Blade Steaks</i></b>								
Cities included	1	0	2	6	5	2	5	21
Market areas included								
Stores assessed	1	0	2	13	13	5	16	50
Brands assessed	1	0	2	7	7	4	7	28
<b>Packages Purchased<sup>3</sup></b>								
Enhanced	5	0	0	19	9	3	20	56
Non-enhanced	0	0	4	43	44	12	67	170

<sup>1</sup> EC = East Central; MA = Mid-Atlantic; NE = New England; PA = Pacific; SE = Southeast; SW = Southwest; WC = West Central

<sup>2</sup> Number of packages of center-cut loin chops used for subjective, in-store assessment.

<sup>3</sup> Number of packages of center-cut loin chops purchased for instrumental assessment at North Dakota State University.

## In-Store Subjective Assessment

Subjective color score (1= pale, grayish pink, white to 6=dark, purplish) on 10 randomly selected boneless and bone-in center-cut loin chop packages for each brand and enhancement type (enhanced (EN) or non-enhanced (NON)) according to the National Pork Board Color Standards (NPB, 2011) under store lighting was assessed by an experienced grader in the self-serve meat case. Subjective marbling score (1=practically devoid of marbling to 10=abundant of marbling) on 10 randomly selected boneless and bone-in center-cut loin chop packages for each brand and enhancement type (enhanced (EN) or non-enhanced (NON)) according to the National Pork Board Marbling Standards (NPB, 2011) under store lighting was assessed by an experienced grader in the self-serve meat case. Each center-cut loin chop randomly selected for evaluation for both subjective color and marbling scores exposed at least 50% of lean muscle in each package. The random selection for center-cut loin chops preference was given to boneless, 2.54-cm-thick center-cut loin chops. However, due to regional differences in pork availability, bone-in center-cut loin chops and the closest thickness for center-cut loin chop samples were also selected for analyzation. When available, 10 packages containing a minimum of at least 2 center-cut loin chop, sirloin chop, and blade steak packages were purchased for each brand or enhancement type (enhanced (EN) or non-enhanced (NON)). Sirloin chop and blade steak packages exposed at least 50% of lean

muscle in each package. Each of the 10 individual packages purchased were labeled 1 thru 10. Depending on the number of center-cut loin chops available per package, and each center-cut loin chop that was analyzed received a letter (A to D) for record purposes. Once purchased, center-cut loin chop, sirloin chop, and blade steak packages were placed in either a Yeti Cooler or hard plastic cooler with reusable frozen ice packs. Coolers were shipped priority overnight to North Dakota State University (NDSU) for further subjective and instrumental measurements in-laboratory as described below.

### **In-Laboratory Subjective Measurements**

Once coolers arrived at NDSU for in-laboratory assessment, arrival time and three internal cooler temperatures (top, middle, and bottom) were recorded. Additionally, all package information was re-recorded. Each package type was opened, and each center-cut loin chop, sirloin chop, and blade steak purchased was placed on a foodservice tray and designated a center-cut loin chop, sirloin chop, or blade steak number. The center-cut loin chops, sirloin chops, and blade steaks were allowed a minimum 15 minute “bloom time”. After bloom, an experienced grader assessed each center-cut loin chop, sirloin chop, and blade steak for subjective color score according to the National Pork Board Color Standards (NPB, 2011) under controlled lighting. After determining color score, the experienced grader assessed the same center-cut loin chops, sirloin chops, and blade steaks for subjective marbling score according to the National Pork Board Marbling Standards (NPB, 2011) under controlled lighting in-laboratory.

### **Instrumental Color Measurement**

After subjective analysis, instrumental color (CIE L\*, a\*, and b\* color space values) were measured using a Minolta Colorimeter (CR-300, 8 mm diameter head, 10° standard observer, C light source; Minolta Company, Ramsey, NJ) that was calibrated to a white tile with Yxy data (Y=94.8, x=.3131, y=.3191) The Minolta head was firmly placed directly in the center of the *Longissimus* muscle of the center-cut loin chop, *Gluteus medius* muscle of the sirloin chop and *Serratus ventralis* muscle of the blade steak on the surface of the meat to record L\*, a\*, and b\* color space values.

### **pH Measurement**

A minimum of one randomly selected center-cut loin chop, sirloin chop, and blade steak from each package was used to obtain pH values. Center-cut loin chop, sirloin chop, and blade steak pH was acquired using a portable pH meter (HI 98240; Hanna Instruments, Italy) equipped with a glass tipped pH probe (FC232D, Hanna Instruments, Italy) which was calibrated to pH 7.01 and 4.01 in two different buffer solutions. The probe was inserted directly into the middle of the *Longissimus* muscle of the center-cut loin chop, *Gluteus medius* muscle of the sirloin chop and *Serratus ventralis* muscle of the blade steak parallel to the cut surface. After every 10 center-cut loin chops, sirloin chops, and blade steaks the pH probe was recalibrated.

### **Warner-Bratzler Shear Force and Cook-Loss Percentage Measurements**

Each center-cut loin chop, sirloin chop, and blade steak that was analyzed for subjective color, subjective marbling and instrumental color was also selected for measuring tenderness using the Warner-Bratzler Shear Force (WBSF) method. Each center-cut loin chop, sirloin chop, and blade steak along with its chop identification number was individually placed in a vacuum package bag, was sealed and frozen at -20°C. Center-cut loin chops, sirloin chops, and blade steaks were thawed in the vacuum sealed package 24 hours in a cooler at 4°C. Once completely thawed, samples were removed from the vacuum sealed package and placed on a silver foodservice tray. Each center-cut loin chop, sirloin chop, and blade steak had a thermocouple (TT-J-36-SLE; Omega Engineering, Inc., Stamford, CT) inserted

into the geometric center of the *Longissimus* muscle of the center-cut loin chop, *Gluteus medius* muscle of the sirloin chop and *Serratus ventralis* muscle of the blade steak to determine internal temperature for each pork sample using a large bore needle (14 g needle; Hamilton 7749-05 8" PTA N714). Each center-cut loin chop, sirloin chop, and blade steak was weighted using a digital electronic weighing scale (model AND EK-300i; A&D Company Limited, Tokyo, Japan) prior to being cooked to determine the on weight. The thermocouple was inserted into a hand-held temperature device (model HH-21; Omega Engineering, Inc., Stamford, CT) to determine the on temperature. As well, before placing the center-cut loin chop, sirloin chop, and blade steak onto the clam-style cooker (George Foreman Grill), the grill was preheated for approximately 10 minutes to 350°F (176.7°C) and the on time was recorded. The center-cut loin chop, sirloin chop, and blade steak was placed on the grill with both cooking plates on both the top and bottom in a fume hood and cooked until it reached a desired internal temperature of 65°C (149°F). Once the center-cut loin chop, sirloin chop, and blade steak reached the desired internal temperature, it was immediately removed from the grill and off temperature and end time was recorded. Cooked samples were then placed back on a different silver foodservice tray. Five minutes after the center-cut loin chop, sirloin chop, and blade steak was removed from the grill, it was re-weighed on the scale to determine the cook-loss percentage. Center-cut loin chops, sirloin chop, and blade steak were cooled for approximately 4 hours or to approximately 22.2°C prior to beginning the WBSF analysis. Six, 1.27 cm diameter cores parallel to the longitudinal orientation of the muscle fibers were removed from each cooked *Longissimus* muscle of the center-cut loin chop, *Gluteus medius* muscle of the sirloin chop, and the *Serratus ventralis* muscle of the blade steak. All six cored samples were then sheared using the WBSF device (United Smart-1 Test Systems SSTM-500; United Calibration Corp., Huntington Beach, CA) certified by the United Testing Systems, Inc. Individually one of the six core samples were inserted and held in-between the 1.168 cm Warner-Bratzler stainless steel blade. This step was repeated until all 6 core samples had undergone the tenderness assessment. The maximum force for each of the six cores were recorded in kg. The average values were converted to Newton's from kg (1 kg= 9.81 N).

### **Statistical Analysis**

Data was analyzed using generalized least squares (PROC MIXED, SAS Institute, Cary, NC). Center-cut loin chops, or sirloin chops, or blade steaks were the experimental unit. The model included enhancement type and the interaction between enhancement type and region as fixed effects and package within region, retailer, store, and brand as a random effect. Additionally, Pearson correlations were calculated across and within enhancement type using PROC CORR (SAS Institute, Cary, NC) to determine the relationship between Minolta color (L\*, a\*, and b\*), pH, and WBSF.

### **Results:**

#### **Results for national pork retail benchmarking study: center-cut loin chop, sirloin chop, and blade steak analysis**

#### **Product Demographics**

The number of packages observed and purchased in each product category for regional totals are further described in Table 2. Overall, in-store 427 EN and 1,028 NON packages of center-cut loin chops were observed for subjective assessment of color and marbling scores. Instrumental in-laboratory assessment

included 427 EN and 1,080 NON center-cut loin chop packages, 78 EN and 155 NON sirloin chop packages, and 56 EN and 170 NON blade steak purchased packages. Regional differences in product availability were found for sirloin chops, by which the EC, MA, NE and SW regions offered a very constrained selection of sirloin chops. In contrast for sirloin chop packages, the PA and WC regions had a much larger selection for purchase. Similarly, for blade steaks, the EC, MA, NE, SE, and SW regions offered very constrained selection of blade steaks. There were no blade steaks available in the MA region for EN product. Whereas, blade steaks were more readily available for purchase within the PA, SE, and WC regions.

### **Subjective Pork Quality Attributes**

Center-cut loin chop packages were the only retail pork cut assessed at the self-serve retail meat case. Table 3 presents the national representation of simple statistics of center-cut loin chops evaluated in-store and in-laboratory for subjective color and marbling score pork quality attributes. Overall, a mean subjective color score value of 2.85 with a standard deviation (0.79) in-store (n= 3795) and mean subjective color score value of 2.74 with a standard deviation (0.79) in-laboratory (n= 5427) was observed for center-cut loin chops. The mean subjective in-store and in-laboratory subjective color scores reported from this present benchmarking study was less than what was determined in previous benchmarking studies. In 2005, Wright et al. (2005) observed a mean subjective color score of 3.52 in boneless loin chops in the retail meat case in the ‘2002 Benchmarking Value in the Pork Supply Chain’ study. Moeller et al. (2010a) reported a mean color score of 3.13 in pork loins. Whereas, Newman (2012) reported a subjective color score of 3.12 of center-cut loin chops in the ‘2012 National Retail Pork Quality Benchmarking’ study. For subjective marbling, in-store a mean marbling score value of  $2.30 \pm 1.07$  and in-laboratory at mean marbling score value of  $2.27 \pm 1.02$  was observed (Table 3). The mean in-store and in-laboratory subjective marbling scores reported from this present benchmarking study were slightly lower than the mean subjective marbling score of 2.37 observed in boneless loin chops by Wright et al. (2005) and subjective marbling score of 2.43 observed in pork loins by Moeller et al. (2010a) and 2.48 observed by Newman (2012) in center-cut loin chops. Overall, subjective color and marbling results from the ‘2015 National Pork Retail Benchmarking’ study are not consistent with the results when compared with Newman (2012), Moeller et al. (2010a), and with the ‘2002 Benchmarking Value in the Pork Supply Chain’ study (Wright et al., 2005). Comparisons of subjective color and marbling to the ‘2012 National Pork Retail Benchmarking’ study (Newman, 2012) will be described in further detail in the proceeding chapter. Consumer acceptability of fresh pork color and marbling at the retail level have been shown in other literature. Papanagiotou et al. (2013) reported marbling is the most important factor to consumers. Font-i-Farinos et al. (2012) sorted consumers into two groups based on their preference for the amount of marbling present in pork; ‘lean loin lovers’ and ‘marbled loin lovers’. The results indicated consumers considered color the main factor when buying pork and both groups in a blind taste panel preferred the more highly marbled loins (Font-i-Farinos et al., 2012). Brewer et al. (2001) reported higher marbled chops were lighter pink in color (2.42) than low and medium marbled chops due to the mixture of white from the intramuscular fat depots and pink color from myoglobin, causing more light reflection on the cut surface when observed for coloring. However, in the present study, results suggest over the years, subjective color and marbling has decreased, leaving consumers with lower quality pork at the retail meat case.

Between EN and NON center-cut loin chops, EN had a higher (darker color) mean subjective color score (3.07 vs. 2.74, respectively,  $P < 0.0001$ ) than NON center-cut loin chops and in-laboratory too, EN had a higher (darker color) mean subjective color score (2.73 vs. 2.66, respectively,  $P < 0.0001$ , Table 4). Results show EN center-cut loin chops were darker both under store lighting, and under controlled lighting than

NON center-cut loin chops. NON center-cut loin chop subjective marbling score was greater (2.02 vs. 2.32, respectively,  $P < 0.0001$ ) than EN and in-laboratory too, NON had a higher marbling score (2.09 vs. 2.31, respectively,  $P < 0.0001$ , Table 4) than EN. Results show NON center-cut loin chops were more marbled than EN center-cut loin chops. Noteworthy, in the present study, the interaction of enhancement type by region were observed for subjective color and marbling scores for center-cut loin chops, sirloin chops, and blade steaks (Table 5). The conclusions of the interaction between enhancement types by region may be due to the different distributors or companies that represent the different pork quality attribute values and the amount of EN and NON product available for consumers to purchase. Yet, for the purpose of this study, the intent was to quantify variation in pork quality parameters in the retail meat case, not recognize the different packers or companies which supply pork to these specific regions previously described. Therefore, the interactions discuss the variation and differences due to enhancement across regions for subjective color and marbling. The SW region significantly had a greater in-store subjective color score (darker color) for EN center-cut loin chops than for NON center-cut loin chops (3.61 vs. 2.78;  $P < 0.05$ ), with no differences observed ( $P > 0.36$ ) in the other 6 regions. Subjective marbling score in-store was significantly lower for EN center-cut loin chops in the SE (1.66 vs 2.44;  $P < 0.05$ ) and WC (1.86 vs 2.38;  $P < 0.05$ ) regions but did not differ ( $P > 0.33$ ) in other regions. The enhancement type by region interactions for subjective color and marbling are not simply explained, but are not likely due to observer bias as experienced graders obtained information in multiple regions.

Sirloin chops and blade steaks subjective color and marbling scores were only assessed in-laboratory. The mean sirloin chop subjective color score was  $3.04 \pm 0.71$ . The mean blade steak subjective color score was  $4.73 \pm 0.92$  (Table 3.). The sirloin chop mean subjective color score was slightly lower than 3.52 observed by Wright et al. (2005), 3.13 observed by Moeller et al. (2010a), and 3.12 observed by Newman (2012). However, the blade steak mean subjective color score was much greater than 3.52 (Wright et al., 2005) and 3.13 (Moeller et al., 2010a) and 3.12 (Newman, 2012) observed in other research. Sirloin chop, and blade steak in-store subjective marbling scores were ( $1.96 \pm 0.79$  and  $2.91 \pm 0.95$ , respectively). The sirloin chop mean subjective marbling score was lower than 2.37 observed by Wright et al. (2005), 2.43 observed by Moeller et al. (2010b), and 2.48 observed by Newman (2012). In comparison, the blade steak mean subjective marbling score was greater than 2.37 (Wright et al., 2005) and 2.43 (Moeller et al., 2010a) and 2.48 (Newman, 2012) presented in other previous research. Overall, blade steaks had greater subjective color and marbling scores than both center-cut loin chops and sirloin chops.

Least square means for enhanced (EN) and non-enhanced (NON) sirloin chops and blade steaks are presented in Table 4. EN sirloin chops had a higher subjective color score than NON sirloin chops (3.04 vs. 3.12, respectively). Thus, indicating NON sirloin chops were lighter in color than EN sirloin chops. EN and NON sirloin chops had the same subjective marbling score of 1.97. EN blade steaks had a similar subjective color score than NON sirloin chops (4.73 vs 4.72, respectively). EN blade steaks significantly had a higher subjective marbling score than NON blade steaks (3.06 vs 2.87, respectively). Overall, regardless of enhancement type, blade steaks had greater subjective color and marbling scores than both center-cut loin chops and sirloin chops.

In the present study, the interaction of enhancement type by region were observed for subjective color and marbling scores (Table 5.). There were no differences observed for enhancement type by region interaction for subjective color or marbling for sirloin chops or blade steaks.

## Instrumental Pork Quality Attributes

The simple statistics for center-cut loin chop, sirloin chop, and blade steak quality attributes of purchased pork are presented in Table 3. Center-cut loin chops had a mean Minolta L\* value of 55.56 which ranged from 43.14 to 72.55. The mean Minolta a\* value was 16.60 ranging from 4.35 to 27.47. The mean Minolta b\* value was 10.33 which ranged from 3.25 to 19.07. The mean pH value was 5.83 which ranged from 4.83 to 7.32. The mean WBSF value was 24.25 N which ranged from 7.71 to 67.99. Sirloin chops had a mean Minolta L\* value of 52.46 which ranged from 41.36 to 61.84. The mean sirloin chop Minolta a\* was 17.34 which ranged from 10.08 to 25.94. The mean sirloin chop Minolta b\* was 9.79 which ranged from 4.94 to 13.71. For pH, results indicate a mean pH value of 5.90 which ranged from 5.26 to 6.93 for sirloin chops. The mean WBSF value for sirloin chops was 20.80 which ranged from 7.71 to 50.18. The mean blade steak Minolta L\* was 45.84 which ranged from 37.82 to 56.97. The mean Minolta a\* was 18.97 which ranged from 12.18 to 28.76 for blade steaks. The mean blade steak Minolta b\* was 7.92 which ranged from 2.61 to 12.38. For pH, results indicate a mean pH value of 6.28 which ranged from 5.02 to 7.12. For WBSF in blade steaks the mean value was 17.41 N which ranged from 6.51 N to 39.46 N. From the present study, blade steaks were darker in color ( $< L^*$ ) and had the most red ( $> a^*$ ). Contrary, center-cut loin chops were whiter ( $> L^*$ ) and had the least red ( $< a^*$ ). Additionally, blade steaks had the greatest pH value, whereas center-cut loin chops and sirloin chops had similar pH values (5.83 and 5.90, respectively). Warner-Bratzler Shear Force mean values for blade steaks and sirloin chops were less (more tender) than center-cut loin chops (more tough). Profiling pork muscle reports (Porcine Myology) exhibit that the *Longissimus* muscle of center-cut loin chops has a lesser proportion of Type I to Type IIB muscle fiber types, where the *Serratus ventralis* muscle of the blade steak has a larger proportion of Type IIB to Type I muscle fiber types. Which indicates, the *Serratus ventralis* muscle exhibits a lower L\* value, a greater a\* and greater pH when compared to the other two cuts.

EN center-cut loin chops were significantly ( $P < 0.0001$ ) darker (lower Minolta L\* value) than NON center-cut loin chops (54.46 vs 56.00, respectively). The results could be due to the fact that enhancing pork with non-meat ingredients results in a greater pH so less proteins are denatured, causing less water-loss and ultimately less water on the cut surface that does not reflect as much light. EN sirloin chops had a slightly higher Minolta L\* value ( $P = 0.20$ ) than NON sirloin chops (53.74 vs. 52.51, respectively). Thus, indicating EN sirloin chops were lighter in color than NON sirloin chops. EN blade steaks Minolta L\* were closely similar between EN and NON (45.81 vs. 45.96, respectively). Therefore, the results explain EN blade steaks were darker in color compared to NON. EN sirloin chops had a Minolta a\* color space value significantly greater ( $P = 0.09$ ) than NON sirloin chops (17.30 vs. 16.24, respectively), concluding EN blade steaks were more red than NON. Similar to sirloin chops, EN blade steaks had a Minolta a\* value significantly greater ( $P = 0.01$ ) or more positive redness than NON blade steaks (19.04 vs. 17.84, respectively).

Results for the mean pH values for center-cut loin chops, sirloin chops, and blade steaks are presented in Table 3. The mean pH value for center-cut loin chops was 5.83 which ranged from 4.83 to 7.32. The mean pH value for sirloin chops was 5.90 which ranged from 5.26 to 6.93, and the mean pH value for blade steaks was 6.28 which ranged from 5.02 to 7.12. EN center-cut loin chops significantly had a higher pH value (6.00 vs 5.74,  $P < 0.0001$ ) than NON center-cut loin chops (Table 4). EN sirloin chops significantly had a higher pH value (6.00 vs. 5.89,  $P = 0.04$ ) than NON sirloin chops. EN blade steaks significantly had a higher pH than NON blade steaks (6.42 vs. 6.28,  $P = 0.04$ ) than NON blade steaks. Overall, as anticipated, enhancing pork significantly increases the pH value for all product categories, and is consistent with the observed lower L\* values of EN center-cut loin chops and blade steaks. Miller (2002) reported the addition of water, sodium or phosphates increases the pH that allows proteins to bind more free water, and less moisture on the cut

surface, resulting in less light reflection and in turn appears darker. Thus, retailers have the option to present darker pork to consumers by enhancing pork.

For tenderness, using the Warner-Bratzler Shear Force (WBSF) method, the mean value for center-cut loin chops was 24.25 N which ranged from 7.7 to 68.0 N, 20.80 N for sirloin chops which ranged from 7.71 to 50.18, and 17.41 for blade steaks which ranged from 6.51 to 39.46 (Table 3). EN center-cut loin chops were significantly more tender (lower WBSF value) than NON center-cut loin chops (20.43 vs. 25.99,  $P < 0.0001$ ). EN sirloin chops were significantly more tender (lower WBSF value) than NON sirloin chops (16.18 vs. 22.92 N,  $P < 0.0001$ ), EN blade steaks were significantly more tender (lower WBSF value) than NON blade steaks (15.74 vs. 19.42 N,  $P = 0.0005$ ), NON Center-cut loin chops had a mean WBSF value lower than what Moeller et al. (2010b) reported with a trained sensory panelists that favored pork with a WBSF value less than 24.5 N but could determine the difference in tenderness for every 4.9 N increase above 24.5 N and did not favor this pork. All other cuts and enhancement type, except for NON center-cut loin chops can be classified nationwide as tender.

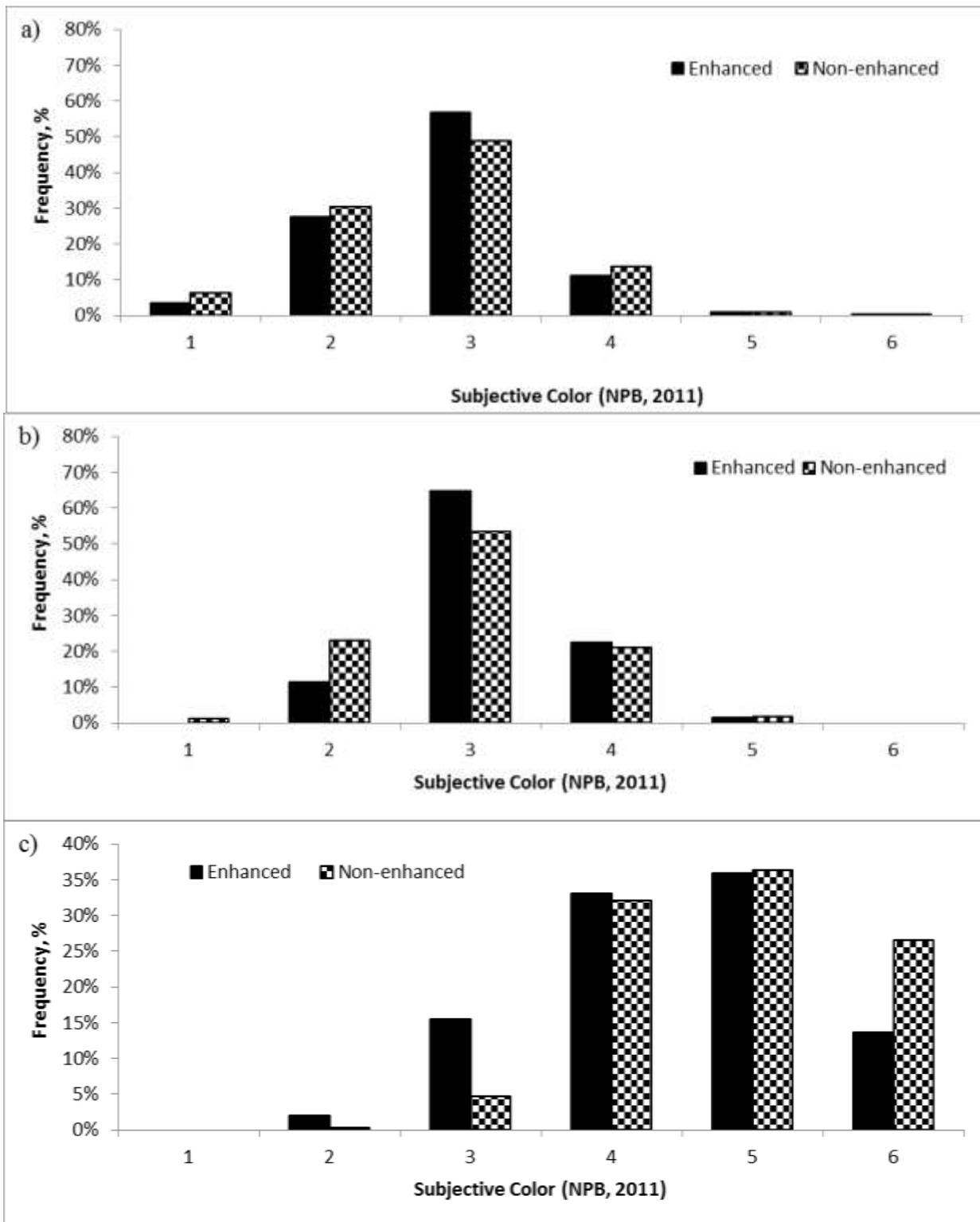
The effect of enhancement type (enhanced (EN) and non-enhanced (NON)) (Table 4.) and enhancement type (enhanced (EN) and non-enhanced (NON)) within region (Table 5.) on pork quality were dependent on product cut and region. The Minolta  $L^*$  value for EN center-cut loin chops was significantly lower (darker color) in the SW (52.2 vs. 52.4,  $P < 0.05$ ), and SW (52.4 vs. 55.2,  $P < 0.05$ ) regions but no differences were observed ( $P > 0.98$ ) in the other regions. There were no differences for Minolta  $L^*$  value for EN and NON sirloin chops in any of the regions. The Minolta  $L^*$  value for NON blade steaks was significantly lower (darker color) in the PA (47.5 vs. 44.76,  $P < 0.05$ ) region than NON blade steaks had a tendency difference to have a lower Minolta  $L^*$  in the WC (47.1 vs. 44.7,  $0.05 < P < 0.10$ ) region than EN, but no differences were observed ( $P > 0.99$ ) in the other regions. The Minolta  $a^*$  value for EN center-cut loin chops was significantly higher (more red) in the WC (19.0 vs. 17.0,  $P < 0.05$ ) region than NON, but no differences were observed ( $P > 0.41$ ) in the other regions. Likewise, the Minolta  $a^*$  value for EN blade steaks were significantly higher (more red) in the WC (21.8 vs. 19.2,  $P < 0.05$ ) region than NON, but no differences were observed ( $P > 0.11$ ) in the other regions. For Minolta  $b^*$ , NON center-cut loin chops significantly had a higher  $b^*$  value in the PA (9.7 vs. 10.4,  $P < 0.05$ ), SE (8.8 vs. 10.9,  $P < 0.05$ ), and SW (8.8 vs. 10.2,  $P < 0.05$ ) regions than EN, but no differences were observed ( $P > 0.43$ ) in the other regions. Whereas, Minolta  $b^*$  for EN blade steaks significantly had a higher  $b^*$  value (more yellow) in the PA (9.4 vs. 6.9,  $P < 0.05$ ) region, and EN blade steaks had a tendency difference to have a higher  $b^*$  in the WC (9.0 vs. 7.7,  $0.05 < P < 0.10$ ) region than NON, but no differences were observed ( $P > 0.96$ ) in the other regions. Many of the regions had significant differences in pH for enhancement type. EN center-cut loin chops significantly had a higher pH value in the PA (6.0 vs. 5.8,  $P < 0.05$ ), SE (6.3 vs. 5.7,  $P < 0.05$ ), SW (6.4 vs. 5.8,  $P < 0.05$ ), and WC (6.0 vs. 5.8,  $P < 0.05$ ) regions than NON center-cut loin chops, but no differences were observed ( $P > 0.99$ ) in the other regions. While, EN blade steaks significantly had a higher pH value in the PA (6.5 vs. 6.2,  $P < 0.05$ ), and SE (6.9 vs. 6.3,  $P < 0.05$ ) regions than NON, but no differences were observed ( $P > 0.14$ ) in the other regions. A majority of the regions had significant differences in tenderness (WBSF) for enhancement type. EN center-cut loin chops significantly had a lower WBSF (more tender) value in the PA (18.8 vs. 25.8 N,  $P < 0.05$ ), SE (17.8 vs. 25.6 N,  $P < 0.05$ ), SW (18.2 vs. 25.7,  $P < 0.05$ ), and WC (18.9 vs. 25.7,  $P < 0.05$ ) regions than NON center-cut loin chops but no differences were observed ( $P > 0.14$ ) in the other regions. EN sirloin chops significantly had a lower WBSF (more tender) value in the PA (18.4 vs. 23.3 N,  $P < 0.05$ ), and WC (14.6 vs. 21.3 N,  $P < 0.05$ ) regions than NON, but no differences were observed ( $P > 0.44$ ) in the other

regions. EN blade steaks only had a tendency difference to have a lower WBSF in the PA (15.7 vs. 19.2,  $0.05 < P < 0.10$ ) region compared to NON blade steaks, but no differences were observed ( $P > 0.14$ ) in the other regions. Overall, there were varying differences between the interaction of enhancement type and region from this present study.

### **Pork Quality Attributes Frequency Distributions**

The distribution of subjective color score measured in-store of enhanced (EN) versus non-enhanced (NON) center-cut loin chops, sirloin chops, and blade steaks are presented in Figure 2.1. The mean subjective color score in-laboratory for EN center-cut loin chops was 2.73 and 2.66 for NON center-cut loin chops ( $P < 0.0001$ ). Approximately half of all center-cut loin chops assessed had a subjective in-laboratory subjective color score of 3 (56.76 % for EN and 48.87 % for NON). The frequency distribution amongst the in-laboratory subjective color scores between EN and NON center-cut loin chops showed little difference. Norman et al. (2003) separated boneless pork loins into three different groups based on subjective color standards (NPB, 2011) and showed 20.8 % of consumers selected pork with a color score of 1 or 2, 26.4 % selected pork with a color score of 3 or 4 and approximately half of the consumers (52.8 %) selected pork with a color score of 5 or 6. In the current study, 31.0 % of EN and 36.5 % of NON center-cut loin chops had a color score of 1 or 2. Moreover, 1.0 % of EN and 0.9 % of NON center-cut loin chops had a color score of 5 or 6. A subjective color score of 1 is described as being pale, pinkish grey to white and a subjective color score 2 is described as being grayish pink. While a subjective color score of 5 is described as being purplish red and a subjective color score 6 is described as dark, purplish red (NPB, 2011). It is important to note that a significant amount of pork loins in the U.S. are sorted in processing plants based on subjective color for export markets or other food-service sectors. Thus, this could be a significant reason for the lower amount of center-cut loin chops in the self-serve retail meat case with color scores of 5 or 6 and greater percentage of pale colored center-cut loin chops in the self-serve retail meat case. Similar to center-cut loin chops, sirloin chops had a majority of subjective color scores of 3 (64.8 % for EN and 53.3 % for NON). Which corresponds to the mean subjective color score for sirloin chops of 3.04 for EN and 3.12 for NON center-cut loin chops ( $P = 0.57$ ). Only 11.4 % of EN and 24.2 % of NON sirloin chops had a color score of 1 or 2. There were no subjective color scores of 6 for either enhancement type, therefore 1.4 % of EN and 1.64% of NON sirloin chops had a color score of 5 or 6. In contrast, blade steaks overall had 92.3 % of subjective color scores greater than 3. This is because the results indicate that the mean subjective color score of 4.73 for EN and 4.72 for NON blade steaks ( $P = 0.96$ ). Only 15.5 % of EN and 4.7 % of NON blade steaks had a subjective color score of 3. Whereas, 1.9 % of EN and 0.3 % of NON blade steaks had a subjective color score of 1 or 2. There were no subjective color scores of 1. Furthermore, 49.5 % of EN and 62.9 % of NON blade steaks had a color score of 5 or 6. Therefore, based on the results, for the product categories, there is not a color issue associated with sirloin chops or blade steaks, but is more of a concern in center-cut loin chops.

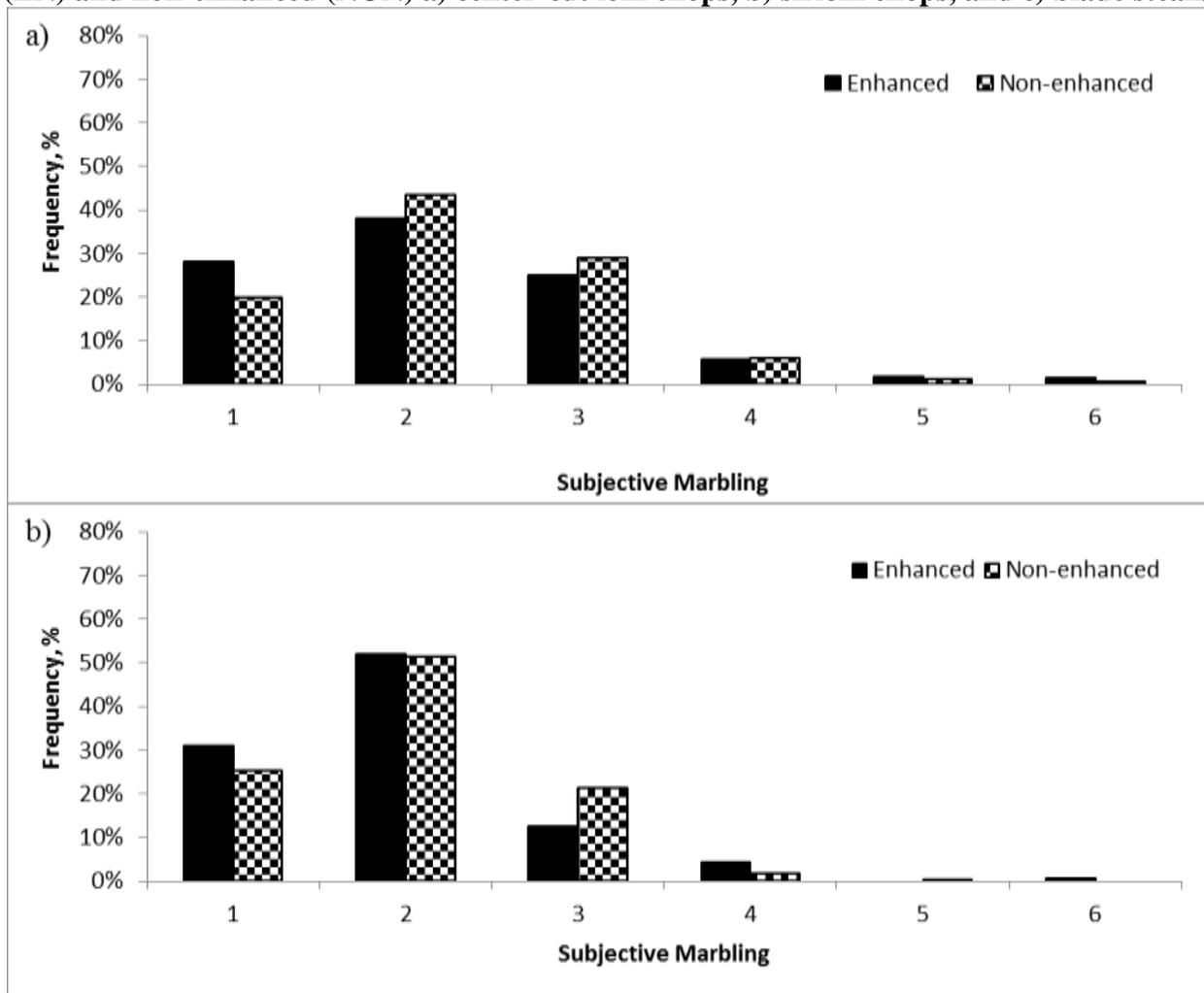
**Figure 2.1. Frequency distribution of subjective color score measured in-laboratory of enhanced (EN) and non-enhanced (NON) a) center-cut loin chops, b) sirloin chops, and c) blade steaks**

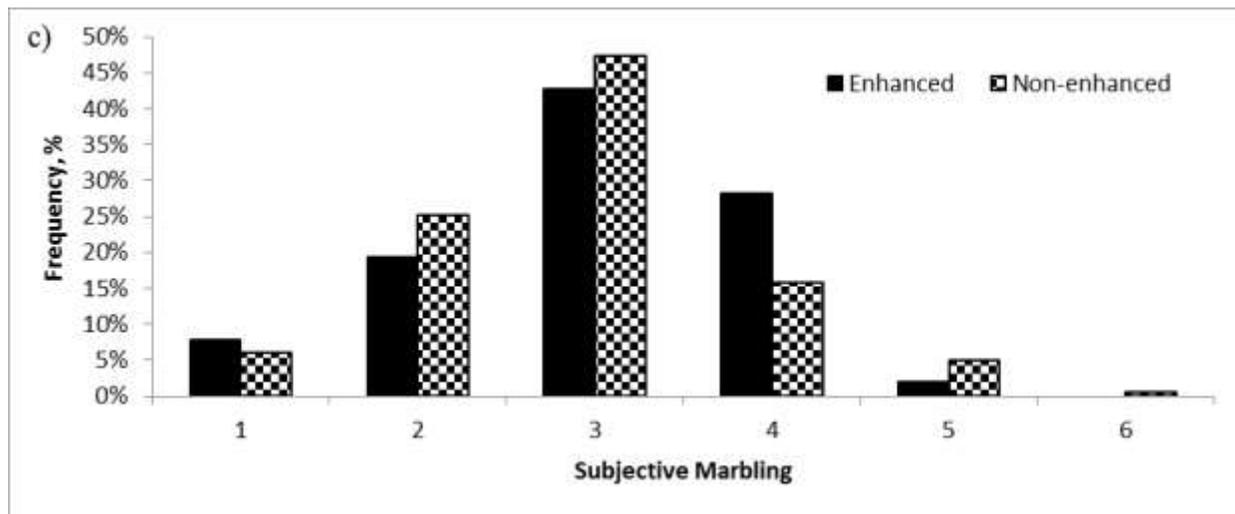


For subjective marbling (Figure 2.2) EN center-cut loin chops had a mean in-laboratory subjective marbling score of 2.09 with 38.1 % scoring a 2 and 50.8 % scoring a 1 or 3 (25.9 % and 24.9 %, respectively). NON center-cut loin chops had a mean in-laboratory subjective marbling score of 2.31 with 43.5 % scoring a 2 and 47.8 % scoring a 1 or 3 (18.8 % and 29.0 %, respectively). EN sirloin chops had a mean subjective marbling score of 1.97 with 51.9 % scoring a 2 and 40.5 % scoring a 1 or 3 (28.1 % and 12.4 %, respectively). NON sirloin chops had a mean subjective marbling score also of 1.97 with 51.5 % scoring a

2 and 46.2 % scoring a 1 or 3 (24.9 % and 21.3 %, respectively). EN blade steaks had a mean subjective marbling score of 3.06 with only 19.4 % scoring a 2 and 50.5 % scoring a 1 or 3 (7.8 % and 42.7 %, respectively). EN blade steak distribution for a subjective marbling score of 4 was 28.2 %. NON blade steak had a mean subjective marbling score also of 2.87 with 25.3 % scoring a 2 and 52.9 % scoring a 1 or 3 (5.5 % and 47.4 %, respectively). Cannanta et al. (2012) reported when IMF was 2.5% or greater tenderness and juiciness increased. Similarly, Fernandez et al. (1999a) reported when IMF values reached 2.5 % juiciness and flavor was enhanced. Furthermore, Font-i-Farinos et al. (2012) recommended 2.2-3.4% minimum of IMF improves eating satisfactoriness. A majority of U.S. pork is exported to countries like Japan who demand high marbling. Rincker et al. (2008) concluded nearly 50% of consumers in a sensory panel selected pork loin chops in a case with the least amount of marbling, but said they would purchase pork that is leaner. Moeller et al. (2010) suggested IMF levels of 5-6 % would improve pork flavor, but contribute very little or have no influence on consumer’s perceptions of juiciness or tenderness attributes. Results from this current study, in compliance with past literature results observing marbling pork quality sensory attributes, suggest that in the self-serve retail meat case nationwide, all cuts have marbling values that reinforce satisfactory eating quality, except for EN sirloin chops.

**Figure 2.2. Frequency distribution of subjective marbling score measured in-laboratory of enhanced (EN) and non-enhanced (NON) a) center-cut loin chops, b) sirloin chops, and c) blade steaks**



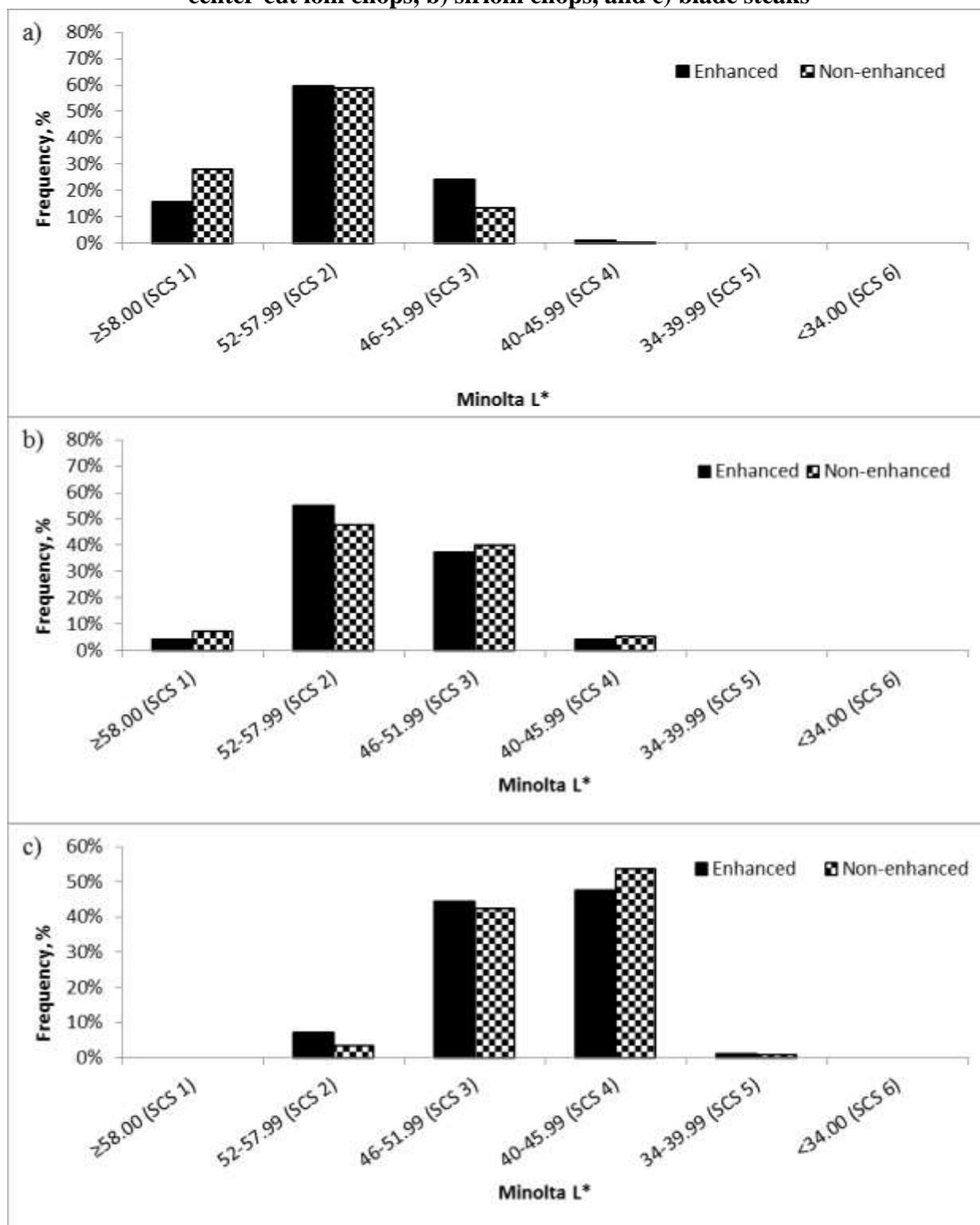


Minolta L\* frequency distribution of enhanced (EN) and non-enhanced (NON) of center-cut loin chop, sirloin chop, and blade steak is presented in Figure 2.3. The mean Minolta L\* value for EN center-cut loin chops was 54.46 and 56.00 for NON center-cut loin chops ( $P < 0.0001$ ), EN sirloin chops was 53.74 and 52.51 for NON center-cut loin chops ( $P < 0.0001$ ), and EN blade steaks was 45.81 and 45.96 for NON center-cut loin chops ( $P = 0.82$ ).

EN center-cut loin chops had a mean Minolta L\* value of 54.46, and 59.5 % of the chops were in the Minolta L\* value range of 52.00 to 57.99, 24.9 % of the chops had a Minolta L\* > 52.00 and 15.5 % had a Minolta L\* > 58.00. NON center-cut loin chops has a mean Minolta L\* value of 56.00, and 58.7 % of the chops were in the Minolta L\* value range of 52.00 to 57.99, 13.4 % of the chops had a Minolta L\* > 52.00 and 28.0 % had a Minolta L\* > 58.00. The instrumental color, Minolta L\* values are based on Meisinger et al. (1999). The National Pork Board subjective color standards (NPB, 2011) for subjective color are provided with a reference to the Minolta L\* values. For instance, a color score of 1 is characterized with a Minolta L\* value of 58.00, while a color score of 6 is characterized to a Minolta L\* value of < 34.00. Therefore, from the present study's results of a subjective in-store mean subjective color score of 3.07 EN and 2.74 NON and in-laboratory mean subjective color of 2.73 EN and 2.66 NON. This would represent a Minolta L\* close to 51.58 for EN in-store subjective color, 53.56 for NON in-store subjective color 53.62 for EN in-laboratory subjective color, and 54.04 for NON in-laboratory subjective color, when compared to the NPB color standards. Yet, the mean Minolta L\* values reported in the current study (54.46 for EN and 56.00 for NON) are analytic of a subjective color score of 2.59 for EN and 2.33 for NON center-cut loin chops. Therefore, experienced graders are reporting a subjective color score darker than the Minolta L\* value. This could be due to the effect of different in-store lighting (fluorescent or white LED or pink LED) at different retail stores, as well as assessing subjective color scores under controlled lighting in-laboratory. Barbut (2001) reported incandescent light increase pork color because there are more a\* wavelengths. EN sirloin chops had a mean Minolta L\* value of 53.74, and 59.5 % of the chops were in the Minolta L\* value range of 52.00 to 57.99, 24.9 % of the chops had a Minolta L\* > 52.00 and 15.5 % had a Minolta L\* > 58.00. NON sirloin chops has a mean Minolta L\* value of 52.91, and 58.7 % of the chops were in the Minolta L\* value range of 52.00 to 57.99, 13.4 % of the chops had a Minolta L\* > 52.00 and 28.0 % had a Minolta L\* > 58.00. EN blade steaks had a mean Minolta L\* value of 45.81, and 59.5 % of the chops were in the Minolta L\* value range of 52.00 to 57.99, 24.9 % of the steaks had a Minolta L\* > 52.00 and 15.5 % had a Minolta L\* > 58.00.

NON blade steaks has a mean Minolta L\* value of 45.96, and 58.7 % of the steaks were in the Minolta L\* value range of 52.00 to 57.99, 13.4 % of the chops had a Minolta L\* > 52.00 and 28.0 % had a Minolta L\* > 58.00. A possible explanation for the differences between subjective and instrumental color values is first, the type of light source retailers use varies in the self-serve meat case. Thus, based on the different light sources in-store, the fresh pork may appear darker or lighter to the experienced grader in-laboratory under controlled lighting. Additionally, in-laboratory, the fresh pork received a minimum of 15 minutes bloom time to be exposed to oxygen. Barbut (2001).

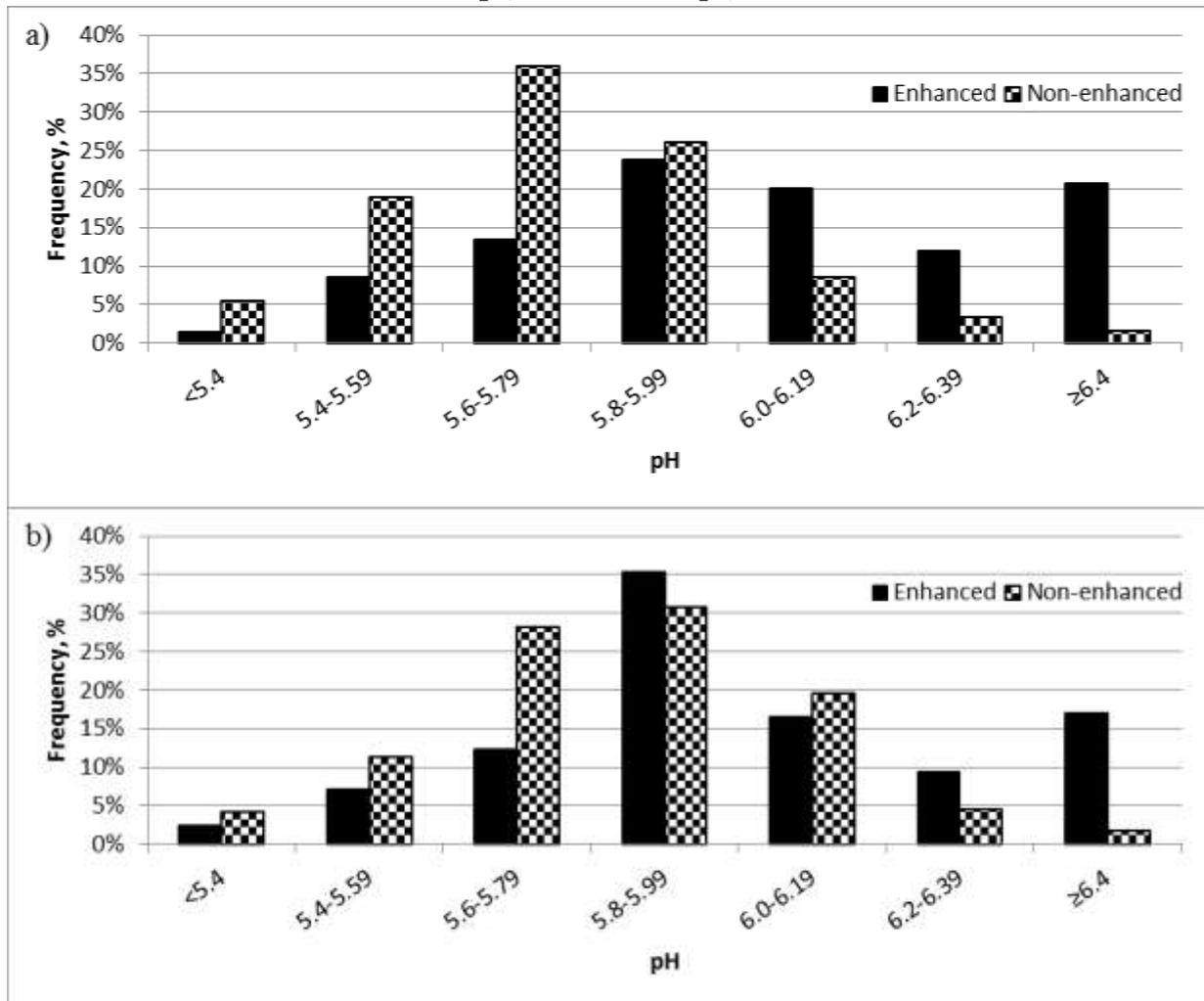
**Figure 2.3. Minolta L\* frequency distribution of enhanced (EN) versus non-enhanced (NON) a) center-cut loin chops, b) sirloin chops, and c) blade steaks**

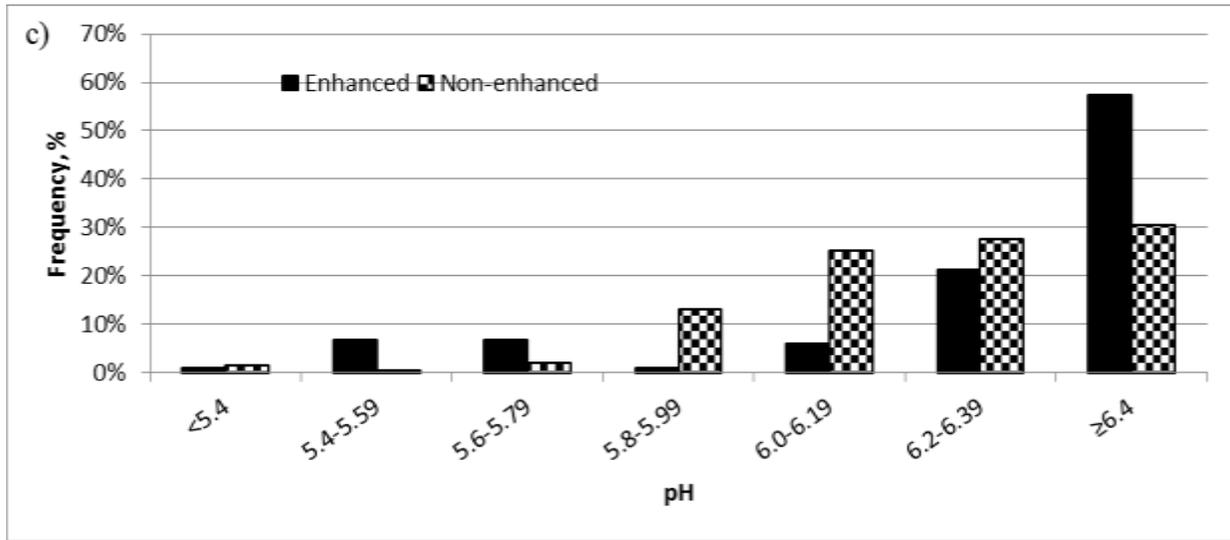


Frequency distribution for pH of enhanced (EN) and non-enhanced (NON) of center-cut loin chop, sirloin chop, and blade steak are presented in Figure 2.4. Moeller et al. (2010a) indicated pork loins with an ultimate pH value between 5.8 and 6.4 had positive sensory responses from a trained panelist. For all cuts, enhanced product had a higher pH. EN center-cut loin chops had a mean pH value of 6.08 and 42.4 % of all center-cut loin chops, 55.9 % of EN center-cut loin chops had a pH value between 5.8 and 6.4. NON center-

cut loin chops had a mean pH value of 5.74. and 37.9 % of NON center-cut loin chops had a pH value between 5.8 and 6.4. While, 20.7 % of EN and 1.6 % NON of center-cut loin chops had a pH value greater than 6.4 and 23.4 % EN and 60.5 % NON center-cut loin chops had a pH value less than 5.8. EN sirloin chops had a mean pH value of 6.00 and 61.2 % had a pH value between 5.8 and 6.4. NON sirloin chops had a mean pH value of 5.89 and approximately half (54.7 %) had a pH value between 5.8 and 6.4. While, 17.1 % of EN and 1.8 % NON of sirloin chops had a pH value greater than 6.4 and 21.8 % EN and 43.5 % NON sirloin chops had a pH value less than 5.8. EN blade steaks had a mean pH value of 6.42 and 28.2 % had a pH value between 5.8 and 6.4. NON blade steaks had a mean pH value of 6.28 and 65.7 % had a pH value between 5.8 and 6.4. While, 57.3 % of EN and 30.5 % of blade steaks had a pH value greater than 6.4 and 14.6 % EN and 3.9 % NON blade steaks had a pH value less than 5.8. Overall, average pH values for blade steaks were greater than center-cut loin chops and sirloin chops. Yet, previous research has mostly been conducted in loin chops and on the effect of pH on eating quality. Thus, the results determined in this present study of overall greater pH in blade steaks and the shift in proportion of samples within greater pH categories cannot be determined without sensory evaluation to support a conclusion of ideal pH for eating quality for consumers. One explanation for the differences in enhancement type for pH is the addition of non-meat ingredients to the pork at the plant to create an enhanced product for retailers. Miller (2001) reported the addition of water, sodium or phosphates increases the pH that allows proteins to bind more free water, and less moisture on the cut surface, resulting in less light reflection and in turn appears darker. Thus, retailers have the option to present darker pork to consumers by enhancing pork.

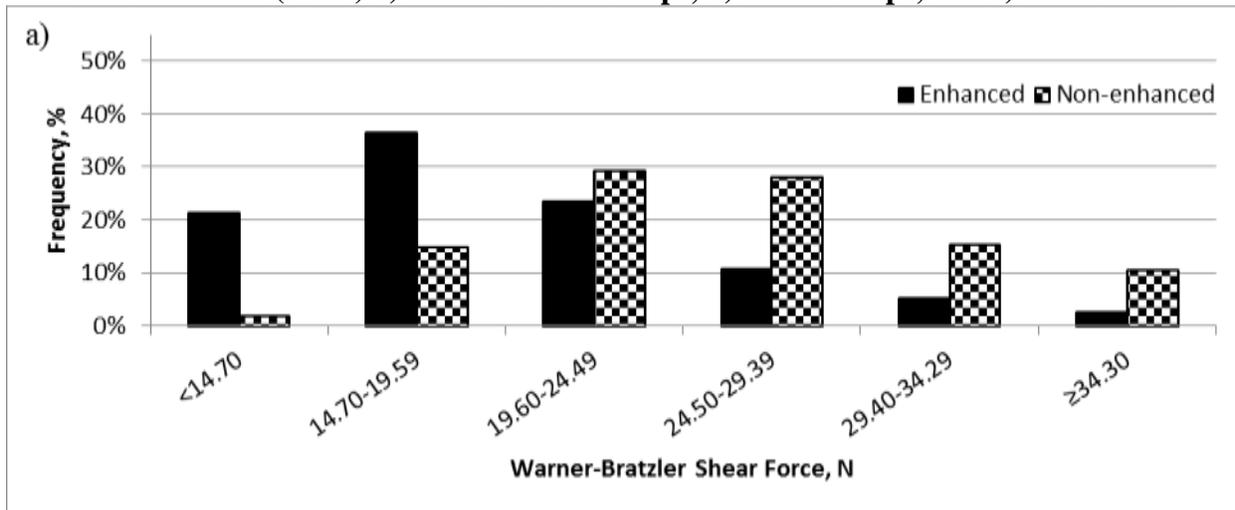
**Figure 2.4. Frequency distribution for pH of enhanced (EN) versus non-enhanced (NON) a) center-cut loin chops, b) sirloin chops, and c) blade steak**

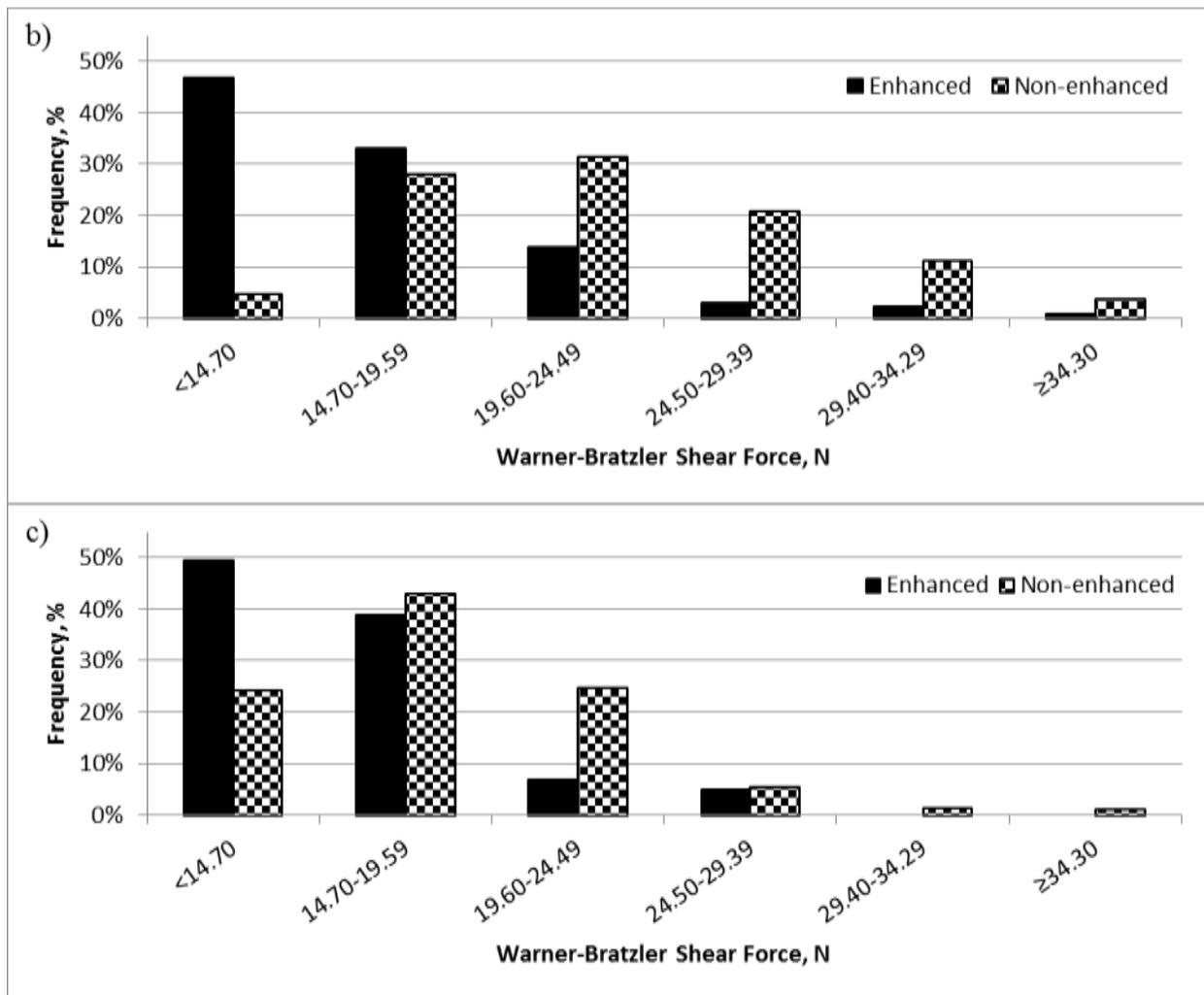




The percentage distribution for Warner-Bratzler Shear Force (WBSF) of enhanced (EN) and non-enhanced (NON) of center-cut loin chop, sirloin chop, and blade steak is presented in Figure 2.5. Enhanced center-cut loin chops had a mean WBSF value of 20.43 N and 23.5 % of the center-cut loin chops were in the WBSF range of 19.6 to 24.5 N, with 57.9% being < 19.6 N and 18.5 % being > 24.5 N. Non-enhanced center-cut loin chops had a mean WBSF value of 25.99 N and 29.2% of the center-cut loin chops were in the WBSF range of 19.6 to 24.5 N, with 16.7 % being < 19.6 N and 54.1 % being > 24.5 N. Enhanced sirloin chops had a mean WBSF value of 16.18 N and 13.9 % of the sirloin chops were in the WBSF range of 19.6 to 24.5 N, with 6.15 % being < 19.6 N and 80.0% being > 24.5 N. Non-enhanced sirloin chops had a mean WBSF value of 22.92 N and 31.4 % of the sirloin chops were in the WBSF range of 19.6 to 24.5 N, with 6.2 % being < 19.6 N and 80.0 % being >24.5 N. Enhanced blade steaks had a mean WBSF value of 15.74 N and 6.8 % of the blade steaks were in the WBSF range of 19.6 to 24.5 N, with 4.9 % being < 19.6 N and 88.4% being > 24.5 N. Non-enhanced blade had a mean WBSF value of 19.42 N and 24.7 % of the blade steaks were in the WBSF range of 19.6 to 24.5 N, with 8.0 % being < 19.6 N and 67.4 % being > 24.5 N.

**Figure 2.5. Frequency distribution for Warner-Bratzler Shear Force (WBSF) of enhanced (EN) and non-enhanced (NON) a) center-cut loin chops, b) sirloin chops, and c) blade steak**





Moeller et al. (2010b) determined consumers positively responded to WBSF values below 24.5 N, for tenderness-like, tenderness-level, juiciness-like, juiciness-level, and overall-like, but for every 4.9 N increase in WBSF values, their overall-like decreased by 4%. From the present study for all cuts, 55.2 % of center-cut loin chops (81.4 % of EN and 45.9 % of NON), 73.3 % of sirloin chops (93.9 % of EN and 64.2 % of NON), and 92.8 % of blade steaks (95.1 % EN and 92.0 % of NON) can be classified as tender pork due to the distribution falling below the threshold of 24.5 N reported by Moeller et al. (2010b).

### Pork Quality Attributes Correlation Coefficients

Correlation coefficients of L\*, a\*, and b\*, pH, and Warner-Bratzler Shear Force in center-cut loin chops, sirloin chops and blade steaks are presented in Table 6. Results indicate Minolta L\* was moderately and negatively correlated with a\* across all cuts and enhancement type, as well as moderately and negatively correlated with pH for all cuts and enhancement type, except for EN blade steaks. In contrast, Minolta L\* was significantly strongly and positively correlated ( $P < 0.05$ ) with b\* regardless of enhancement type or cut evaluated in the present study. In blade steaks for all enhancement types, and NON center-cut loin chops, Minolta a\* and b\* were positively correlated. Norman et al. (2003) noted L\* is negatively correlated with a\* ( $r = -0.32$ ) and in center-cut loin chops positively correlated (0.62) with b\*. Additionally, a\* and b\* within center-cut loin chops are positively correlated (.40) (Norman et al., 2003), in which all results found agree with the present study. Minolta a\* and WBSF were negatively correlated for all EN product in all cuts, and NON blade steaks. There was a positive correlation between a\* and pH in sirloin chops and EN center-cut loin chops. Minolta b\* was positively and moderately correlated with WBSF center-cut loin chops. As well

as, Minolta b\* had a negative correlation with pH for all cuts and enhancement type, except for EN blade steaks.

## **Results for comparison of 2012 national pork retail benchmarking study versus 2015 national pork retail benchmarking study**

### **Product Demographics**

Regional totals for the number of packages observed and purchased in 2015 are presented in Table 2. In 2012, 531 EN and 660 NON packages of center-cut loin chops were observed in-store for subjective evaluation of color and marbling scores. Compared to 2015, in-store 427 EN and 1,028 NON packages of center-cut loin chops were observed for subjective assessment of color and marbling scores. Thus, there were more EN center-cut loin chop packages assessed for subjective color and marbling scores in-store in 2012 than 2015. As well, there were more NON center-cut loin chop packages assessed for subjective color and marbling scores in-store in 2015 than 2012. In 2012, instrumental evaluation included 577 EN and 683 NON center-cut loin chop, 207 EN and 124 NON sirloin chop, and 203 EN and 234 NON blade steak purchased packages. In 2015, instrumental in-laboratory assessment included 427 EN and 1,080 NON center-cut loin chop packages, 78 EN and 155 NON sirloin chop packages, and 56 EN and 170 NON blade steak purchased packages. Therefore, for instrumental assessment, similar to in-store subjective color and marbling, there were more EN center-cut loin chop packages assessed than NON in 2012 than 2015, as well as there were more NON center-cut loin chop packages assessed for instrumental measurements in 2015 than 2012. For instrumental assessment in sirloin chops, there were more EN packages assessed in 2012 than 2015. In 2015 there were more NON sirloin chop packages assessed for instrumental evaluation than in 2012. For blade steaks there were more EN packages assessed for instrumental measurements in 2012 than 2015. In 2015, there were more NON packages assessed for blade steak packages assessed for instrumental than in 2012. Overall, there were more EN packages available in 2012 than 2015, and there were more NON packages available in 2015 than 2012. One explanation for the difference in number of EN and NON packages available is the different brands available in the retail meat case for consumers. Currently, in general, consumers have a negative attitude towards enhancing pork due to the addition of non-meat ingredients, especially sodium and how it affects their health.

Regional differences in 2012, in product availability were found for sirloin chops, whereby the NE, EC, and MA regions offered a very limited selection of sirloin chops. In contrast, the PA region had a much greater selection of sirloin chops available. Blade steaks were more available within the EC, PA, SE, and WC regions than within the NE, MA, and SW regions. In 2015, regional differences in product availability were found for sirloin chops, by which the EC, MA, NE and SW regions offered a very constrained selection of sirloin chops. In contrast for sirloin chop packages, the PA and WC regions had a much larger selection for purchase. Similarly, for blade steaks, the EC, MA, NE, SE, and SW regions offered very constrained selection of blade steaks. There were no blade steaks available in the MA region. Whereas, blade steaks were more readily available for purchase within the PA, SE, and WC regions. Similarly in comparing 2012 and 2015, sirloin chops in the EC, NE and SW regions all offered a lesser amount of sirloin chops, as well as for both years the PA region offered a greater amount of sirloin chops. There was less selection available for blade steaks in the SE and SW region in 2015 than 2012, but for

both years the EC, MA and SE regions offered a lesser amount available of blade steaks. Both years in the PA region sirloin chops were more readily available for selection, yet in 2015 the WC region also had a larger selection for sirloin chops, in which 2012 the WC did not offer more product.

### Subjective Pork Quality Attributes

The simple statistics of means for subjective color and marbling are presented Table 3 for 2015. The overall mean subjective color score was 3.12 in 2012 (n= 2788) and 2.85 in 2015 (n= 3795) for center-cut loin chops. Due to current events of the West Port Union dispute in 2015, when center-cut loin chops were purchased between January and April 2015, the 2015 subjective color results were expected to obtain a higher color score from the additional percentage of meat stored in cold storage and not exported to other countries that pay premiums to processors for darker colored meat. Yet, based on the results, this was not the case. Another explanation for the differences in color scores between the two times the ‘National Pork Retail Benchmarking’ study was conducted could be the different amount of experienced graders assessing subjective color score in-store. In 2012, there were 6 universities involved in the research efforts, but only 3 during the 2015 project, thus there could be more variation in reporting subjective color score in 2012 than 2015. Both mean subjective color score values of 3.12 and 2.85 were lower than 3.52 of what Wright et al. (2005) reported in center-cut loin chops in the retail meat case. Since the last analyzation of benchmarking pork quality in the retail meat case, the subjective color score has decreased.

**Table 3. National representation of simple statistics of center-cut loin chop, sirloin chop, and blade steak quality attributes.**

	n	Mean	Minimum	Maximum	SD	CV%
<b>Center-cut loin chops</b>						
Color <sup>1</sup>						
In-store	3795	2.85	1.00	5.00	0.79	27.75
In laboratory	5427	2.74	1.00	6.00	0.79	28.84
Marbling <sup>2</sup>						
In-store	3795	2.30	1.00	10.00	1.07	46.60
In laboratory	5427	2.27	1.00	10.00	1.02	45.03
L* <sup>3</sup>	5488	55.56	43.14	72.55	3.63	6.54
a* <sup>4</sup>	5493	16.60	4.35	27.47	2.30	13.86
b* <sup>5</sup>	5493	10.33	3.25	19.07	1.53	14.80
pH	2428	5.83	4.83	7.32	0.32	5.54
WBSF <sup>6</sup> , N	3067	24.25	7.71	67.99	7.23	29.83
<b>Sirloin chops</b>						
Color <sup>1</sup>	636	3.04	1.00	5.00	0.71	23.26
Marbling <sup>2</sup>	647	1.96	0.00	6.00	0.79	40.50
L* <sup>3</sup>	345	52.46	41.36	61.84	3.58	6.83
a* <sup>4</sup>	346	17.34	10.08	25.94	2.59	14.96
b* <sup>5</sup>	346	9.79	4.94	13.71	1.77	18.11
pH	508	5.90	5.26	6.93	0.30	5.16
WBSF <sup>6</sup> , N	423	20.80	7.71	50.18	6.71	32.26
<b>Blade steaks</b>						
Color <sup>1</sup>	483	4.76	2.00	6.00	0.92	19.28
Marbling <sup>2</sup>	487	2.91	0.00	6.00	0.95	32.65
L* <sup>3</sup>	470	45.84	37.82	56.97	3.29	7.17
a* <sup>4</sup>	470	18.97	12.18	28.76	2.13	11.22
b* <sup>5</sup>	470	7.92	2.61	12.38	1.76	22.17
pH	441	6.28	5.02	7.12	0.33	5.24
WBSF <sup>6</sup> , N	391	17.41	6.51	39.46	4.78	27.45

<sup>1</sup> Color scale: 1 = pale pinkish gray to white; 6 = dark purplish red (NPB, 2011). Sirloins and blade steaks were only evaluated for subjective color in the laboratory.

<sup>2</sup> Marbling scale: 1 = devoid; 10 = abundant (NPB, 2011). Sirloins and blade steaks were only evaluated for subjective marbling in the laboratory.

<sup>3</sup> Lightness scale: 0 = black; 100 = white.

<sup>4</sup> Redness scale: < 0 = green; > 0 = red.

<sup>5</sup> Yellowness scale: < 0 = blue; > 0 = yellow.

<sup>6</sup> WBSF = Warner-Bratzler shear force.

The overall mean subjective marbling score was 2.48 in 2012 (n= 2760) and 2.30 in 2015 (n= 3795) for center-cut loin chops. The mean in-store subjective marbling scores reported from the 2012 benchmarking study was slightly greater than the mean subjective marbling score of 2.37 observed in boneless loin chops by Wright et al. (2005) and subjective marbling score of 2.43 observed in pork loins by Moeller et al. (2010a). In contrast, from the current 2015 benchmarking study the mean subjective marbling score was slightly lower than the means reported from Wright et al. (2005) of 2.37 and Moeller et al. (2010a) of 2.43. Overall, subjective color and marbling results from 2012 and 2015 are not consistent with one another, or with previous literature quantifying mean color and marbling scores in center-cut loin chops.

Least square means of enhanced and non-enhanced center-cut loin chops, sirloin chops, and blade steaks for 2012 are presented in Table 4 and for 2015 are presented in Table 5. EN center-cut loin chops in 2012 had numerically greater subjective color scores (3.25 vs. 3.17;  $P = 0.08$ ). EN had a higher (darker color) mean subjective color score (3.07 vs. 2.74, respectively,  $P < 0.0001$ ) than NON center-cut loin chops in 2015. Results show for both years, EN center-cut loin chops were darker both under store lighting, and under controlled lighting in-laboratory than NON center-cut loin chops. EN center-cut loin chops in 2012 had numerically lower subjective marbling (2.39 vs. 2.47;  $P = 0.08$ ) when compared with NON center-cut loin chops. In 2015, there were similar results, in which EN center-cut loin chops significantly had lower subjective marbling score (2.02 vs. 2.32, respectively,  $P < 0.0001$ ) when compared with NON center-cut loin chops. In the 2012 benchmarking study, sirloin chops and blade steaks were not assessed for subjective color and marbling scores in-laboratory, however in 2015 sirloin chops and blade steaks were assessed for subjective color and marbling scores in-laboratory. Therefore, from 2015, EN sirloin chops had a higher subjective color score than NON sirloin chops (3.04 vs. 3.12, respectively). Thus, indicating NON sirloin chops were lighter in color than EN sirloin chops. EN and NON sirloin chops had the same subjective marbling score of 1.97. EN blade steaks had a similar subjective color score than NON sirloin chops (4.73 vs 4.72, respectively). EN blade steaks significantly had a higher subjective marbling score than NON blade steaks (3.06 vs 2.87, respectively). Overall, regardless of enhancement type, blade steaks had greater subjective color and marbling scores than both center-cut loin chops and sirloin chops.

**Table 4 2012 National representation of simple statistics of center-cut loin chop, sirloin chop, and blade steak quality attributes.**

	n	Mean	Minimum	Maximum	SD	CV%
<b>Center-cut loin chops</b>						
Color <sup>1</sup>	2788	3.12	1.00	6.00	0.85	27.2
Marbling <sup>2</sup>	2760	2.48	1.00	6.00	0.95	38.3
L* <sup>3</sup>	1707	55.30	41.44	68.62	3.70	6.7
a* <sup>4</sup>	1708	5.89	-6.90	16.96	3.12	53.0
b* <sup>5</sup>	1708	3.73	-2.87	11.78	1.86	49.9
pH	1799	5.86	4.60	6.85	0.27	4.6
WBSF <sup>6</sup> , N	1912	23.39	8.38	63.59	6.82	29.2
<b>Sirloin chops</b>						
L* <sup>3</sup>	918	51.92	43.06	61.64	3.22	6.2
a* <sup>4</sup>	918	19.50	9.44	27.07	2.74	14.1
b* <sup>5</sup>	918	10.06	5.38	71.78	2.63	26.1
pH	1063	5.88	5.11	6.87	0.29	4.9
WBSF <sup>6</sup> , N	1019	18.71	7.71	40.11	5.17	27.6

**Blade steaks**

L* <sup>3</sup>	829	45.27	38.76	56.66	2.79	6.2
a* <sup>4</sup>	829	19.70	11.54	26.67	2.12	10.8
b* <sup>5</sup>	829	8.13	3.79	12.44	1.71	21.0
pH	850	6.22	5.55	6.98	0.27	4.3
WBSF <sup>6</sup> , N	749	17.12	7.08	39.86	4.65	27.2

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<sup>1</sup> Color scale: 1 = pale pinkish gray to white; 6 = dark purplish red (NPB, 2011).

<sup>2</sup> Marbling scale: 1 = devoid; 10 = abundant (NPB, 2011).

<sup>3</sup> Lightness scale: 0 = black; 100 = white.

<sup>4</sup> Redness scale: < 0 = green; > 0 = red.

<sup>5</sup> Yellowness scale: < 0 = blue; > 0 = yellow.

<sup>6</sup> WBSF = Warner-Bratzler shear force.

**Table 5. Least square means (S.E.) of enhanced (EN) and non-enhanced (NON) center-cut loin chop, sirloin chop, and blade steak quality attributes nationwide.**

	EN	NON	P-value
<b>Center-cut loin chops</b>			
Color <sup>1</sup>			
In-store evaluation	3.07 (0.06)	2.74 (0.02)	< .0001
In laboratory evaluation	2.73 (0.06)	2.66 (0.02)	< .0001
Marbling <sup>2</sup>			
In-store evaluation	2.02 (0.08)	2.32 (0.03)	< .0001
In laboratory evaluation	2.09 (0.07)	2.31 (0.03)	< .0001
L* <sup>3</sup>	54.46 (0.26)	55.9972 (0.10)	< .0001
a* <sup>4</sup>	16.19 (0.15)	16.00 (0.06)	0.26
b* <sup>5</sup>	9.59 (0.11)	10.38 (0.04)	< .0001
pH	6.00 (0.02)	5.74 (0.01)	< .0001
WBSF <sup>6</sup> , N	20.43 (0.50)	25.99 (0.19)	< .0001
<b>Sirloin chops</b>			
Color <sup>1</sup>	3.04 (0.11)	3.12 (0.08)	0.57
Marbling <sup>2</sup>	1.97 (0.12)	1.97 (0.08)	0.99
L* <sup>3</sup>	53.74 (0.83)	52.51 (0.49)	0.20
a* <sup>4</sup>	17.30 (0.53)	16.24 (0.31)	0.09
b* <sup>5</sup>	10.21 (0.40)	9.66 (0.23)	0.24
pH	6.00 (0.05)	5.89 (0.03)	0.04
WBSF <sup>6</sup> , N	16.18 (1.04)	22.92 (0.67)	< 0.0001
<b>Blade steaks</b>			
Color <sup>1</sup>	4.73 (0.15)	4.72 (0.18)	0.96
Marbling <sup>2</sup>	3.06 (0.17)	2.87 (0.11)	0.37
L* <sup>3</sup>	45.81 (0.56)	45.96 (0.38)	0.82
a* <sup>4</sup>	19.04 (0.38)	17.84 (0.26)	0.01
b* <sup>5</sup>	8.18 (0.30)	7.65 (0.20)	0.14
pH	6.42 (0.05)	6.28 (0.05)	0.04
WBSF <sup>6</sup> , N	15.74 (0.75)	19.42 (0.71)	0.0005

<sup>1</sup> Color scale: 1 = pale pinkish gray to white; 6 = dark purplish red (NPB, 2011). Sirloins and blade steaks were only evaluated for subjective color in the laboratory.

<sup>2</sup> Marbling scale: 1 = devoid; 10 = abundant (NPB, 2011). Sirloins and blade steaks were only evaluated for subjective marbling in the laboratory.

<sup>3</sup> Lightness scale: 0 = black; 100 = white.

<sup>4</sup> Redness scale: < 0 = green; > 0 = red.

<sup>5</sup> Yellowness scale: < 0 = blue; > 0 = yellow.

<sup>6</sup> WBSF = Warner-Bratzler shear force.

The interaction of enhancement type by region were observed for subjective color and marbling scores for center-cut loin chops, sirloin chops, and blade steaks are presented in Table 6 for 2012 and Table 7 for 2015. For 2012, the SW region significantly had a greater subjective color score in EN center-cut loin chops than NON (3.89 vs. 3.30;  $P < 0.01$ ) with no differences ( $P > 0.90$ ) observed in other regions. Subjective marbling score was lower for EN center-cut loin chops than NON the EC (2.34 vs. 2.95;  $P < 0.01$ ), MA (1.99 vs. 2.28;  $P < 0.01$ , and the SE (2.60 vs. 3.05;  $P < 0.01$ ) regions but did not differ ( $P > 0.70$ ) in the other regions. For 2015, the SW region significantly had a greater in-store subjective color score (darker color) for EN center-cut loin chops than for NON center-cut loin chops (3.61 vs. 2.78;  $P < 0.05$ ), with no differences observed ( $P > 0.36$ ) in the other 6 regions. Subjective marbling score in-store was significantly lower for EN center-cut loin chops in the SE (1.66 vs 2.44;  $P < 0.05$ ) and WC (1.86 vs 2.38;  $P < 0.05$ ) regions but did not differ ( $P > 0.33$ ) in other regions. In both 2012 and 2015 the SW region

significantly had a greater subjective color score in EN center-cut loin chops than NON. Additionally, results from both studies in the SE region, EN center-cut loin chops had significantly lower subjective marbling scores. However, in 2012 the EC and MA regions for EN center-cut loin chops had significantly lower subjective marbling scores, where 2015 did not have any significant differences between enhancement type in the EC and MA region, but did have significant lower EN subjective marbling score in the WC region than NON center-cut loin chops, but there were no differences in the WC region in 2012. The enhancement type by region interactions for subjective color and marbling in 2012 and 2015 are not simply explained, but are not likely due to observer bias as experienced graders obtained information in multiple regions.

**Table 6. 2012 Least squares means (S.E.) per region of enhanced (EN) and non-enhanced (NON) center-cut loin chop quality attributes.**

	Region <sup>1</sup>														P-values		
	EC		MA		NE		PA		SE		SW		WC				
	EN	NON	R	E	R*E												
<b>Center-cut loin chops</b>																	
Color <sup>2</sup>	2.66 (0.09)	2.84 (0.10)	3.28 (0.11)	3.08 (0.06)	3.60 (0.14)	3.65 (0.08)	3.37 (0.07)	3.29 (0.06)	3.30 (0.06)	3.35 (0.07)	3.89 <sup>a</sup> (0.09)	3.30 <sup>b</sup> (0.10)	2.69 (0.07)	2.70 (0.07)	<0.01	0.08	<0.01
Marbling <sup>3</sup>	2.34 <sup>a</sup> (0.10)	2.95 <sup>b</sup> (0.11)	1.99 (0.13)	2.28 (0.07)	2.07 (0.16)	2.19 (0.09)	2.34 (0.08)	2.34 (0.07)	2.60 <sup>a</sup> (0.07)	3.05 <sup>b</sup> (0.08)	2.44 (0.11)	2.33 (0.11)	2.42 (0.08)	2.34 (0.08)	<0.01	<0.01	<0.01
L* <sup>4</sup>	54.90 (0.39)	56.74 (0.46)	53.90 <sup>a</sup> (0.49)	57.29 <sup>b</sup> (0.28)	54.22 (0.66)	55.41 (0.38)	54.76 (0.33)	55.81 (0.29)	55.12 (0.27)	56.62 (0.46)	51.02 <sup>a</sup> (0.42)	55.28 <sup>b</sup> (0.42)	54.50 (0.33)	55.29 (0.32)	<0.01	<0.01	<0.01
a* <sup>5</sup>	4.68 (0.35)	6.11 (0.40)	5.56 <sup>c</sup> (0.44)	7.13 <sup>d</sup> (0.25)	6.81 (0.57)	6.24 (0.33)	5.39 (0.29)	6.35 (0.25)	5.82 (0.24)	4.82 (0.40)	8.15 (0.36)	7.97 (0.37)	4.25 (0.29)	4.63 (0.28)	<0.01	0.05	<0.01
b* <sup>6</sup>	3.10 (0.19)	4.03 (0.23)	4.31 <sup>a</sup> (0.24)	2.94 <sup>b</sup> (0.14)	3.47 (0.32)	3.51 (0.19)	3.19 <sup>a</sup> (0.16)	4.24 <sup>b</sup> (0.14)	3.50 (0.14)	3.28 (0.23)	2.89 (0.21)	3.10 (0.21)	4.78 (0.16)	5.17 (0.16)	<0.01	0.17	<0.01
pH	5.90 <sup>a</sup> (0.03)	5.75 <sup>b</sup> (0.03)	5.89 <sup>a</sup> (0.04)	5.74 <sup>b</sup> (0.02)	5.80 (0.05)	5.70 (0.03)	5.93 <sup>c</sup> (0.02)	5.83 <sup>d</sup> (0.02)	5.94 <sup>a</sup> (0.02)	5.81 <sup>b</sup> (0.03)	6.25 <sup>a</sup> (0.03)	5.75 <sup>b</sup> (0.03)	5.97 <sup>a</sup> (0.02)	5.82 <sup>b</sup> (0.02)	<0.01	<0.01	<0.01
WBSF <sup>7</sup> , N	23.18 (0.67)	24.88 (0.79)	19.40 <sup>a</sup> (0.94)	24.22 <sup>b</sup> (0.52)	22.14 (1.10)	24.41 (0.62)	20.03 <sup>a</sup> (0.57)	26.33 <sup>b</sup> (0.50)	21.77 <sup>a</sup> (0.48)	24.59 <sup>b</sup> (0.72)	17.27 <sup>a</sup> (0.72)	25.51 <sup>b</sup> (0.71)	21.99 <sup>a</sup> (0.57)	26.43 <sup>b</sup> (0.54)	<0.01	<0.01	<0.01
<b>Sirloin chops</b>																	
L* <sup>4</sup>	50.15 <sup>a</sup> (0.87)	55.44 <sup>b</sup> (0.87)	51.36 (1.42)	49.91 (0.75)	51.54 (3.14)	51.28 (1.09)	52.42 (0.27)	52.12 (0.36)	51.29 (0.37)	51.87 (0.88)	50.42 (0.45)	52.71 (0.75)	52.25 (0.44)	52.57 (0.67)	0.20	0.12	<0.01
a* <sup>5</sup>	22.21 <sup>a</sup> (0.77)	16.74 <sup>b</sup> (0.77)	20.05 (1.26)	18.03 (0.65)	17.43 (2.48)	18.17 (0.97)	20.01 <sup>a</sup> (0.24)	18.14 <sup>b</sup> (0.31)	20.15 <sup>a</sup> (0.33)	15.52 <sup>b</sup> (0.78)	20.01 (0.39)	20.42 (0.70)	20.43 <sup>a</sup> (0.38)	17.19 <sup>b</sup> (0.58)	<0.01	<0.01	<0.01
b* <sup>6</sup>	9.08 (0.58)	10.83 (0.58)	10.21 (0.95)	8.61 (0.53)	9.02 (2.51)	10.27 (0.72)	10.49 (0.18)	10.19 (0.25)	9.94 (0.25)	11.72 (0.60)	8.74 <sup>a</sup> (0.30)	11.65 <sup>b</sup> (0.45)	9.94 (0.30)	8.54 (0.47)	<0.01	0.16	<0.01
pH	6.21 <sup>a</sup> (0.07)	5.63 <sup>b</sup> (0.07)	5.94 (0.12)	5.87 (0.06)	5.89 (0.21)	5.36 (0.09)	5.83 (0.02)	5.73 (0.03)	6.01 <sup>a</sup> (0.03)	5.71 <sup>b</sup> (0.07)	6.22 <sup>a</sup> (0.04)	5.73 <sup>b</sup> (0.06)	5.88 <sup>a</sup> (0.04)	5.71 <sup>b</sup> (0.05)	<0.01	<0.01	<0.01
WBSF <sup>7</sup> , N	15.30 <sup>a</sup> (1.08)	25.44 <sup>b</sup> (1.10)	14.56 (1.73)	18.99 (0.91)	15.60 (3.39)	24.75 (1.52)	16.91 <sup>a</sup> (0.35)	23.61 <sup>b</sup> (0.44)	17.88 (0.46)	19.85 (1.11)	14.74 <sup>a</sup> (0.56)	20.03 <sup>b</sup> (1.02)	16.93 <sup>a</sup> (0.54)	25.31 <sup>b</sup> (0.81)	<0.01	<0.01	<0.01
<b>Blade steaks</b>																	
L* <sup>4</sup>	44.69 (0.34)	45.85 (0.53)	45.34 (0.68)	45.62 (0.65)	45.37 (1.20)	43.49 (0.94)	45.37 (0.40)	44.71 (0.38)	46.61 (0.30)	45.36 (0.61)	43.51 (1.11)	45.01 (0.84)	44.55 (0.48)	45.49 (0.33)	0.16	0.97	0.04
a* <sup>5</sup>	18.90 (0.23)	18.73 (0.36)	21.60 <sup>a</sup> (0.46)	19.36 <sup>b</sup> (0.44)	22.28 <sup>c</sup> (0.82)	18.93 <sup>d</sup> (0.64)	20.95 <sup>a</sup> (0.27)	19.18 <sup>b</sup> (0.26)	20.26 <sup>a</sup> (0.20)	18.15 <sup>b</sup> (0.42)	20.19 (0.76)	19.19 (0.57)	20.72 <sup>a</sup> (0.33)	18.70 <sup>b</sup> (0.23)	<0.01	<0.01	<0.01
b* <sup>6</sup>	7.72 (0.19)	8.52 (0.31)	9.39 <sup>c</sup> (0.39)	7.72 <sup>d</sup> (0.37)	9.56 (0.69)	8.28 (0.54)	8.94 (0.23)	8.05 (0.22)	8.94 <sup>a</sup> (0.17)	7.56 <sup>b</sup> (0.35)	6.58 (0.64)	6.82 (0.48)	7.41 (0.28)	8.00 (0.19)	<0.01	0.02	<0.01
pH	6.17 (0.03)	6.09 (0.05)	6.28 (0.07)	6.26 (0.06)	6.06 (0.11)	6.04 (0.09)	6.23 (0.04)	6.22 (0.04)	6.29 (0.03)	6.17 (0.06)	6.35 (0.11)	6.37 (0.09)	6.13 (0.05)	6.11 (0.03)	<0.01	0.31	0.84
WBSF <sup>7</sup> , N	17.77 (0.55)	16.48 (0.85)	15.02 <sup>a</sup> (1.06)	19.82 <sup>b</sup> (0.96)	15.75 (1.90)	13.84 (1.51)	15.92 (0.64)	17.84 (0.61)	16.77 (0.47)	18.06 (0.95)	13.38 (1.70)	14.06 (1.43)	15.69 <sup>a</sup> (0.87)	19.83 <sup>b</sup> (0.54)	0.02	0.02	<0.01

<sup>1</sup> EC = East Central, MA = Middle Atlantic, NE = New England, PA = Pacific, SE = Southeast, SW = Southwest, WC = West Central.

<sup>2</sup> Color scale: 1 = pale pinkish gray to white; 6 = dark purplish red (NPB, 2011).

<sup>3</sup> Marbling scale: 1 = devoid; 10 = abundant (NPB, 2011).

<sup>4</sup> Lightness scale: 0 = black; 100 = white.

<sup>5</sup> Redness scale: < 0 = green; > 0 = red.

<sup>6</sup> Yellowness scale: < 0 = blue; > 0 = yellow.

<sup>7</sup> WBSF = Warner-Bratzler shear force.

<sup>a, b</sup> Least square means with a, b in the same region differ by  $P < 0.05$ .

<sup>c, d</sup> Least square means with c, d in the same region differ by  $0.05 < P < 0.10$ .

**Table 7. Least squares means (S.E.) per region of enhanced (EN) and non-enhanced (NON) center-cut loin chop quality attributes.**

	Region <sup>1</sup>														<i>P</i> -values		
	EC		MA		NE		PA		SE		SW		WC		R	E	R*E
	EN	NON	EN	NON	EN	NON	EN	NON	EN	NON	EN	NON	EN	NON			
<b>Center-cut loin chops</b>																	
<b>Color<sup>2</sup></b>																	
In-store <sup>2</sup>	2.69 (0.13)	2.63 (0.06)	2.32 (0.06)	2.90 (0.22)	2.62 (0.07)	2.86 (0.08)	2.79 (0.05)	3.37 (0.13)	3.01 (0.06)	3.61a (0.15)	2.78b (0.08)	3.00 (0.07)	3.00 (0.05)	< 0.0001	< 0.0001		
In-laboratory <sup>2</sup>	2.84 (0.13)	2.65 (0.06)	2.54 (0.07)	1.86 (0.23)	2.42 (0.08)	2.76 (0.09)	2.68 (0.05)	3.12 (0.13)	2.71 (0.05)	2.95 (0.15)	2.72 (0.08)	2.84 (0.07)	2.90 (0.05)	0.2843	< 0.0001		
<b>Marbling<sup>3</sup></b>																	
In-store <sup>3</sup>	1.76 (0.18)	2.28 (0.08)	2.18 (0.09)	2.30 (0.31)	2.51 (0.10)	2.52 (0.12)	2.43 (0.07)	1.66a (0.18)	2.44b (0.08)	2.04 (0.21)	2.04 (0.11)	1.86a (0.10)	2.38b (0.07)	0.0005	< 0.0001		
In-laboratory <sup>3</sup>	2.00 (0.15)	2.21 (0.07)	2.19 (0.08)	1.58 (0.28)	2.44 (0.09)	2.43 (0.11)	2.34 (0.06)	2.05 (0.16)	2.41 (0.06)	2.51 (0.18)	2.41 (0.10)	1.94 (0.09)	2.15 (0.06)	0.0045	0.0001		
L* <sup>4</sup>	53.55a (0.56)	55.91b (0.26)	56.69 (0.28)	57.82 (1.02)	56.37 (0.31)	55.44 (0.39)	55.85 (0.22)	52.23a (0.58)	56.36b (0.24)	52.44a (0.67)	55.23b (0.36)	55.28 (0.33)	55.58 (0.23)	< 0.0001	< 0.0001		
a* <sup>5</sup>	14.90a (0.33)	16.31b (0.15)	15.10 (0.17)	14.86 (0.60)	14.79 (0.19)	15.97 (0.23)	16.03 (0.13)	16.26 (0.34)	17.17 (0.14)	16.18 (0.39)	15.60 (0.21)	18.96a (0.19)	17.03b (0.14)	0.2622	< 0.0001		
b* <sup>6</sup>	9.21a (0.23)	10.57b (0.11)	10.28 (0.12)	10.97 (0.43)	9.89 (0.13)	9.73a (0.16)	10.42b (0.09)	8.77a (0.24)	10.89b (0.10)	8.80a (0.28)	10.15b (0.15)	10.08 (0.14)	10.43 (0.10)	< 0.0001	< 0.0001		
pH	5.66 (0.04)	5.72 (0.02)	5.65 (0.02)	5.71 (0.08)	5.73 (0.02)	5.96a (0.03)	5.79b (0.02)	6.33a (0.05)	5.70b (0.02)	6.36a (0.05)	5.84b (0.03)	5.98a (0.03)	5.76b (0.01)	< 0.0001	< 0.0001		
WBSF <sup>7</sup> , N	23.69 (0.97)	26.86 (0.48)	27.09 (0.60)	25.23 (2.10)	25.08 (0.57)	18.80a (0.68)	25.82b (0.36)	17.80a (1.08)	25.58b (0.43)	18.23a (1.36)	25.74b (0.62)	18.86a (0.60)	25.73b (0.43)	< 0.0001	< 0.0001		
<b>Sirloin chops</b>																	
<b>Color<sup>2</sup></b>																	
	3.01 (0.19)		4.00 (0.35)	2.50 (0.26)	2.70 (0.17)	3.27 (0.15)	2.98 (0.10)		3.03 (0.10)	3.17 (0.43)	3.24 (0.21)	3.24 (0.12)	2.77 (0.19)	0.5655	0.0118		
<b>Marbling<sup>3</sup></b>																	
	1.74 (0.19)		2.04 (0.35)	1.83 (0.26)	2.20 (0.15)	2.35 (0.15)	1.96 (0.10)		1.86 (0.10)	2.33 (0.44)	2.16 (0.21)	1.60 (0.12)	1.59 (0.20)	0.9875	0.0049		
L* <sup>4</sup>	54.42 (1.01)		49.45 (1.82)	55.78 (2.06)	55.82 (1.12)	53.16 (0.82)	52.48 (0.64)		51.79 (0.59)	53.23 (3.28)	51.11 (1.35)	52.12 (0.74)	54.43 (1.21)	0.2036	0.0141		
a* <sup>5</sup>	17.00 (0.65)		15.51 (1.17)	15.98 (1.32)	14.49 (0.69)	17.64 (0.53)	17.24 (0.41)		16.93 (0.38)	16.66 (2.11)	15.26 (0.87)	19.23 (0.47)	17.99 (0.77)	0.0873	0.0007		
b* <sup>6</sup>	9.68 (0.48)		9.07 (0.86)	11.77 (1.01)	9.95 (0.51)	10.64 (0.39)	9.98 (0.31)		9.08 (0.28)	9.04 (1.57)	8.60 (0.65)	9.91 (0.35)	11.29 (0.58)	0.2384	0.0115		

pH	5.49 (0.07)	5.93 (0.13)	5.80 (0.10)	5.75 (0.06)	5.98 (0.06)	5.91 (0.04)	5.79 (0.04)	6.64 (0.18)	6.09 (0.08)	6.07 (0.04)	5.80 (0.07)	0.0352	< 0.0001	
WBSF <sup>7</sup> , N	17.28 (1.60)	25.86 (2.82)	19.08 (2.35)	21.42 (1.27)	18.38a (1.24)	23.30b (0.79)	23.88 (0.78)	11.51 (4.08)	21.79 (1.82)	14.62a (0.94)	21.29b (1.47)	< 0.0001	0.1007	
<b>Blade steaks</b>														
Color <sup>2</sup>	5.20 (0.34)			5.00 (0.86)	4.60 (0.20)	4.78 (0.12)	5.00 (0.45)	4.96 (0.11)	4.50 (0.45)	4.15 (0.22)	4.36 (0.18)	4.69 (0.12)	0.9581	0.0359
Marbling <sup>3</sup>	3.10 (0.38)			2.47 (0.46)	2.85 (0.22)	2.99 (0.14)	3.67 (0.50)	2.83 (0.13)	2.50 (0.50)	3.25 (0.25)	3.17 (0.20)	2.80 (0.13)	0.3677	0.4198
L* <sup>4</sup>	44.03 (1.26)			47.10 (1.52)	47.54a (0.73)	44.76b (0.46)	44.75 (1.63)	46.47 (0.42)	45.65 (1.63)	46.73 (0.82)	47.06c (0.65)	44.73d (0.44)	0.8222	0.0060
a* <sup>5</sup>	17.90 (0.86)			15.01 (1.04)	20.25 (0.50)	18.52 (0.31)	17.57 (1.11)	18.52 (0.29)	17.73 (1.11)	17.96 (0.56)	21.76a (0.45)	19.19b (0.30)	0.0102	< 0.0001
b* <sup>6</sup>	7.48 (0.67)			6.58 (0.80)	9.40a (0.39)	6.98b (0.24)	7.15 (0.86)	7.91 (0.22)	7.87 (0.86)	9.09 (0.43)	9.01c (0.34)	7.71d (0.23)	0.1423	0.0001
pH	5.67 (0.12)			6.34 (0.21)	6.54a (0.07)	6.21b (0.04)	6.87a (0.15)	6.29b (0.04)	6.70 (0.15)	6.21 (0.08)	6.34 (0.06)	6.33 (0.04)	0.0367	< 0.0001
WBSF <sup>7</sup> , N	15.93 (1.70)			20.01 (3.18)	15.69c (0.98)	19.17d (0.64)	16.36 (2.19)	18.06 (0.57)	15.75 (2.19)	22.74 (1.18)	14.98 (0.88)	17.11 (0.59)	0.0005	0.0101

<sup>1</sup> EC = East Central, MA = Middle Atlantic, NE = New England, PA = Pacific, SE = Southeast, SW = Southwest, WC = West Central.

<sup>2</sup> Color scale: 1 = pale pinkish gray to white; 6 = dark purplish red (NPB, 2011).0.0001. Sirloins and blade steaks were only evaluated for subjective color in the laboratory.

<sup>3</sup> Marbling scale: 1 = devoid; 10 = abundant (NPB, 2011). Sirloins and blade steaks were only evaluated for subjective marbling in the laboratory.

<sup>4</sup> Lightness scale: 0 = black; 100 = white.

<sup>5</sup> Redness scale: < 0 = green; > 0 = red.

<sup>6</sup> Yellowness scale: < 0 = blue; > 0 = yellow.

<sup>7</sup> WBSF = Warner-Bratzler shear force.

<sup>a, b</sup> Least square means with a, b in the same region differ by  $P < 0.05$ .

<sup>c, d</sup> Least square means with c, d in the same region differ by  $0.05 < P < 0.10$ .

## Instrumental Pork Quality Attributes

The simple statistics for center-cut loin chop, sirloin chop, and blade steak quality attributes of purchased pork are presented in Table 8 for 2012 and Table 3 for 2015. The overall mean L\* value for center-cut loin chops was 55.30 in 2012 (n= 1707) and 55.56 in 2015 (n= 5488). The overall L\* value for sirloin chops was 51.92 in 2012 (n= 918) and 52.46 in 2015 (n=345). The overall L\* value for blade steaks was 45.27 in 2012 (n= 829) and 45.84 in 2015 (n=470). The overall mean a\* value for center-cut loin chops was 5.89 in 2012 (n= 1708) and 16.60 in 2015 (n= 5493). The overall a\* value for sirloin chops was 19.50 in 2012 (n= 918) and 17.34 in 2015 (n= 346). The overall a\* value for blade steaks was 19.70 in 2012 (n= 829) and 18.97 in 2015 (n= 470). The overall mean b\* value for center-cut loin chops was 3.73 in 2012 (n= 1708) and 10.33 in 2015 (n= 5493). The overall b\* value for sirloin chops was 10.06 in 2012 (n= 918) and 9.79 in 2015 (n= 346). The overall b\* value for blade steaks was 8.13 in 2012 (n= 829) and 7.92 in 2015 (n= 470). The overall mean pH value for center-cut loin chops was 5.86 in 2012 (n= 1799) and 5.83 in 2015 (n= 2428). The overall pH value for sirloin chops was 5.88 in 2012 (n= 1063) and 5.90 in 2015 (n= 508). The overall pH value for blade steaks was 6.22 in 2012 (n= 850) and 6.28 in 2015 (n= 441). The overall mean WBSF value for center-cut loin chops was 23.39 N in 2012 (n= 1912) and 24.25 N in 2015 (n= 3067). The overall WBSF value for sirloin chops was 18.71 N in 2012 (n= 1019) and 20.80 N in 2015 (n= 423). The overall WBSF value for blade steaks was 17.12 N in 2012 (n= 749) and 17.41 N in 2015 (n= 391). For both 2012 and the present study results, blade steaks were darker in color (< L\*) and had the most red (> a\*). Contrary, center-cut loin chops were whiter (> L\*) and had the least red (< a\*). Additionally, blade steaks had the greatest pH value, whereas center-cut loin chops and sirloin chops had similar pH values. Warner-Bratzler Shear Force mean values for blade steaks and sirloin chops were less (more tender) than center-cut loin chops (more tough). Profiling pork muscle reports (Porcine Myology) exhibit that the *Longissimus* muscle of center-cut loin chops has a lesser proportion of Type I to Type IIB muscle fiber types, where the *Serratus ventralis* muscle of the blade steak has a larger proportion of Type IIB to Type I muscle fiber types. Which indicates, the *Serratus ventralis* muscle exhibits a lower L\* value, a greater a\* and greater pH when compared to the other two cuts.

**Table 8. 2012 Center-cut loin chop, sirloin chop, and blade steak demographics by region across the United States.**

	Region <sup>1</sup>							National
	EC	MA	NE	PA	SE	SW	WC	
<i>Center-Cut Loin Chops</i>								
Cities included	8	10	3	15	13	5	13	67
Market areas included	5	4	2	6	6	3	6	32
Stores assessed	12	16	9	25	23	13	19	117
Brands assessed	10	13	10	17	12	9	17	57
<b>Packages Observed<sup>2</sup></b>								
Enhanced	70	47	30	95	121	60	108	531
Non-enhanced	51	120	70	142	104	72	101	660
<b>Packages Purchased<sup>3</sup></b>								
Enhanced	70	47	30	110	146	67	107	577
Non-enhanced	53	153	92	146	63	63	113	683
<i>Sirloin Chops</i>								
Cities included	3	3	3	12	11	5	8	45
Market areas included	3	3	2	6	7	3	6	30
Stores assessed	3	3	2	19	13	9	10	59
Brands assessed	3	3	2	12	7	4	8	31
<b>Packages Purchased<sup>4</sup></b>								
Enhanced	11	6	1	82	44	31	32	207
Non-enhanced	10	14	5	58	12	9	16	124

<i>Blade Steaks</i>								
Cities included	6	5	2	11	10	3	9	16
Market areas included	5	2	2	6	6	3	6	30
Stores assessed	10	5	4	14	17	5	14	69
Brands assessed	6	5	3	10	9	5	13	35
<b>Packages Purchased<sup>4</sup></b>								
Enhanced	38	10	6	41	75	5	28	203
Non-enhanced	50	15	9	53	36	11	60	234

**Table 9. 2012 Least square means (S.E.) of enhanced (EN) and non-enhanced (NON) center-cut loin chop, sirloin chop, and blade steak quality attributes nationwide.**

	EN	NON	P-value
<b>Center-cut loin chops</b>			
Color <sup>1</sup>	3.25 (0.04)	3.17 (0.03)	0.08
Marbling <sup>2</sup>	2.32 (0.04)	2.50 (0.03)	<0.001
L* <sup>3</sup>	54.06 (0.16)	56.06 (0.14)	<0.001
a* <sup>4</sup>	5.81 (0.14)	6.18 (0.13)	0.05
b* <sup>5</sup>	3.61 (0.08)	3.75 (0.07)	0.17
pH	5.96 (0.01)	5.77 (0.01)	<0.001
WBSF <sup>6</sup> , N	20.83 (0.28)	25.20 (0.24)	<0.001
<b>Sirloin chops</b>			
L* <sup>3</sup>	51.35 (0.52)	52.27 (0.30)	0.12
a* <sup>4</sup>	20.04 (0.42)	17.75 (0.27)	<0.001
b* <sup>5</sup>	9.63 (0.40)	10.26 (0.20)	0.16
pH	6.00 (0.04)	5.68 (0.02)	<0.001
WBSF <sup>6</sup> , N	15.99 (0.58)	23.00 (0.39)	<0.001
<b>Blade steaks</b>			
L* <sup>3</sup>	45.06 (0.28)	45.08 (0.24)	0.97
a* <sup>4</sup>	20.70 (0.19)	18.89 (0.17)	<0.001
b* <sup>5</sup>	8.36 (0.16)	7.85 (0.14)	0.02
pH	6.22 (0.03)	6.18 (0.02)	0.31
WBSF <sup>6</sup> , N	15.76 (0.44)	17.13 (0.39)	0.02

<sup>1</sup> Color scale: 1 = pale pinkish gray to white; 6 = dark purplish red (NPB, 2011).

<sup>2</sup> Marbling scale: 1 = devoid; 10 = abundant (NPB, 2011).

<sup>3</sup> Lightness scale: 0 = black; 100 = white.

<sup>4</sup> Redness scale: < 0 = green; > 0 = red.

<sup>5</sup> Yellowness scale: < 0 = blue; > 0 = yellow.

<sup>6</sup> WBSF = Warner-Bratzler shear force.

In 2012, EN center-cut loin chops were significantly ( $P < 0.01$ ) darker (lower Minolta L\* value) than NON center-cut loin chops (54.31 vs 56.10, respectively). The results could be due to the fact that enhancing pork with non-meat ingredients results in a greater pH so less proteins are denatured during the conversion of muscle to meat, causing less water-loss and ultimately less water appearance on the cut surface that does not reflect as much light, but instead absorbs more light. EN sirloin chops had a slightly lower Minolta L\* value ( $P = 0.13$ ) than NON sirloin chops (51.33 vs. 52.24, respectively). Thus, indicating EN sirloin chops were darker in color than NON sirloin chops. EN blade steaks Minolta L\* were closely similar between EN and NON (45.05 vs. 45.08;  $P = 0.95$ ). Therefore, the results explain EN blade steaks were darker in color compared to NON. EN sirloin chops had a Minolta a\* color space value significantly greater ( $P < 0.01$ ) than NON sirloin chops (20.06 vs. 17.68, respectively), concluding EN blade steaks were

more red than NON. Similar to sirloin chops, EN blade steaks had a Minolta  $a^*$  value significantly greater ( $P < 0.01$ ) or more positive redness than NON blade steaks (20.79 vs. 18.89, respectively). EN center-cut loin chops significantly had a lower  $b^*$  value than NON center-cut loin chops (3.62 vs. 3.82;  $P = 0.05$ ). In contrast, EN blade steaks significantly has a higher  $b^*$  value than NON blade steaks (8.37 vs. 7.85;  $P = 0.02$ ). In 2015, EN center-cut loin chops were significantly ( $P < 0.0001$ ) darker (lower Minolta  $L^*$  value) than NON center-cut loin chops (54.46 vs 56.00, respectively). The results could be due to the fact that enhancing pork with non-meat ingredients results in a greater pH so less proteins are denatured, causing less water-loss and ultimately less water on the cut surface that does not reflect as much light. EN sirloin chops had a slightly higher Minolta  $L^*$  value ( $P = 0.20$ ) than NON sirloin chops (53.74 vs. 52.51, respectively). Thus, indicating EN sirloin chops were lighter in color than NON sirloin chops. EN blade steaks Minolta  $L^*$  were closely similar between EN and NON (45.81 vs. 45.96, respectfully). Therefore, the results explain EN blade steaks were darker in color compared to NON. EN sirloin chops had a Minolta  $a^*$  color space value significantly greater ( $P = 0.09$ ) than NON sirloin chops (17.30 vs. 16.24, respectively), concluding EN blade steaks were more red than NON. Similar to sirloin chops, EN blade steaks had a Minolta  $a^*$  value significantly greater ( $P = 0.01$ ) or more positive redness than NON blade steaks (19.04 vs. 17.84, respectively). Overall, in 2012 and 2015 EN center-cut loin chops significantly had a lower Minolta  $L^*$  than NON, and both studies found no significant differences in EN and NON Minolta  $L^*$  values for sirloin chops or blade steaks. Yet, in 2012, for all cuts, EN center-cut loin chops (54.31 vs. 54.46, respectively), sirloin chops (51.33 vs. 53.74, respectively), and blade steaks (45.05 vs. 45.81, respectively), had a lower Minolta  $L^*$  than in 2015. Thus, EN center-cut loin chops, sirloin chops, and blade steaks were darker in color in 2012 than 2015. In contrast, NON center-cut loin chops had a lower Minolta  $L^*$  value in 2015 than 2012 (56.10 vs. 56.00, respectively). In 2012, versus 2015, NON sirloin chops (52.24 vs. 52.51, respectively) and blade steaks (45.08 vs. 45.96, respectively) had a lower Minolta  $L^*$  value. Thus, NON sirloin chops and blade steaks were darker in color in 2012 than 2015, but not for center-cut loin chops. EN center-cut loin chop  $a^*$  was greater in 2015 than 2012 (5.61 vs. 16.19, respectively). EN sirloin chops (20.06 vs. 17.30, respectively) and blade steaks (20.79 vs. 19.04, respectively)  $a^*$  value was greater (more red) in 2012 than 2015. NON center-cut loin chops (3.82 vs. 10.38, respectively) and sirloin chops (9.69 vs. 10.21, respectively)  $b^*$  was greater in 2015 than 2012. Similar to EN blade steaks, NON blade steaks  $b^*$  was greater in 2012 than 2015 (8.37 vs. 8.18, respectively).

In 2012, results for the mean pH values for center-cut loin chops, sirloin chops, and blade steaks are presented in Table 9. The mean pH value for center-cut loin chops was 5.87 which ranged from 4.60 to 7.20. The mean pH value for sirloin chops was 5.89 which ranged from 5.11 to 7.39, and the mean pH value for blade steaks was 6.22 which ranged from 5.25 to 7.12. EN center-cut loin chops significantly had a higher pH value (5.98 vs 5.78,  $P < 0.01$ ) than NON center-cut loin chops. EN sirloin chops significantly had a higher pH value (6.01 vs. 5.68,  $P < 0.01$ ) than NON sirloin chops. EN blade steaks had no significant difference pH than NON blade steaks (6.22 vs. 6.16,  $P = 0.15$ ) than NON blade steaks. In 2015, results for the mean pH values for center-cut loin chops, sirloin chops, and blade steaks are presented in Table 3. The mean pH value for center-cut loin chops was 5.83 which ranged from 4.83 to 7.32. The mean pH value for sirloin chops was 5.90 which ranged from 5.26 to 6.93, and the mean pH value for blade steaks was 6.28 which ranged from 5.02 to 7.12. EN center-cut loin chops significantly had a higher pH value (6.00 vs 5.74,  $P < 0.0001$ ) than NON center-cut loin chops (Table 4). EN sirloin chops significantly had a higher pH value (6.00 vs. 5.89,  $P = 0.04$ ) than NON sirloin chops. EN blade steaks significantly had a higher pH than NON blade steaks (6.42 vs. 6.28,  $P = 0.04$ ) than NON blade steaks. Overall, as anticipated, enhancing pork significantly increases the pH value for all product categories. EN center-cut loin chops (6.00 vs. 5.98, respectively) and blade steaks (6.22 vs. 6.42, respectively) had a higher pH in 2012 than 2015. EN sirloin

chops in 2012 had a slightly higher pH value in 2012 than 2015 (6.01 vs. 6.00, respectively). NON center-cut loin chops had a higher pH value in 2012 than 2015 (5.78 vs. 5.74, respectively). NON sirloin chops (5.68 vs. 5.89, respectively) and blade steaks (6.16 vs. 6.28, respectively) had a lower pH values in 2012 than 2015. Miller (2001) reported the addition of water, sodium or phosphates increases the pH that allows proteins to bind more free water, and less moisture on the cut surface, resulting in less light reflection and in turn appears darker. Thus, retailers have the option to present darker pork to consumers by enhancing pork.

For tenderness, using the Warner-Bratzler Shear Force (WBSF) method, in 2012 the mean value for center-cut loin chops was 23.35 N which ranged from 8.38 to 55.35 N, 18.71 N for sirloin chops which ranged from 7.71 to 40.11, and 17.12 for blade steaks which ranged from 7.08 to 39.86 (Table 9). EN center-cut loin chops were significantly more tender (lower WBSF value) than NON center-cut loin chops (21.00 vs. 25.24,  $P < 0.01$ ). EN sirloin chops were significantly more tender (lower WBSF value) than NON sirloin chops (15.99 vs. 23.00 N,  $P < 0.01$ ), EN blade steaks were significantly more tender (lower WBSF value) than NON blade steaks (15.76 vs. 17.13 N,  $P = 0.02$ ). All cuts had a mean WBSF value lower than what Moeller et al. (2010b) reported with a trained sensory panelists that favored pork with a WBSF value less than 24.5 N but could determine the difference in tenderness for every 4.9 N increase above 24.5 N and did not favor this pork. Thus, in 2012, all cuts, regardless of enhancement type can be classified as tender pork. The mean value for center-cut loin chops for 2015 was 24.25 N which ranged from 7.7 to 68.0 N, 20.80 N for sirloin chops which ranged from 7.71 to 50.18, and 17.41 for blade steaks which ranged from 6.51 to 39.46. EN center-cut loin chops were significantly more tender (lower WBSF value) than NON center-cut loin chops (20.43 vs. 25.99,  $P < 0.0001$ ). EN sirloin chops were significantly more tender (lower WBSF value) than NON sirloin chops (16.18 vs. 22.92 N,  $P < 0.0001$ ), EN blade steaks were significantly more tender (lower WBSF value) than NON blade steaks (15.74 vs. 19.42 N,  $P = 0.0005$ ). EN center-cut loin chops (21.00 vs. 20.43, respectively) and blade steaks (15.76 N vs. 15.74 N, respectively) were more tough (higher WBSF value) in 2012 than 2015. EN sirloin chops were more tender (lower WBSF value) in 2012 than 2015 (15.99 N vs. 16.18 N, respectively). NON center-cut loin chops (25.24 N vs. 25.99 N, respectively) and blade steaks (17.13 N vs. 19.42 N, respectively) were more tender in 2012 than 2015. All product categories had a mean WBSF value lower than what Moeller et al. (2010b) reported with a trained sensory panelists that favored pork with a WBSF value less than 24.5 N but could determine the difference in tenderness for every 4.9 N increase above 24.5 N and did not favor this pork. Therefore, all cuts and enhancement type, from both studies can be classified nationwide as tender.

The differences in region, enhancement type and the interaction of region by enhancement type are presented in Table 10. Where regional differences in  $L^*$  were significant (e.g. SW), greater  $L^*$  values and lesser pH values for NON chops corresponded to increased WBSF values when compared to EN chops. Findings for sirloin chops were different for  $L^*$  across the regions, with enhancement improving  $L^*$  (darker) numerically in the EC, SE, SW, and WC regions; however, enhancement improved pH (greater) and WBSF (lesser) numerically in all regions and significantly in EC, SE, SW, and WC regions. Conversely, enhancement had little practical effect on  $L^*$ , no effect on pH across the regions, and inconsistently small effects on WBSF of the blade steaks, a cut that inherently was darker as measured by  $L^*$ , of a greater pH, and the most tender as indicated by WBSF. In 2015, the effect of enhancement type (enhanced (EN) and non-enhanced (NON)) (Table 9) and enhancement type (enhanced (EN) and non-enhanced (NON)) within region (Table 7) on pork quality were dependent on product cut and region. The

Minolta L\* value for EN center-cut loin chops was significantly lower (darker color) in the SW (52.2 vs. 52.4,  $P < 0.05$ ), and SW (52.4 vs. 55.2,  $P < 0.05$ ) regions but no differences were observed ( $P > 0.98$ ) in the other regions. There were no differences for Minolta L\* value for EN and NON sirloin chops in any of the regions. The Minolta L\* value for NON blade steaks was significantly lower (darker color) in the PA (47.5 vs. 44.76,  $P < 0.05$ ) region than NON blade steaks had a tendency difference to have a lower Minolta L\* in the WC (47.1 vs. 44.7,  $0.05 < P < 0.10$ ) region than EN, but no differences were observed ( $P > 0.99$ ) in the other regions. The Minolta a\* value for EN center-cut loin chops was significantly higher (more red) in the WC (19.0 vs. 17.0,  $P < 0.05$ ) region than NON, but no differences were observed ( $P > 0.41$ ) in the other regions. Likewise, the Minolta a\* value for EN blade steaks were significantly higher (more red) in the WC (21.8 vs. 19.2,  $P < 0.05$ ) region than NON, but no differences were observed ( $P > 0.11$ ) in the other regions. For Minolta b\*, NON center-cut loin chops significantly had a higher b\* value in the PA (9.7 vs. 10.4,  $P < 0.05$ ), SE (8.8 vs. 10.9,  $P < 0.05$ ), and SW (8.8 vs. 10.2,  $P < 0.05$ ) regions than EN, but no differences were observed ( $P > 0.43$ ) in the other regions. Whereas, Minolta b\* for EN blade steaks significantly had a higher b\* value (more yellow) in the PA (9.4 vs. 6.9,  $P < 0.05$ ) region, and EN blade steaks had a tendency difference to have a higher b\* in the WC (9.0 vs. 7.7,  $0.05 < P < 0.10$ ) region than NON, but no differences were observed ( $P > 0.96$ ) in the other regions. Many of the regions had significant differences in pH for enhancement type. EN center-cut loin chops significantly had a higher pH value in the PA (6.0 vs. 5.8,  $P < 0.05$ ), SE (6.3 vs. 5.7,  $P < 0.05$ ), SW (6.4 vs. 5.8,  $P < 0.05$ ), and WC (6.0 vs. 5.8,  $P < 0.05$ ) regions than NON center-cut loin chops, but no differences were observed ( $P > 0.99$ ) in the other regions. While, EN blade steaks significantly had a higher pH value in the PA (6.5 vs. 6.2,  $P < 0.05$ ), and SE (6.9 vs. 6.3,  $P < 0.05$ ) regions than NON, but no differences were observed ( $P > 0.14$ ) in the other regions. A majority of the regions had significant differences in tenderness (WBSF) for enhancement type. EN center-cut loin chops significantly had a lower WBSF (more tender) value in the PA (18.8 vs. 25.8 N,  $P < 0.05$ ), SE (17.8 vs. 25.6 N,  $P < 0.05$ ), SW (18.2 vs. 25.7,  $P < 0.05$ ), and WC (18.9 vs. 25.7,  $P < 0.05$ ) regions than NON center-cut loin chops but no differences were observed ( $P > 0.14$ ) in the other regions. EN sirloin chops significantly had a lower WBSF (more tender) value in the PA (18.4 vs. 23.3 N,  $P < 0.05$ ), and WC (14.6 vs. 21.3 N,  $P < 0.05$ ) regions than NON, but no differences were observed ( $P > 0.44$ ) in the other regions. EN blade steaks only had a tendency difference to have a lower WBSF in the PA (15.7 vs. 19.2,  $0.05 < P < 0.10$ ) region compared to NON blade steaks, but no differences were observed ( $P > 0.14$ ) in the other regions. Overall, there were varying differences between the interaction of enhancement type and region from this present study. One major difference between the 2012 and 2015 study is for the L\*, a\*, and b\*, pH and WBSF least square means per region in 2012 included region, enhancement type and the interaction between region and enhancement type, whereas in 2015 it only included enhancement type and the interaction between region and enhancement type. However, both in 2012 and 2015 there were significant differences in Minolta L\* enhancement types in the SE and SW regions for center-cut loin chops. In 2012, there were additional differences in Minolta L\* for the EC, MA, and PA regions. In 2015 there were no differences for sirloin chop Minolta L\* values, but in 2012 there were differences in enhancement type in the EC and SW region. For blade steaks Minolta L\* in 2012, there were no differences by enhancement type or region, but in 2015 there was a difference in the PA region and a tendency difference in the WC region. For a\* in center-cut loin chops, comparing 2012 to 2015, there were no similar regions that there was significant differences in enhancement type. In 2012, there were a\* value differences between EN and NON in the EC, MA, PA, SE and SW regions for center-cut loin chops, whereas in 2015 there was only a significant difference in the WC region for center-cut loin chops. Similarly, in sirloin chops there were no similar regions where there was significant differences in enhancement type for a\*. In 2012, there was significant difference in enhancement type in the EC, PA, SE, and WC regions for a\*, but there were no

differences found in 2015. Blade steaks a\* value, WC was the only region that both the 2012 and 2015 found significant differences in enhancement type by region. In 2012, there were additional significant differences in the MA, NE, PA, SE, and SW regions. Center-cut loin chop b\* differences were only similar in the PA region for both years. In 2012, there were additional differences in enhancement type by region in the EC, and MA regions, but in 2012, additional differences were also found in SE, and SW regions. There were no differences in 2015 for b\*, but in 2012 there were regional differences in enhancement type for the EC, PA, SW, and WC regions. Blade steaks b\* differences were only similar in the PA region for both years. In 2012, there were additional differences in enhancement type for blade steak b\* for the EC, MA, and SE regions. As well, in 2015 there was a tendency difference in enhancement type in the WC region for blade steak b\* value. In both studies, there were significant differences in enhancement type in the PA, SE, SW, and WC regions for pH. However, in 2012, there was also a significant difference in enhancement type in the EC, and MA regions for pH. For sirloin chops there were no similar significant differences per region for pH in 2012 and 2015. In 2012, there were significant pH differences in enhancement type in the EC, NE, PA, SE, SW, and WC regions, but there were no enhancement type differences in sirloin chops in pH per region in 2015. For blade steaks there were no similar significant differences per region for pH in 2012 and 2015. In 2015, there were significant pH differences in enhancement type in the PA, and SE regions, but there were no enhancement type differences in sirloin chops in pH per region in 2012. In both studies, there were significant differences in enhancement type in the PA, SE, SW, and WC regions for WBSF. However, in 2012, there was also a significant difference in enhancement type in the MA region for WBSF. Sirloin chops had significant WBSF differences in enhancement type for both years in the PA, and WC regions. Yet, in 2012 there were additional significant differences in enhancement type for sirloin chops in the EC, MA, NE, and SW regions. Blade steaks had no similar differences in 2012 and 2015 for enhancement type per region. In 2012, there were significant differences in the MA, PA, and WC regions for WBSF, but in 2015 there was a tendency difference in enhancement type in the PA region for WBSF. Therefore, from the two studies, some of the regions have similar enhancement type differences per region for different instrumental pork quality attributes for center-cut loin chops, sirloin chops, and blade steaks. Overall, the results from both studies suggest enhancing pork improves the pH value and also improves tenderness. However, it is muscle cut dependent and likely due to the type of enhancement solution(s) added by the processor.

**Table 10. 2012 Least squares means (S.E.) per region of enhanced (EN) and non-enhanced (NON) center-cut loin chop quality attributes.**

	Region <sup>1</sup>														<i>P</i> -values		
	EC		MA		NE		PA		SE		SW		WC				
	EN	NON	R	E	R*E												
<b>Center-cut loin chops</b>																	
Color <sup>2</sup>	2.66 (0.09)	2.84 (0.10)	3.28 (0.11)	3.08 (0.06)	3.60 (0.14)	3.65 (0.08)	3.37 (0.07)	3.29 (0.06)	3.30 (0.06)	3.35 (0.07)	3.89 <sup>a</sup> (0.09)	3.30 <sup>b</sup> (0.10)	2.69 (0.07)	2.70 (0.07)	<0.01	0.08	<0.01
Marbling <sup>3</sup>	2.34 <sup>a</sup> (0.10)	2.95 <sup>b</sup> (0.11)	1.99 (0.13)	2.28 (0.07)	2.07 (0.16)	2.19 (0.09)	2.34 (0.08)	2.34 (0.07)	2.60 <sup>a</sup> (0.07)	3.05 <sup>b</sup> (0.08)	2.44 (0.11)	2.33 (0.11)	2.42 (0.08)	2.34 (0.08)	<0.01	<0.01	<0.01
L* <sup>4</sup>	54.90 (0.39)	56.74 (0.46)	53.90 <sup>a</sup> (0.49)	57.29 <sup>b</sup> (0.28)	54.22 (0.66)	55.41 (0.38)	54.76 (0.33)	55.81 (0.29)	55.12 (0.27)	56.62 (0.46)	51.02 <sup>a</sup> (0.42)	55.28 <sup>b</sup> (0.42)	54.50 (0.33)	55.29 (0.32)	<0.01	<0.01	<0.01
a* <sup>5</sup>	4.68 (0.35)	6.11 (0.40)	5.56 <sup>c</sup> (0.44)	7.13 <sup>d</sup> (0.25)	6.81 (0.57)	6.24 (0.33)	5.39 (0.29)	6.35 (0.25)	5.82 (0.24)	4.82 (0.40)	8.15 (0.36)	7.97 (0.37)	4.25 (0.29)	4.63 (0.28)	<0.01	0.05	<0.01
b* <sup>6</sup>	3.10 (0.19)	4.03 (0.23)	4.31 <sup>a</sup> (0.24)	2.94 <sup>b</sup> (0.14)	3.47 (0.32)	3.51 (0.19)	3.19 <sup>a</sup> (0.16)	4.24 <sup>b</sup> (0.14)	3.50 (0.14)	3.28 (0.23)	2.89 (0.21)	3.10 (0.21)	4.78 (0.16)	5.17 (0.16)	<0.01	0.17	<0.01
pH	5.90 <sup>a</sup> (0.03)	5.75 <sup>b</sup> (0.03)	5.89 <sup>a</sup> (0.04)	5.74 <sup>b</sup> (0.02)	5.80 (0.05)	5.70 (0.03)	5.93 <sup>c</sup> (0.02)	5.83 <sup>d</sup> (0.02)	5.94 <sup>a</sup> (0.02)	5.81 <sup>b</sup> (0.03)	6.25 <sup>a</sup> (0.03)	5.75 <sup>b</sup> (0.03)	5.97 <sup>a</sup> (0.02)	5.82 <sup>b</sup> (0.02)	<0.01	<0.01	<0.01
WBSF <sup>7</sup> , N	23.18 (0.67)	24.88 (0.79)	19.40 <sup>a</sup> (0.94)	24.22 <sup>b</sup> (0.52)	22.14 (1.10)	24.41 (0.62)	20.03 <sup>a</sup> (0.57)	26.33 <sup>b</sup> (0.50)	21.77 <sup>a</sup> (0.48)	24.59 <sup>b</sup> (0.72)	17.27 <sup>a</sup> (0.72)	25.51 <sup>b</sup> (0.71)	21.99 <sup>a</sup> (0.57)	26.43 <sup>b</sup> (0.54)	<0.01	<0.01	<0.01
<b>Sirloin chops</b>																	
L* <sup>4</sup>	50.15 <sup>a</sup> (0.87)	55.44 <sup>b</sup> (0.87)	51.36 (1.42)	49.91 (0.75)	51.54 (3.14)	51.28 (1.09)	52.42 (0.27)	52.12 (0.36)	51.29 (0.37)	51.87 (0.88)	50.42 (0.45)	52.71 (0.75)	52.25 (0.44)	52.57 (0.67)	0.20	0.12	<0.01
a* <sup>5</sup>	22.21 <sup>a</sup> (0.77)	16.74 <sup>b</sup> (0.77)	20.05 (1.26)	18.03 (0.65)	17.43 (2.48)	18.17 (0.97)	20.01 <sup>a</sup> (0.24)	18.14 <sup>b</sup> (0.31)	20.15 <sup>a</sup> (0.33)	15.52 <sup>b</sup> (0.78)	20.01 (0.39)	20.42 (0.70)	20.43 <sup>a</sup> (0.38)	17.19 <sup>b</sup> (0.58)	<0.01	<0.01	<0.01
b* <sup>6</sup>	9.08 (0.58)	10.83 (0.58)	10.21 (0.95)	8.61 (0.53)	9.02 (2.51)	10.27 (0.72)	10.49 (0.18)	10.19 (0.25)	9.94 (0.25)	11.72 (0.60)	8.74 <sup>a</sup> (0.30)	11.65 <sup>b</sup> (0.45)	9.94 (0.30)	8.54 (0.47)	<0.01	0.16	<0.01
pH	6.21 <sup>a</sup> (0.07)	5.63 <sup>b</sup> (0.07)	5.94 (0.12)	5.87 (0.06)	5.89 (0.21)	5.36 (0.09)	5.83 (0.02)	5.73 (0.03)	6.01 <sup>a</sup> (0.03)	5.71 <sup>b</sup> (0.07)	6.22 <sup>a</sup> (0.04)	5.73 <sup>b</sup> (0.06)	5.88 <sup>a</sup> (0.04)	5.71 <sup>b</sup> (0.05)	<0.01	<0.01	<0.01
WBSF <sup>7</sup> , N	15.30 <sup>a</sup> (1.08)	25.44 <sup>b</sup> (1.10)	14.56 (1.73)	18.99 (0.91)	15.60 (3.39)	24.75 (1.52)	16.91 <sup>a</sup> (0.35)	23.61 <sup>b</sup> (0.44)	17.88 (0.46)	19.85 (1.11)	14.74 <sup>a</sup> (0.56)	20.03 <sup>b</sup> (1.02)	16.93 <sup>a</sup> (0.54)	25.31 <sup>b</sup> (0.81)	<0.01	<0.01	<0.01
<b>Blade steaks</b>																	
L* <sup>4</sup>	44.69 (0.34)	45.85 (0.53)	45.34 (0.68)	45.62 (0.65)	45.37 (1.20)	43.49 (0.94)	45.37 (0.40)	44.71 (0.38)	46.61 (0.30)	45.36 (0.61)	43.51 (1.11)	45.01 (0.84)	44.55 (0.48)	45.49 (0.33)	0.16	0.97	0.04
a* <sup>5</sup>	18.90 (0.23)	18.73 (0.36)	21.60 <sup>a</sup> (0.46)	19.36 <sup>b</sup> (0.44)	22.28 <sup>c</sup> (0.82)	18.93 <sup>d</sup> (0.64)	20.95 <sup>a</sup> (0.27)	19.18 <sup>b</sup> (0.26)	20.26 <sup>a</sup> (0.20)	18.15 <sup>b</sup> (0.42)	20.19 (0.76)	19.19 (0.57)	20.72 <sup>a</sup> (0.33)	18.70 <sup>b</sup> (0.23)	<0.01	<0.01	<0.01
b* <sup>6</sup>	7.72 (0.19)	8.52 (0.31)	9.39 <sup>c</sup> (0.39)	7.72 <sup>d</sup> (0.37)	9.56 (0.69)	8.28 (0.54)	8.94 (0.23)	8.05 (0.22)	8.94 <sup>a</sup> (0.17)	7.56 <sup>b</sup> (0.35)	6.58 (0.64)	6.82 (0.48)	7.41 (0.28)	8.00 (0.19)	<0.01	0.02	<0.01
pH	6.17 (0.03)	6.09 (0.05)	6.28 (0.07)	6.26 (0.06)	6.06 (0.11)	6.04 (0.09)	6.23 (0.04)	6.22 (0.04)	6.29 (0.03)	6.17 (0.06)	6.35 (0.11)	6.37 (0.09)	6.13 (0.05)	6.11 (0.03)	<0.01	0.31	0.84
WBSF <sup>7</sup> , N	17.77 (0.55)	16.48 (0.85)	15.02 <sup>a</sup> (1.06)	19.82 <sup>b</sup> (0.96)	15.75 (1.90)	13.84 (1.51)	15.92 (0.64)	17.84 (0.61)	16.77 (0.47)	18.06 (0.95)	13.38 (1.70)	14.06 (1.43)	15.69 <sup>a</sup> (0.87)	19.83 <sup>b</sup> (0.54)	0.02	0.02	<0.01

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<sup>1</sup> EC = East Central, MA = Middle Atlantic, NE = New England, PA = Pacific, SE = Southeast, SW = Southwest, WC = West Central.

<sup>2</sup> Color scale: 1 = pale pinkish gray to white; 6 = dark purplish red (NPB, 2011).

<sup>3</sup> Marbling scale: 1 = devoid; 10 = abundant (NPB, 2011).

<sup>4</sup> Lightness scale: 0 = black; 100 = white.

<sup>5</sup> Redness scale: < 0 = green; > 0 = red.

<sup>6</sup> Yellowness scale: < 0 = blue; > 0 = yellow.

<sup>7</sup> WBSF = Warner-Bratzler shear force.

<sup>a, b</sup> Least square means with a, b in the same region differ by  $P < 0.05$ .

<sup>c, d</sup> Least square means with c, d in the same region differ by  $0.05 < P < 0.10$ .

## Pork Quality Frequency Distributions

The frequency distribution of subjective color scores from 2012 and 2015 in-store and in-laboratory for enhanced and non-enhanced center-cut loin chops according to the National Pork Board Color Standards (NPB, 2011) are presented in Figure 1. The mean subjective color score in 2012 was 3.12, while in 2015 in-store the subjective color score was 2.85. Approximately half of all center-cut loin chops evaluated having a color score of 3 (52.9 % for EN and 47.9 % for NON) in 2012, and (52.9 % for EN and 52.9 % for NON) in 2015. The frequency distribution amongst the in-laboratory subjective color scores between EN and NON center-cut loin chops showed little difference. Norman et al. (2003) separated boneless pork loins into three different groups based on subjective color standards (NPB, 2011) and showed 20.8 % of consumers selected pork with a color score of 1 or 2, 26.4 % selected pork with a color score of 3 or 4 and approximately half of the consumers (52.8 %) selected pork with a color score of 5 or 6. In 2012, 18.0 % of EN and 21.7 % of NON center-cut loin chops had a color score of 1 or 2. Moreover, 29.1 % of EN and 30.4 % of NON center-cut loin chops had a color score greater than 3. Whereas in the current study, 23.3 % of EN and 32.7 % of NON center-cut loin chops had a color score of 1 or 2. Moreover, 23.8 % of EN and 14.4 % of NON center-cut loin chops had a color score greater than 3.

**Figure 1. Frequency distribution of subjective color scores from 2012, and 2015 in-store (S), and 2015 in-laboratory (L) for enhanced (EN) and non-enhanced (NON) center-cut loin chops.**

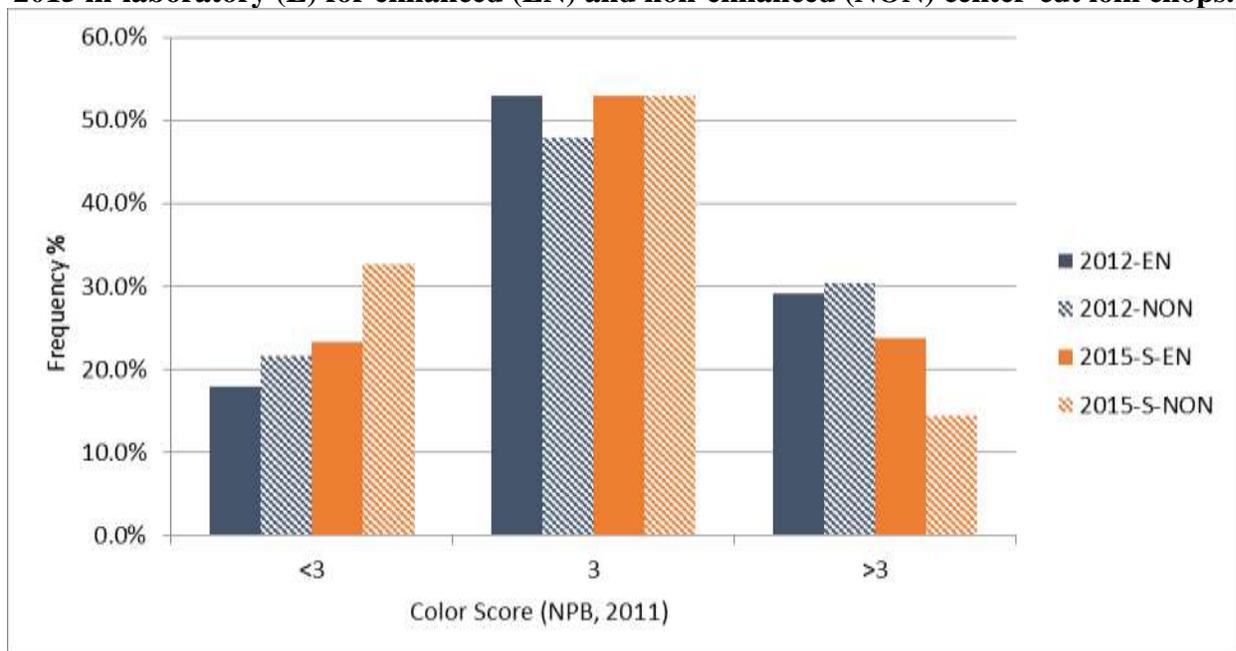
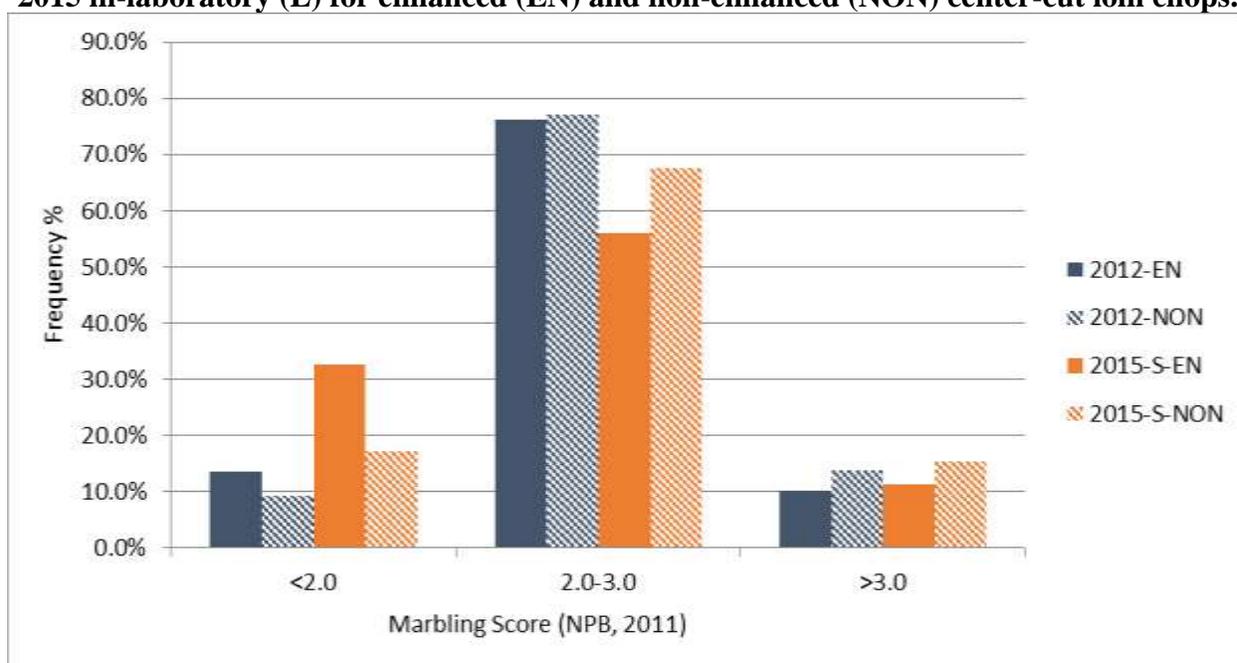


Figure 2 presents the frequency distribution of subjective marbling scores from 2012 and 2015 in-store and in-laboratory for enhanced and non-enhanced center-cut loin chops according to the National Pork Board Marbling Standards (NPB, 2011). The mean subjective marbling score in 2012 was 2.48, while in 2015 in-store the subjective marbling score was 2.30. The majority of center-cut loin chops in 2012 had subjective marbling scores of 2 or 3 (76.1 % for EN chops, respectively; 77.0 % for NON chops, respectively). Similarly, in 2015, a majority of center-cut loin chops had a subjective marbling score of 2 or 3 (56.1 % for EN chops, respectively, 67.5 % of NON chops, respectively). In 2012, a larger percentage of center-cut loin chops scored a 2 or 3, then in 2015. Cannanta et al. (2012) reported when IMF was 2.5% or greater tenderness and juiciness increased. Similarly, Fernandaz et al. (1999a) reported when IMF values reached 2.5 % juiciness and flavor was enhanced. Furthermore, Font-i-Farfois et al. (2012)

recommended 2.2-3.4% minimum of IMF improves eating satisfactoriness. A majority of U.S. pork is exported to countries like Japan who demand high marbling. Rincker et al. (2008) concluded nearly 50% of consumers in a sensory panel selected pork loin chops in a case with the least amount of marbling, but said they would purchase pork that is leaner. Moeller et al. (2010) suggested IMF levels of 5-6 % would improve pork flavor, but contribute very little or have no influence on consumer's perceptions of juiciness or tenderness attributes. Results from this current study, and in 2012 are in compliance with past literature results observing marbling pork quality sensory attributes, suggest that in the self-serve retail meat case nationwide, all cuts have marbling values that reinforce satisfactory eating quality, except for EN sirloin chops from the current study.

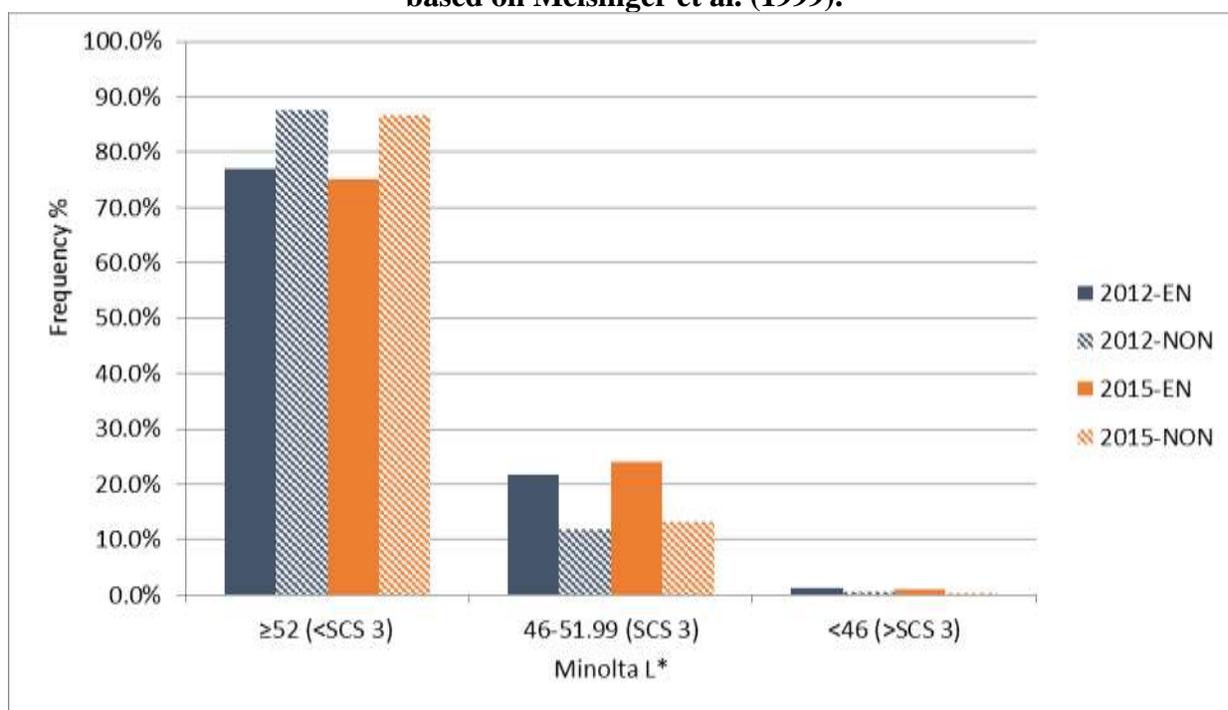
**Figure 2. Frequency distribution of subjective marbling scores from 2012, 2015 in-store (S), and 2015 in-laboratory (L) for enhanced (EN) and non-enhanced (NON) center-cut loin chops.**



The frequency distribution of Minolta L\* values from 2012 and 2015 of enhanced and non-enhanced center-cut loin chops are presented in Figure 3. The thresholds are categorized as being less than or equal to a Minolta L\* value of 52, in the range of 46.00 to 51.99, and greater than 46. In 2012, EN center-cut loin chops had 21.7 % in the Minolta L\* value range of 46.00 to 51.99, 77.1 % of the chops had a Minolta L\* > 52.00 and 1.2 % had a Minolta L\* < 46.00. NON center-cut loin chops had 11.9 % of the chops in the Minolta L\* value range of 46.00 to 51.99, 87.7 % of the chops had a Minolta L\* > 52.00 and 0.5 % had a Minolta L\* < 46.00. In 2015, EN center-cut loin chops had 24.0 % in the Minolta L\* value range of 46.00 to 51.99, 75.1 % of the chops had a Minolta L\* > 52.00 and 0.9 % had a Minolta L\* < 46.00. NON center-cut loin chops had 13.2 % of the chops in the Minolta L\* value range of 46.00 to 51.99, 86.6 % of the chops had a Minolta L\* > 52.00 and 0.2 % had a Minolta L\* < 46.00. Therefore, in 2012, there was a larger percentage of EN and NON center-cut loin chops that had a Minolta L\* value > 52.00, and larger percentage of EN and NON center-cut loin chops that had a Minolta L\* value < 46.00. But in 2015, EN and NON center-cut loin chops had a larger percentage fall in the range of 46.00 to 51.99. Overall, in both years, there is a larger percentage of Minolta L\* values that fall >52.00, which is categorized as having a subjective color score less than 3, and a very small percentage regardless of

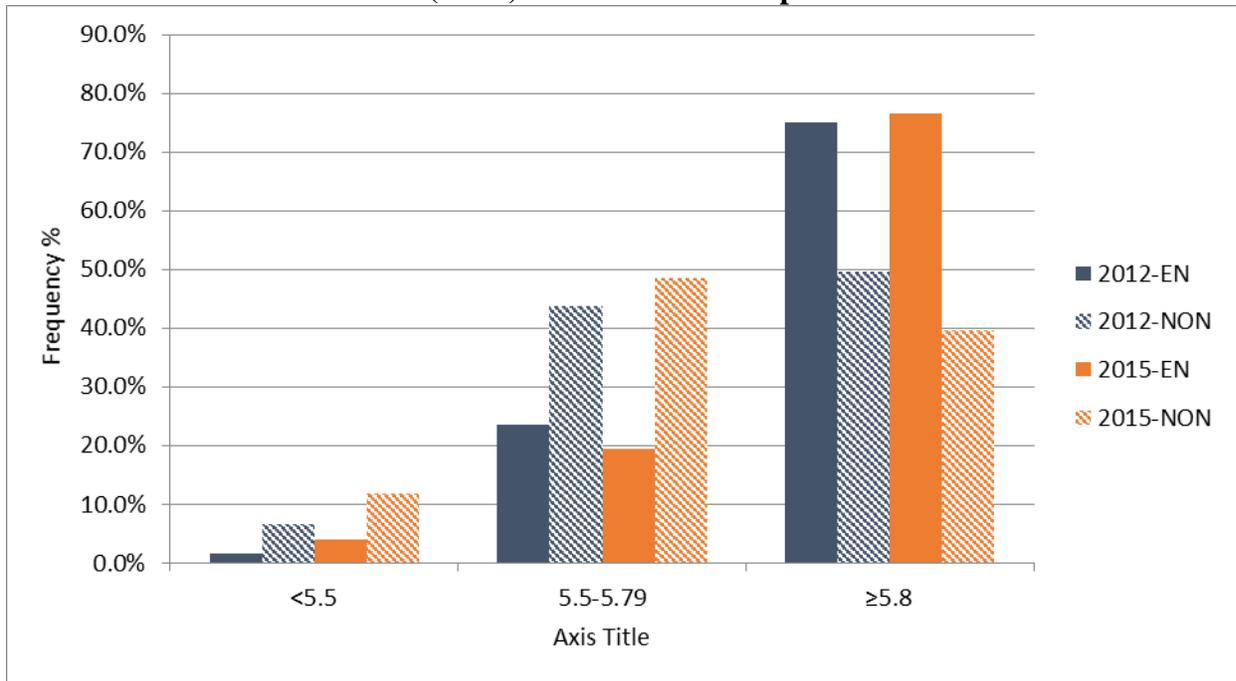
enhancement type with Minolta L\* values < 46.00. Thus, results indicate over the years, consumers are being offered a majority of lighter colored pork in the retail meat case.

**Figure 3. Minolta L\* frequency distribution from 2012 and 2015 of enhanced (EN) and non-enhanced (NON) center-cut loin chops. Subjective color scores assigned to Minolta L\* values are based on Meisinger et al. (1999).**



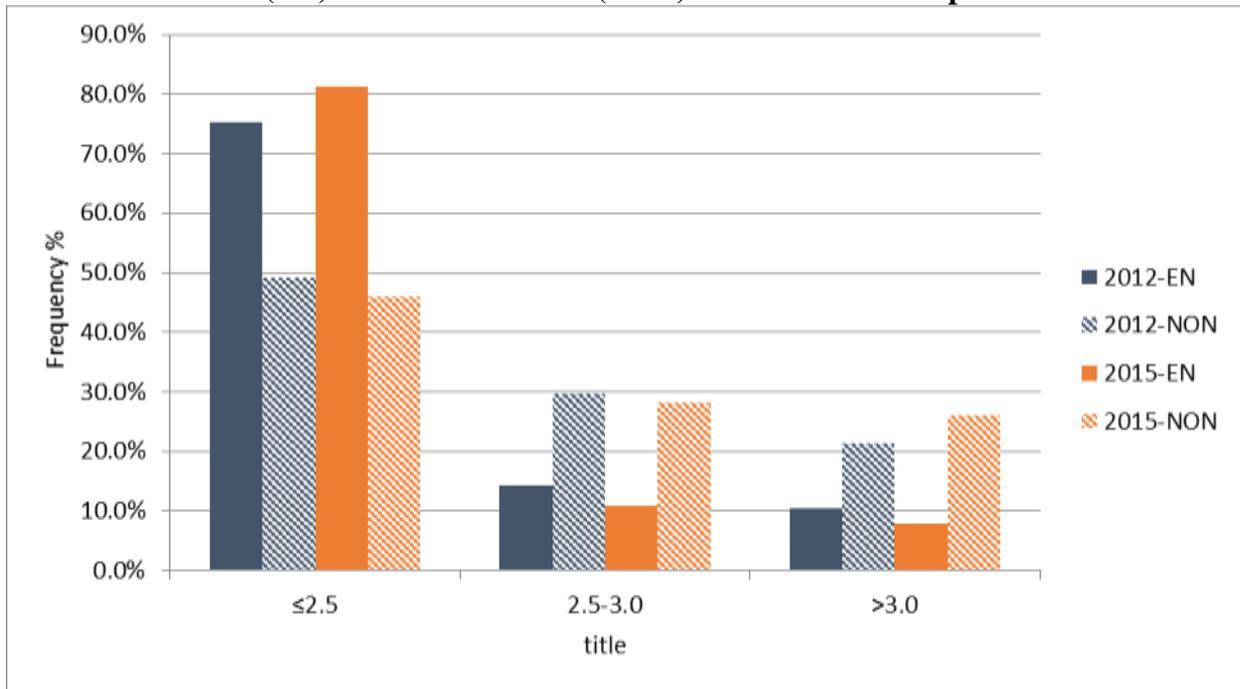
The frequency distribution of pH values from 2012 and 2015 of enhanced and non-enhanced center-cut loin chops are presented in Figure 4. Within center-cut chops for 2012, 23.5 % of EN chops, and 43.9 % of NON chops had a pH between 5.50 and 5.79. A small percentage of EN Three fourths of EN center-cut loin chops (75.0 %) and approximately one fourth of NON center-cut loin chops (49.6 %) had a pH greater than 5.8, resulting in a large percentage of all center-cut loin chops that may have improved eating quality with pH alone as a quality classification. As anticipated, pH was greater for both years in EN center-cut loin chops than NON center-cut loin chops that were > 5.8. For both years a larger percentage of pH values for NON center-cut loin chops fell in the range 5.5 to 5.79 than EN center-cut loin chops. Additionally, NON center-cut loin chops had a larger percentage of pH values < 5.5 for both studies. One explanation for the differences in enhancement type for pH is the addition of non-meat ingredients to the pork at the plant to create an enhanced product for retailers. Miller (2001) reported the addition of water, sodium or phosphates increases the pH that allows proteins to bind more free water, and less moisture on the cut surface, resulting in less light reflection and in turn appears darker. Moeller et al. (2010a) indicated pork loins with an ultimate pH value between 5.8 and 6.4 had positive sensory responses from a trained panelist. Thus, retailers have the option to present darker pork to consumers by enhancing pork.

**Figure 4. Frequency distribution of pH from 2012 and 2015 of enhanced (EN) and non-enhanced (NON) center-cut loin chops.**



The WBSF frequency distribution in 2012 and 2015 for enhanced and non-enhanced center-cut loin chops is presented in Figure 5. In 2012, over three fourths (75.5 %) of EN and approximately half (49.1 %) of NON center-cut loin chops had a WBSF value less than or equal to 24.5 N. A larger percent of NON center-cut loin chops had a WBSF in the 24.5 to 29.4 N range (29.6 % vs. 14.2 %, respectively) than EN center-cut loin chops. As well, a larger percent of NON center-cut loin chops had WBSF values > 29.4 N (21.3 % vs. 10.4 %, respectively) than EN center-cut loin chops. In 2015, over three fourths (81.3 %) of EN and close to half (45.9 %) of NON center-cut loin chops had a WBSF value less than or equal to 24.5 N. A larger percent of NON center-cut loin chops had a WBSF in the 24.5 to 29.4 N range (28.2 % vs. 10.8 %, respectively) than EN center-cut loin chops. As well, a larger percent of NON center-cut loin chops had WBSF values > 29.4 N (26.0 % vs. 7.9 %, respectively) than EN center-cut loin chops.

**Figure 5. Warner-Bratzler Shear Force frequency distribution from 2012 and 2015 of enhanced (EN) and non-enhanced (NON) center-cut loin chops.**



Therefore, there is slightly a larger proportion of EN center-cut loin chops that have a WBSF value < 24.5 N in 2015 than 2012. However, there is slightly a larger proportion of NON center-cut loin chops that have a WBSF value < 24.5 N in 2012 than 2015. Moeller et al. (2010b) determined consumers positively responded to WBSF values below 24.5 N, for tenderness-like, tenderness-level, juiciness-like, juiciness-level, and overall-like, but for every 4.9 N increase in WBSF values, their overall-like decreased by 4%. Thus, regardless of enhancement type, a majority of pork in the U.S. meat case is classified as tender due to the distribution falling below the threshold of 24.5 N reported by Moeller et al. (2010b).

**Discussion:** Explain your research results and include a summary of the results that is of immediate or future benefit to pork producers.

Thus, the data observed in-store under the retail self-serve lighting and in-laboratory under controlled lighting suggests there is a considerable amount of variation in the retail meat case. In the present study investigators reported in-laboratory center-cut loin chops (31.0 % of EN, and 36.5 % of NON), and sirloin chops (64.8 % for EN and 53.3 % for NON) had a majority of subjective color scores of 3. Whereas, 49.5 % of EN and 62.9 % of NON blade steaks had a color score of 5 or 6, and a lower distribution for subjective color score of 3. Blade steak results indicate that the pork industry is currently providing a desirable color score for blade steaks. Subjective color score for center-cut loin chops has decreased over the past ten years regardless if analyzed in-store under retail lighting or in-laboratory under controlled lighting (2.85 vs. 2.74, respectively) from when Wright et al. (2005) and Newman (2012) conducted subjective color score in the retail meat case. In contrast, for subjective marbling, values were fairly consistent between EN and NON regardless of product category. Instrumental Minolta L\* color results indicate that there is a sizeable amount of variation as well. An L\* value between 46.00-51.99 is indicative of a subjective color score 3, data from the present study suggest only 24.05 % of EN center-cut loin chops and 13.16 % of NON center-cut loin chops had an L\* value represented in the range. A majority of L\* values > 52.00 had a color score below 3 for center-cut loin chops (75.1 % for EN and 86.6% of NON), sirloin chops (58.9 % for EN and 54.8 % for NON), and blade steaks (7.1 % for EN and

3.23 % for NON). From this study there is a large inconsistency between the subjective and instrumental color, particularly in center-cut loin chops and sirloin chops. As expected, pH for EN was generally greater than NON for all cuts. Results indicate that for center-cut loin chops, overall 55.2 %, 81.4 % of EN and 45.9 % of NON, sirloin chops overall 73.3 %, 93.9 % of EN and 64.2 % of NON, and blade steaks overall 92.8 %, 95.2 % of EN and 92.0 % of NON, were tender ( $WBSF \leq 24.5$  N) and ultimately would provide consumers a positive eating experience based on results from Moeller et al. (2010) regardless of cut. From the results we can conclude that there is a wide range of variation in center-cut loin chops in the self-serve meat case. Benchmarking pork quality is essential to quantify the variation to express quality attributes being represented at the retail meat case for producers, processors and other industry stakeholders to use as a tool to implement necessary changes to reduce the variation, increase consumer demand and help in meeting the NPB 2020 Strategic Plan goal of reducing color scores of 1 and 2 by 10% by the year 2020 (NPB, 2014).

Based on the results from this current benchmarking study, compared to the study being conducted three years prior, there are certainly differences and similarities. Specifically, subjective color score has reduced over the years (3.12 vs. 2.85, respectively), subjective marbling score has also reduced over the years (2.48 vs. 2.30, respectively). Instrumental pork quality attributes for EN product had higher pH values than NON, as well as were more tender (lower WBSF) than NON center-cut loin chops in both years. It is important to continue benchmarking pork quality at the retail level to identify how and what pork quality values are currently to make any necessary changes at each segment level in the swine industry to display what the industry is providing consumers at the retail self-serve meat case. Based on the results of this study, there is a great deal of pork quality variation which exists in the pork retail self-serve meat case nationwide. Consumers are being offered a wide variety of pork quality variation within package, retail store, and region and between enhanced and non-enhanced pork products, specifically for center-cut loin chops, sirloin chops and blade steaks. Benchmarking pork quality is essential to use as a tool to assist in meeting the National Pork Board's 2020 Strategic Plan Objectives to improve pork quality for consumers. Benchmarking pork quality is imperative to quantify what the swine industry as a whole is presenting to consumers at the retail level. Furthermore, it can be used as a benchmarking tool to implement or identify any changes necessary for swine producers, processors, and other industry stakeholders to improve pork quality since it has decreased in various quality attributes since the last 'National Pork Retail Benchmarking Study' and to ultimately increase pork demand and create a pork quality grading system in the future based on the variation observed in the present study.

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