RESEARCH REPORT

PORK QUALITY

Title: National Pork Retail Benchmarking Study - **NPB #11-163**

Investigator: Dr. David Newman

Institution: North Dakota State University

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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, 117 retailers in 67 cities were selected for sampling using a novel selection model. Center-cut loin chops were observed in-store, in package, to obtain subjective color (n=2795), and marbling (n=2767) scores. 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; n=2795)) and marbling (NPB 1-6, 2011; n=2767)).
- A subset of loins was then sent to Texas A&M for objective quality measures of pH, Minolta color (L*, a*, b*), and Warner Bratzler shear force (WBSF; n=1910).

Frequency distributions for all four quality measures are shown below:

Figure 1. Frequency distribution of subjective color scores for enhanced and non-enhanced center-cut loin chops.

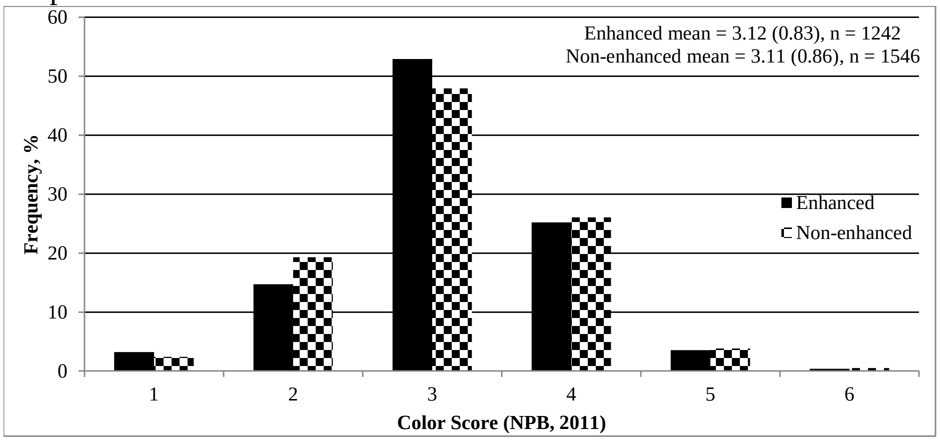


Figure 2. Minolta L* frequency distribution of enhanced and non-enhanced center-cut loin chops.

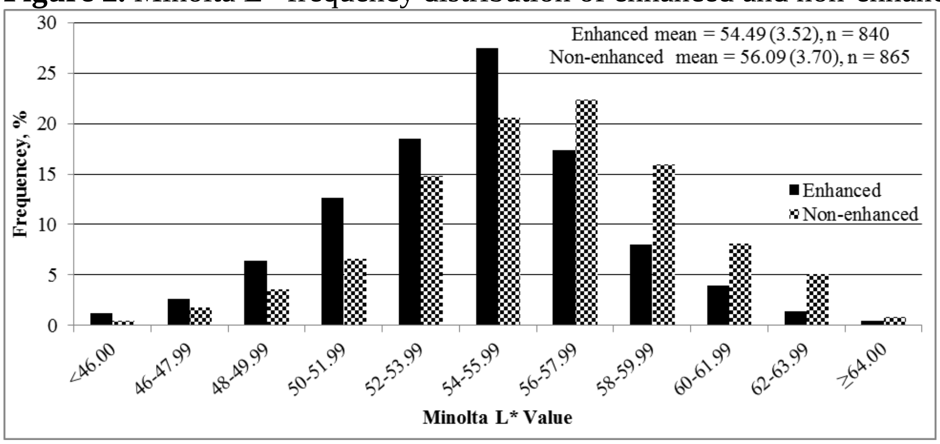


Figure 3. Frequency distribution of subjective marbling scores for enhanced and non-enhanced center-cut loin chops.

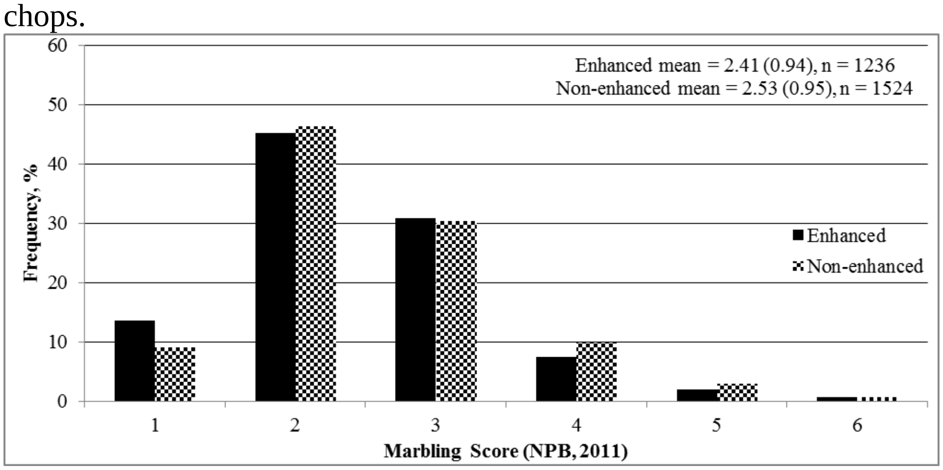
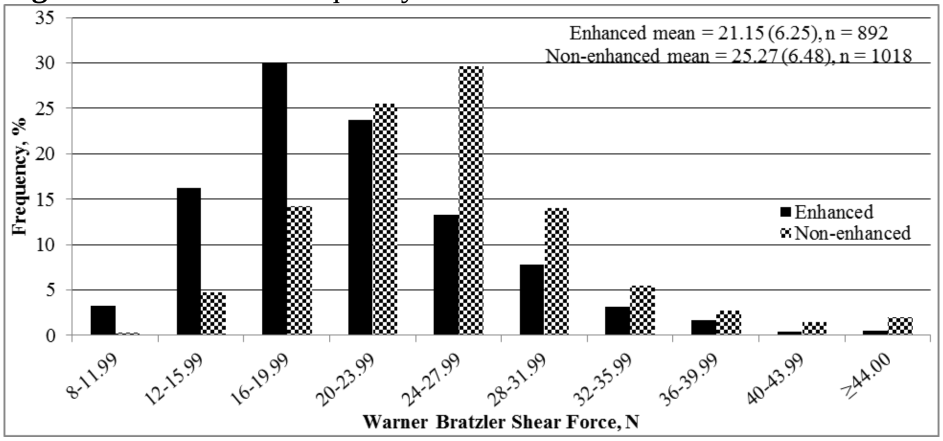


Figure 4. Shear force frequency distribution of enhanced and non-enhanced center-cut loin chops.



These results should be compared to Pork Board recommendations that color should be in a range of 3.0 to 5.0, Intramuscular Fat "Marbling" should be in the range of 2 to 4. For tenderness, positive consumer responses are observed when shear force values are less than 24.5. **An obvious conclusion of the results is that a significant proportion of US pork fails to meet standards associated with good eating quality.**

The authors encountered some discrepancies between subjective and objective measures of color. For subjective color score 93% of center-cut loins had a subjective color score range between 2-4. However, Minolta L* color indicates that "true" objective color is very different. Currently, the NPB color standards chart for subjective color evaluation are provided with a reference to a Minolta L* values. For example, a color score of 1 is associated with a Minolta L* value of 61, and a color score of 6 is associated to a Minolta L* value of 31. Thus, from the current study's subjective mean color results of 3.12 for En and 3.11 for Non, a Minolta L* value close to 49 would be expected when comparing values to NPB color standards. However, mean Minolta L* values reported in the present study (54.49 for En and 56.09 for Non) are indicative of a subjective color score of 2.0 (referenced Minolta L* value of 55). This indicates that the percentage of center cut-loins with pale pork (NPB color score <2) and reduced quality is much higher (than subjective observation) once purchased.

This research provides retailers, processors, and other pork industry stakeholders with benchmark values of pork quality in center-cut loin chops, sirloin chops, and blade steaks which information to reduce variation and improve pork quality at the retail level. 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. This research is especially critical for future discussion on the development of tools to quantify and develop grading standards for pork. Any attempt to develop a pork-grading standard requires knowledge of the mean and standard deviation of current pork quality measures in the retail pork supply.

Contact: Dr. David Newman
North Dakota State University
David.newman@ndsu.edu
701-231-7366

National Retail Pork Quality Benchmarking Study

Abstract: The objective of this study was to benchmark fresh pork quality in retail meat cases in the United States. Nationally, 117 retailers in 67 cities were selected for sampling. Center-cut loin chops were observed in-store, in package, to obtain subjective color (n=2795), and marbling (n=2767) scores. 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). Means for enhanced and non-enhanced loin chops were: color (3.19 vs. 3.18, SEM=0.03), marbling (2.39 vs. 2.47; SEM=0.04), pH (5.98 vs. 5.78; SEM=0.01), L* (54.31 vs. 56.10; SEM=0.15), a* (5.61 vs. 6.23; SEM=0.13), b* (3.62 vs. 3.82; SEM=0.08), and WBSF (21.00 vs. 25.24; SEM=0.25N), respectively. Means for enhanced vs. non-enhanced sirloin chops were: pH (6.01 vs. 5.68; SED=0.05), L* (51.33 vs. 52.24; SED=0.61), a* (20.06 vs. 17.68; SED=0.52), b* (9.69 vs. 9.94; SED=0.32), and WBSF (15.99 vs. 23.00; SED=0.70N), respectively. Means for enhanced vs. non-enhanced blade steaks were: pH (6.22 vs. 6.16; SED=0.04), L* (45.05 vs. 45.08; SED=0.37), a* (20.79 vs. 18.89; SED=0.26), b* (8.37 vs. 7.85; SED=0.21), and WBSF (15.76 vs. 17.13; SED=0.59N), respectively. This research provides retailers, processors, and other pork industry stakeholders with benchmark values of pork quality in center-cut loin chops, sirloin chops, and blade steaks which information to reduce variation and improve pork quality at the retail level.

Key words: benchmark; chops; pork; quality; retail

1. Introduction

At the retail level, pork quality has been shown to be variable whether pork is fresh, processed, or enhanced (Wright et al., 2005). Variables considered at the time of purchase include product color, marbling, fat cover, and drip loss (Brewer et al., 2001 and Ngapo et al., 2005). Moeller et al. (2010a) reported that palatability, or eating quality, a culmination of taste, flavor, juiciness, and tenderness, is an important factor in the selection of pork at the consumer level. Therefore, it is understood that consumer acceptance of pork results from a complex combination of visual appeal and eating satisfaction (Lee et al., 2012).

In 2011 the National Pork Board unveiled the marketing campaign "*PORK® Be Inspired*". The new campaign established goals for domestic pork consumers, who were identified as "pork champions." Consumer segmentation research (National Pork Board, 2012) characterized "pork champions" as men and women who are predominantly medium to heavy fresh pork users, representing 82 million Americans and 68% of all in-home fresh pork consumption. Campaign goals include a 10% increase in fresh pork consumption per capita and a 10% increase in real per capita domestic expenditures. According to United States Department of Agriculture statistics, approximately 75% of the U.S. pork supply was consumed domestically (USDA, 2012). This percentage does not take into account factors that could increase the supply of domestic product including a reduction in pork exports or increased domestic production. With such a high proportion of domestic pork consumption it is important to focus on the consistency and quality of pork products presented to pork consumers at the retail level. Also, consumers who purchase fresh pork and feel comfortable cooking it correctly could have drastically different eating experiences, regardless of cooking method, based on the differing degrees of quality available at retail locations.

Pork quality attributes have been extensively studied looking at their effects on overall eating satisfaction. Brewer et al. (2001) reported that highly marbled chops were more juicy and tender than lean chops. Cannata et al. (2010) also found that visual marbling influenced sensory qualities of pork. However, both Moeller et al.

(2010a) and Rincker et al. (2008) reported that pork intramuscular fat (IMF) had very little, if any influence on consumer satisfaction and their overall perception of tenderness, juiciness, pork flavor, and oiliness. Furthermore, Font-i-Furnols et al. (2012) reported that marbling had varying effects on consumer preference in different countries. Therefore, it is important to note that there are many variables that contribute to consumers' satisfaction of pork (Cannata et al., 2010).

According to Norman et al. (2003) darker colored pork chops were more tender and juicy than lighter colored pork chops, also noting that darker colored chops had a higher pH value. Norman et al. (2003) also noted that high pH improved water holding capacity, which was indicative of a juicier pork chop. Darker colored pork had 3.4% greater cook yield than lighter colored pork. This further supported the concept that pork with a higher pH has a higher tendency to hold water accounting for increased cook yield. Moeller et al. (2010a) reported that as the pH of pork increased 0.20 units from 5.40 to 6.40, consumer ratings of juiciness increased 4.7%. Aberle et al. (2001) support this theory, stating that higher pH values are associated with meat having greater water holding capacity, resulting in a juicier cooked product.

Moeller et al. (2010a) reported that consumer perceptions of pork eating quality were greatly influenced by fresh pork ultimate pH, cooked pork WBSF, loin IMF, and end-point cooked temperature. In Belgium, consumers perceived pork as being the worst meat choice when compared to poultry and beef when leanness, healthiness, taste, quality, and tenderness were considered (Verbeke & Viaene 1999). This may help explain why Brewer et al. (2001) found that leaner chops with low (1.05%) or medium (2.33%) amounts of marbling had higher overall appearance acceptability scores than highly (3.46%) marbled chops. Contradicting overall appearance acceptability, Brewer et al. (2001) also reported that highly marbled chops were more juicy and tender than lean chops. Therefore, providing consumers with consistent, high quality and palatable pork products appealing to consumers at the retail level must be addressed by industry stakeholders to ensure customer satisfaction.

Many studies have been conducted to benchmark value in the pork supply chain or to quantify pork quality characteristics. The Pork Chain Quality Audit Survey was conducted to identify, quantify, and rank factors influencing pork quality at the slaughter and fabrication segments of the pork chain (Cannon et al. 1996). The 2004 National Meat Case Study assessed what meat products were offered to consumers and how they were offered in the retail meat case (Reicks et al., 2008). Person et al. (2005a) evaluated how boneless and bone-in ham quality was affected by PSE pork at the processing segment. Person et al. (2005b) evaluated the relationship between belly thickness, processing yields, and consumer preferences of bacon at the processing segment of the industry. Wright et al. (2005) benchmarked loin, ham, and belly pork products at the retail level evaluating the price/value relationship of each and determined the opportunities lost with pork quality defects. Furthermore, Moeller et al. (2010a,b) studied consumers and trained sensory panelist's perceptions of pork eating quality as affected by pork quality attributes and end point cooked temperature. Based on these results, researchers and pork industry stakeholders are better able to understand the type of pork that consumers prefer and/or demand at the retail level. However, there has not been any research conducted to simply quantify the quality and the variation in pork quality that consumers are offered at the retail level of the pork industry. Because the pork industry does not currently utilize a quality grading system, packers and processors do not purchase or sort a large volume of domestic pork based on quality attributes. Likewise retailers offer very little pork based on quality attributes. There are no cues at the meat case to inform and educate consumers about pork quality. With no visual quality indicators such as pork color, consumers have little knowledge about what to look for. A grocery shopper intercept study (National Pork Board, 2012) found that consumers were generally confused when purchasing pork products and that pork color does not register as a major consumer purchasing decision factor. Purchasing factors were further compounded by the variation of pork quality that was found in the meat case. Thus, pork consumers were left with a lack of information about pork quality selection in the retail meat case.

Our objective was to gather nationwide pork quality attribute benchmarking values. This study was designed to provide producers, processors, and retailers in the pork industry with important information regarding pork quality and how to better serve consumers. This data can be used to help reduce the amount of pork quality variation of pork center-cut loin chops at the retail level.

2. Materials and Methods

2.1. Retail store sampling

With the collaboration of six Universities including North Dakota State University, Texas A&M University, The University of Florida, The Pennsylvania State University, The Ohio State University, and California Polytechnic State University, 117 retail stores in 32 market areas were visited (Table 1). Each University had a principal investigator assisted by a trained team. Prior to data collection, each of the six teams met in Kansas City, MO for a training workshop. At this workshop, investigators finalized the data collection protocol and performed a mock collection at a local retail grocery.

Retail stores were sampled between February and April 2012, collecting data between the hours of 9 A.M. and 5 P.M. local time. Center-cut loin chop packages (n=1191) were selected from the self-serve case to represent different loins and evaluated for subjective measurements of color (National Pork Board 1-6, 2011) and marbling (National Pork Board 1-6, 2011) in 67 cities across the United States (Table 1). Of the 117 stores, sirloin chops were purchased in 59 and blade steaks were purchased in 69 (Table 1). Using the 2011 Marketing Guidebook (Stagnito Media, 2011), individual market areas to be sampled were identified (Table 2) in 7 different regions and then retail stores within each market area were selected based on the following representation criteria: 1) Geographic population distribution and major retailers, both national and regional. 2) Top 5 Supermarkets in each market area. 3) Retail stores where middle class income consumers most frequently shop.

2.2. Subjective center-cut loin chops evaluation

Ten packages of center-cut loin chops of each representative brand and each enhancement type (Enhanced (En) and Non-enhanced (Non)) were selected to represent different loins in the self-serve meat case and were evaluated. The principal investigator of each team performed the evaluation of subjective color and marbling (National Pork Board, 2011) under the lighting in the meat case. Selection preference was given to boneless center-cut loin chops but due to regional differences in product availability, bone-in chops were used as well. Every chop that was at least 50% visible in each package was evaluated for each of the previously mentioned attributes.

2.3. Objective package selection

When available, ten packages of center-cut loin chops, sirloin chops, and blade steaks of each representative brand and each enhancement type (enhanced (En) and non-enhanced (Non)) were randomly selected from the self-serve meat case and purchased. Due to regional differences in product availability, bone-in chops were purchased when boneless chops were unavailable. Likewise, 2.54-cm thick chops and steaks were preferred. However, when unavailable, the next thickest available chops or steaks were purchased. After purchasing, center-cut loin chops were shipped overnight in coolers on reusable frozen ice packs to Texas A&M University (TAMU) and sirloin chops and blade steaks were shipped to North Dakota State University (NDSU) for further objective pork quality.

2.4. Minolta color and pH measurement

Upon arrival at TAMU or NDSU, packages were opened and allowed to bloom for a minimum of 10 min. Two center-cut loin chops from each package were randomly selected for pH and Minolta color measurements. The *Gluteus medius* muscle of sirloin chops and the *Serratus ventralis* muscle of blade steaks were used to obtain pH, objective color, and Warner-Bratzler shear force values. In the event that either of these muscles were too small for the 50 mm orifice of the Minolta Colorimeter to cover, too thin to obtain pH, or too small to obtain cores for WBSF, then any of the remaining measurements would be obtained if possible. After bloom, objective color (CIE L*, a*, and b* color space values) was measured using a Minolta Colorimeter (CR-300, 8 mm diameter head, 10° standard observer, D^{65} light source for center-cut loin chops and CR-410, 50 mm diameter head, 2˚ observer, C light source for sirloin chops and blade steaks; Minolta Company, Ramsey, NJ) calibrated using a white tile. To obtain pH measurements, a portable pH meter (HI 98240 for center-cut loin chops and HI 99163 for sirloin chops and blade steaks; Hanna Instruments, Italy) equipped with a glass-tipped pH probe was used.

2.5. Warner-Bratzler shear force

Two different chops from each package purchased were randomly selected for Warner Bratzler shear force (WBSF). The two WBSF chops were vacuum sealed and frozen. Prior to cooking, chops and steaks were thawed for 48 h in a cooler at 4ºC and then cooked using a clam-style cooker (George Foreman Grill) to an internal temperature of 65ºC. Internal temperatures of center-cut loin chops were monitored using iron constantan thermocouples inserted into the geometric center of each chop (TT-J-36-SLE; Omega Engineering, Inc., Stanford, CT) and a hand-held temperature recorder (HH-21; Omega Engineering, Inc., Stanford, CT). Internal temperatures of sirloin chops and blade steaks were monitored from the geometric center with a copper-constantan insulated wire (Neoflon PFA) and temperatures were recorded using a hand-held temperature recorder (HH801B; Omega Engineering Inc., Stanford, CT). Chops and steaks were cooled for 4 h to approximately 22.2ºC prior to shear force assessment. Four to six 1.27-cm diameter cores were removed from each chop or steak parallel to the longitudinal orientation of the muscle fibers. Each core was sheared with a Warner-Bratzler shearing device (center-cut loin chops: United Smart-1 Test System SSTM-500; United Calibration Corp., Huntington Beach, CA; sirloin chops and blade steaks: G-R Electrical Manufacturing Co., Manhattan, KS) perpendicular to the muscle fibers. Maximum force for each core was recorded in kg, and analyzed as the average of the cores removed from each chop or steak. All averaged values were converted into Newton’s from kg (1 kg = 9.80665002864 N).

2.6. Statistical analysis

Data were analyzed using general least squares (PROC MIXED, SAS Institute, Cary, NC). Chops or steaks were the experimental unit. The model included region, enhancement type, and the interaction of region and enhancement type as fixed effects and package within region, retailer, store, and brand as random effect. Differences were considered significant if $P < 0.05$.

3. Results and discussion

3.1. Product demographics

The number of En and Non center-cut loin chop packages used for subjective assessment of pork color and marbling as well as the number of packages purchased for objective assessments (pH, Minolta color, and WBSF) per region can be found in Table 1. Also, presented in Table 1 are the numbers of En and Non sirloin chop and blade steak packages purchased and used for objective assessments (pH, Minolta color, and WBSF) per region. Overall, 531 En and 660 Non packages of center-cut loin chops were used for subjective assessments. Similarly, 577 En and 683 Non packages of center-cut loin chops were purchased for objective assessments. A total of 1,191 packages of center-cut loin chops were observed for subjective attributes in the retail meat case and 1,260 packages were purchased to obtain additional objective measurements. Overall, 207 En and 124 Non packages of sirloin chops were purchased. Regionally, differences were seen in product availability of sirloin chops. In the NE, EC, and MA regions, there was a very limited selection of sirloin chops available to consumers. On the contrary, the PA region had a much greater selection of sirloin chops available. Similarly, 203 En and 234 Non packages of blade steaks were purchased. Once again, there were regional differences in product availability of blade steaks. The EC, PA, SE, and WC had a larger selection of blade steaks available than the 3 remaining regions.

3.2. Subjective pork quality attributes

Overall, a mean color score of 3.12 was observed for center-cut loin chops in the retail meat case (Table 3). This average color score was slightly less than what was observed by Wright et al. (2005) where boneless loin chops gathered in the retail meat case were reported as having a mean color score of 3.52, albeit the scores are still characterized as having a reddish-pink lean color. A mean marbling score of 2.48 was observed (Table 3) which is slightly greater than the mean marbling score of 2.37 that was observed by Wright et al. (2005) in boneless loin chops. These results suggest that subjective pork quality attributes observed in the retail meat case are fairly consistent with what was observed previously by Wright et al. (2005).

There were small differences between En and Non center-cut loin chop color scores (3.19 vs. 3.18, respectively, $P = 0.78$) or marbling score (2.39 vs. 2.47, respectively, $P = 0.08$) (Table 4). Figure 1 presents the distribution of color score for En and Non center-cut loin chops. The mean color score for En chops was 3.12, of which 53% of the chops had a color score of 3 and 40% scored 2 or 4 (15% & 25%, respectively). Furthermore, 18% of En chops had a color score less than 3 while 29% had a color score greater than 3. The mean color score for Non chops was 3.11, of which 48% of the chops had a color score of 3 and 45% scored 2 or 4 (19% & 26%, respectively). Furthermore, 22% of Non chops had a color score less than 3 while 30% had a color score greater than 3. Interestingly, 93% of both En and Non chops were reported as having a color score between 2 and 4. A color score of 2 is characterized as being grayish pink and a 4 as being dark reddish pink; thus, these data suggest that there is still a considerable amount of variation in the retail meat case. Table 3 further illustrates the variation in color scores observed in retail outlets, with the standard deviation being nearly equal (0.85) to a single unit of measurement and a corresponding coefficient of variation of 27.12%. Both of these statistics suggest that a sizeable amount of variation in pork quality was observed in the retail meat case. Similar results were observed for marbling (Fig. 2.) where En chops had a mean score of 2.41 with 45% scoring a 2 and 45% scoring a 1 or 3 (14% & 31% respectively). The mean marbling score for Non chops was 2.53 with 47% scoring 2 and 40% scoring a 1 or 3 (9% & 31% respectively). Again, a sizeable amount of variation in marbling score was observed, with a standard deviation of 0.95 units and coefficient of variation of 38.14%.

3.3. Objective pork quality attributes

Presented in Table 3 are simple statistics of center-cut loin chops, sirloin chops, and blade steaks quality attributes. Overall, sirloin chops had a mean Minolta L* value of 51.92 while blade steaks had a mean of 45.27. Center-cut loins were found to have a mean Minolta score of 55.30. Of these three cuts, blade steaks were darkest and center-cut loin chops lightest. For Minolta a*, sirloin chops averaged 19.50 while blade steaks averaged 19.70, with standard deviations of 2.74 and 2.12, respectively. Center-cut loin chops scored lower (mean=5.89) and were more variable (Std. Dev. = 3.11) than either sirloin chops or blade steaks. The same trend was found for Minolta b* values. Sirloin chops had a mean of 9.99 (Std. Dev. = 1.66) while blade steaks had a mean of 8.13 (Std. Dev. = 1.71). Center-cut loin chops had lower (mean = 3.74) and more variable (Std. Dev. = 1.84) Minolta b* values than either sirloin chops or blade steaks. Sirloin chops were found to have a lower pH than blade steaks (5.88 vs. 6.22, respectively). Center-cut loin chops were found to have a similar pH to the pH of sirloin chops in this study (5.87 vs. 5.88, respectively). Sirloin chops were tougher than blade steaks (WBSF = 18.71 vs. 17.12 N, respectively). Center-cut loin chops were even tougher than sirloin chops (WBSF = 23.35 vs. 18.71 N, respectively).

Least squares means for En and Non center-cut loin chops, sirloin chops, and blade steaks are presented in Table 4. Minolta L* values were similar between En and Non meat for both sirloin chops and blade steaks ($P = 0.12$ and 0.39, respectively). However, Non center-cut loin chops were found to have greater L* values than En center-cut loin chops ($P < 0.01$). Minolta a* values were greater in En sirloin chops and blade steaks when compared to Non sirloin chops and blade steaks ($P < 0.01$). This is in the opposite direction of center-cut loin chops where Non chops had greater a* values than En chops ($P < 0.01$). Enhancement type had no effect on b* for sirloin chops ($P = 0.77$) while En blade steaks had significantly greater b* values than Non steaks ($P < 0.01$). The effect of enhancement type on center-cut loin chops was different from both sirloin chops and blade steaks with Non chops having greater b* values than En chops ($P = 0.05$). Results for pH were consistent across cuts of meat with both En sirloin chops and blade steaks having higher pH than Non chops and steaks ($P < 0.01$ and $P = 0.02$, respectively). Similarly, En center-cut loin chops also had higher pH than Non chops ($P < 0.01$). En meat was more tender, having lower ($P < 0.01$) WBSF values than Non meat for sirloin chops, blade steaks, and center-cut loin chops. While enhancement effects on pH and WBSF were consistent across cuts of meat, the effect of enhancement on Minolta coloring was not.

The frequency distribution for Minolta L* values for En and Non center-cut loin chops are given in Figure 3. En chops had a mean L* value of 54.49 and 28% of these chops were in the L* value range of 54.00 to 55.99, 41% of the chops had an L* <54.00 and 31% had an L* >55.99. Non chops had a mean L* value of 56.09 and 22% of these chops were in the L* value range of 56.00 to 57.99, 48% of the chops had an L* <56.00 and 30% had an L* >57.99. Currently, the NPB color standards chart for subjective color evaluation are provided with a reference to a Minolta L* values. For example, a color score of 1 is associated with a Minolta L* value of 61, and a color score of 6 is associated to a Minolta L* value of 31. Thus, from the current study's subjective mean color results of 3.12 for En and 3.11 for Non, a Minolta L* value close to 49 would be expected when comparing values to NPB color standards. However, mean Minolta L* values reported in the present study (54.49 for En and 56.09 for Non) are indicative of a subjective color score of 2.0 (referenced Minolta L* value of 55). One possible explanation for this is that different retailers use different light sources in their self-serve meat cases causing pork to appear darker or lighter than what it actually is under a controlled light source. Additionally, color scores were determined in store and Minolta L* values were determined after shipment. Barbut (2001) reported that pork presented under incandescent (INC) lighting was more desirable ($P<0.05$) than pork presented under both fluorescent (FL) and metal halide (MH) light sources. Pork presented under INC lighting was described as pink. Under FL lighting, pork was described as being pink brown or dark pink. Under MH light sources, pork was described as brown or dull pink. Barbut (2001) went on to say that under both MH and FL light sources, pork reflected more light, and so appeared lighter. Another possible explanation is that by adding non-meat ingredients to pork to create an enhanced product, a higher pH is obtained which allows pork proteins to bind more free water and allows less moisture to appear on the meat surface (Miller, 2002). When less moisture appears on the surface of meat, less light is reflected resulting in a darker appearing product (Miller, 2002). Therefore, by enhancing pork, retailers are in turn able to provide pork products that appear darker to consumers when evaluated at the retail store.

Frequency distribution for Minolta L* values for En and Non sirloin chops and blade steaks are given in Figure 3. On average, blade steaks are darker than sirloin chops with 84.5% of Non and 82.8% of En steaks being below an L* value of 48. On the other hand, only 13.0% of Non and 11.4% of En chops were below 48. The majority of sirloin chops fell between 48 and 56 with 76.5% of Non and 80.4% of En chops falling in this range. The majority of blade steaks fell between 42 and 48 with 73.1% of Non and 73.5% of En steaks falling in this range. Moeller et al. (2010a) found no relationship between L* and consumer responses for overall-like.

Packaging type is also known to affect the appearance of fresh meat color. Carpenter et al. (2001) reported that beef packaged in overwrapped packages with polyvinyl chloride (PVC) was more appealing to consumers than beef packaged in modified atmosphere packaging (MAP) and vacuum skin packaging (VSP). They found that beef packaged in MAP were more likely to be described as purple or brown than either PVC or VSP and that PVC overwrapped beef was most often described as red. Carpenter et al. (2001) suggested that the red color of beef was not as visually distinct in MAP because the meat was not in contact with the surface of the package as it would be in VSP or PVC overwrap. In the current study, investigators found that a majority (90%, not reported) of pork center-cut loin chops were sold in the retail case in PVC overwrapped packages. However, not all of the packages were presented with the meat actually touching the overwrap which may explain some of the subjective vs. objective color score discrepancies. Future research that evaluates the correlation of L* to subjective color scoring is needed. This could prove to be beneficial to researchers and other pork industry stakeholders to better analyze and quantify pork lean color as a quality attribute.

Frequency distribution of WBSF for En and Non center-cut loin chops are given in Figure 4. En chops had a mean WBSF value of 21.15 and 24% of these chops were in the WBSF value range of 20.00 to 23.99 followed by 49% of the chops being <20.00 and 27% being >23.99. Non chops had a mean WBSF value of 25.27 and 30% of these chops were in the WBSF value range of 24.00 to 27.99 followed by 45% of the chops being <24.00 and 25% being >27.99. According to Moeller et al., (2010a) positive consumer responses were observed for overall-like, juiciness-like, and juiciness-level of pork loin chops if WBSF values were less than 24.5 N. Furthermore, Moeller et al. (2010a) reported that for every 4.9 N increase in WBSF above 24.5 N the proportion of consumer responses of ≥6 for overall-like decreased by 4%. In the current study, we found that 73% of the En chops and 45% of the Non chops had WBSF values <24.00 suggesting that consumers would be more likely to have a positive eating experience if they purchased En chops.

Frequency distribution of WBSF for En and Non sirloin chops and blade steaks are given in Figure 4. According to Moeller et al. (2010a), positive consumer responses were observed for overall-like, juiciness-like, and juiciness-level of pork loin chops when WBSF values were less than 24.5 N. Furthermore, Moeller et al. (2010a) reported that for every 4.9 N increase in WBSF above 24.5, a sizeable negative consumer response was given. For sirloin chops, 63.9% of Non chops and 95.7% of En chops fell below 24.5 N with 64.2% of Non chops and 60.4% of En chops between 14.7 and 24.5 N. For blade steaks, 89.9% of Non steaks and 95.9% of En steaks fell below 24.5 N with 58.5% of Non steaks and 63.9% of En steaks between 14.7 and 24.5 N. This suggests that if consumers perceive the consumption of sirloin chops and blade steaks to be similar to the consumption of loin chops, then consumers would most likely have a positive eating experience regardless of cut or enhancement type. The least favorable eating experience would come from Non sirloin chops where 36.1% of chops were above 24.5 N and would have been rated as unfavorable based on averages from the Moeller et al. (2010a) study.

Presented in Table 5 are least squares means of En and Non sirloin chops and blade steaks quality attributes per region. Enhancement type did not affect L* of sirloin chops or blade steaks ($P > 0.05$) except sirloin chops in the EC and SW regions where Non chops had higher L* values than En chops ($P < 0.05$). However, Non center-cut loin chops had higher ($P < 0.05$) L* values than En chops in 5 of the 7 regions (EC, MA, PA, SE, and SW). Effect of enhancement on a* varied between regions with En sirloin chops having higher a* values in the EC, PA, SE, and WC regions than Non chops and En blade steaks having higher a* values in the MA, NE, PA, SE, and WC regions than Non steaks ($P < 0.05$). Although not significant ($P > 0.05$), En sirloin chops in the MA region and En blade steaks in the EC and SW regions had numerically higher a* values than Non meat. However, in the NE and SW regions, Non sirloin chops had higher a* values when compared to En chops, although not significantly ($P > 0.05$). En center-cut loin chops were found to have higher a* values in the SE region while Non center-cut loin chops were found to have higher a* values in the EC, MA, and PA regions ($P < 0.05$). The effect of enhancement type on b* values varied greatly with En meat having higher b* values than Non meat for sirloin chops in the WC region ($P < 0.05$), for blade steaks in the MA, PA, and SE regions ($P < 0.05$), and for center-cut loin chops in the MA region ($P < 0.05$). On the other hand, Non meat had higher b* values than En meat for sirloin chops in the EC and SW regions ($P < 0.05$), for blade steaks in the EC region ($P < 0.05$), and for center-cut loin chops in the EC and PA regions ($P < 0.05$). Across regions and cuts of meat, pH was higher, although not always significantly, for En meat compared to Non meat except for blade steaks in the SW region (6.35 vs. 6.37, respectively). All regions except MA had significantly higher pH for En sirloin chops than Non chops ($P < 0.05$). No region had significant differences in En vs. Non blade steaks ($P > 0.05$). All regions except NE had higher pH for En center-cut loin chops than Non chops ($P < 0.05$). With the exception of blade steaks in the EC and NE regions, enhancement decreased WBSF when compared to Non meat. This was significant ($P < 0.05$) for all regions except EC and NE for center-cut loin chops, SE for sirloin chops, and in the MA, PA, and WC regions for blade steaks. The effect of enhancement on pH and WBSF was fairly consistent across the 3 cuts of meat in each of the regions; however, the effect on Minolta color varied greatly.

Presented in Table 6 are the correlation coefficients among quality traits of sirloin chops and blade steaks. All correlations differed significantly from zero at $P < 0.01$ except L* and a* for blade steaks ($P < 0.05$). There were strong negative correlations between pH and WBSF (-0.44 and -0.56 for sirloin chops and blade steaks, respectively) indicating that as pH increased, WBSF decreased. Andrews et al. (2000) found that as pork loin pH increased from 5.5 to 5.8 and from 5.8 to 6.2, significantly less moisture was lost during cooking. When pH decreases too rapidly during post-mortem glycolysis, proteins in pork denature which results in their inability to bind free water. When cooked, these products are unable to hold onto the free water and so the water is lost as exudate. In such cases, a negative consumer response is seen for juiciness, tenderness-like, and tenderness-level (Moeller et al., 2010a). This helps support the current study's findings that higher pH was indicative of a lower WBSF. There were also strong negative correlations between pH and L* (-0.44 and -0.51 for sirloin chops and blade steaks, respectively) indicating that as pH increased, L* decreased suggesting that as pH values increased, meat was darker in color. Since both L* and WBSF had strong negative correlations with pH, it would be expected that L* and WBSF have a strong positive correlation. However, this study only found moderate correlations between L* and WBSF (0.18 and 0.37 for sirloin chops and blade steaks, respectively). Minolta a* also had moderate correlations with WBSF although negative (-0.18 and -0.15 for sirloin chops and blade steaks, respectively). These results indicate that consumers would prefer darker, redder meat as it would be expected to be more tender.

4. Conclusion

Consumers are offered pork products with a considerable amount of variation within package, retail store, region, and between enhanced and non-enhanced products. In the current study investigators reported that 93% of both En and Non chops had a subjective color score range between 2 and 4. Of that percentage, 18% En chops and 22% of Non chops scored less than a color score 3. Objective Minolta L* color results indicate that there is a sizeable amount of variation available. With a subjective color score of 3 being indicative of an L* value of 49, data from the present study suggested that only 10% of En chops and 6% of Non chops had an L* value of ≤49. Results indicate that 73% of En chops and 45% of Non chops were tender (WBSF ≤ 24.5N) and would provide consumers with a positive eating experience based on consumer response criteria relating WBSF levels with tenderness and overall like response criteria reported by Moeller et al. (2010a). Results of the present study suggest that the pork industry's advancements in enhancement technology for pork loins has resulted in pork that is more tender and darker in visual color score. However, the pork industry must explore all options available to provide consistent pork quality in both En and Non pork products.

Results of this study show that there is a considerable amount of variation in meat within package, retail store, and region and between enhanced and non-enhanced products. There are also differences between cuts of meat. Data from this study show that blade steaks are darker than sirloin chops and enhancement had little effect on Minolta L* value. Results indicate that 95.7% of En chops, 63.9% of Non chops, 95.9% of En steaks, and 89.9% of Non steaks were tender (WBSF < 24.5 N) and would provide consumer with a pleasurable eating experience based on findings by Moeller et al. (2010a) in regards to WBSF relationship with tenderness and overall-like. Results from this study showed that the pork industry's advancements in enhancement technology for sirloin chops and blade steaks have resulted in more tender meat with little effect on color.

The current study was conducted to quantify pork quality at the point of purchase, in the retail store. Quantifying pork quality attributes and their variation in retail outlets allow the development of benchmarks for existing and targets for future improvement of pork offered to consumers. Benchmarking data offers value across the entire pork chain, including the opportunity to identify root causes of variation in quality as well as the development of strategies to mitigate existing issues and improve the overall quality of pork offered to consumers. Long-term, benchmarking data can be used to identify approaches that will increase consumer demand for pork by positively influencing the overall pork eating experience.

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Table 1. Center-cut loin chop, sirloin chop, and blade steak demographics by region across the United States.

	EC[1]	MA[1]	NE[1]	PA[1]	SE[1]	SW[1]	WC[1]	National
Center-cut loin chops								
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
Packages Observed[2]								
Enhanced	70	47	30	95	121	60	108	531
Non-Enhanced	51	120	70	142	104	72	101	660
Packages Purchased[3]								
Enhanced	70	47	30	110	146	67	107	577
Non-Enhanced	53	153	92	146	63	63	113	683
Sirloin Chops								
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
Packages Purchased[4]								
Enhanced	11	6	1	82	44	31	32	207
Non- Enhanced	10	14	5	58	12	9	16	124
Blade Steaks								
Cities included	6	5	2	11	10	3	9	46
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
Packages Purchased[4]								
Enhanced	38	10	6	41	75	5	28	203
Non-Enhanced	50	15	9	53	36	11	60	234

[1] EC = East Central, MA = Middle Atlantic, NE = New England, PA = Pacific, SE = Southeast, SW = Southwest, WC = West Central.
[2] Number of packages used for subjective, within store assessment.
[3] Number of packages purchased for objective assessment at Texas A&M University.
[4] Number of packages purchased for objective assessment at North Dakota State University.

Table 2. Identification of market areas included in retail store sample, per region.

	Region						
	EC[1]	MA[1]	NE[1]	PA[1]	SE[1]	SW[1]	WC[1]
Market Areas	Cincinnati Cleveland Detroit Indianapolis Pittsburgh	Baltimore Buffalo New York-City Philadelphia	Boston Hartford	Los-Angeles Phoenix Portland Salt Lake-City San-Francisco Seattle	Atlanta Charlotte Memphis Miami Nashville Tampa	Dallas Houston San-Antonio	Chicago Denver Des Moines Milwaukee Minneapolis St. Louis

[1] EC = East Central, MA = Middle Atlantic, NE = New England, PA = Pacific, SE = Southeast, SW = Southwest, WC = West Central.

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

Trait	n	Mean	Min.	Max.	SD	CV
Center-cut loin chops						
Color[1]	2795	3.12	1.00	6.00	0.85	27.12
Marbling[2]	2767	2.48	1.00	6.00	0.95	38.14
L*[3]	1705	55.30	41.44	68.62	3.70	6.69
a*[4]	1705	5.89	-6.90	16.96	3.11	52.87
b*[5]	1705	3.74	-1.21	11.78	1.84	49.19
pH	1817	5.87	4.60	7.20	0.30	5.03
WBSF[6], N	1910	23.35	8.38	55.35	6.70	28.68
Sirloin chops						
L*[3]	936	51.88	43.06	63.04	3.26	6.28
a*[4]	937	19.48	6.24	29.47	2.84	14.57
b*[5]	937	10.05	4.64	20.53	1.87	18.61
pH	1071	5.89	5.11	7.39	0.31	5.22
WBSF[6], N	1019	18.71	7.71	40.11	5.17	27.65
Blade steaks						
L*[3]	833	45.27	38.76	56.66	2.79	6.16
a*[4]	833	19.71	8.40	29.22	2.22	11.26
b*[5]	833	8.13	3.79	12.44	1.72	21.11
pH	853	6.22	5.25	7.12	0.27	4.38
WBSF[6], N	749	17.12	7.08	39.86	4.65	27.16

[1] Color scale: 1 = pale pinkish gray to white; 6 = dark purplish red (NPB, 2011).
[2] Marbling scale: 1 = devoid; 10 = abundant (NPB, 2011).
[3] Lightness scale: 0 = black; 100 = white.
[4] Redness scale: negative number = green; positive number = red.
[5] Yellowness scale: negative number = blue; positive number = yellow.
[6] WBSF = Warner Bratzler shear force.

Table 4. Least squares means of enhanced (En) and non-enhanced (Non) center-cut loin chop, sirloin chop, and blade steak quality attributes in a national sample.

Trait	En	Non	SEM	*P* - value
Center-cut loin chops				
Color[1]	3.19	3.18	0.03	0.78
Marbling[2]	2.39	2.47	0.04	0.08
L*[3]	54.31	56.10	0.15	<0.01
a*[4]	5.61	6.23	0.13	<0.01
b*[5]	3.62	3.82	0.08	0.05
pH	5.98	5.78	0.01	<0.01
WBSF[6], N	21.00	25.24	0.25	<0.01
Sirloin chops				
L*[3]	51.33	52.24	0.61	0.13
a*[4]	20.06	17.68	0.52	<0.01
b*[5]	9.69	9.94	0.32	0.43
pH	6.01	5.68	0.05	<0.01
WBSF[6], N	15.99	23.00	0.70	<0.01
Blade steaks				
L*[3]	45.05	45.08	0.37	0.95
a*[4]	20.79	18.89	0.26	<0.01
b*[5]	8.37	7.85	0.21	0.02
pH	6.22	6.16	0.04	0.15
WBSF[6], N	15.76	17.13	0.59	0.02

[1] Color scale: 1 = pale pinkish gray to white; 6 = dark purplish red (NPB, 2011).
[2] Marbling scale: 1 = devoid; 10 = abundant (NPB, 2011).
[3] Lightness scale: 0 = black; 100 = white.
[4] Redness scale: negative number = green; positive number = red.
[5] Yellowness scale: negative number = blue; positive number = yellow.
[6] WBSF = Warner Bratzler shear force.

Table 5. Least square means per region of enhanced (En) and non-enhanced (Non) center-cut loin chops, sirloin chops, and blade steaks quality attributes.

	Region														*P*-value		
	EC[1]		MA[1]		NE[1]		PA[1]		SE[1]		SW[1]		WC[1]				
	En	Non	En	Non	En	Non	En	Non	En	Non	En	Non	En	Non	R	E	R*E
Center-cut loin chops																	
Color[2]	2.66	2.84	3.28	3.08	3.60	3.65	3.37	3.29	3.30	3.35	3.89[a]	3.30[b]	2.69	2.70	<0.01	0.08	<0.01
Marbling[3]	2.34[a]	2.95[b]	1.99[a]	2.28[b]	2.08	2.19	2.34	2.34	2.60[a]	3.05[b]	2.44	2.33	2.42	2.34	<0.01	<0.01	<0.01
L*[4]	54.90[a]	56.74[b]	53.90[a]	57.29[b]	54.28	55.41	54.76[a]	55.81[b]	55.12[a]	56.62[b]	51.02[a]	55.35[b]	54.50	55.29	<0.01	<0.01	<0.01
a*[5]	4.68[a]	6.11[b]	5.56[a]	7.13[b]	6.80	6.24	5.39[a]	6.35[b]	5.82[a]	4.82[b]	8.15	7.98	4.27	4.63	<0.01	0.05	<0.01
b*[6]	3.10[a]	4.03[b]	4.31[a]	2.94[b]	3.47	3.51	3.19[a]	4.24[b]	3.50	3.28	2.89	3.18	4.79	5.17	<0.01	0.14	<0.01
pH	5.90[a]	5.75[b]	5.89[a]	5.74[b]	5.80	5.70	5.93[a]	5.83[b]	5.95[a]	5.81[b]	6.41[a]	5.75[b]	5.97[a]	5.82[b]	<0.01	<0.01	<0.01
WBSF[7], N	23.18	24.88	19.40[a]	24.22[b]	22.15	24.41	20.02[a]	26.21[b]	21.77[a]	24.59[b]	17.27[a]	25.51[b]	21.99[a]	26.24[b]	<0.01	<0.01	<0.01
Sirloin chops																	
L*[4]	50.16[a]	55.74[b]	51.35	49.91	51.54	51.28	52.42	52.12	51.26	51.63	50.36[a]	52.78[b]	52.21	52.23	0.17	0.13	<0.01
a*[5]	22.21[a]	16.73[b]	20.05	18.03	17.43	18.17	20.01[a]	18.04[b]	20.19[a]	15.16[b]	20.01	20.50	20.51[a]	17.10[b]	<0.01	<0.01	<0.01
b*[6]	9.07[a]	10.98[b]	10.15	8.59	9.02	10.30	10.58	10.24	10.13	9.34	8.90[a]	11.71[b]	9.95[a]	8.41[b]	<0.01	0.43	<0.01
pH	6.21[a]	5.63[b]	5.94	5.87	5.89[a]	5.36[b]	5.83[a]	5.73[b]	6.04[a]	5.71[b]	6.25[a]	5.73[b]	5.88[a]	5.71[b]	<0.01	<0.01	<0.01
WBSF[7], N	15.30[a]	25.44[b]	14.56[a]	18.99[b]	15.60[a]	24.75[b]	16.91[a]	23.62[b]	17.88	19.85	14.74[a]	23.03[b]	16.93[a]	25.31[b]	<0.01	<0.01	<0.01
Blade steaks																	
L*[4]	44.69	45.85	45.34	45.62	45.37	43.49	45.35	44.71	46.61	45.36	43.42	45.01	44.58	45.49	0.15	0.95	0.04
a*[5]	18.90	18.74	21.59[a]	19.36[b]	22.27[a]	18.93[b]	20.79[a]	19.18[b]	20.26[a]	18.15[b]	20.89	19.19	20.83[a]	18.70[b]	<0.01	<0.01	0.01
b*[6]	7.72[a]	8.52[b]	9.39[a]	7.72[b]	9.56	8.28	8.91[a]	8.05[b]	8.94[a]	7.56[b]	6.58	6.82	7.47	8.00	<0.01	0.02	<0.01
pH	6.17	6.09	6.28	6.26	6.06	6.04	6.23	6.22	6.29	6.17	6.35	6.26	6.13	6.11	<0.01	0.15	0.85
WBSF[7], N	17.77	16.48	15.02[a]	19.82[b]	15.75	13.84	15.92[a]	17.84[b]	16.77	18.06	13.38	14.06	15.69[a]	19.83[b]	0.02	0.02	<0.01

[1] EC = East Central, MA = Middle Atlantic, NE = New England, PA = Pacific, SE = Southeast, SW = Southwest, WC = West Central.
[2] Color scale: 1 = pale pinkish gray to white; 6 = dark purplish red (NPB, 2011).
[3] Marbling scale: 1 = devoid; 10 = abundant (NPB, 2011).
[4] Lightness scale: 0 = black; 100 = white.
[5] Redness scale: negative number = green; positive number = red.
[6] Yellowness scale: negative number = blue; positive number = yellow.
[7] WBSF = Warner Bratzler shear force.

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Table 6. Correlation coefficients among objective quality traits of sirloin chops and blade steaks.[1]

	pH	L*	a*	b*	WBSF,N
pH		-0.45**	0.37**	-0.37**	-0.55**
L*[2]	-0.44**		-0.24**	0.58**	0.22**
a*[3]	0.19**	-0.03		0.14**	-0.35**
b*[4]	-0.37**	0.68**	0.40**		0.17**
WBSF[5], N	-0.53**	0.33**	-0.25**	0.22**	

[1] Correlations above and to right of diagonal are for sirloin chops. Correlations below and to the left of diagonal are for blade steaks.
[2] Lightness scale: 0 = black; 100 = white.
[3] Redness scale: negative number = green; positive number = red.
[4] Yellowness scale: negative number = blue; positive number = yellow.
[5] WBSF = Warner Bratzler shear force.
** Correlation differs from zero ($P < 0.01$).
* Correlation differs from zero ($P < 0.05$).

Figure 1. Frequency distribution of subjective color scores for enhanced and non-enhanced center-cut loin chops.

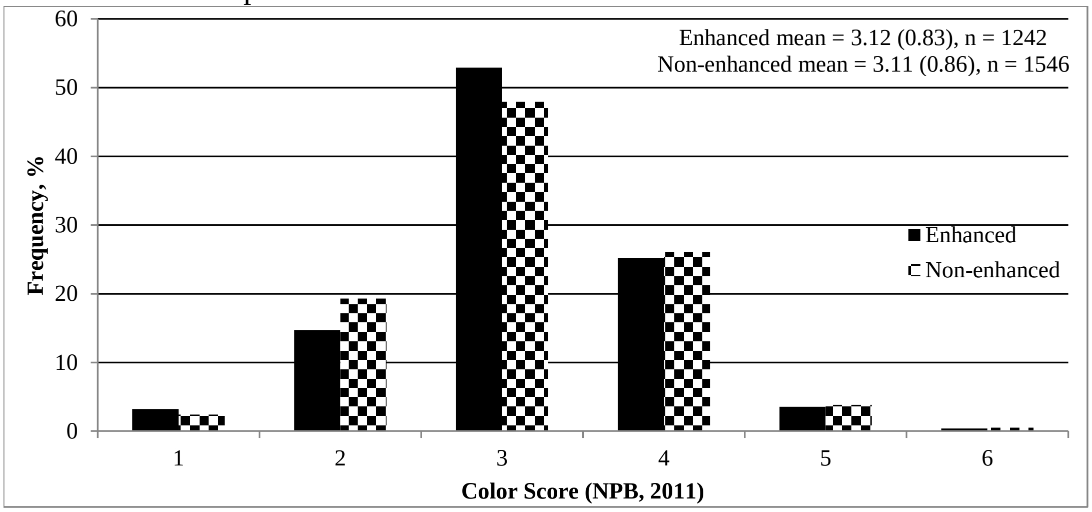


Figure 2. Frequency distribution of subjective marbling scores for enhanced and non-enhanced center-cut loin chops.

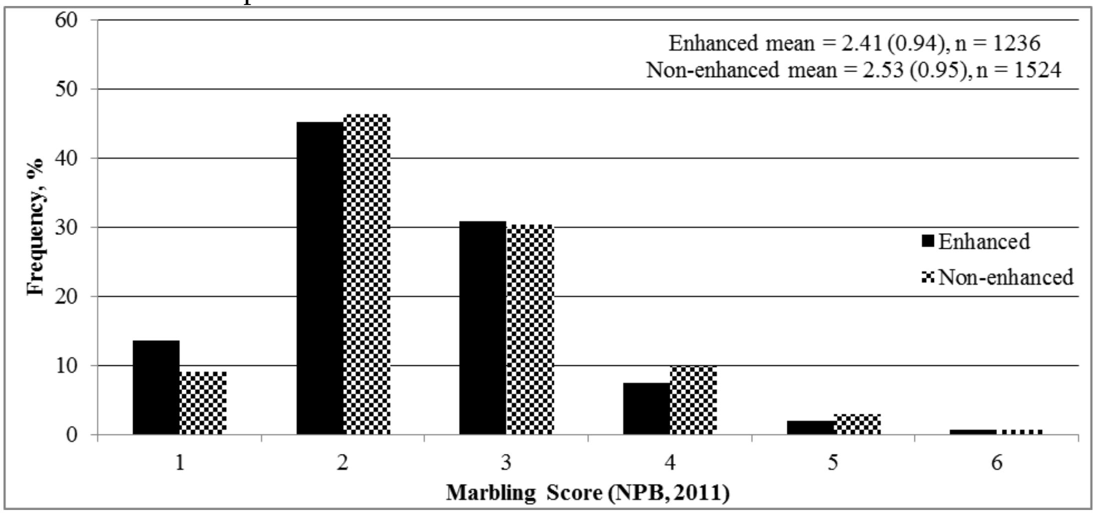
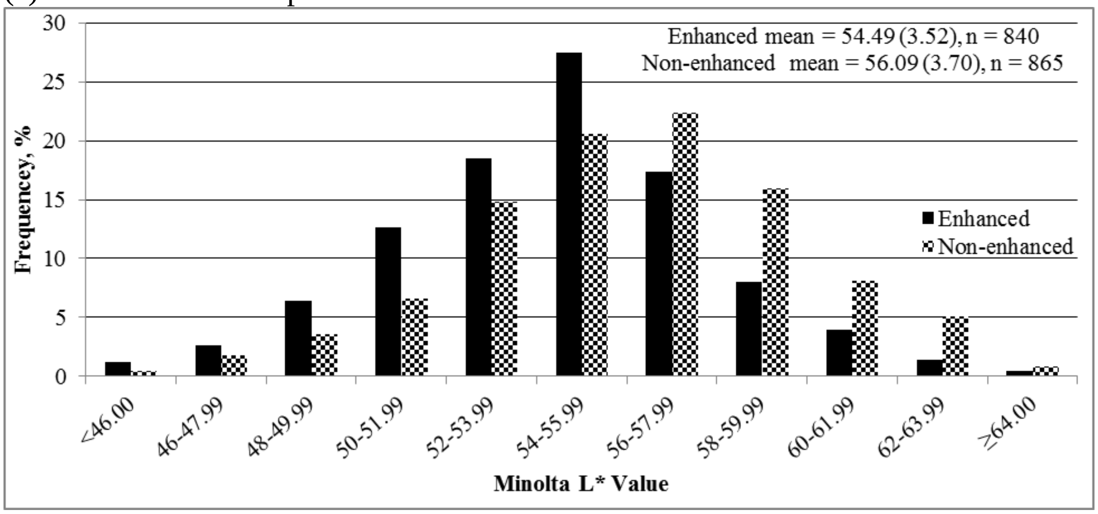
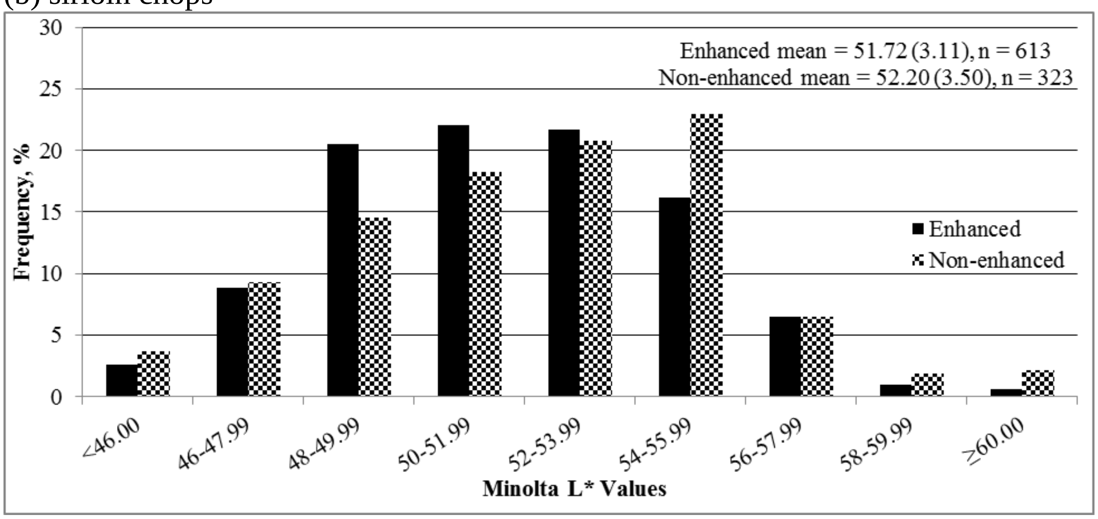


Figure 3. Minolta L* frequency distribution of enhanced and non-enhanced center-cut loin chops, sirloin chops, and blade steaks.

(a) center-cut loin chops



(b) sirloin chops



(c) blade steaks

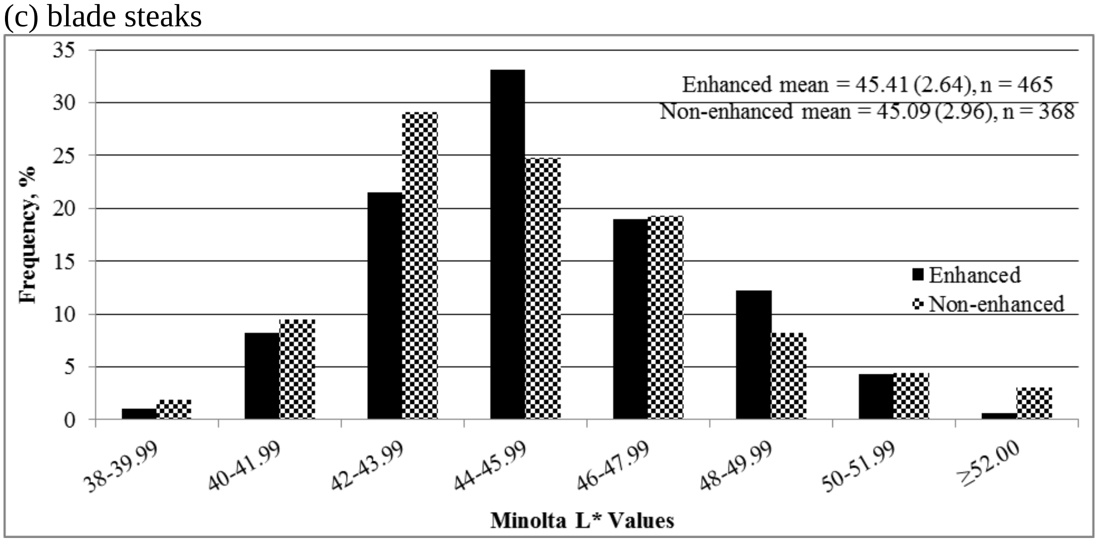
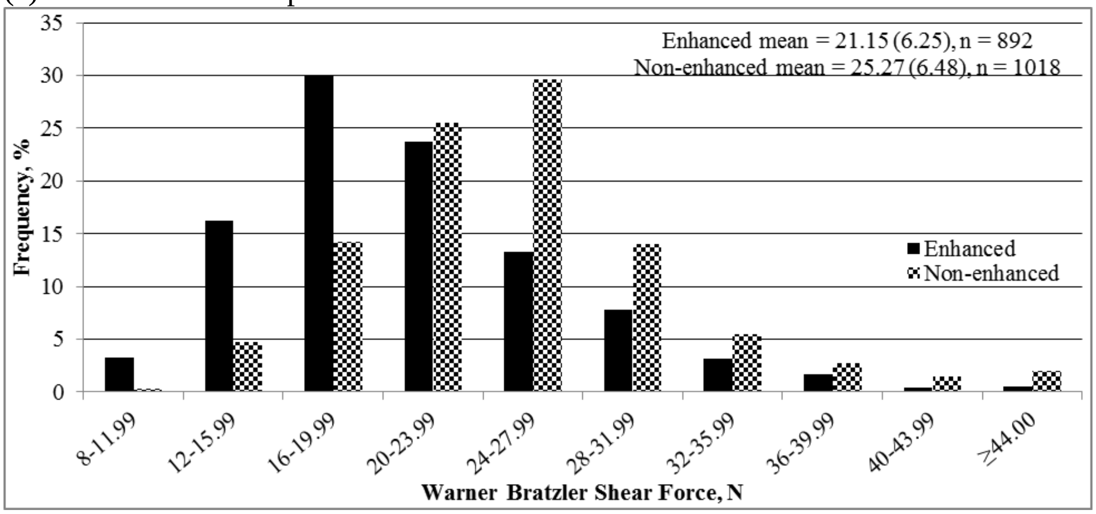
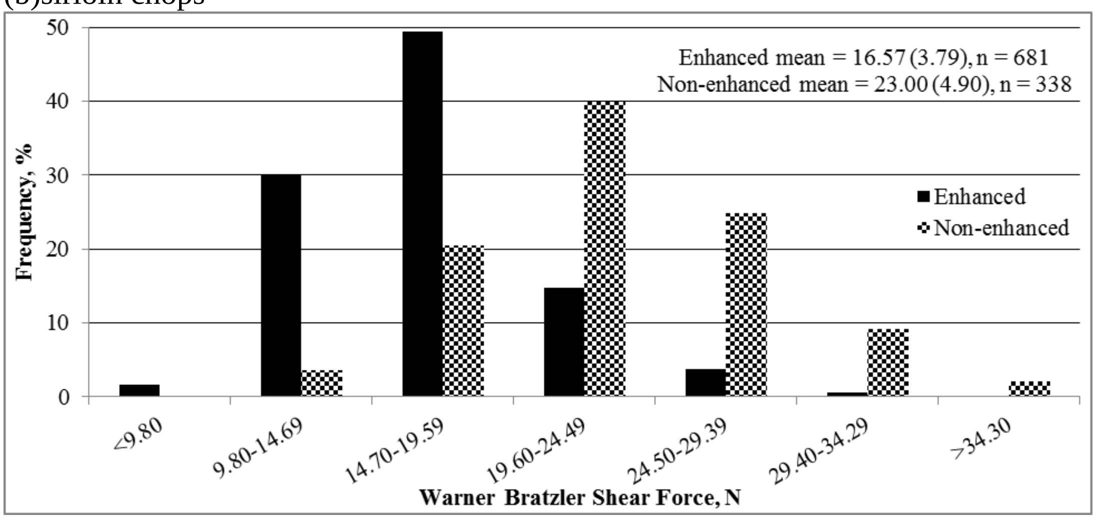


Figure 4. Shear force frequency distribution of enhanced and non-enhanced center-cut loin chops, sirloin chops, and blade steaks.

(a) center-cut loin chops



(b)sirloin chops



(c) blade steaks