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Correlation Comparisons of Early and Aged Quality Traits of Pork Aged Either as Intact Loins or Case-Ready Chops[1,2,3]

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Abstract: Approximately half of retail pork chops in the U.S. arrive at the store in case-ready packages. The other half arrives as intact-loins and are sliced when needed. Cutting chops from loins may increase moisture loss leading to lighter colored and less juicy meat. Therefore, it is possible that correlations between loin quality traits observed early postmortem (PM) and aged quality traits would differ between intact-loin aged (ILA) chops and case-ready aged (CRA) chops. Loins (288 total) were selected to fill a matrix that varied in visual color and marbling. Loins were assigned to 1 of 2 packaging treatments ($n = 144$): ILA or CRA. Loins assigned as ILA remained vacuum-packaged at 4°C until 12 d PM, sliced and chop surface was evaluated. Loins assigned to CRA were sliced into 28-mm thick chops at 2 d PM, packaged in individual Styrofoam trays overwrapped in polyvinyl-chloride (PVC) film, and gas flushed in bulk packages. Quality parameters of packaging treatments at early and aged time points were compared as a randomized complete block design. Pearson correlation coefficients between early and aged quality traits for packaging treatments were transformed using Fisher's r to z transformation for independent correlation comparisons of packaging treatments. Chops from ILA were darker and redder at 12 d PM than CRA chops ($P < 0.0001$). Lightness and redness values on ventral surface for ILA loins ($r = 0.52$ lightness; $r = 0.63$ redness) and CRA loins ($r = 0.45$ lightness; $r = 0.61$ redness) at 1 d PM were both correlated with aged lightness and redness values on aged chop face at 12 d PM and the correlations did not differ ($P \geq 0.43$) for either trait. Overall, aging intact loins in vacuum-packaging improved color after 12 d of aging compared with aging chops in case-ready packaging. Despite the differences between aging methods, the correlations between early and aged loin quality didn't differ.

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Introduction

During fabrication, deboning a loin allows for fresh quality evaluations to be conducted on the ventral surface of the exposed lean (King et al., 2011). After fabrication, loins are either packaged as intact loins and aged or immediately sliced into chops and aged before they are presented to consumers. A 2004 survey identified that almost half (48.7%) of all pork chops sold in the U.S. arrives at the store in "case-ready" packages (Reicks et al., 2008). This means loins were cut into chops at early postmortem and aged as chops, often in modified atmosphere packaging. The remaining 51.3% of pork loins are aged in non-case-ready packaging and are sliced into chops after a period of aging (Reicks et al., 2008). Recently, Harsh et al. (2018) reported correlations among early postmortem ventral loin quality with aged chop quality. In general, early postmortem ventral color traits are correlated with aged chop color traits and ventral marbling estimates are correlated with aged chop marbling. However, it is not known if those correlations differ between pork chops aged as loins or when aged as case-ready chops.

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[2]Mention of trade names, proprietary products, or specified equipment does not constitute a guarantee or warranty by the USDA and does not imply approval to the exclusion of other products that may be suitable.

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After whole muscles are cut, moisture loss can increase over time (den Hertog-Meischke et al., 1997). The water-soluble protein myoglobin is expelled from the muscle with the loss of moisture (Huff-Lonergan et al., 2002; Stetzer and McKeith, 2003; Fischer, 2007) and could lead to an increase in lightness values when aged as chops. Thus, it was hypothesized that slicing and packaging chops in case-ready packages early postmortem would result in correlation differences when compared with chops aged as intact loins. Therefore, the objective was to compare the correlations of the quality of chops from loins aged intact to those aged in case-ready packaging. Due to these potential changes, a second objective was to determine whether correlations between early postmortem ventral loin quality traits and aged chop surface quality traits differed between packaging methods.

Materials and Methods

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

Processing facility data collection

Pigs used for this study were from 2 separate production systems with different genetic sources representative of the genetic variation found in the industry today, as confidentially identified by the packer. Pigs were immobilized using carbon dioxide and terminated via exsanguination. Carcasses were blast-chilled for approximately 90 min and then held in an equilibration cooler until approximately 22 h postmortem, at which point they were fabricated into primal cuts. Loins were further cut into boneless strap-on (longissimus dorsi with iliocostarum attached) center cut pork loins [NAMP # 414, PSO 3; North American Meat Institution (NAMI), 2014] and imaged using a VQG pork loin grading camera on the ventral side of the loin immediately after boning. The VQG camera was used to select for variation in color and intramuscular fat content among loins as described by the Klehm et al. (2018). The VQG camera was used to select loins with variation in color (max NPPC score = 5.0, min NPPC score = 1.5) and intramuscular fat content (max NPPC marbling score = 4.0, min NPPC marbling score = 1.0; Klehm et al., 2018).

A target of 36 loins were selected from each production focus for a total of 72 loins from each collection day. Four collection days were each separated by a 3 to 4 wk period in the winter-spring season, totaling 288 loins overall. Within a production focus, an equal variation in color and marbling scores were targeted for each of the designated packaging treatments: intact loins aged (ILA; $n = 144$) until 12 d postmortem then sliced or case-ready aged (CRA; $n = 144$) loins sliced at 2 d postmortem and aged until 12 d postmortem. Selected loins were removed from the de-boning line and subsequently evaluated for CIE instrumental lightness (L*), redness (a*), and yellowness (b*; CIE, 1978), pH, visual color, visual marbling, subjective firmness, and weight. Ventral evaluations were measured near the area of the 10th rib. Instrumental lightness (L*), redness (a*), and yellowness (b*) scores were measured using a Konica Minolta CR-400 colorimeter (D65 light source, 2° observer, 8 mm aperture; Minolta Camera Company, Osaka, Japan) that was calibrated with a white tile prior to evaluations. Loin pH was measured using a MPI pH meter (Meat Probes Inc. pH-Meter, Topeka, KS) with a glass electrode probe that was calibrated prior to evaluations using pH 4 and pH 7 calibration buffers stored at 4°C. A trained technician evaluated visual color and visual marbling, using National Pork Producers Council (NPPC, 1999) color and marbling standards and subjective firmness using National Pork Producers Council (NPPC, 1991) scale. Visual color was assigned using a 6-point scale (1 = pale, grayish-pink; 6 = dark, purplish-red); visual marbling was assigned using a 10 point scale (1 = 1% intramuscular fat; 10 = 10% intramuscular fat), and subjective firmness was assigned using a 5 point scale (1 = soft; 5 = firm). All evaluations were determined in half score increments. Boneless loins were vacuum-packaged and transported in coolers with ice packs to the University of Illinois Meat Science Laboratory for aging and further evaluations.

Loins aged intact

Loins selected to be ILA remained in vacuum packages in boxes and stored in a dark cooler (4°C) until 12 d postmortem. At 12 d postmortem, loins were removed from their packaging and allowed a minimum of 30 min for oxygenation of myoglobin prior to ventral loin quality evaluation. Ventral loin evaluations at 12 d postmortem were performed by the same trained technician who conducted quality evaluations on 1 d postmortem, followed the same procedures, and used the same equipment as previously described. Ventral aged evaluations consisted of CIE instrumental lightness (L*), redness (a*), and yellowness (b*), pH, visual color, visual marbling, subjective firmness, and weight. Loins were then sliced into 28 mm thick chops [NAMP # 1413, PSO 3; North American

Meat Institution (NAMI), 2014] using a PUMA slicer (TREIF USA Inc., Shelton, CT). Chops were collected for meat quality evaluation starting from the anterior end of the loin, with the first selected chop containing a posterior portion of the spinalis dorsi (Fig. 1; Klehm et al., 2018). Chops were assigned to meat quality evaluations in the following order: Chop 1) Warner-Bratzler shear force (WBSF), Chop 2) proximate analyses, Chops 3 through 10) chop face surface quality evaluations. Chop 1 was vacuum-packaged and stored at 4°C until 14 d postmortem for evaluation of instrumental tenderness. Chop 2 was trimmed of subcutaneous fat, connective tissue, and accessory muscles, vacuum-packaged, and stored at –20°C until proximate analyses. Chops 3 through 10 were allowed at least 30 min for oxygenation of myoglobin before surface evaluations were conducted on 1 chop selected randomly. Evaluations for instrumental CIE lightness, redness, and yellowness and visual color, marbling, and subjective firmness used the same equipment and procedures described for 1 d postmortem evaluations.

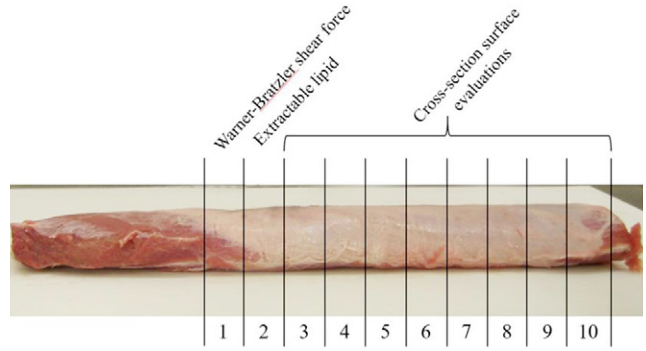

Fig. 1. Loins sliced into 28-mm thick chops were designated for different evaluations by anatomical location. Chop 1, the most anterior chop with the most posterior portion of the spinalis dorsi, was designated for Warner-Bratzler shear force. Chop 2 was selected to determine extractable lipid content. Chops 3 through 10 were randomly selected for chop face surface evaluations and then packaged in polyvinyl-chloride film overwrapped trays packaged in gas-flushed bulk packages. Evaluations included visual color visual marbling, subjective firmness, and instrumental lightness, redness, and yellowness (Klehm et al., 2018).

Case-ready aged chops

Loins selected to be CRA were removed from their vacuum-sealed packaging at 2 d postmortem. Loins were sliced into 28-mm thick chops using a PUMA slicer (TREIF USA Inc., Shelton, CT). Chops were collected and quality traits were assessed using the same protocol as whole loin aged chops. Chops were packaged with an absorbent pad (Ultra ZAP Soaker, The Brenmar Company, Omaha, NE) in a 13.65cm^2 tray (polystyrene Cascades Evok) and overwrapped in polyvinyl chloride (PVC) film (O_2 transmission = 23,250 mL × m^2 × d–1, 72 gauge; Resinite Packaging Films, Borden, Inc., North Andover, MA). Individual overwrap packaged chops originating from the same loin were placed in a 35.56 cm × 50.80 cm vacuum sealable bag gas-flushed with 600 millibars of a gas mixture (0.2 to 0.4% carbon monoxide, 23 to 30% carbon dioxide, and 60 to 80% nitrogen). Packages were boxed and aged in a dark cooler at 4°C until 9 d postmortem. At 9 d postmortem, chops were removed from boxes and bulk packaging, and placed in simulated retail display under fluorescent lighting (General Electric 32W, 122cm fluorescent Kitchen/Bath bulb in an Utilitech 121 cm 2-light fixture suspended 30.5 cm above the chops, color rendering index = 78, light color temperature = 3000 K, and 2450 mean lumens) in the individual overwrapped packages, to simulate retail case conditions. Procedures for bulk MAP packaging and retail display followed generally recognized as safe (GRAS) notice No. GRN 000083 MAP system for packaging fresh cuts of case-ready muscle meat. At 12 d postmortem (after 3 d of simulated retail display), chops were evaluated for instrumental CIE lightness, redness, and yellowness with the same equipment and procedures described at 1 d postmortem (Fig. 2).

Warner-Bratzler Shear Force

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

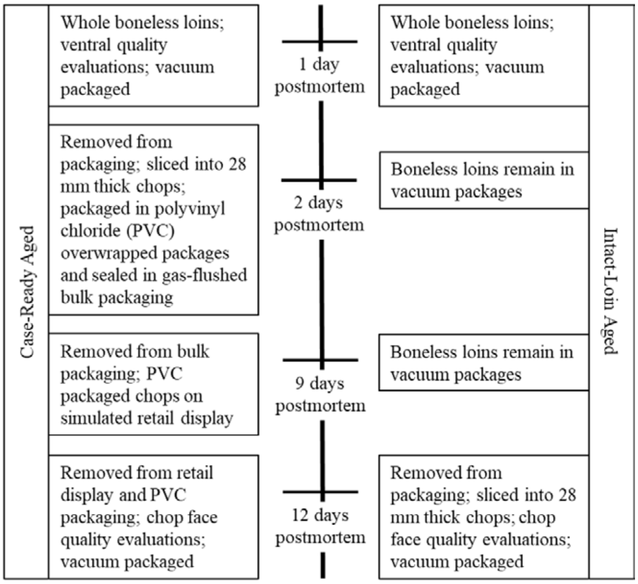

Fig. 2. Timeline of packaging treatments; chops sorted into vacuum-packed (VP) or wrapped in Styrofoam trays with polyvinyl-chloride film (PVC).

UK) equipped with a Warner-Bratzler shear force blade at a speed of 3.3 mm/s and load cell capacity of 100 kg. The force of each of the 4 cores were averaged and reported as Warner-Bratzler shear force.

Proximate analysis

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

Statistical analyses

Loin quality parameters measured at 1 d postmortem after being grouped by packaging treatment were compared using a one-way ANOVA in the MIXED procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC). The model included the fixed effect of aging treatment and the random effect of slaughter date. Each individual loin served as the experimental unit for all dependent variables. Least squares means and standard errors were reported for all measured attributes and were considered different at $P \leq 0.05$ for all analyses. Chop quality parameters from CRA chops at 2 d, 9 d, 12 d postmortem and ILA chops at 12 d postmortem were compared using a one-way ANOVA in the MIXED procedure of SAS 9.4. The model included the fixed effect of day postmortem and the random effect of slaughter date. Each individual chop served as the experimental unit for all dependent variables. Least squares means and standard errors were reported for all measured attributes and were considered different at $P \leq 0.05$ for all analyses.

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

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

Equation 1.

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

Where r is the Pearson correlation coefficient, and z is the transformed correlation coefficient. The z here calculated should not be confused with the z-score associated with approximations of the normal distribution. Fisher's transformed z values were then merged into a single data set for comparison of independent correlation coefficients. Data were compared based on the following equation:

Equation 2.

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

Where $Z_{calculated}$ is the calculated z-score, the test statistic which follows a normal distribution, z_{ILA} is the transformed correlation coefficient of the ILA variables, z_{CRA} is the transformed correlation coefficient of the CRA variables, n_{ILA} is the number of observations for the ILA variables, and n_{CRA} is the number of observations for the CRA variables. The correlations between 1 d postmortem ventral loin traits with 14 d WBSF and cooking loss (r_{13}) was compared with the correlations between 12 d postmortem loin traits with 14 d WBSF and cooking loss (r_{23}). Because the correlations being calculated were not derived from different, independent populations and the correlations being compared shared a common trait (14 d WBSF or cooking loss), they were considered dependent. That is, r_{12} is correlated with r_{13}, therefore the influence of the relationship of between 1 d postmortem and 12 d postmortem ventral loin quality traits (r_{12}) must be accounted for when comparing r_{13} with r_{23} (Kenny, 1987). To achieve this, 3 sets of Pearson correlation coefficients were calculated (r_{13}, r_{23}, and r_{12}) and the correlation coefficients transformed using Fishers r to z equation (Eq. [1]). Then, the test statistic, t was calculated using the following equation from Zou (2007):

Equation 3.

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

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

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

Table 1. Least squares means of quality parameters measured on 1 d postmortem between chops aged as intact loins or as chops in case-ready packaging

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

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

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

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

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

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

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

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

Results

Early postmortem ventral loin evaluations

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

Comparison of 2 d, 9 d, and 12 d postmortem chop quality traits on chops packaged as case-ready

Chops sliced at 2 d postmortem became 23.7% lighter and 12.9% redder at 9 d postmortem after aging in gas-flushed bulk packaging (Table 2). Lightness did not change after aging in a simulated retail display, however chops did become 17.8% less red. Chops aged as case-ready were 13.6% lighter and 11.6% less red at 12 d postmortem than chops aged as intact loins.

Table 2. Effects of packaging treatment on instrumental color measured on chops at different time points

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

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

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

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

[4]Case-ready aged chops after slicing (2 d postmortem).

[5]Case-ready aged chops prior to simulated retail display (9 d postmortem) directly after exposure from gas flushed bulk packaging.

[6]Case-ready aged chops after simulated retail display (12 d postmortem).

[7]Intact loin aged chops after slicing (12 d postmortem).

Comparison of early and aged loin quality traits

Because ILA loins were evaluated on the ventral surface by the same observer, using the same equipment, and at approximately the same anatomical location at both 1d and 12d postmortem, these values can be directly compared to determine the change in quality traits with aging. The ventral surface of ILA loins at 12 d postmortem were 7.1% lighter ($P < 0.0001$), 12.4% redder ($P < 0.0001$), and 78.9% yellower ($P < 0.0001$) when compared to 1 d postmortem (Table 3). Loin pH decreased ($P < 0.0001$) from 5.73 at 1 d to 5.66 at 12 d postmortem. Subjective color and marbling scores ($P <$ 0.65) did not change over the course of the aging period, but NPPC firmness scores ($P < 0.0001$) decreased from 2.81 at 1 d to 2.37 at 12 d postmortem.

Comparison of correlations between early and aged quality traits of different packaging treatments

Early postmortem ventral lightness was moderately correlated with 12 d aged chop lightness values for both packaging treatments (ILA, $r = 0.52$; CRA, $r = 0.45$), with no difference ($P = 0.43$) in the correlation coefficients between the packaging treatments (Table 4). Early postmortem ventral redness was moderately correlated with 12 d aged chop redness values for both packaging treatments (ILA, $r = 0.63$; CRA, $r = 0.61$), with no difference ($P = 0.76$) between the correlation coefficients. Early postmortem ventral yellowness was moderately correlated with 12 d aged yellowness for both packaging treatments (ILA, $r = 0.54$; CRA, $r = 0.35$), with a stronger correlation ($P = 0.04$) between yellowness at 1 d and 12 d for ILA chops than CRA chops.

Table 3. Comparison of ventral loin quality traits on intact aged loins at early (1 d) and aged (12 d) postmortem[1]

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

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

[2]Standard error of the difference of the mean.

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

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

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

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

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

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

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

The correlation between ventral loin quality traits and 14 d cooked WBSF and cook loss values were compared on ILA between 1 d and 12 d postmortem (Table 5). No moderate correlations were found.

Discussion

Early postmortem loin quality traits observed during fabrication are used by packers to sort loins into quality-based programs (Agricultural Marketing

Table 4. Comparison of independent Fisher's r to z transformed correlation coefficients (rho) of early postmortem loin color and aged postmortem chop color

Early postmortem loin variable	Aged postmortem chop variable	Intact loin aged Rho	Intact loin aged 95% confidence limit[1] Lower	Intact loin aged 95% confidence limit[1] Upper	Case-ready aged Rho	Case-ready aged 95% confidence limit[1] Lower	Case-ready aged 95% confidence limit[1] Upper	*P*-value[5]
Lightness[2], L*	Lightness[2], L*	0.52	0.39	0.63	0.45	0.31	0.57	0.43
Redness[3], a*	Redness[3], a*	0.63	0.11	0.41	0.61	0.11	0.41	0.76
Yellowness[4], b*	Yellowness[4], b*	0.54	0.42	0.65	0.35	0.20	0.49	0.04

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

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

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

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

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

Table 5. Comparison of dependent correlation coefficients (rho) from intact aged loins at early (1 d) postmortem and aged (12 d) postmortem to Warner-Bratzler shear force (WBSF) and cook loss

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

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

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

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

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

Packaging type during aging did influence loin chop quality. Chops from ILA loins were darker and redder than CRA chops. While purge during aging was not quantified in this study, it is interesting to speculate that moisture loss may underlie the differences between pork loin quality in the two packaging methods. The disruption of cellular structure by cutting the epimysium increases the surface area available for exudation of moisture (purge), and along with it water-soluble proteins, such as myoglobin (Huff-Lonergan and Lonergan, 2005). The exudation of myoglobin in the form of purge, increases lightness and reduces redness of meat (Joo et al., 1999). Therefore, the cutting of loins for packaging of CRA chops would likely lead to increased purge and thus, the observed lighter, less red chops. In the present study, the lightness difference of 6.75 units were observed between the 2 packaging treatments is enough to create concern in regard to consumer perception and purchasing intent (Mancini and Hunt, 2005).

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

Given the changes in loin quality traits with aging and the observed differences in aged quality traits between packaging methods, the relationships between early and aged quality traits within each packaging method were estimated and then compared. The relationship between early and aged color did not differ between packaging methods for lightness (L*) or redness (a*). In each packaging method, the correlation between early and aged L* and between early and aged a* would be considered weak. There was a difference, however, between packaging methods for correlations between early and aged yellowness (b*). The correlation between these measures was moderate positive for ILA chops and weak positive for CRA chops. Overall, despite differences in the ultimate aged traits between the packaging types, the relationship between early and aged quality was not different between the 2 packaging methods.

Ultimately, loins are sorted into quality groups for two purposes. First, some consumers desire darker loin chops with more marbling. Therefore, estimations of quality can relate to purchase intent. Then, consumers will cook and eat those chops. Therefore, sorting loins by quality should also result in differences in eating experiences to result in increases in repeat purchases of similar pork products. Thus, the relationships between early and aged quality traits on WBSF, a measure of tenderness, and cook loss, a measure of juiciness, were estimated and compared on ILA chops. Previously, early postmortem quality traits such as color and pH were moderately correlated (r = 0.30 to 0.50; Huff-Lonergan et al., 2002; Boler et al., 2010) and are suggested to predict traits of eating quality such as tenderness. Weak negative correlations between tenderness and color score were reported by Huff-Lonergan et al. (2002; r = –0.15) and Boler et al. (2010; r = –0.28), whereas Nam et al. (2009) concluded a positive correlation between Warner-Braztler shear force and color score. In the present study, only weak correlation were observed between 1 d postmortem ventral loin variables and 12 d postmortem ventral loin variables. Positive correlations between NPPC color and WBSF were observed as well as negative correlations between NPPC marbling and WBSF. Negative correlations between marbling and WBSF have been previously reported in numerous studies (Hodgson et al., 1991; r = –0.36; Huff-Lonergan et al., 2002; r = –0.27; Boler et al., 2010; r = –0.32). Given how aging decreases WBSF, it is interesting that relationships between quality traits and

WBSF did not differ between the two time points. This suggests that factors not analyzed in this experiment may play a larger role than previously thought.

Conclusions

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

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