



Determining the *Longissimus lumborum* and *Psoas major* Beef Steak Color Life Threshold and Effect of Postmortem Aging Time Using Meta-analysis

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Abstract: Using meta-analysis, the color life threshold for beef *longissimus lumborum* (LL) and *psoas major* (PM) steaks during retail display (phase 1) and the effect of postmortem aging time (phase 2) on the display color life of LL and PM steaks were determined. In phase 1, data were retrieved from 13 refereed journal articles for LL and 3 refereed journal articles for PM, which included a^* and subjective visual scores. The total display day observations for LL and PM were 148 and 27, respectively. Lower bound estimates using a 95% confidence interval for a^* as a threshold for the display color life of LL and PM steaks were 20.24 and 20.99, respectively. For phase 2, data were retrieved from 26 refereed journal articles for LL and 10 referred journal articles for PM, which included a^* and postmortem aging time. The total display day observations for LL and PM in phase 2 were 255 and 71, respectively. For LL steaks, the actual postmortem aging time was grouped into 5 categories: 0–7 d, 8–14 d, 15–21 d, 22–28 d, and 29–65 d. Additionally, the postmortem aging time of PM steaks was grouped into 2 categories: 0–7 d and 8–21 d. The first 21-d postmortem aging time for LL steaks had the longest color life, with 7 d. Additionally, 22 to 28 d of postmortem aging time and 29 to 65 d of postmortem aging time had 5 d and 4 d, respectively, of color life for LL steaks. The borderline acceptability estimated for PM steaks with 0–7 d and 8–21 d of postmortem aging time was 3 d and 2 d of color life, respectively. Estimations from this meta-analysis demonstrate that using LL and PM subprimals that have a postmortem aging time of 21 d or less and 7 d or less, respectively, would optimize the retail display color life of aerobically packaged steaks.

Key words: beef, color life, meta-analysis, postmortem aging time

Meat and Muscle Biology 5(1): 41, 1–11 (2021)

doi:10.22175/mmb.12526

Submitted 29 April 2021

Accepted 26 August 2021

Introduction

The meat industry, foodservice, retail businesses, and all individuals in the supply chain that commercialize meat have control of the color life of meat. One important aspect that plays a role in meat discoloration during retail display of aerobically packaged steaks is the time from animal harvest, or postmortem aging time. Colle et al. (2015) concluded that extended postmortem aging time has a strong impact on the color life of various muscles. They also indicated that extended postmortem aging time in USDA Select strip loins

longer than 14 d was detrimental for its color life. The 2010/2011 National Beef Tenderness Survey reported that postmortem aging time for vacuum-packaged subprimals under refrigerated conditions ranged from 1 to 358 d and from 9 to 67 d at the retail level and with foodservice, respectively (Guelker et al., 2013). Overall, beef held for extended times under vacuum may exhibit color issues after steaks are cut, aerobically packaged, and displayed at the retail level. According to the 2015 National Beef Tenderness Survey, postmortem aging time of strip loins at retail was shown to vary from 6 to 101 d, with a post-fabrication storage average of 27.2 d (Martinez et al., 2017).

By understanding the factors that affect meat color stability when displayed, including the influence of postmortem aging time, the retail display life of fresh meat can be optimized, thus preventing meat waste at the retail level. It is well established that meat color is used by consumers as an indicator of freshness and wholesomeness when selecting their meat purchases (Kropf, 1993). There are several factors that affect the appearance of fresh meat color, including processing, packaging, distribution, and display temperature (Mancini and Hunt, 2005). These variables also affect the rate at which the process of meat discoloration occurs, resulting in revenue loss at the retail level. Discoloration of meat has been extensively researched through objective and subjective methods utilizing instrumental color methodologies and trained panelists, respectively, during shelf-life studies as well as the relationship between them in order to determine color life thresholds (Hunt et al., 2004; Colle et al., 2015; Steele et al., 2016). Visual color scores determined by trained panelists have been associated with a strong correlation with consumers' purchasing intent when beef is not red (Carpenter et al., 2001). As a result, Mancini and Hunt (2005) stated that visual scores determined by a trained panel is the gold standard to know consumer liking responses.

Traditionally, 2 categories—color-stable and color-labile muscle—have been established based on the biochemical characteristics that affect the color stability of beef muscles (McKenna et al., 2005). The *longissimus lumborum* (LL) muscle, or strip loin, belongs to the color-stable muscle category and exhibits excellent color stability properties during retail display (Seyfert et al., 2006; Joseph et al., 2012). On the other hand, the *psaos major* (PM), or tenderloin, a color-labile muscle, has less color life when displayed (Seyfert et al., 2006). Historically, the comparison between these muscles has served as a good model because of the difference in their muscle biochemistry. In addition, the LL and PM are readily accessible at retail owing to their popularity among meat shoppers.

A meta-analysis was used to combine data from several studies in order to develop a single conclusion that has greater statistical power by providing sufficient statistics, where multiple data points are used to provide information about a sample mean and sample variance. To the best of our knowledge, there have been no meta-analyses evaluating the color life of fresh meat in the literature. Therefore, the objective of this study was to determine the color life threshold for LL and PM steaks during retail display using published visual and instrumental color data (phase 1) and the effect of

postmortem aging time on the display color life of LL and PM steaks (phase 2).

Materials and Methods

Meta-analysis

Phase 1. An electronic literature search was conducted to retrieve studies that have evaluated the effects of display day on LL and PM muscle using spectrophotometers with illuminant A. A literature search was conducted via the Kansas State University Libraries utilizing the Centre for Agriculture and Bioscience International search engine for articles from 2000 to 2020. The search was restricted to studies presented in English in peer-reviewed journals. Visual scores from each experiment for LL were standardized for an 8-point line scale in which 1 = very bright red, 2 = bright red, 3 = dull red, 4 = slightly dark red, 5 = moderately dark red, 6 = dark red to tannish red, 7 = dark reddish tan, and 8 = tan to brown. Additionally, the PM visual color values were used based on a 5-point scale in which 1 = very bright cherry red, 2 = bright cherry red, 3 = slightly dark red to tannish red, 4 = moderately grayish tan to brown, and 5 = tan to brown; a score of 3.5 was considered borderline acceptable by the trained panelist (Seyfert et al., 2007). Studies used in this meta-analysis are shown in Table 1. There were 5 identified visual color score thresholds for LL and 3 identified for PM in the literature, and an average was calculated to be used in the model for LL and PM. The response variable “visual score” was based on subjective measurement of color, which included meat color, meat discoloration, and muscle darkening scores that convey the same information and were converted into the same scale. A simple linear transformation was used to rescale visual color scores to fit on a 1- to 8-point line scale. The reported score was divided by the maximum possible score and multiplied by 8. The same procedure was performed for their SEM. Based on these criteria, the final database resulted in 13 papers for LL and 3 papers for PM, using illuminant A. The total display day observations for LL and PM were 148 and 27, respectively, and are equal to each data point corresponding to each display day within an experiment within each paper.

Phase 2. Similarly, an electronic literature search was conducted to study the postmortem aging time effect on the color life of LL and PM using illuminant A to assess meat color. The final database resulted in 26 papers for LL and 10 papers for PM. For LL steaks, the actual postmortem aging times were grouped into

Table 1. Summary of papers using illuminant A used in the regression analysis to predict redness of LL and PM steaks¹

Author(s)	Source ²	Colorimeter	Aperture size	Scans ³	Display days	Steak thickness	pH ⁴	Temperature °C ⁵	Lighting type ⁶	Muscle ¹
Steele et al. (2016)	J	HunterLab MiniScan™ EZ	31.8 mm	3	0, 1, 2	2.54 cm	5.62	1.2°C	F, LED	LL
Colle et al. (2015)	J	Hunter MiniScan EZ	25 mm	2	0, 1, 2, 3, 4	2.54 cm	5.62	3.0°C	N	LL
Kim et al. (2006)	J	HunterLab MiniScan® XE Plus	2.54 cm	3	2, 9, 14	2.54 cm	5.85	1.0°C	F	LL
Rogers et al. (2010)	J	HunterLab MiniScan® XE Plus	2.54 cm	3	0, 2, 4	2.54 cm	NR	0.9°C ± 2.3°C	F	LL
Grobbe (2008)	J	HunterLab MiniScan® XE Plus Spectrophotometer	2.54 cm	3	0, 7	2.54 cm	5.50	2.0°C	F	LL
Seyfert et al. (2006)	J	HunterLab MiniScan® XE Plus Spectrophotometer	2.54 cm	3	0, 1, 2, 3, 4, 5, 6, 7	2.54 cm	5.62	1.7°C ± 3.2°C	F	LL, PM
English (2015)	D	HunterLab MiniScan® XE Plus Spectrophotometer	2.50 cm	2	0, 1, 2, 3, 4, 5, 6	2.54 cm	5.60	2.0°C ± 1°C	F	LL
Mitacek et al. (2018)	J	HunterLab MiniScan® XE Plus Spectrophotometer	2.50 cm	3	0, 1, 2, 3, 4, 5, 6	2.50 cm	5.50	2.0°C ± 1°C	F	LL
Seyfert et al. (2007)	J	HunterLab MiniScan® XE Plus Spectrophotometer	2.54 cm	3	0, 4, 7	2.54 cm	5.50, 5.60	0.2°C ± 3.1°C	F	LL, PM
Hutchison (2007)	D	HunterLab MiniScan® XE Plus Spectrophotometer	2.54 cm	3	0, 1, 2, 3, 4, 5, 6	2.54 cm	5.75	2.0°C ± 5.0°C	F	LL
Gonzalez et al. (2009)	J	HunterLab MiniScan® XE Plus Spectrophotometer	2.54 cm	2	0, 1, 2, 3, 4, 5	1.27 cm	NR	2.0°C ± 3.0°C	F	LL
Daniel et al. (2009)	J	HunterLab MiniScan® XE Plus Spectrophotometer	2.54 cm	3	0, 1, 2, 3, 4, 5, 6	2.54 cm	5.6	2.0°C	F	LL
Limsupavanich (2005)	D	HunterLab MiniScan® XE Spectrophotometer	3.18 cm	3	0, 1, 3, 5	NR	5.50, 5.80	0.0°C ± 3.0°C	F	LL, PM
Abraham et al. (2017)	J	HunterLab MiniScan® XE Spectrophotometer	2.50 cm	2	0, 1, 3, 5, 7	2.50 cm	5.61, 5.72	2.0°C ± 1.0°C	F	LL, PM
Nair et al. (2018)	J	HunterLab LabScan XE Colorimeter	2.54 cm	3	0, 3, 6	1.92 cm	NR	2.0°C	D	LL, PM
Joseph et al. (2012)	J	HunterLab LabScan XE Colorimeter	2.54 cm	4	0, 5, 9	2.54 cm	5.53, 5.66	2.0°C	F	LL, PM
Phelps et al. (2014)	J	HunterLab MiniScan™ EZ	2.54 cm	3	0, 2, 4, 5, 6, 7	2.54 cm	5.61	3.0°C ± 2.0°C	F	LL
Phelps et al. (2016)	J	HunterLab MiniScan™ EZ	2.54 cm	3	0, 1, 2, 3, 4, 5, 6, 7	2.54 cm	5.65	0.3°C ± 0.9°C	F	LL
Purohit et al. (2015)	J	HunterLab MiniScan™ EZ	2.54 cm	3	1, 5, 9	2.54 cm	5.82, 5.85	2.0°C ± 1.0°C	F	LL, PM
Ramanathan et al. (2011)	J	HunterLab MiniScan® XE Plus Spectrophotometer	2.54 cm	3	0, 5, 13	1.91 cm	5.60	1.0°C	D	LL
Ramanathan et al. (2018)	J	HunterLab MiniScan® XE Plus Spectrophotometer	2.50 cm	2	0, 1, 2, 3	2.50 cm	5.60	2.0°C ± 1.0°C	F	LL
Mancini et al. (2018)	J	HunterLab Miniscan XE Plus	2.54 cm	2-3	0, 1, 2, 3, 4, 5, 6,	2.54 cm	NR	4.0°C	F	LL, PM
King et al. (2011a)	J	HunterLab MiniScan® XE Plus Spectrophotometer	25 mm	2	0, 1, 3, 6, 9	2.54 cm	5.59	1.0°C	F	LL
Kim et al. (2016)	J	HunterLab MiniScan™ EZ	25 mm	3	1, 4, 7	2.50 cm	NR	2.5°C	F	LL
McKenna et al. (2005)	J	HunterLab MiniScan® XE Plus	31.8 mm	3	0, 1, 2, 3, 4, 5, 6,	2.54 cm	5.77, 5.73	2.2°C ± 2°C	F	LL, PM
Canto et al. (2016)	J	CM-600D, Konica Minolta Sensing	8 mm	3	0, 3, 6, 9	2.54 cm	5.52	4.0°C	NR	LL, PM
Wu et al. (2020)	J	Model SP62, X-Rite, Inc	8 mm	4	0, 3, 5, 7	2.50 cm	5.53	2.0°C ± 1.0°C	LED	LL
Najar-Villarreal et al. (2021)	J	HunterLab MiniScan™ EZ	2.54 cm	3	0, 3, 6, 9, 12, 15	2.54 cm	5.56	0.0°C ± 4.0°C	F	LL
Sakamoto (2017)	D	HunterLab MiniScan® XE Plus	2.50 cm	3	0, 2, 3, 4, 6	2.00 cm	5.34-5.58	3.0°C ± 1.0°C	F	LL

Table 1. (Continued)

Author(s)	Source ²	Colorimeter	Aperture size	Scans ³	Display days	Steak thickness	pH ⁴	Temperature °C ⁵	Lighting type ⁶	Muscle ¹
Phelps et al. (2020)	J	HunterLab MiniScan™ EZ	2.54 cm	3	0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10	2.54 cm	NR	2.0°C ± 1.0°C	F	LL
Canto et al. (2015)	J	HunterLab MiniScan® XE Plus	2.54 cm	2	0, 11	2.54 cm	5.70	1.0°C	F	LL
King et al. (2011b)	J	HunterLab MiniScan® XE Plus	25 mm	2	0, 1, 2, 3, 4, 5, 6,	2.54 cm	5.58	1.0°C	F	LT
Kim et al. (2009)	J	HunterLab MiniScan® XE Plus	31.8 mm	3	0, 1, 2, 3, 4, 5, 6, 7	2.54 cm	5.71, 5.73	1.0°C	F	LL, PM

¹Muscles used in this study: LL = *longissimus lumborum*; PM = *psoas major*.

²Source of data: D = dissertation; J = peer-review journal.

³Number of scans per steak within the study.

⁴The pH average of muscles: LT = *longissimus thoracis*; PM = *psoas major*.

⁵Temperature of simulated retail display.

⁶Type of lighting used during retail display: D = dark; F = fluorescence; LED = light emitting diode; N = natural.

NR = not reported.

5 categories: 0–7 d, 8–14 d, 15–21 d, 22–28 d, and 29–65 d. Each category consisted of 5 to 16 experiments, totaling 48 experiments. For PM steaks, the actual postmortem aging times were grouped into 2 categories: 0–7 d and 8–21 d. Each category consisted of 11 and 5 experiments, respectively. The total display day observations for LL and PM were 255 and 71, respectively.

Selection criteria for inclusion and exclusion

In order to be included in the final database for LL and PM, experiments had to meet the following criteria: (1) colorimeter type, (2) aperture size, (3) number of scans, (4) display days, (5) steak thickness, (6) pH of meat, (7) storage temperature, (8) objective color measures, (9) subjective color measures, (10) oxygen-permeable packaging (polyvinyl chloride) or modified atmosphere packaging with 80% O₂ and 20% CO₂, and (11) lighting type. Studies evaluating the effect of enhancement solutions on LL meat color were considered for this study. In addition to these parameters, the variable postmortem aging time was included, and studies evaluating the effect of enhancements or other packaging different than oxygen-permeable packaging for LL and PM steaks were not considered for phase 2. To estimate a^* redness values, studies assessing meat color using a colorimeter with illuminant A were excluded if visual color data were not reported in hedonic scales. Furthermore, experiments had to provide display day means and SEM had to be included in the meta-analysis.

Statistical analysis

Statistical analysis was performed using SAS version 9.4 (SAS Institute, Inc., Cary, NC) PROC MIXED. The inverse variance weighting in meta-analysis was carried out via the WEIGHT statement followed by a variable equal to the inverse of the variance of the reported mean response. The phase 1 analysis implemented a hierarchical linear model (Singer, 1998; Sullivan et al. 1999), with the reported a^* mean being the response variable and the a^* mean being the linear regressor (i.e., fixed effect). Experiment was defined as the combination of paper, actual postmortem aging time, and study repeat. There were 29 experiments for LL steaks and 6 experiments for PM steaks. The model contained 3 random components: 2 represented the variation of intercept and slope at the experiment level, and the third represented the random error at the display-day-by-experiment level. The variance-covariance of the intercept and slope was taken as unstructured. The phase 2 analysis implemented a hierarchical linear model with display day and postmortem aging time being the regressors. Fixed effects of the model included postmortem aging group (a categorical variable), display day (linear effect of a numeric variable), display day squared (quadratic effect of a numeric variable), interactions of postmortem aging group with display day (linear effect heterogeneous with respect to postmortem aging group), and interaction of postmortem aging group and display day squared (i.e., quadratic effects heterogeneous with respect to postmortem aging group). The model contained 4 random components: 3 represented

the variation of intercept, linear coefficient, and quadratic coefficient at the experiment level; the fourth represented the random error at the display-day-by-experiment level. The variance-covariance of regression coefficients were taken as unstructured. Only a^* redness was included in the model because all studies reported this measure. Using a confidence interval of 95%, the a^* threshold was calculated using 5.9 and 3.5 using illuminant A for LL and PM muscles, respectively.

Results and Discussion

Phase 1

The estimates for a^* redness using 5.9 and 3.5 as a borderline acceptability for color life of LL and PM steaks with a 95% confidence interval can be found in Table 2. For LL steaks, the a^* values for borderline acceptability estimated in phase 1 for LL were 22.15 for the estimate and 24.07 and 20.24 for the higher and lower bounds, respectively, for a^* redness using a 95% confidence interval. In addition, the a^* values for borderline acceptability for PM steaks were 22.37 for the estimate and 23.75 and 20.99 for the higher and lower bounds, respectively, for a^* redness using a 95% confidence interval. It has been previously reported that for a response known to decrease over time, the lower one-sided 95% confidence limit should be used (U.S. Department of Health and Human Services-FDA-Center for Veterinary Medicine, 2014). Thus, the a^* color value lower bounds—20.24 and 20.99—were selected as borderline acceptability for LL and PM, respectively. By observing the linear trend and the normality assumption in Figures 1 and 2, the adequacy of the model for LL and PM, respectively, for phase 1, can be inferred. The plots of residuals versus predicted values (Figure 1, plot a) and (Figure 2, plot c) were analyzed and suggest that a linear trend with a constant variance was reasonable, indicating that the estimations calculated were precise for LL and PM steaks, respectively, for phase 1. In addition, the studentized residuals

Table 2. Estimations¹ for a^* redness using illuminant A for discoloration for *longissimus lumborum* (LL) and *psoas major* (PM) steaks, respectively

Measurement	Estimate	Lower Bound	Upper Bound
LL	22.15	20.24	24.07
PM	22.37	20.99	23.75

¹These values were estimated using a 95% confidence interval.

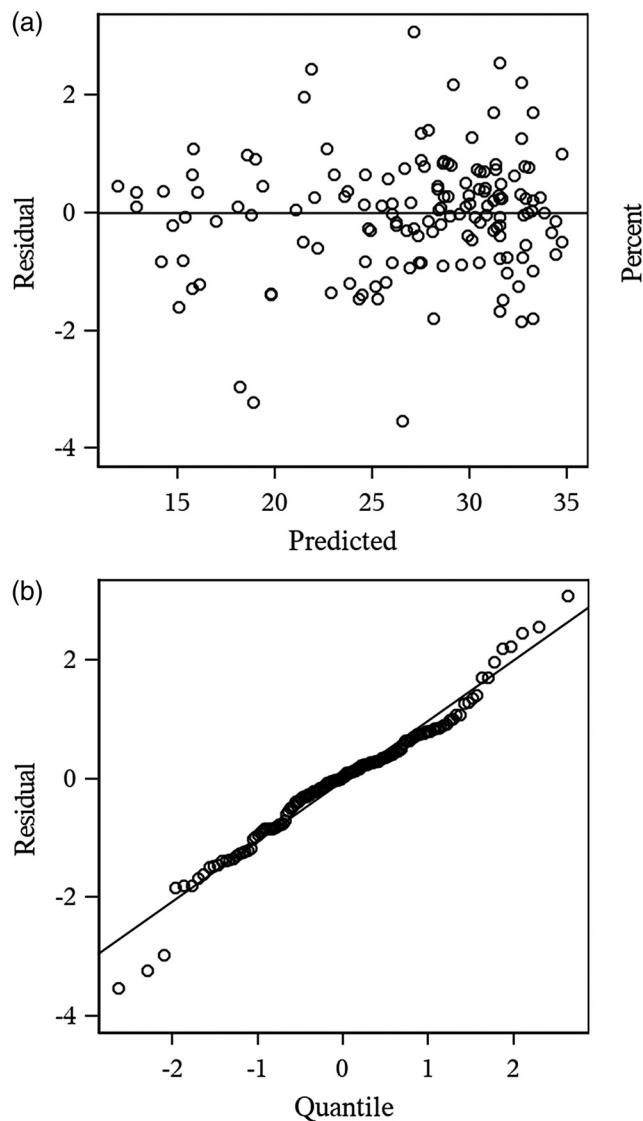


Figure 1. Plots of residual versus predicted values relative to the line of distribution (a) and studentized residual (b) of a^* redness for *longissimus lumborum* for phase 1.

plots (Figure 1, plot b) and (Figure 2, plot d) suggest that the normality assumption was met and no evidence for outliers and heteroscedasticity was observed for LL and PM.

Historically, LL (also known as the strip loin) is a heavily researched muscle, and it is widely used in the meat science literature. Overall, this muscle provides a good lean tissue area to be assessed by researchers. As a result, a great number of referred journal articles for LL were found in the literature compared with the number found for the PM muscle. These 2 muscles are popular among consumers and are normally found in display cases at the retail level.

Simulated retail display time ranged from 0 d to 15 d among all experiments. Temperature averages

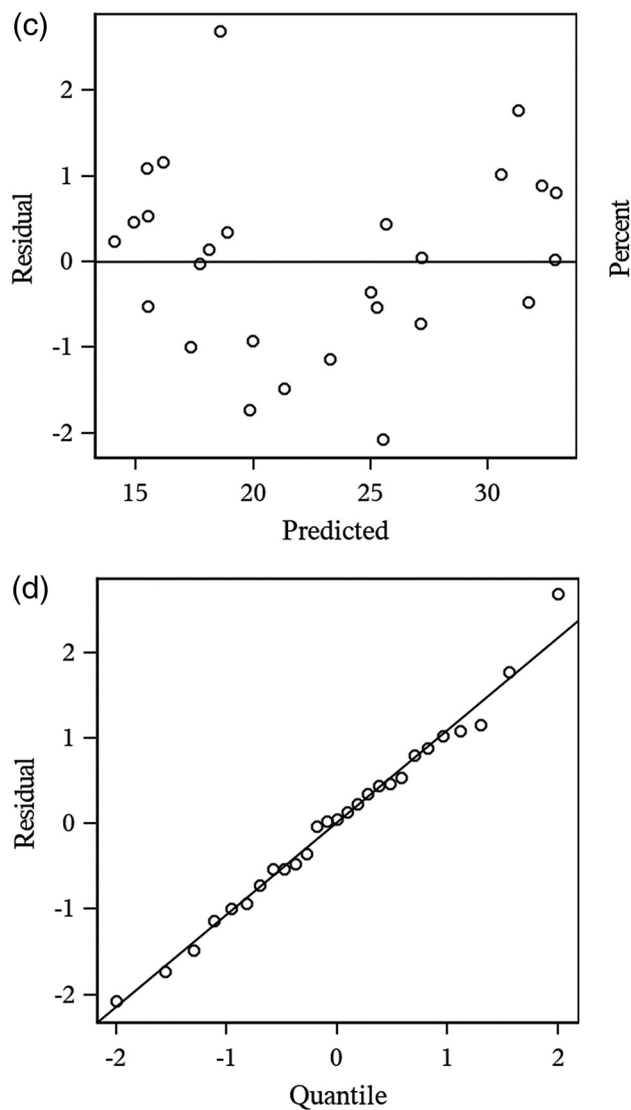


Figure 2. Plots of residual versus predicted values relative to the line of distribution (c) and studentized residual (d) of a^* redness for *psoas major* for phase 1.

for simulated display studies were -3°C to 7°C . Mancini et al. (2002) conducted a national retail survey and reported an average display case temperature of 4.4°C at retail. The pH of LL and PM steaks ranged from 5.50 to 5.82 in the papers used in this study. To objectively assess the color of fresh meat, colorimeters or spectrophotometers such as the Minolta-branded instrument (Chiyoda-ku, Tokyo, Japan) or the Hunter Associates Laboratory instrument (Reston, VA) have been used in 644 and 339 articles, respectively (Tapp et al., 2011). Some of the specifications that can be used to assess color on meat products are illuminant A, C, and D65, which measure tristimulus values, including L^* , a^* , and b^* . Upon the completion of the search of meat color papers, nearly 50% (data not shown) were journal

articles reporting data using illuminant D65 and/or C, but these data are not comparable with illuminant A. The light source or type of illuminant plays an important role in the color being measured on meat and meat products, and the American Meat Science Association (AMSA, 2012) color guidelines recommend the use of illuminant A owing to the higher proportion of long, red wavelengths, which have been determined to have higher correlations with visual color scores. It is noteworthy to mention that a^* was reported in the literature in higher proportion compared with L^* and b^* .

It has been previously reported that there were some inconsistencies in publications when apparatus specifications were reported, and some authors failed to thoroughly describe the essential specifications when assessing meat color as recommended by the AMSA (2012) Meat Color Measurement Guidelines. For instance, Tapp et al. (2011) conducted a survey of 1,068 published (1998 to 2007) manuscripts and found that 3% of studies failed to include instrument type, 52.4% failed to report number of scans on each sample, and 73.6% failed to include aperture size. The number scans reported in the experiments used in this analysis ranged from 2 to 4 scans per sample. In addition, a standardized method to visually assess beef color was not observed across the experiments reviewed for this study; researchers used hedonic and 100% scales interchangeably in their results. Because this meta-analysis followed AMSA (2012) color guidelines, papers using other types of visual color scales were not comparable to one another and were excluded.

Estimations for the meta-analysis were calculated using visual color scores and a^* instrumental color data from papers using illuminant A. In past literature, met-myoglobin formation or discoloration on the surface of 20% has been widely used in the literature as an acceptable color threshold to determine borderline acceptability using instrumental color results (Hood and Riordan, 1973). It is noteworthy to mention that this research was published more than 50 years ago. Therefore, the estimations calculated in this study represent the most current data published within the last 20 years (2000 to 2020). Additionally, they reflect current beef production practices and may indicate the length of time that aerobically packaged LL and PM steaks have acceptable color. The borderline thresholds estimated using the present data set may only be used for LL and PM, whereas other meta-analyses should be performed for other muscles depending upon the literature that is available.

Phase 2

Several studies have shown that antemortem factors can affect meat color, including age, sex, genetics, and nutrition (Faustman and Cassens, 1990; Suman and Joseph, 2013). Meat scientists conducting meat color research using high forage/grass feeding systems have found that the meat produced uses energy differently (more oxidative) and can result in darker lean meat (Muir et al., 1998; Vestergaard et al., 2000). It is well established that the ultimate pH of meat plays a role in meat color. Generally, high-pH meat is biochemically different and has shown increased oxygen consumption than normal-pH meat (English et al., 2016). Thus, those experiments using high-pH treatments were excluded from the meta-analysis. Overall, most of the meat used in the current studies was procured and sourced from a commodity cattle production system in the US, which are primarily cattle finished on a concentrate diet.

To date, meat packers utilize postmortem aging time as means to guarantee tenderness, and 14 d of postmortem aging time is a meat industry standard to ensure a good consumer eating experience; however, undergoing postmortem aging time that exceeds 14 d may lead to poor color stability (Ramanathan et al., 2020). English et al. (2016) compared LL aged 21, 42, and 62 d and reported that extended aging had a detrimental effect on color stability during retail display. They demonstrated that LL steaks with >42 d of postmortem aging time bloomed less than LL steaks with 21 d postmortem aging time and deduced that this lack of blooming was due to the increased purge loss containing myoglobin during postmortem aging time (English et al., 2016). In addition, these authors reported that extended aging increased oxygen consumption, which may influence the consumer-preferred red color of beef. Postmortem strategies to optimize the color life of fresh meat are key throughout the supply chain. Other exogenous factors influencing beef color are storage, display conditions, packaging, and the addition of antioxidants, among others (Faustman and Cassens, 1990; Mancini and Hunt, 2005; Suman and Joseph, 2013). For phase 2, papers that included beef packaged in polyvinyl chloride film and modified atmosphere packaging 80% O₂/20% CO₂ were used for the meta-analysis, but other types of modified atmosphere packaging such as CO were excluded.

Plots of residuals versus predicted values and studentized residuals plots can be observed in Figure 3 for LL for phase 2. The residuals versus predicted values plot (Figure 3, plot e) indicates that a linear trend with a

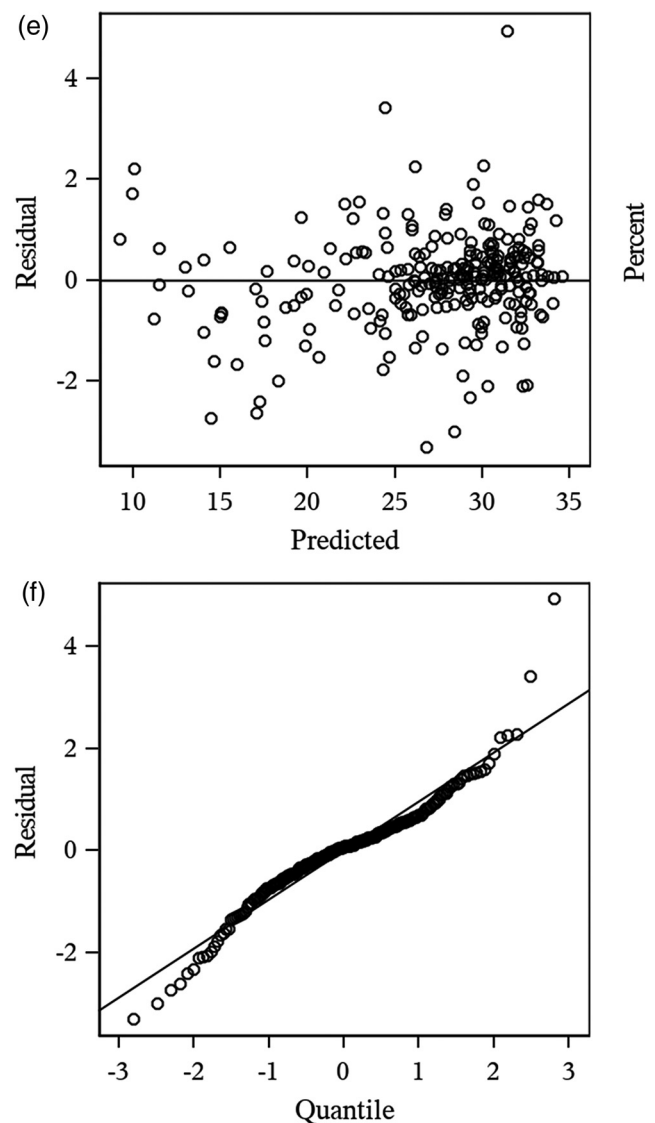


Figure 3. Plots of residual versus predicted values relative to the line of distribution (e) and studentized residual (f) of a^* redness for *longissimus lumborum* for phase 2.

constant variance is reasonable and (Figure 3, plot f) indicates that the normal assumption about the errors is reasonable as well. The residuals versus predicted values (plot g) and studentized residuals plots (plot h) for PM can be found in Figure 4. An outlier in the studentized residuals plots and line of distribution for the PM in phase 2 was observed. Having one value as an outlier is not preferred but still is important to include all values in the model regardless of how far they are from all data points. As a following step, these estimates will be challenged in a validation color life study using the LL and PM muscles at different postmortem aging times to assess our model.

The estimates of color life of LL steaks during retail display are shown in Figure 5. The a^* value used

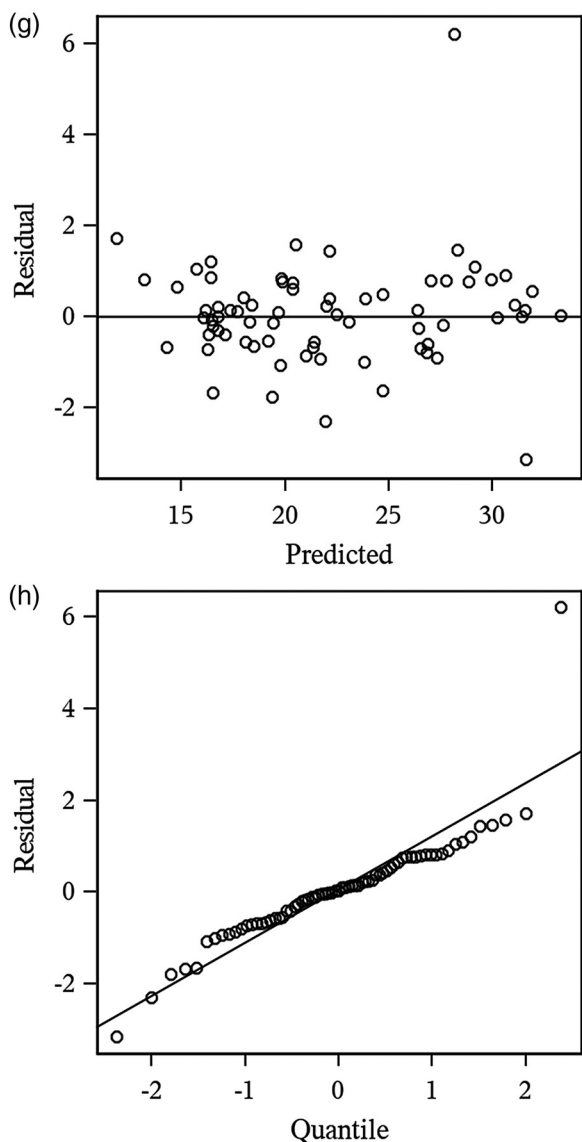


Figure 4. Plots of residual versus predicted values relative to the line of distribution (g) and studentized residual (h) of a^* redness for *psoas major* for phase 2.

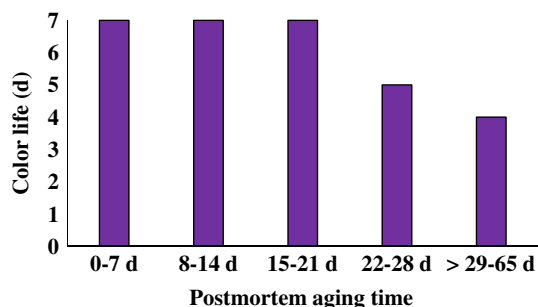


Figure 5. Estimates of color life of *longissimus lumborum* steaks during retail display using a^* redness scores.

for LL was 20.24. The first 21 d of postmortem aging time (storage before display) were found to have the longest color life, with 7 d of color life for LL steaks.

Percent

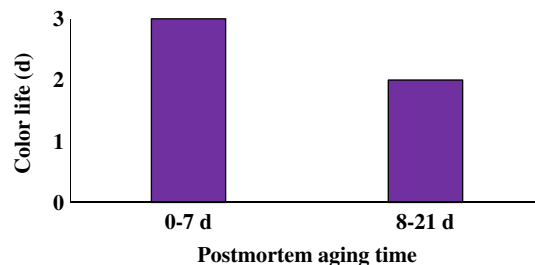


Figure 6. Estimates of color life of *psoas major* steaks during retail display using a^* redness scores.

Additionally, the color life of LL steaks with postmortem aging time 29–65 d and 22–28 d was 5 and 4 d, respectively. For PM, the estimates of color life of LL are shown in Figure 6. The estimated time before borderline acceptability for 0- to 7-d postmortem aging time was 3 d for PM steaks. The color life of PM steaks with 8 to 21 d of postmortem aging time was only 2 d. Colle et al. (2015) reported the same decline in redness color life of LL steaks for extended postmortem aging time. They reported that a^* values of LL steaks decreased during simulated retail display when strip loins were aged 14 d or longer. In addition, English et al. (2016) compared LL aged 21, 42, and 62 d and reported that extended aging had a detrimental effect on color stability during retail display.

Conclusions

These estimations may be applicable when procuring commodity meat with a normal pH from a grain feeding system. There were some limitations, including few papers available in the literature and an outlier for the PM data. Using meat produced from cattle raised under different feeding systems,—primarily grass-fed, which is typically found in other countries—may not provide an accurate estimation owing to their inherent color differences. Overall, knowing the postmortem age of LL and PM subprimals could serve as a tool for retailers to identify the potential display color life of LL and PM steaks displayed under aerobic packaging conditions. Estimations calculated using trained panel data and a^* redness values retrieved from this meta-analysis demonstrate that using LL and PM subprimals that have a postmortem aging time age of 21 d or less and 7 d or less, respectively, would optimize the retail display color life of aerobically packaged steaks.

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