Title: Determining the relationship between early postmortem loin quality attributes and aged loin quality attributes using meta-analysis techniques, **NPB #16-221**

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Industry Summary:

Predicting and improving quality is an important goal for the pork industry. The adoption of a U.S. pork quality grading system has been proposed as a potential strategy, of considerable interest, to improving pork quality. However, there are a number of considerations that must be taken into account for such a quality grading system to have clear value to the industry. While factors like the evaluation of quality attributes on-line have been addressed, what is less understood is the association between quality attributes measured at the time of grading and quality traits observed by the consumer after 10-28 d of storage. Therefore, the objective of this work was to determine those relationships using meta-analysis techniques. By performing a meta-analysis, data from several studies can be combined to provide more statistical power. According to Hunter and Schmidt (1990) a meta-analysis is a review of the literature, both published and unpublished, based on a structured statistical approach. Therefore, all available data were considered as candidates for inclusion. The following inclusion criteria were established for studies to provide the most industry-applicable conclusions. First, all studies included must have slaughtered pigs in commercial facilities. Second, studies must have measured loin quality traits on the ventral surface of the loins on day 1 postmortem. Third, quality measurements must have been collected on the same loins again after an aging period that ranged from 12 to 28 days. Original experimental objectives were not taken into account and often times multiple treatments (e.g. dietary, genotype, or slaughter day) were represented within a data set.

Ultimately, eleven independent experiments including a total of 3,957 loins were selected for inclusion in the analysis. First, correlations were determined between fresh pork loin quality attributes evaluated at the packer level (1d postmortem) with those at evaluated after aging for 12 to 28d. Early postmortem color was moderately, not strongly, correlated with aged ventral color and aged chop face color. But no early postmortem color traits were moderately or strongly correlated with measures of eating experience (instrumental tenderness, cook loss, sensory tenderness, juiciness, or flavor). Next, early and aged quality traits were compared within loins to determine the magnitudes of changes in the traits that occur with aging. Instrumental measures of color indicated that loins became lighter, redder, and more yellow during aging. Visual color also changed during the aging period, but the magnitude of the change was only 0.21 units. A

change of only 0.21 units likely means the average consumer would not be able to detect the difference in visual color between early and aged loins. Finally, using a holo-analysis, regression equations were constructed to predict sensory traits from early postmortem quality measures. Early postmortem quality measurements were only marginally predictive of eating quality on pork loin chops. The regression model including extractable lipid, pH and firmness explained only 13% of the variability in sensory evaluations of tenderness. Early postmortem quality traits could predict 28% of the variability in flavor.

Results of this study indicate that early postmortem quality traits are related to those same traits measured after aging. However, those traits are not perfectly correlated. Therefore, it is possible that a loin designated "high quality" based on color observations at the time of quality evaluation in the plant may not necessarily appear "high quality" to a consumer. Furthermore, early postmortem quality traits like color, marbling, pH and firmness, even when combined, offered limited predictive ability for eating quality traits like tenderness, juiciness and flavor. However, it should be noted that eating quality in the studies used for this analysis was from trained sensory panels and therefore, thresholds of acceptability to consumers cannot be established from these data. Further work is needed to validate the usefulness of early postmortem quality traits measured on the ventral surface of loins as predictors of consumer perceptions of eating quality of pork loins.

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Scientific Abstract:

Meta-analysis techniques were used to estimate the effects of aging on pork loin quality. In total, 11 independent data sets was used to determine changes in quality parameters and correlations between fresh pork loin attributes evaluated at the packer level (1d postmortem) with those at the retail or consumer level (12 to 28d). In total, the data sets used encompassed observations on approximately 3,957 loins. Ventral loin surfaces become 8% lighter ($P < 0.0001$), 44.5% redder ($P < 0.0001$), and 46% more yellow ($P < 0.0001$) during the aging period. Visual color also changed during the aging period, but the magnitude of the change was only 0.21 units ($P < 0.0001$). Therefore, it is apparent that color of the ventral surface changes during the postmortem aging period. While the differences represent a substantial change from an instrumental perspective, the visual change in color will likely not influence consumer purchasing decisions as consumers likely will not perceive this small difference. Because color and visual marbling change during aging, it is necessary to determine the correlation between early and aged pork quality parameters. Pearson correlation coefficients within original data sets were calculated using the CORR procedure of SAS and then sample-weighted mean correlations ($\bar{r}$) and variances [Var(r)] were calculated across data sets. Early postmortem ventral instrumental lightness (L*) was only moderately correlated with aged ventral L* ($\bar{r}$ = 0.50), aged ventral subjective color ($\bar{r}$ = -0.38), aged chop face (freshly cut) L* ($\bar{r}$ = 0.44), and aged chop face subjective color ($\bar{r}$ = -0.38). Early postmortem ventral instrumental redness (a*) also exhibited moderate correlations with aged ventral a* ($\bar{r}$ = 0.49) and aged chop face a* ($\bar{r}$ = 0.46). No strong correlations ($|\bar{r}| \geq 0.68$) were observed between early postmortem ventral L* or a* and any instrumental color or visual color, marbling or firmness trait on the aged ventral surface of the loin or the aged chop face. Early postmortem ventral visual color was moderately correlated with aged ventral L* ($\bar{r}$ = -0.51), aged ventral visual color ($\bar{r}$ = 0.50), aged chop face L* ($\bar{r}$ = -0.43), and aged chop face visual color ($\bar{r}$ = 0.43). No instrumental or visual color parameters were either moderately ($|\bar{r}|$ = 0.36 to

0.67) or strongly correlated ($|\bar{r}| \geq 0.68$) to traits associated with eating experience (instrumental tenderness, cook loss, sensory tenderness, juiciness, or flavor). Early postmortem ventral visual marbling was moderately correlated with aged ventral marbling ($\bar{r}$ = 0.63) and aged chop face visual marbling ($\bar{r}$ = 0.56). Early postmortem ventral visual marbling was not strongly correlated ($|\bar{r}| \geq 0.68$) to any instrumental color or visual color, marbling or firmness trait on the aged ventral surface of the loin or the aged freshly cut chop face. Early postmortem ultimate pH was moderately correlated with aged ventral L* ($\bar{r}$ = -0.43), aged ventral yellowness (b*; $\bar{r}$ = 0.-43), aged ventral subjective color ($\bar{r}$ = 0.36), and aged subjective color of the chop face ($\bar{r}$ = 0.36). Ultimate pH was neither moderately nor strongly correlated to any trait associated with eating experience. Finally, stepwise regression using a holo-analysis approach was used to determine the predictive ability of early postmortem traits of those associated with eating quality and purchasing intent. Early postmortem quality measures were only marginally predictive of sensory tenderness (R^2 = 0.13) or juiciness (R^2 = 0.09). In other words, even when the model could include all 5 of these measures, less than 13% of the variability in tenderness and juiciness could be explained. The combination of color, marbling, firmness, and pH were moderately predictive (R^2 = 0.28) of sensory flavor (Table 10). On the other hand, early postmortem pork quality traits were predictive of traits associated with purchasing intent (e.g. aged chop color and aged chop marbling). The combination of the color, marbling, firmness, pH and extractable lipid were moderately predictive (R^2 = 0.26) and aged chop marbling (R^2 = 0.28) when chemical extractable lipid was not included as a candidate predictor variable. Including chemical extractable lipid along with early color, marbling, firmness, and pH was highly predictive (R^2 = 0.52) of aged chop marbling.

In conclusion, pork quality traits change during the aging process. Even though color and marbling are important pork quality traits in consumers purchasing decisions, they are poorly related to traits associated with eating experience. On the other hand, early color and marbling are correlated with aged color and marbling. Thusly, the combination of traditional pork quality parameters measured at processing facility at the time of fabrication are poorly predicative of eating experience, but may provide indication of traits associated with purchasing intent.

Introduction:

Predicting and improving quality is an important goal for the pork industry. The adoption of a U.S. pork quality grading system has been proposed as a potential strategy, of considerable interest, to improving pork quality. However, there are a number of considerations that must be taken into account for such a quality grading system to have clear value to the industry. While factors like the evaluation of quality attributes on-line have been addressed, what is less understood is the association between quality attributes measured at time of grading and when they reach the consumer after 10-14 d of storage.

Pork loin quality is typically measured by the packer on the ventral side of whole, boneless loins and is used to predict the quality of loin chops at the retail level and the consumer eating experience. However, it is known that quality attributes such as color and tenderness can change during the 12-28 d of storage between packer evaluations and purchase by consumers. Though there are several published works and unpublished data sets available that measure quality at both the packer and consumer level, results from individual studies are variable regarding the relationships between packer and consumer quality evaluations. One method to provide clarity to those relationships is the use of a meta-analysis. By combining the results from several studies into a systematic and statistical review of the issue, we can increase our power to determine the relationships between pork quality measurements occurring at different times in the supply chain.

In order to institute standards or systems to evaluate and reward producers for delivering high quality pork to packers, we must first understand the relationship between packer and consumer evaluations of quality. The current information gap restricts the ability of the industry to make meaningful improvements to pork quality, thereby limiting the U.S. pork industry's ability to position pork a center of the plate option for domestic and international consumers.

Objectives:

Objective 1. Correlate fresh loin quality parameters (muscle pH, color, marbling, firmness) evaluated early postmortem with aged loin quality parameters at approximately 10-28 d postmortem through a meta-analysis of the available data and literature.

Objective 2. Evaluate the magnitude of difference in loin quality parameters evaluated early postmortem and aged loin quality parameters at 10-28 d postmortem using paired t-tests of the available data and literature.

Objective 3. Develop a prediction equation for aged loin quality at 10-28 d postmortem using quality parameters evaluated early postmortem through a holo-analysis of the available internal and collaborator data sets.

Materials & Methods:

Eleven independent experiments were selected for inclusion in the analysis. Inclusion criteria included studies where pigs were slaughtered at a commercial facility, loins were evaluated on the ventral surface of the loins on day 1 postmortem, and then again after an aging period that ranged from 12 to 28 days. Original experimental objectives were not taken into account and often times multiple treatments (e.g. dietary, genotype, or slaughter day) were represented within a data set. Data from published and unpublished experiments were considered and used in the analysis. According to Hunter and Schmidt (1990) a meta-analysis is a review of the literature, both published and unpublished, based on a structured statistical approach. Therefore, all available data were considered as candidates for inclusion.

Eight independent variables were identified as potential indicators of aged quality and sensory traits. All independent variables were traits that could be measured at a processing facility in real time using non-invasive methods (methodology that would not decrease the total value of the loin). All 8 variables were measured on the ventral surface of the loin and included instrumental lightness (L*), redness (a*), yellowness (b*), visual color, visual marbling, subjective firmness, and ultimate pH. Extractable lipid was also included as an independent variable because extractable lipid should not change during postmortem aging, but the visual detection of marbling may be influenced by things such as lighting or temperature of the loin. Using extractable lipid as an independent variable provided an objective measurement for marbling.

Instrumental color values were measured with either a Minolta colorimeter or a Hunter miniscan spectrophotometer and used either D65 (noon daylight, 6500 K) or C (average north sky daylight, 6774 K) illuminant (AMSA, 2012). Because the objective was to determine the correlation between early and postmortem loin quality traits and because correlations do not have units, data from both machines and both illuminants were pooled. Oxygenation of myoglobin was not controlled and likely differed among studies. However, all data were collected as dictated by the constraints of fresh pork data collection at the respective processing facility.

Visual color and marbling used the National Pork Producers Council standards for evaluation of fresh pork loins (NPPC, 1999). Likewise, subjective firmness scores were determined using the National Pork Producers Council standards for firmness (NPPC, 1991).

Extractable lipid data were collected on chops trimmed of all subcutaneous fat and accessory muscles. Lipid was then extracted using petroleum ether or a mixture of chloroform and methanol.

Instrumental tenderness was determined using either Warner-Bratzler shear force or Slice shear force on chops that were cooked to either 63°C or 71°C

Meta-analysis Data from original data sets were previously analyzed based on the objectives of the respective original experiment. Therefore, each data set was first independently re-analyzed to determine the correlations between 8 independent variables (early postmortem traits) and 17 dependent variables (aged postmortem traits). Pearson correlation coefficients for original data sets were calculated using the CORR procedure of SAS. A data set consisting of the study name, number of observations, and the correlation coefficient was generated for each of the 136 combinations of independent and dependent variables. Then, the sample-weighted mean correlation ($\bar{r}$) and sample-weighted variance [Var(r)] was calculated such that studies with larger samples sizes were given more weight than studies with smaller sample sizes. The sample-weighted mean correlation was calculated using the equation: $\bar{r} = \frac{\sum(N_i \times r_i)}{\sum N_i}$ where N_i is the sample size for each study and r_i is the observed correlation coefficient. Sample-weighted variance was calculated using the equation: $(r) = \frac{\sum(N_i \times (r_i - \bar{r})^2)}{\sum N_i}$. Because the greatest source of variability across original studies is sampling error (Hunter and Schmidt, 2004), the next step in the process was calculating sampling error variance. Sampling error variance was calculated using the equation: $Var(e) = \frac{(1-\bar{r}^2)^2}{(\bar{N}-1)}$ where $\bar{r}$ is the sample-weighted mean correlation and $\bar{N}$ is the average sample size of the original studies. From there, 95% confidence intervals were calculated based on the sample-weighted mean correlation (rho). Lower confidence limits were calculated as: $\bar{r} - \left(1.96 \times \left(\frac{1-(\bar{r}^2)}{\sqrt{N-K}}\right)\right)$ where N equals the total number of observations across all studies and K equals the number of studies included in the meta-analysis. Upper confidence limits were calculated as: $\bar{r} + \left(1.96 \times \left(\frac{1-(\bar{r}^2)}{\sqrt{N-K}}\right)\right)$. Final relationships were considered different from zero when the 95% confidence interval did not include zero. Correlations were considered low/weak when $|\bar{r}| \leq 0.35$, moderately correlated when $|\bar{r}| = 0.36$ to 0.67, and strongly correlated when $|\bar{r}| = 0.68$ to 1.0, similar to Taylor (1990).

Paired T-test Individual loin served as the experimental unit for determination of changes in quality estimates between early and aged traits. Differences in early and aged loin quality variables within a loin were compared using the paired option of the PROC T Test in SAS. Statistical significance was accepted as different at $P \leq 0.05$.

Holo-analysis Unlike a meta-analysis that requires qualification for data to be included in the analysis, a holo-analysis is defined as the integration of all available data on a specific topic. Therefore, entire data sets rather than means from analyzed data sets were used to conduct a holo-analysis of the ability of non-invasive early postmortem loin quality traits (e.g. visual color, visual marbling, subjective firmness, and pH) collected on the ventral surface of the loin to predict traits associated with eating experience and purchasing intent. Because variables such as instrument selection, illuminant selection, degree of observer selection and machine aperture size all known to influence instrumental color, CIE lightness (L*), redness (a*), and yellowness (b*) were not included in the list of predictor (independent variables). Likewise, because slice shear force and Warner-Bratzler shear force estimate tenderness in different magnitudes, instrumental tenderness was not included in the list of dependent variables. Data were analyzed using the REG procedure in SAS. Dependent variables included sensory tenderness, juiciness, flavor (variables associated with eating experience) as well as visual color and marbling of the cut surface of aged pork chops (traits associated with purchasing intent). Independent variables included: visual color, visual marbling, and subjective firmness on the ventral surface of a 1 d postmortem boneless pork loin. Also included was pH and extractable lipid. Extractable lipid was included in the list of independent variables because intramuscular lipid should not change during aging. Further, the ability to assess visual marbling is largely a function of the skill level of the technician. Extractable lipid provided a quantifiable measure of marbling. A linear regression equation was developed using the independent candidate variables to predict all dependent variables. The initial regression model included each of the 5 independent variables. Multicollinearity among independent variables was assessed using a variance inflation factor (**VIF)** statistic. However, no parameters exceeded VIF values of 2, therefore, all independent variables remained as candidate variables for selection in the model. Influence of individual observations on the estimated dependent variable was determined using the difference of fit (DFITTS) statistic. Observations were considered to have excessive influence on the estimation of the regression parameters when DFITTS $\geq 2\left[(p/n)^{1/2}\right]$, where p = was the number of parameters considered and n is the total number of observations. Using the stepwise selection method, independent variables were required to have a significant *F* statistic at the SLENTRY and SLSTAY level = 0.15 to be included and remain in the final model.

Results:

Objective 1

For each early postmortem quality trait measured on the ventral surface of loins, correlation coefficients with aged ventral and chop face quality measures and with sensory and tenderness measures were calculated. Noted on the following tables are the total observations for each trait and the number of studies those observations represent. The sample-weighted mean correlation (rho) is the estimated correlation coefficient that describes the strength of the relationship between the two traits and the lower and upper confidence intervals give an estimate of the variability about the estimation of rho.

Early postmortem ventral instrumental lightness (L*) was moderately correlated with aged ventral lightness ($\bar{r}$ = 0.50), aged ventral subjective color ($\bar{r}$ = -0.38), aged instrumental lightness of the chop face ($\bar{r}$ = 0.44), and aged subjective color ($\bar{r}$ = -0.38) of the chop face (Table 1). Early postmortem ventral instrumental lightness was not strongly correlated ($|\bar{r}| \geq 0.68$) to any instrumental color or subjective color, marbling or firmness trait on the aged ventral surface of the loin or the aged but freshly cut chop face.

able 1. Correlation coefficients of early (1d) postmortem ventral loin surface instrumental lightness *) values with aged loin and chop quality parameters

				5% Confidence interval		
em	Total observations	Number of studies	Rho[1]	ower limit	pper limit	Sampling variance
ged ventral surface						
ghtness, L*	3957	8	0.50	0.48	0.53	0.0011
edness, a*	3957	8	-0.09	-0.12	-0.06	0.0020
ellowness, b*	3957	8	0.32	0.29	0.35	0.0016
ubjective color	4108	9	-0.38	-0.40	-0.35	0.0016
ubjective marbling	4108	9	0.04	0.01	0.08	0.0022
ubjective firmness	4108	9	-0.08	-0.11	-0.05	0.0022
ged chop face						
ghtness, L*	4213	11	0.44	0.41	0.46	0.0017
edness, a*	4213	11	-0.05	-0.08	-0.02	0.0026
ellowness, b*	4213	11	0.31	0.28	0.33	0.0021
ubjective color	4108	9	-0.38	-0.40	-0.35	0.0016

ıbjective marbling	3889	9	0.07	0.04	0.10	0.0023
ıbjective firmness	3180	7	-0.02	-0.06	0.01	0.0022
ensory estimates						
strumental tenderness[2]	5075	11	-0.16	-0.19	-0.13	0.0021
ook loss	5073	11	0.20	0.17	0.22	0.0020
ensory tenderness	1556	7	-0.06	-0.11	-0.01	0.0045
ensory juiciness	1556	7	-0.07	-0.12	-0.02	0.0045
ensory flavor	1405	6	0.01	-0.04	0.06	0.0043

ample weighted mean correlation

ncludes Warner-Bratzler and slice shear force evaluated chops cooked to 63° C through 71° C.

Early postmortem ventral instrumental redness (a*) was moderately correlated with aged ventral redness ($\bar{r}$ = 0.49) and aged instrumental redness of the chop face ($\bar{r}$ = 0.46, Table 2). Early postmortem ventral instrumental redness was not strongly correlated ($|\bar{r}| \geq 0.68$) to any instrumental color or subjective color, marbling or firmness trait on the aged ventral surface of the loin or the aged but freshly cut chop face.

able 2. Correlation coefficients of early (1d) postmortem ventral loin surface instrumental redness *) values with aged loin and chop quality parameters

				5% Confidence interval		
em	Total observations	Number of studies	Rho[1]	ower limit	Jpper limit	Sampling variance
ged ventral surface						
ghtness, L*	3957	8	-0.06	-0.09	-0.03	0.0020
edness, a*	3957	8	0.49	0.47	0.52	0.0012
ellowness, b*	3957	8	0.28	0.26	0.31	0.0017
ıbjective color	4108	9	0.11	0.08	0.14	0.0021
ıbjective marbling	4108	9	0.04	0.01	0.07	0.0022
ıbjective firmness	4108	9	0.06	0.03	0.09	0.0022
ged chop face						
ghtness, L*	4213	11	-0.05	-0.08	-0.02	0.0026
edness, a*	4213	11	0.46	0.43	0.48	0.0016
ellowness, b*	4213	11	0.21	0.18	0.24	0.0024
ıbjective color	3889	9	0.09	0.05	0.12	0.0023
ıbjective marbling	3889	9	0.11	0.07	0.14	0.0023
ıbjective firmness	3180	7	0.03	-0.01	0.06	0.0022
ensory estimates						
strumental tenderness[2]	5075	11	-0.07	-0.10	-0.04	0.0021
ook loss	5073	11	0.05	0.02	0.07	0.0022
ensory tenderness	1556	7	-0.07	-0.12	-0.02	0.0045
ensory juiciness	1556	7	-0.05	-0.10	0.00	0.0045
ensory flavor	1405	6	-0.06	-0.11	-0.01	0.0043

ample weighted mean correlation

ncludes Warner-Bratzler and slice shear force evaluated chops cooked to 63° C through 71° C.

Early postmortem ventral instrumental yellowness (b*) was moderately correlated ($\bar{r}$ = 0.37) with aged ventral lightness (Table 3). Early postmortem ventral instrumental yellowness was not strongly correlated ($|\bar{r}| \geq 0.68$) to any instrumental color or subjective color, marbling or firmness trait on the aged ventral surface of the loin or the aged but freshly cut chop face.

able 3. Correlation coefficients of early (1d) postmortem ventral loin surface instrumental yellowness b*) values with aged loin and chop quality parameters

em	Total observations	Number of studies	Rho[1]	5% Confidence interval Lower limit	Upper limit	Sampling variance
ged ventral surface						
ightness, L*	3957	8	0.37	0.34	0.40	0.0015
edness, a*	3957	8	0.10	0.07	0.13	0.0020
ellowness, b*	3957	8	0.33	0.30	0.36	0.0016
ubjective color	4108	9	-0.26	-0.29	-0.23	0.0019
ubjective marbling	4108	9	0.04	0.01	0.07	0.0022
ubjective firmness	4108	9	-0.03	-0.06	0.00	0.0022
ged chop face						
ightness, L*	4213	11	0.28	0.25	0.30	0.0022
edness, a*	4213	11	0.07	0.04	0.10	0.0026
ellowness, b*	4213	11	0.27	0.24	0.30	0.0022
ubjective color	3889	9	-0.23	-0.26	-0.20	0.0021
ubjective marbling	3889	9	0.09	0.06	0.12	0.0023
ubjective firmness	3180	7	0.00	-0.04	0.03	0.0022
ensory estimates						
strumental tenderness[2]	5075	11	-0.17	-0.20	-0.15	0.0020
ook loss	5073	11	0.17	0.14	0.19	0.0021
ensory tenderness	1556	7	-0.02	-0.07	0.03	0.0045
ensory juiciness	1556	7	-0.02	-0.07	0.03	0.0045
ensory flavor	1405	6	0.00	-0.05	0.05	0.0043

Sample weighted mean correlation

ncludes Warner-Bratzler and slice shear force evaluated chops cooked to 63° C through 71° C.

Early postmortem ventral subjective color was moderately correlated with aged ventral lightness ($\bar{r}$ = -0.51), aged ventral subjective color ($\bar{r}$ = 0.50), aged instrumental lightness of the chop face ($\bar{r}$ = -0.43), and aged subjective color ($\bar{r}$ = 0.43) of the chop face (Table 4). Early postmortem ventral instrumental lightness was not strongly correlated ($|\bar{r}| \geq 0.68$) to any instrumental color or subjective color, marbling or firmness trait on the aged ventral surface of the loin or the aged but freshly cut chop face.

No instrumental or visual color parameters were moderately ($|\bar{r}|$ = 0.36 to 0.67) or strongly correlated ($|\bar{r}| \geq 0.68$) to traits associated with eating experience (instrumental tenderness, cook loss, sensory tenderness, juiciness, or flavor).

able 4. Correlation coefficients of early (1d) postmortem ventral loin surface visual color with ged loin and chop quality parameters

				5% Confidence interval		
em	Total observations	Number of studies	Rho[1]	ower limit	Jpper limit	Sampling variance
ged ventral surface						
ightness, L*	4110	8	-0.51	-0.53	-0.48	0.0011
edness, a*	4110	8	0.22	0.19	0.25	0.0018
ellowness, b*	4110	8	-0.21	-0.24	-0.18	0.0018
ubjective color	4260	9	0.50	0.48	0.52	0.0012
ubjective marbling	4260	9	0.15	0.13	0.18	0.0020
ubjective firmness	4260	9	0.17	0.14	0.19	0.0020
ged chop face						
ightness, L*	4357	11	-0.43	-0.46	-0.41	0.0017
edness, a*	4357	11	0.21	0.18	0.24	0.0023
ellowness, b*	4357	11	-0.16	-0.18	-0.13	0.0024
ubjective color	4042	9	0.43	0.41	0.46	0.0015
ubjective marbling	4040	9	0.12	0.09	0.15	0.0022
ubjective firmness	3187	7	0.04	0.00	0.07	0.0022
ensory estimates						
strumental tenderness[2]	5223	11	-0.01	-0.03	0.02	0.0021
ook loss	5223	11	-0.21	-0.23	-0.18	0.0019
ensory tenderness	1552	7	0.05	0.00	0.10	0.0045
ensory juiciness	1552	7	0.08	0.03	0.13	0.0045
ensory flavor	1401	6	0.09	0.04	0.14	0.0042

ample weighted mean correlation

ncludes Warner-Bratzler and slice shear force evaluated chops cooked to 63° C through 71° C.

Extractable lipid was moderately correlated with aged ventral marbling ($\bar{r}$ = 0.62) and strongly correlated with aged visual marbling of the chop face ($\bar{r}$ = 0.69, Table 5). Extractable lipid was not moderately or strongly correlated ($|\bar{r}| \leq 0.31$) to any instrumental color or visual color, visual marbling or subjective firmness trait on the aged ventral surface of the loin or the aged but freshly cut chop face.

able 5. Correlation coefficients of loin extractable lipid values with aged loin and chop quality arameters

em	Total observations	Number of studies	Rho[1]	5% Confidence interval Lower limit	Upper limit	Sampling variance
ged ventral surface						
ghtness, L*	4097	8	0.17	0.14	0.20	0.0018
edness, a*	4097	8	0.10	0.07	0.13	0.0019
ellowness, b*	4097	8	0.21	0.18	0.23	0.0018
ubjective color	4250	9	0.01	-0.02	0.04	0.0021
ubjective marbling	4250	9	0.62	0.60	0.63	0.0008
ubjective firmness	4250	9	0.25	0.22	0.28	0.0019
ged chop face						
ghtness, L*	3543	10	0.15	0.12	0.18	0.0027
edness, a*	3543	10	0.23	0.19	0.26	0.0025
ellowness, b*	3543	10	0.31	0.28	0.34	0.0023
ubjective color	3225	8	-0.02	-0.06	0.01	0.0025
ubjective marbling	3223	8	0.69	0.67	0.71	0.0007
ubjective firmness	2377	6	0.14	0.10	0.18	0.0024
ensory estimates						
strumental tenderness[2]	4407	10	-0.13	-0.16	-0.10	0.0022
ook loss	4406	10	-0.07	-0.10	-0.04	0.0023
ensory tenderness	1555	7	0.10	0.05	0.15	0.0044
ensory juiciness	1555	7	0.03	-0.02	0.08	0.0045
ensory flavor	1401	6	0.07	0.02	0.13	0.0043

Sample weighted mean correlation

ncludes Warner-Bratzler and slice shear force evaluated chops cooked to 63° C through 71° C.

Early postmortem ventral visual marbling was moderately correlated with aged ventral marbling ($\bar{r}$ = 0.63) and aged subjective marbling of the chop face ($\bar{r}$ = 0.56, Table 6). Early postmortem ventral subjective marbling was not strongly correlated ($|\bar{r}| \geq 0.68$) to any instrumental color or subjective color, marbling or firmness trait on the aged ventral surface of the loin or the aged but freshly cut chop face.

able 6. Correlation coefficients of early (1d) postmortem ventral loin surface visual marbling with ged loin and chop quality parameters

				5% Confidence interval		
em	Total observations	Number of studies	Rho[1]	ower limit	Jpper limit	Sampling variance
ged ventral surface						
ghtness, L*	4103	8	-0.09	-0.12	-0.06	0.0019
edness, a*	4103	8	0.03	0.00	0.06	0.0020
ellowness, b*	4103	8	-0.04	-0.07	-0.01	0.0019
ubjective color	4253	9	0.21	0.18	0.24	0.0019
ubjective marbling	4253	9	0.63	0.61	0.64	0.0008
ubjective firmness	4253	9	0.26	0.23	0.29	0.0018
ged chop face						
ghtness, L*	4352	11	-0.08	-0.11	-0.05	0.0025
edness, a*	4352	11	0.12	0.09	0.15	0.0025
ellowness, b*	4352	11	0.06	0.03	0.09	0.0025
ubjective color	4037	9	0.23	0.20	0.26	0.0020
ubjective marbling	4035	9	0.56	0.54	0.58	0.0011
ubjective firmness	3186	7	0.12	0.09	0.16	0.0021
ensory estimates						
strumental tenderness[2]	5216	11	-0.09	-0.11	-0.06	0.0021
ook loss	5216	11	-0.14	-0.17	-0.11	0.0020
ensory tenderness	1549	7	0.12	0.07	0.16	0.0044
ensory juiciness	1549	7	0.04	-0.01	0.09	0.0045
ensory flavor	1398	6	0.00	-0.06	0.05	0.0043

ample-weighted mean correlation

ncludes Warner-Bratzler and slice shear force evaluated chops cooked to 63° C through 71° C.

Early postmortem ventral firmness was not strongly ($|\bar{r}| \geq 0.68$) or moderately ($|\bar{r}|$ = 0.36 to 0.67) correlated with any instrumental color or subjective color, marbling or firmness trait on the aged ventral surface of the loin or the aged but freshly cut chop face. Nor was early postmortem ventral firmness strongly ($|\bar{r}| \geq 0.68$) or moderately ($|\bar{r}|$ = 0.36 to 0.67) correlated with any traits associated with eating experience (Table 7).

able 7. Correlation coefficients of early (1d) postmortem ventral loin surface subjective firmness with ged loin and chop quality parameters

				5% Confidence interval		
em	Total observations	Number of studies	Rho[1]	ower limit	pper limit	Sampling variance
ged ventral surface						
ghtness, L*	4107	8	-0.16	-0.19	-0.13	0.0018
edness, a*	4107	8	0.01	-0.02	0.04	0.0020
ellowness, b*	4107	8	-0.06	-0.09	-0.03	0.0019
ubjective color	4257	9	0.21	0.18	0.24	0.0019
ubjective marbling	4257	9	0.28	0.25	0.31	0.0018
ubjective firmness	4257	9	0.26	0.23	0.28	0.0019
ged chop face						
ghtness, L*	4354	11	-0.13	-0.16	-0.10	0.0024
edness, a*	4354	11	0.04	0.01	0.07	0.0025
ellowness, b*	4354	11	-0.03	0.00	-0.06	0.0025
ubjective color	4039	9	0.19	0.16	0.22	0.0021
ubjective marbling	4037	9	0.24	0.21	0.27	0.0020
ubjective firmness	3185	7	0.09	0.06	0.13	0.0022
ensory estimates						
strumental tenderness[2]	5220	11	-0.06	-0.09	-0.03	0.0021
ook loss	5220	11	-0.15	-0.18	-0.12	0.0020
ensory tenderness	1552	7	0.12	0.07	0.17	0.0044
ensory juiciness	1552	7	0.08	0.03	0.13	0.0045
ensory flavor	1401	6	0.07	0.02	0.13	0.0043

ample weighted mean correlation

ncludes Warner-Bratzler and slice shear force evaluated chops cooked to 63° C through 71° C.

Early postmortem ultimate pH was moderately correlated with aged ventral lightness ($\bar{r}$ = -0.43), aged ventral yellowness ($\bar{r}$ = 0.-43), aged ventral subjective color ($\bar{r}$ = 0.36), and aged subjective color of the chop face ($\bar{r}$ = 0.36, Table 8). Ultimate pH was not moderately ($|\bar{r}|$ = 0.36 to 0.67) or strongly correlated ($|\bar{r}| \geq 0.68$) to traits associated with eating experience.

able 8. Correlation coefficients of early (1d) postmortem loin ultimate pH values with aged loin and 1op quality parameters

				5% Confidence interval		
em	Total observations	Number of studies	Rho[1]	ower limit	Jpper limit	Sampling variance
ged ventral surface						
ghtness, L*	3739	8	-0.43	-0.45	-0.40	0.0014
edness, a*	3739	8	-0.19	-0.23	-0.16	0.0020
ellowness, b*	3739	8	-0.43	-0.46	-0.40	0.0014
ıbjective color	3889	9	0.36	0.34	0.39	0.0017
ıbjective marbling	3889	9	0.20	0.16	0.23	0.0021
ıbjective firmness	3889	9	0.10	0.07	0.13	0.0023
ged chop face						
ghtness, L*	4155	11	-0.35	-0.37	-0.32	0.0021
edness, a*	4155	11	-0.15	-0.18	-0.12	0.0025
ellowness, b*	4155	11	-0.28	-0.31	-0.25	0.0023
ıbjective color	3840	9	0.36	0.33	0.39	0.0018
ıbjective marbling	3838	9	0.15	0.12	0.19	0.0022
ıbjective firmness	3095	7	-0.01	-0.05	0.03	0.0023
ensory estimates						
strumental tenderness[2]	4855	11	-0.05	-0.08	-0.02	0.0023
ook loss	4855	11	-0.29	-0.32	-0.26	0.0019
ensory tenderness	1398	7	0.21	0.16	0.26	0.0046
ensory juiciness	1398	7	0.12	0.07	0.17	0.0049
ensory flavor	1247	6	0.05	-0.01	0.10	0.0048

ample weighted mean correlation

ncludes Warner-Bratzler and slice shear force evaluated chops cooked to 63° C through 71° C.

Objective 2

Using t-tests to determine the differences between early and aged postmortem traits allows for an estimate of the magnitudes of the changes expected in these traits with aging. Because of the very large sample size used in this study, this t-test analysis indicates statistical differences even with very small changes. Therefore, the magnitude of these changes is likely more useful for interpretation than the statement of statistical significance.

Ventral loin surfaces become 8% lighter ($P < 0.0001$), 44.5% redder ($P < 0.0001$), and 46% more yellow ($P < 0.0001$) during the aging period (Table 9). Visual color also changed during the aging period, but the magnitude of the change was only 0.21 units ($P < 0.0001$). Therefore, it is apparent that color of the ventral surface changes during the postmortem aging period. While the differences represent a substantial change from an instrumental perspective, the visual change in color will likely not influence consumer purchasing decisions as consumers likely will not perceive this small difference. Likewise, visual marbling and subjective firmness scores were statistically different ($P < 0.0001$), but each changed less than a half of one respective NPPC unit. The magnitude of these changes likely will not impact consumer perception between early and aged quality.

able 9. Comparison of early postmortem (1d) ventral loin quality traits with ged (12 - 28d) postmortem ventral loin quality traits of intact boneless pork loins.

		Days postmortem				
em	oins, n	Early	Aged	Difference	SED[2]	*P*-value
ghtness[3], L*	3956	47.55	51.53	-3.99	0.05	< 0.0001
edness[4], a*	3957	6.51	10.24	-3.72	0.05	< 0.0001
ellowness[5], b*	3957	4.78	7.64	-2.86	2.41	< 0.0001
isual color[6]	4259	2.86	3.06	-0.21	0.01	< 0.0001
isual marbling[7]	4253	2.42	2.04	0.38	0.01	< 0.0001
ubjective firmness[8]	4257	2.89	2.63	0.25	0.01	< 0.0001

Early and aged postmortem quality data were compared using a paired-T test on he same loin

Standard error of the difference of the mean

L* measures darkness to lightness (greater L* indicates a lighter color)

a* measures redness (greater a* indicates a redder color)

b* measures yellowness (greater b* indicates a more yellow color)

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

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

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

Objective 3

Using regression analysis is one way to determine the predictive ability of a set of traits for a potential outcome. For this study, eating experience (sensory panel evaluations of tenderness, juiciness and flavor) and factors influencing consumer purchase intent were of most interest. As potential predictors of these traits, quality measures that can easily be evaluated on the fabrication line of commercial processing facilities (e.g. visual color, visual marbling, subjective firmness, and muscle pH) were used. Regression equations for each trait are available on Table 10.

Early postmortem quality measures were only marginally predictive of sensory tenderness (R^2 = 0.13) or juiciness (R^2 = 0.09). In other words, even when the model could include all 5 of these measures, less than 13% of the variability in tenderness and juiciness could be explained. The combination of color, marbling, firmness, and pH were moderately predictive (R^2 = 0.28) of sensory flavor (Table 10). On the other hand, early postmortem pork quality traits were predictive of traits associated with purchasing intent (e.g. aged chop color and aged chop marbling). The combination of the color, marbling, firmness, pH and extractable lipid were moderately predictive (R^2 = 0.26) and aged chop marbling (R^2 = 0.28) when chemical extractable lipid was not included as a candidate predictor variable. Including chemical extractable lipid along with early color, marbling, firmness, and pH was highly predictive (R^2 = 0.52) of aged chop marbling. The discrepancy in predictive ability of aged chop marbling by including or excluding extractable lipid is likely due to the skill level of the technician evaluating visual marbling as extractable lipid is the more objective measure.

able 10. Stepwise regression predicting traits associated with eating experience and purchasing intent (dependent variables) using non-vasive early postmortem ventral surface loin traits (independent variables)

			Independent Variables - Partial R^2					
ependent variable (trait)	Regression equation[1]	odel R^2	Extractable lipid	pH	Firmness	Color	Marbling	Model *P*-value
ating experience								
enderness	= -5.61 + 0.37a + 2.13b + 0.29c + 15d	0.13	0.07	0.05	0.02	0.00		< 0.0001
iciness	= -0.61 + 0.22a + 1.20b + 0.16c + 16e + 0.15d	0.09	0.05	0.02	0.01	0.00	0.01	< 0.0001
avor	= 22.00 - 2.70b + 1.04e - 0.83a - 99d + 0.20c	0.28	0.09	0.07	0.00	0.05	0.06	< 0.0001
rchasing intent								
ged chop color	= -0.67 + 0.34d + 0.46b + 0.07c + 06e - 0.04a	0.26	-0.04	0.46	0.07	0.34	0.06	< 0.0001
ged chop marbling	= -1.46 + 0.40a + 0.16e + 0.10d + 29b + 0.05c	0.52	0.46	0.00	0.00	0.01	0.04	< 0.0001
ged chop marbling[2]	= -0.46 + 0.34e + 0.13c + 0.24 - 04	0.28		0.24	0.13	-0.04	0.34	< 0.0001

= extractable lipid, b = ultimate pH, c = ventral firmness, d = ventral color, e = ventral marbling

rediction of chop marbling without extractable lipid included as a candidate variable

II. Discussion:

From these results, the following conclusions can be drawn.

1) Individual early postmortem traits are moderately correlated with aged postmortem quality traits. Therefore, color and marbling observed early postmortem is related to those same traits observed after aging. But these correlations are moderate at best. Therefore, it is possible that a loin designated "high quality" at the time of quality evaluation in the plant may not necessarily appear "high quality" to a consumer.

2.) Loin color becomes lighter and redder with age, but these changes are not drastic enough that consumers would perceive a difference between early and aged loins. Therefore, it is likely that color observed at plants at the time of quality assessment would be similar to that observed by consumers. Additionally, observations of marbling were greater at early postmortem times than after aging, but the magnitude of this difference was less than 0.5 marbling scores.

3.) Early postmortem quality measurements were only marginally predictive of eating quality on pork loin chops. The regression model including extractable lipid, pH and firmness explained only 13% of the variability in sensory evaluations of tenderness. Early postmortem quality traits could predict 28% of the variability in flavor.

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