Relationships among early postmortem loin quality and aged loin and pork chop quality characteristics between barrows and gilts

J. E. Lowell,* M. F. Overholt,* B. N. Harsh,* C. A. Stahl,† A. C. Dilger,* and D. D. Boler*[1]

*Department of Animal Sciences, University of Illinois, Urbana-Champaign,
61801 and †Choice Genetics USA, West Des Moines, IA 50266

ABSTRACT: Rapid assessment of pork quality by packers necessitates using early postmortem (~1 d) traits as an indication of aged pork quality (~14 d). Efforts have been made to develop a grading system based on color and marbling of the ventral side of boneless loins. In order for this system to be successful, there must be a correlation between early postmortem quality traits observed by packers and the same traits observed by consumers after aging. However, the strength and direction of those correlations are unclear. It is also unknown if the correlations between early and aged postmortem quality differ between barrows (B) and gilts (G). Therefore, the objectives were to determine correlations between early postmortem loin quality characteristics and aged loin quality characteristics, and determine if those correlations differed between barrows and gilts. Early postmortem (~1 d) quality traits included: instrumental and subjective color, marbling and firmness, and loin pH on the ventral surface of the loin. Loins were aged until 14 d postmortem in vacuum packages. Aged quality traits included traits evaluated early as well as shear force and cook loss. Correlations were compared between barrows and gilts using a Fisher's z test. Overall, early subjective firmness scores of barrows were greater ($P < 0.001$) than those of gilts. No other early quality traits differed between sexes. Early pH was correlated with aged pH ($r = 0.80$ B; 0.75 G), ventral lightness ($r = -0.57$ B; -0.54 G), ventral yellowness ($r = -0.55$ B; -0.55 G), subjective ventral color ($r = 0.55$, B; 0.41 G), and subjective chop color ($r = 0.42$ B; 0.44 G). Correlations of early pH and aged quality did not differ between sexes. Early lightness was correlated with aged ventral pH ($r = -0.56$) and subjective color ($r = -0.39$) in barrows but not gilts ($P \leq 0.04$). Early lightness was correlated with aged lightness ($r = 0.60$ B; 0.51 G) and yellowness ($r = 0.49$ B; 0.55 G), but was not correlated with to any aged chop quality traits. Early marbling was correlated with ventral color ($r = 0.42$) in barrows and ventral marbling ($r = 0.67$ B; 0.66 G) and chop marbling ($r = 0.57$ B; 0.59 G) in barrows and gilts. In summary, early pH and lightness were correlated with aged quality characteristics and correlations rarely differed between barrows and gilts. Sex does not need to be accounted for when relating early and aged quality characteristics.

Key words: aged loin quality, correlation, loin quality, pork, quality

INTRODUCTION

Rapid assessment of pork quality by packers necessitates the use of early postmortem (~ 1 d) traits as an indication of aged pork quality (~ 14 d) and eating experience (Lonergan et al., 2017; Shackelford et al., 2017). Color and marbling are loin quality traits most influential to consumer purchasing decisions (Moeller et al., 2010) and influence the palatability of pork (Huff-Lonergan et al., 2002). The National Pork Board and USDA are developing a grading system based on color and marbling on the ventral side of boneless loins at 1d postmortem (Lusk et al., 2017). For this system to be successful, a strong correlation between early postmortem color and marbling traits observed by packers and the same traits observed by consumers after a period of aging must exist. However, the strengths of those relationships are unclear.

Furthermore, the relationships of early and aged quality traits of pork loins may be influenced by other factors including aging environment (temperature, packaging, length of aging) and traits inherent to the

pigs or loins themselves (diet, management practices, sex of pigs, pH of loins). Therefore, before general conclusions can be made about relationships between early and aged quality measurements, the influence of these external factors must be established. In particular, it is imperative to compare these relationships between barrows and gilts, as each represents about half of the pigs slaughtered. Differences in quality traits between barrows and gilts have long been recognized (Martel et al., 1988), and recently variability differences of quality traits were identified between sexes (Overholt et al., 2016). It is possible differences in relationships among early and aged loin quality traits also exist.

Therefore, the objectives were to determine correlations between early postmortem loin quality characteristics and aged loin and chop quality characteristics, and determine if those correlations differ between barrows and gilts.

MATERIALS AND METHODS

Pig Background

Pigs were slaughtered at a federally inspected abattoir under the supervision of the USDA Food Safety and Inspection Service. Loins were obtained from that facility therefore, no Institutional Animal Care and Use Committee approval was needed. Pigs (328 total) were sourced from a single genetic line and were raised under the same commercial conditions. Each pig was tattooed on the ham with a unique number prior to transportation to the abattoir. Pigs were transported approximately 195 km and held in lairage for a minimum of 3 h prior to slaughter. Pigs were immobilized via carbon dioxide gas and terminated by exsanguination. A sequential identification number was written on the shoulder of each carcass with a crayon after evisceration. At the same time, the individual tattoo was recorded so that it could be matched with the sequential number written on the shoulder. Hot carcass weight was recorded immediately before each carcass entered a blast chiller. Following the approximately 90 min blast-chill, carcasses were transferred to an equilibration cooler, where they remained for approximately 20 h until fabrication. Early and aged loin quality evaluations were collected on 133 barrow carcasses and 195 gilt carcasses slaughtered on 3 different days (d 1 = 103 pigs, d 2 pigs = 168, d 3 = 57 pigs).

Abattoir Data Collection

While in the carcass cooler, back-fat thickness was determined by measuring the midline fat thickness at the 10th rib. As carcasses moved out of the carcass cooler just prior to fabrication they were weighed again to determine chilled carcass weight. Cooler shrink (%) was calculated using the following equation:

$$\text{Cooler shrink (\%)} = [(\text{HCW, kg} - \text{Chilled carcass weight, kg}) / \text{HCW, kg}] \times 100$$

Identification buttons (Volk Enterprises, Turlock, CA), corresponding to the sequential identification number written on the shoulder of the carcasses, were placed into Canadian back loins (NAMP #414, NAMI, 2014) after fabrication. Loins were vacuum packaged and placed in boxes. Loins were transported on ice, in coolers, approximately 32 km to the University of Illinois Meat Science Laboratory (Urbana, IL).

Early Postmortem Pork Quality Evaluation

Immediately on arrival to the University of Illinois, boneless loins were removed from the packaging and weighed. Oxygenation of the loins was allowed to occur for at least 20 min before quality evaluations took place. After oxygenation, quality measurements for instrumental lightness (L*), redness (a*), yellowness (b*; CIE, 1978), subjective color (NPPC, 1999), subjective marbling (NPPC, 1999), subjective firmness (NPPC, 1991), and early postmortem ultimate pH was collected on the ventral surface of the boneless loins by trained University of Illinois personnel. Instrumental color was measured with a Minolta CR-400 Chroma meter (Minolta Camera Co., Ltd., Osaka, Japan) using a D65 illuminant, an 8 mm aperture, and calibrated using a white tile. Subjective color and marbling scores (NPPC, 1999), and firmness scores (NPPC, 1991) were determined by a single individual. Ultimate pH (~22 to 24 h postmortem) was measured using a handheld MPI pH meter fitted with a glass electrode (MPI pH-Meter, Topeka, KS; 2-point calibration; pH 4 and pH 7). After 1d postmortem quality measures were complete, loins were vacuum packaged and aged for 13 d at 4°C.

Aged Postmortem Pork Quality Evaluation

Loin and Chop Quality. At 14 d postmortem, loins were removed from the packaging, allowed to drip for approximately 20 min, and weighed again. Purge loss (%) was calculated using the following equation: *Purge Loss, % = [(1 d weight, kg – 14 d weight, kg) / 1 d weight, kg] × 100.*

Loins were exposed to oxygen (fat side against the table and lean side up) for at least 20 min and then quality measurements for instrumental color, subjective color, subjective marbling, subjective firmness, and aged ultimate pH were conducted on the ventral surface of the loins, using the same procedures as the 1 d postmor-

tem quality evaluations. Brewer et al. (2001) reported that time of oxygen exposure from 0 min through 30 min had no effect on instrumental L*. Instrumental a* values did not change after 10 min of oxygen exposure. Thus, 20 min was sufficient to allow for appropriate oxygenation of myoglobin. Ambient room temperature during evaluations was approximately 4°C.

After quality evaluations were completed on the ventral surface of the loins, they were sliced into 2.54 cm thick chops using a push-feed style Treif Puma slicer (Treif model 700 F; Treif, Oberlahr, Germany). Three chops were collected from each loin for further evaluation. The first chop collected was the first chop completely posterior to the spinalis dorsi. Chops 2 and 3 were collected immediately posterior to chop 1. Chops 1 and 3 were exposed to oxygen for at least 20 min before evaluation. Then, instrumental lightness (L*), redness (a*), and yellowness (b*) were measured at 2 locations on the cut surface of both chops 1 and 3 for a total of four instrumental color measurements per experimental unit (loin). The 4 measurements for L*, a*, and b* were then averaged, and the average of the 4 measurements was reported as instrumental color. Subjective color measures (NPPC, 1999) were evaluated on the cut surface of chops 1 and 3, by a single individual, and the average of the 2 subjective color values was reported as subjective color. Chops 1 and 3 were then vacuum packaged and stored at –2°C until they were used to determine cook loss (%) and Warner-Bratzler shear force (WBSF). Chop 2 was evaluated for subjective marbling (NPPC, 1999) and then packaged in Whirl-Pak bags (Nasco, Ft. Atkinson, WI) and stored at –2°C until determination of moisture and extractable lipid.

Cook Loss and Warner-Bratzler Shear Force

Chops 1 and 3 from each loin were removed from frozen storage at least 24 h prior to analysis and allowed to thaw thoroughly at 4°C. Chops were individually weighed and then cooked on a Farberware Open Hearth grill (model 455N, Walter Kidde, New York, NY) on 1 side to an internal temperature of 34°C, flipped, and then cooked until they reached an internal temperature of 68°C, at which point they were removed from the grill. During cooking, internal temperature was monitored using copper-constantan thermocouples (Type T, Omega Engineering, Stamford, CT) placed in the geometrical center of each chop and connected to a digital scanning thermometer (model 92000–00, Barnat Co., Barrington, IL). Chops were cooled to approximately 25°C, and weighed again to determine cook loss percentage. Three 1.25 cm diameter cores from each chop were removed parallel to the orientation of the muscle fibers and sheared using a Texture Analyzer TA.HD Plus (Texture

Technologies Corp., Scarsdale, NY/Stable Mirosystems, Godalming, UK) with a blade speed of 3.33 mm/s and a load cell capacity of 100 kg. Warner-Bratzler shear force values from 3 cores from chop 1 and 3 cores from chop 3, for a total of 6 cores, were averaged to determine a single WBSF value for each experimental unit (loin).

Proximate Composition

Chops stored for moisture and extractable lipid determination were allowed to partially thaw at 25°C, taking care to prevent loss of exudate. Chops were prepared for evaluation by trimming all subcutaneous fat and secondary muscles before homogenizing in a Cuisinart (East Windsor, NJ) food processor. Any exudate from the package was added to the meat prior to homogenization. Samples were blended for approximately 90 s in the mixer until they were visually homogenized. Moisture was determined by drying duplicate 10-g samples from each loin chop in a drying oven set to 110°C for at least 24 h. Extractable lipid content was determined using the chloroform-methanol solvent method described by Novakofski et al. (1989).

Statistical Analyses

Because early and late quality evaluations were compared within a loin from the same pig, pig served as the experimental unit for all statistical analyses. Carcass and loin quality characteristics from barrows and gilts were compared using a 1-way ANOVA in the MIXED procedure of SAS 9.4 (SAS Inst. Inc., Cary, NC). The model included the fixed effect of sex and the random effect of slaughter date. Differences in quality traits between barrow and gilts were considered different at $P \le 0.05$.

Comparisons of independent correlation coefficients between barrows and gilts were achieved following the example of Kenny (1987) using a z-test for comparing 2 independent correlations. First, data were grouped into two individual data sets by sex (barrows and gilts). For each of these 2 datasets, Pearson correlation coefficients were calculated and transformed using the Fisher's r to z transformation with the FISHER option of the CORR procedure in SAS. The Fisher's r to z transformation was defined as:

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

and used to ensure the transformed coefficients were nearly normally distributed and to make the variance of correlations approximately the same regardless of the value of the population correlation (Kenny, 1987). Where r is the Pearson correlation coefficient and z is the trans-

formed value of the correlation coefficient. If the z value is statistically significant, then the correlations between the 2 populations (barrows and gilts) differ (Kenny, 1987). Correlations were considered weak (in absolute value) at $r < 0.35$, correlations were considered moderate at $0.36 \geq r < 0.67$, and strong correlations were those $r \geq 0.68$ (Taylor, 1990). Next, Fisher's transformed z values were merged into a single data set and compared using the equation:

$$z = \frac{z_{barrows} - z_{gilts}}{\sqrt{\dfrac{1}{n_{barrows} - 3} + \dfrac{1}{n_{gilts} - 3}}}$$

Taylor (1990) cautions that correlation coefficients of 0.20 in data sets with more than 100 observations, like in this data set, can be statistically different from 0 ($\alpha = 0.05$), but have little practical importance. Therefore, differences in relationships of early and aged postmortem loin quality between barrows and gilts were considered different at $P \leq 0.05$ but must have had a correlation coefficient of $|r| \geq 0.36$ to be discussed as practically relevant.

Correlation coefficients differed between barrows and gilts on 4 occasions. In each of those occasions, independent slopes for barrows and gilts were compared

using the REG procedure in SAS by independently calculating the slopes and mean squared error of each sex. Then using the standard error of the difference between the 2 slopes, slopes were compared to confirm differences in relationships between barrows and gilts.

RESULTS

Difference between Barrows and Gilts for Early and Late Postmortem Quality Characteristics

Mean differences between barrows and gilts were expected. Barrows were heavier and fatter than gilts ($P \leq 0.01$, Table 1), but had loins that were lighter as a percentage of HCW ($P \leq 0.0001$). Early postmortem loin subjective firmness was greater ($P \leq 0.001$) for loins from barrows compared with those from gilts (Table 1). There were no differences ($P \geq 0.06$) for any other early postmortem loin quality traits between barrows and gilts. Aged ventral subjective marbling ($P = 0.02$), ultimate pH ($P = 0.04$), and percent purge ($P \leq 0.01$) were greater in loins from barrows compared with loins from gilts (Table 2). There were no differences ($P \geq 0.35$) for any other aged ventral loin quality traits between barrows and gilts. Aged loin chop subjective color ($P = 0.04$), subjective marbling ($P \leq 0.0001$), and extract-

Table 1. Carcass characteristics and early postmortem meat quality traits of barrows and gilts collected on the ventral side of the longissimus muscle

	Sex			
Item	Barrows	Gilts	SEM	P-value
Pigs, n	133	195		
Carcass characteristics				
Ending live wt, kg	133.54	131.42	1.55	0.01
Hot carcass wt, kg	101.88	100.58	1.03	0.06
Carcass yield, %	76.22	76.53	1.06	0.30
Chilled carcass wt, kg	100.25	99.00	1.07	0.07
Cooler shrink[1], %	1.48	1.52	0.15	0.84
Last rib midline fat thickness, cm	2.88	2.59	0.16	< 0.0001
Canadian back loin (NAMP #414) wt, kg	3.62	3.85	0.07	< 0.0001
% chilled carcass wt	7.23	7.79	0.08	< 0.0001
Early postmortem ventral quality traits				
Instrumental color[2]				
Lightness, L*	46.91	46.09	0.94	0.09
Redness, a*	8.88	8.90	0.78	0.92
Yellowness, b*	0.41	0.09	0.70	0.06
Subjective evaluations				
Color score	3.61	3.67	0.34	0.15
Marbling score	2.46	2.32	0.17	0.06
Firmness score	3.40	3.19	0.20	< 0.001
Loin pH[3]	5.62	5.59	0.02	0.06

[1]Cooler shrink = [(HCW − chilled carcass wt, kg) / HCW] × 100.

[2]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).

[3]Loin pH was measured on the ventral surface of the boneless loins at the area of the 10th rib.

Table 2. Aged postmortem (14 d) meat quality traits of barrows and gilts collected on the ventral side or chop face of the longissimus muscle

Item	Sex			
	Barrows	Gilts	SEM	P-value
Pigs, n	133	195		
Ventral				
Instrumental color[1]				
Lightness, L*	50.29	50.01	0.26	0.41
Redness, a*	8.48	8.59	0.16	0.41
Yellowness, b*	3.25	3.18	0.21	0.64
Subjective evaluations				
Color score	3.39	3.38	0.19	0.80
Marbling score	2.57	2.40	0.22	0.02
Firmness score	3.24	3.29	0.17	0.35
Ultimate pH	5.72	5.70	0.03	0.04
Purge loss[2], %	4.11	3.35	0.62	< 0.01
Chop				
Instrumental color[1]				
Lightness, L*	51.28	51.02	0.37	0.32
Redness, a*	8.86	8.89	0.22	0.74
Yellowness, b*	4.10	3.98	0.15	0.26
Subjective evaluations				
Color score	3.53	3.45	0.24	0.04
Marbling score	2.55	2.16	0.26	< 0.0001
Moisture, %	73.91	74.17	0.31	0.04
Extractable lipid, %	2.71	2.31	0.20	< 0.01
Warner-Bratzler shear force, kg	2.27	2.29	0.05	0.49
Cook loss, %	19.31	19.20	0.83	0.66

[1]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).

[2]Purge loss = [(1 d weight, kg – 14 d weight, kg) / 1 d weight, kg] ×100.

able lipid percentage ($P \leq 0.01$) was greater in loin chops from barrows compared with loin chops from gilts. Moisture percentage was less ($P = 0.04$) in chops from barrows compared with chops from gilts. There were no differences in any other aged loin chop quality characteristics between barrows and gilts.

Comparison of Barrow and Gilt Correlation Coefficients between Early Postmortem and Aged Quality Traits

Kenny (1987) cautions that it is inappropriate to conclude correlations statistically differ between 2 treatment groups when the independent correlation of 1 treatment group is different from 0 and the other independent correlation may or not be different from 0. One must explicitly test whether the 2 correlations differ and not rely on the significance tests of the correlations calculated individually (Kenny, 1987). One caveat with the interpretation of a correlation is that it does not provide any information as to why relationships may differ between barrows and gilts. Early loin pH was correlated with aged pH ($r = 0.80$ barrows; 0.75 gilts), ventral lightness ($r = -0.57$ barrows; –0.54 gilts), ventral yellowness ($r = -0.55$ barrows; –0.55 gilts), subjective ventral color ($r = 0.55$, barrows; 0.41 gilts), and subjective chop color ($r = 0.42$ barrows; 0.44 gilts; Table 3). Early loin pH was not related to ventral redness, ventral marbling, ventral firmness, chop lightness, chop redness, chop yellowness, or chop marbling (Table 3). Correlation coefficients with

Table 3. Comparison of Fisher's r to z transformed correlation coefficients comparisons (rho) of early postmortem loin pH values with aged loin quality and chop quality of barrows and gilts[1,2]

Aged postmortem variable	Barrow pH			Gilt pH			
		95% Confidence limit			95% Confidence limit		
	Rho	Lower	Upper	Rho	Lower	Upper	P-value[3]
Loin							
Loin pH	0.80	0.72	0.85	0.75	0.69	0.81	0.38
Ventral lightness, L*	–0.57	–0.68	–0.44	–0.54	–0.63	–0.43	0.67
Ventral redness, a*	–0.23	–0.39	–0.06	–0.28	–0.41	–0.14	0.65
Ventral yellowness, b*	–0.55	–0.66	–0.41	–0.55	–0.64	–0.44	0.96
Ventral color	0.55	0.41	0.66	0.41	0.28	0.52	0.11
Ventral marbling	0.29	0.12	0.45	0.30	0.16	0.42	0.99
Ventral firmness	0.11	–0.06	0.28	0.06	–0.09	0.20	0.62
Chop							
Lightness, L*	0.10	–0.09	0.27	0.08	–0.07	0.22	0.88
Redness, a*	0.16	–0.02	0.33	0.09	–0.06	0.23	0.53
Yellowness, b*	0.12	–0.06	0.30	0.12	–0.03	0.26	0.97
Color	0.42	0.26	0.56	0.44	0.31	0.55	0.88
Marbling	0.17	–0.01	0.34	0.31	0.17	0.44	0.19

[1]Early postmortem traits were evaluated 1 d postmortem.

[2]Aged postmortem traits were evaluated 14 d postmortem.

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts.

early pH and aged quality traits did not differ between barrows and gilts for any quality trait (Table 3).

Early Postmortem Ventral Instrumental Lightness (L*). Early lightness was correlated with aged ventral pH ($r = -0.56$) and subjective color ($r = -0.39$) in barrows but not gilts ($P \leq 0.04$; Table 4). Early lightness was correlated with aged lightness ($r = 0.60$ barrows; 0.51 gilts) and yellowness ($r = 0.49$ barrows; $r = 0.55$ gilts) in both barrows and gilts. Early ventral lightness was not correlated to aged ventral redness, subjective marbling, or firmness, nor was it correlated with any instrumental or subjective color trait on the chop face. Early ventral lightness was also not correlated with chop marbling (Table 4). Correlation coefficients did not differ for early instrumental lightness and aged quality traits between barrows and gilts except for aged pH (Fig. 1). Even so, independent slopes of prediction lines between barrows ($\beta_1 = -0.016$) and gilts ($\beta_1 = -0.008$) for instrumental lightness and aged pH did not differ ($P = 0.10$). On the other hand, independent slopes of prediction lines between barrows ($\beta_1 = -0.067$) and gilts ($\beta_1 = -0.010$) for early instrumental lightness and subjective color were different ($P = 0.02$, Fig. 2).

Table 4. Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem instrumental lightness (L*) values with aged loin quality and chop quality of barrows and gilts[1,2]

| | Barrow L* | | | Gilt L* | | | |
| | | 95% Confidence limit | | | 95% Confidence limit | | |
Aged postmortem variable	Rho	Lower	Upper	Rho	Lower	Upper	P-value[3]
Loin							
Loin pH	−0.56	−0.70	−0.37	−0.25	−0.44	−0.05	0.02
Ventral lightness, L*	0.60	0.42	0.73	0.51	0.33	0.65	0.43
Ventral redness, a*	−0.25	−0.46	−0.02	−0.01	−0.22	0.20	0.13
Ventral yellowness, b*	0.49	0.29	0.65	0.55	0.39	0.68	0.59
Ventral color	−0.39	−0.57	−0.17	−0.08	−0.28	0.13	0.04
Ventral marbling	−0.06	−0.29	0.18	0.14	−0.08	0.34	0.22
Ventral firmness	−0.02	−0.25	0.21	0.24	0.03	0.43	0.10
Chop							
Lightness, L*	0.03	−0.21	0.26	0.06	−0.15	0.27	0.84
Redness, a*	0.04	−0.20	0.27	−0.03	−0.24	0.18	0.66
Yellowness, b*	0.07	−0.17	0.30	−0.04	−0.25	0.17	0.49
Color	−0.24	−0.45	−0.01	0.05	−0.16	0.26	0.07
Marbling	0.24	0.00	0.45	0.13	−0.08	0.33	0.49

[1]Early postmortem traits were evaluated 1 d postmortem.

[2]Aged postmortem traits were evaluated 14 d postmortem.

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts.
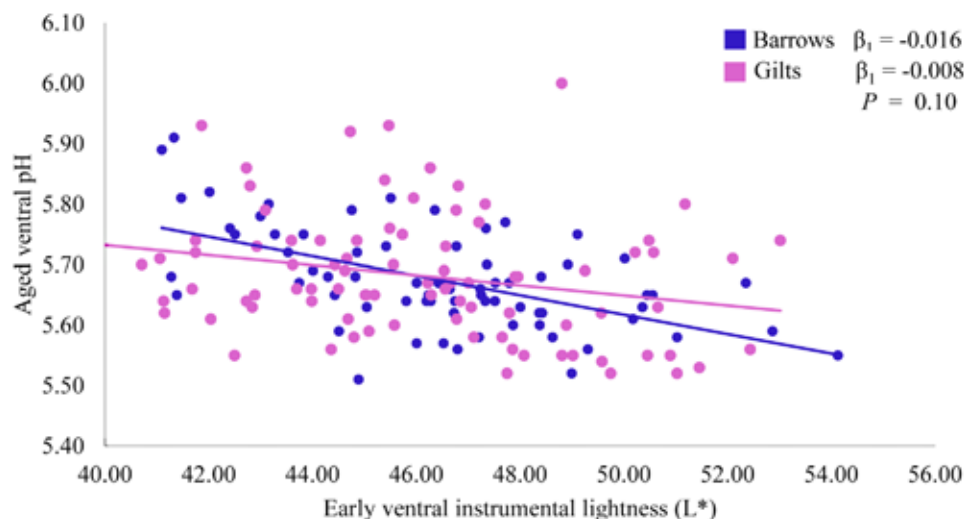

Figure 1. Differences correlation coefficients between early postmortem (1 d) ventral instrumental lightness (L*) and aged (14 d) loin pH of barrows and gilts. Probability values compare slopes (β_1) of the regression lines between barrows and gilts.

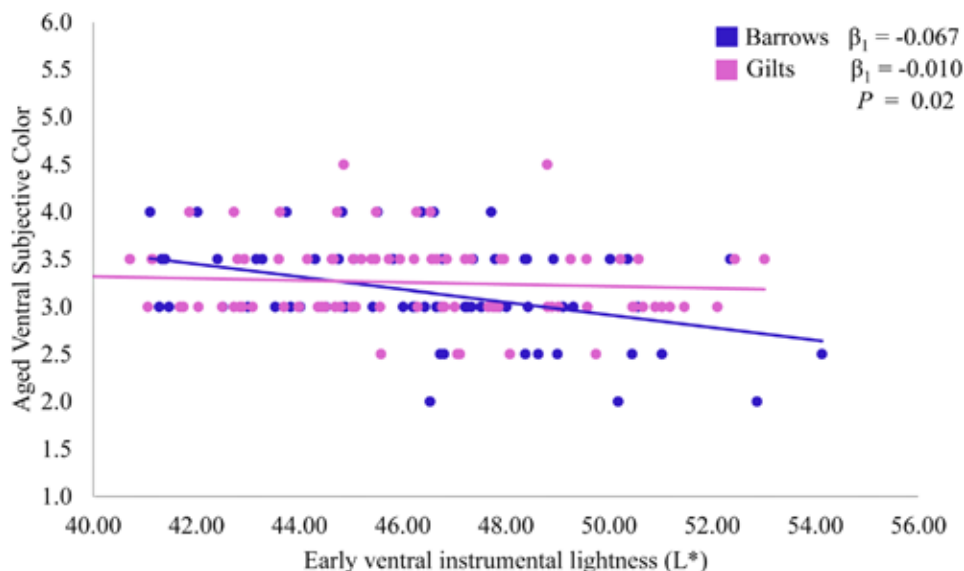Translate basic science to industry innovation

Figure 2. Differences in correlation coefficients between early postmortem (1 d) ventral instrumental lightness (L*) and aged (14 d) ventral subjective color scores of barrows and gilts. Probability values compare slopes (β_1) of the regression lines between barrows and gilts.

Early Postmortem Ventral Instrumental Redness (a*) and Yellowness (b*). Early redness was correlated with ventral color ($r = 0.44$ barrows; 0.51 gilts) and chop color ($r = 0.62$ barrows; 0.41 gilts) in barrows and gilts and ventral firmness ($r = 0.39$) in barrows (Table 5). However, correlation coefficients of early redness and aged quality traits did not differ between barrows and gilts for any quality trait (Table 5).

Early instrumental yellowness was correlated with ventral color ($r = –0.61$) and chop color ($r = –0.51$) in barrows and aged ventral pH ($r = –0.47$ barrows; –0.60 gilts) in barrows and gilts (Table 6). Correlation coefficients with early yellowness and aged quality traits did not differ between barrows and gilts for any quality trait (Table 6).

Early Postmortem Ventral Subjective Color. Early subjective color was not correlated with any aged quality traits (Table 7). The correlation coefficients between early subjective color and ventral redness differed ($P = 0.04$) between barrows and gilts where the correla-

Table 5. Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem instrumental redness (a*) values with aged loin quality and chop quality of barrows and gilts[1,2]

Aged postmortem variable	Barrow a*			Gilt a*			
		95% Confidence limit			95% Confidence limit		
	Rho	Lower	Upper	Rho	Lower	Upper	P-value[3]
Loin							
Loin pH	0.03	–0.21	0.26	0.19	–0.02	0.39	0.31
Ventral lightness, L*	–0.14	–0.36	0.10	–0.06	–0.27	0.15	0.64
Ventral redness, a*	0.17	–0.07	0.39	0.18	–0.03	0.38	0.92
Ventral yellowness, b*	0.18	–0.06	0.40	0.26	0.05	0.45	0.61
Ventral color	0.44	0.22	0.61	0.51	0.34	0.65	0.56
Ventral marbling	0.22	–0.01	0.44	0.34	0.15	0.52	0.42
Ventral firmness	0.39	0.17	0.57	0.29	0.08	0.47	0.50
Chop							
Lightness, L*	0.03	–0.20	0.27	–0.15	–0.35	0.06	0.25
Redness, a*	0.12	–0.11	0.35	0.38	0.19	0.55	0.09
Yellowness, b*	0.09	–0.14	0.32	0.08	–0.13	0.28	0.92
Color	0.62	0.44	0.74	0.49	0.31	0.64	0.27
Marbling	0.33	0.11	0.53	0.40	0.21	0.56	0.65

[1]Early postmortem traits were evaluated 1 d postmortem.

[2]Aged postmortem traits were evaluated 14 d postmortem.

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts.

Table 6. Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem instrumental yellowness (b*) values with aged loin quality and chop quality of barrows and gilts[1,2]

| Aged postmortem variable | Barrow b* | | | Gilt b* | | | |
| | Rho | 95% Confidence limit | | Rho | 95% Confidence limit | | P-value[3] |
		Lower	Upper		Lower	Upper	
Loin							
Loin pH	−0.47	−0.64	−0.27	−0.60	−0.72	−0.44	0.29
Ventral lightness, L*	0.36	0.14	0.55	0.42	0.23	0.58	0.68
Ventral redness, a*	0.05	−0.19	0.28	0.31	0.11	0.49	0.09
Ventral yellowness, b*	0.10	−0.14	0.33	0.36	0.17	0.53	0.09
Ventral color	−0.61	−0.74	−0.43	−0.45	−0.60	−0.27	0.19
Ventral marbling	−0.23	−0.44	0.01	−0.31	−0.49	−0.11	0.58
Ventral firmness	−0.24	−0.45	−0.01	−0.22	−0.41	−0.01	0.90
Chop							
Lightness, L*	−0.08	−0.31	0.16	−0.11	−0.31	0.10	0.87
Redness, a*	−0.13	−0.35	0.11	−0.22	−0.41	−0.01	0.56
Yellowness, b*	−0.09	−0.32	0.15	−0.23	−0.42	−0.03	0.35
Color	−0.51	−0.67	−0.32	−0.53	−0.67	−0.36	0.87
Marbling	−0.17	−0.39	0.07	−0.31	−0.49	−0.10	0.37

[1]Early postmortem traits were evaluated 1 d postmortem.

[2]Aged postmortem traits were evaluated 14 d postmortem.

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts.

Table 7. Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem subjective color values with aged loin quality and chop quality of barrows and gilts[1,2]

| Aged postmortem variable | Barrow color | | | Gilt color | | | |
| | Rho | 95% Confidence limit | | Rho | 95% Confidence limit | | P-value[3] |
		Lower	Upper		Lower	Upper	
Loin							
Loin pH	−0.04	−0.21	0.14	0.06	−0.08	0.20	0.40
Ventral lightness, L*	−0.23	−0.39	−0.06	−0.28	−0.41	−0.15	0.61
Ventral redness, a*	0.28	0.11	0.43	0.05	−0.10	0.19	0.04
Ventral yellowness, b*	−0.03	−0.21	0.15	−0.20	−0.34	−0.06	0.13
Ventral color	0.15	−0.03	0.31	−0.02	−0.16	0.13	0.16
Ventral marbling	−0.04	−0.22	0.14	0.10	−0.04	0.24	0.22
Ventral firmness	−0.14	−0.31	0.03	0.06	−0.09	0.19	0.09
Chop							
Lightness, L*	−0.04	−0.22	0.14	−0.14	−0.28	0.01	0.41
Redness, a*	−0.12	−0.30	0.06	0.02	−0.13	0.17	0.22
Yellowness, b*	−0.06	−0.23	0.13	0.02	−0.13	0.16	0.56
Color	0.13	−0.05	0.30	0.11	−0.04	0.25	0.87
Marbling	−0.12	−0.29	0.06	−0.03	−0.18	0.12	0.46

[1]Early postmortem traits were evaluated 1 d postmortem.

[2]Aged postmortem traits were evaluated 14 d postmortem.

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts.

tions in barrows was different from 0 (95% CI range = 0.11 to 0.43) but was not different from 0 in gilts (95% CI range = −0.10 to 0.19). This was supported by independent slopes of prediction lines between barrows ($\beta_1 = 0.516$) and gilts ($\beta_1 = 0.085$) for early postmortem ventral subjective color and aged ventral instrumental redness values were different ($P = 0.04$, Fig. 3).

Early Postmortem Ventral Subjective Marbling. Early subjective marbling was correlated with aged ventral marbling ($r = 0.67$ barrows; $r = 0.66$ gilts) and chop marbling ($r = 0.57$ barrows; 0.59 gilts) in barrows and gilts and aged ventral color ($r = 0.42$) and aged chop color ($r = 0.37$) in barrows (Table 8). Correlation coefficients of early marbling and aged
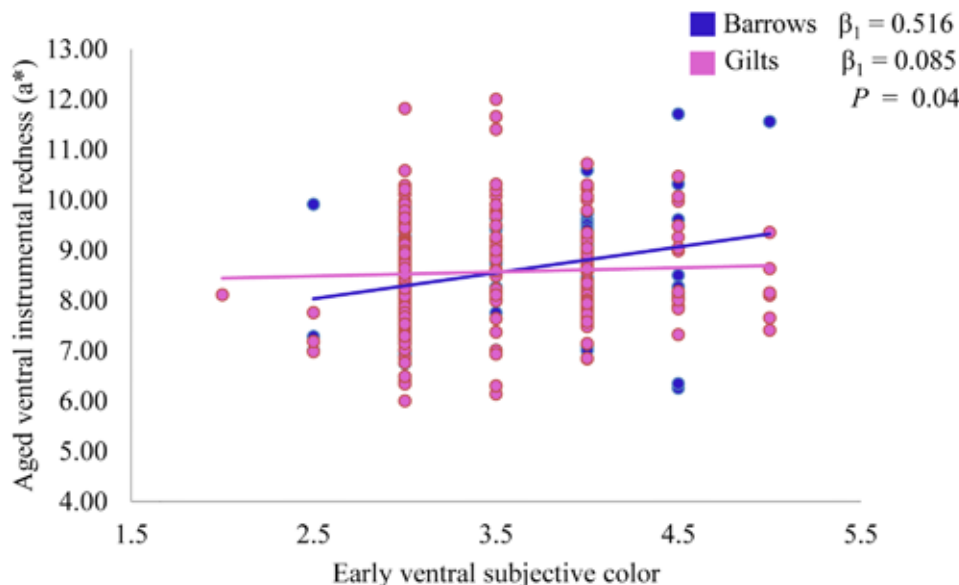
Figure 3. Differences correlation coefficients between early postmortem (1 d) subjective color scores and aged (14 d) ventral instrumental redness (a*) of barrows and gilts. Probability values compare slopes (β_1) of the regression lines between barrows and gilts.

Table 8. Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem subjective marbling values with aged loin quality and chop quality of barrows and gilts[1,2]

| | Barrow marbling | | | Gilt marbling | | | |
| | | 95% Confidence limit | | | 95% Confidence limit | | |
Aged postmortem variable	Rho	Lower	Upper	Rho	Lower	Upper	P-value[3]
Loin							
Loin pH	0.35	0.19	0.50	0.24	0.10	0.37	0.29
Ventral lightness, L*	−0.15	−0.32	0.03	−0.13	−0.26	0.02	0.85
Ventral redness, a*	0.01	−0.17	0.18	0.02	−0.12	0.16	0.92
Ventral yellowness, b*	−0.03	−0.20	0.15	−0.06	−0.20	0.08	0.74
Ventral color	0.42	0.27	0.56	0.30	0.16	0.42	0.21
Ventral marbling	0.67	0.56	0.75	0.66	0.57	0.73	0.86
Ventral firmness	0.08	−0.10	0.25	0.26	0.13	0.39	0.10
Chop							
Lightness, L*	0.16	−0.02	0.34	0.06	−0.09	0.20	0.36
Redness, a*	0.06	−0.12	0.24	0.25	0.11	0.39	0.09
Yellowness, b*	0.03	−0.15	0.21	0.16	0.02	0.31	0.27
Color	0.37	0.21	0.52	0.30	0.16	0.42	0.45
Marbling	0.57	0.43	0.68	0.59	0.48	0.67	0.83

[1]Early postmortem traits were evaluated 1 d postmortem.

[2]Aged postmortem traits were evaluated 14 d postmortem.

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts.

quality traits did not differ between barrows and gilts for any quality trait (Table 8).

Early Postmortem Quality Traits and Warner-Bratzler Shear Force and Cook Loss. No early postmortem quality traits were correlated with WBSF or cook loss in barrows (Table 9). Early loin pH (r = –0.41) and ventral yellowness (r = 0.45) were correlated with cook loss in gilts. The correlation coefficients between early postmortem ventral firmness and WBSF differed (P = 0.04) between barrows and gilts (Table 9). Ventral firmness was weakly (r = 0.18) but positively correlated with WBSF in barrows (Table 9). Ventral firmness was weakly (r = –0.21) but inversely correlated with WBSF in gilts. This is supported by independent slopes of prediction lines between barrows (β_1 = 0.112) and gilts (β_1 = –0.039) for early postmortem ventral subjective firmness and WBSF values were different (P = 0.04, Fig. 4).

Translate basic science to industry innovation

Table 9. Comparison of Fisher's r to z transformed correlation coefficients (rho) of early postmortem loin quality traits between barrows and gilts with Warner-Bratzler shear force (WBSF) and cook loss[1,2]

| | Barrow WBSF | | | Gilt WBSF | | | |
| | | 95% Confidence limit | | | 95% Confidence limit | | |
Early postmortem variable	Rho	Lower	Upper	Rho	Lower	Upper	P-value[3]
WBSF							
Loin pH	0.27	0.09	0.43	0.09	–0.05	0.24	0.13
Ventral lightness, L*	–0.22	–0.43	0.02	–0.26	–0.44	–0.05	0.82
Ventral redness, a*	0.08	–0.16	0.31	–0.17	–0.37	0.04	0.12
Ventral yellowness, b*	–0.22	–0.43	0.02	–0.05	–0.26	0.16	0.31
Ventral color	0.00	–0.18	0.18	–0.05	–0.19	0.10	0.71
Ventral marbling	0.13	–0.05	0.30	0.00	–0.15	0.14	0.27
Ventral firmness	0.18	–0.01	0.35	–0.07	–0.21	0.08	0.04
Cook Loss, %							
Loin pH	–0.25	–0.41	–0.08	–0.41	–0.53	–0.28	0.13
Ventral lightness, L*	0.08	–0.16	0.31	–0.01	–0.22	0.20	0.57
Ventral redness, a*	–0.22	–0.43	0.02	–0.24	–0.43	–0.03	0.89
Ventral yellowness, b*	0.17	–0.07	0.39	0.45	0.27	0.61	0.05
Ventral color	0.03	–0.15	0.21	0.02	–0.13	0.16	0.89
Ventral marbling	–0.25	–0.41	–0.07	–0.21	–0.34	–0.07	0.72
Ventral firmness	–0.21	–0.37	–0.03	–0.26	–0.39	–0.12	0.64

[1]Early postmortem traits were evaluated 1 d postmortem.

[2]Chops for Warner-Bratzler shear force and cook loss were aged for 14 d postmortem prior to analyses.

[3]Probablity value comparing correlation coefficients of meat quality traits between barrows and gilts.
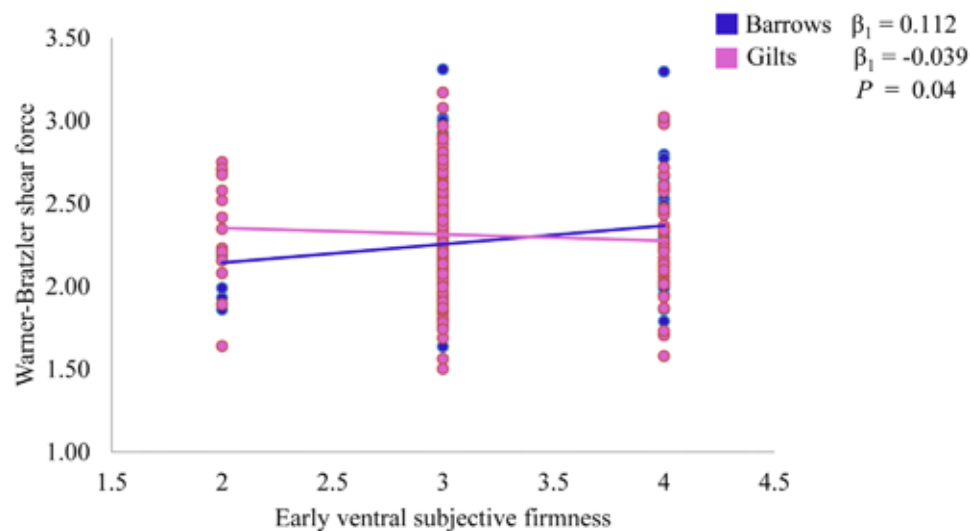

Figure 4. Differences in correlation coefficients between early postmortem (1 d) ventral subjective firmness scores and aged (14 d) Warner-Bratzler shear force values of barrows and gilts. Probability values compare slopes (β_1) of the regression lines between barrows and gilts.

DISCUSSION

While both packers and consumers use similar traits to assess the quality of pork loins, the surface they assess and the time postmortem when they make those assessments are different. Packers assess loin quality based on color and marbling on the ventral surface of loins during carcass fabrication at 1d postmortem (King et al., 2011). At this time, darker loins with more marbling are often selected for premium-based programs (Holmer and Sutton, 2009, Lusk et al., 2017). In contrast, consumers assess color (Mancini and Hunt, 2005) and sometimes marbling on the surface of loin chops at the time of purchase (Moeller et al., 2010). Consumers discriminate against chops that are too light or too dark, or are discolored. Consumers then determine eating quality, and therefore, repeat purchase intent, on tenderness and juiciness of cooked loin chops. There has been some indication that marbling positively affects tenderness and

juiciness. Pork chops with increased marbling have been perceived by consumers and trained sensory panelists to be juicier and more tender (Lonergan et al., 2007), but results appeared to be more pH dependent than marbling dependent. Others have reported no influence of marbling on tenderness and juiciness even over large ranges in marbling scores (Rincker et al., 2008, Wilson et al., 2017). The ultimate goal of packer selection of "high quality" loins is to increase consumer satisfaction and therefore increase consumer purchases of product. Therefore, early postmortem quality characteristics and eating experience must be related. Indeed, these correlation coefficients have been previously established (Huff-Lonergan et al., 2002) However, the relationship between early postmortem characteristics observed on the ventral side of loins and the same traits measured after aging on either the ventral side of loins or the face of chops from those loins has not been well established. Thus, one objective of this work was to determine correlations between early postmortem loin quality characteristics and aged loin and chop quality characteristics.

Packers in the U.S. have historically monitored loin pH as an indication of loin quality. Loin pH is correlated with other pork quality traits such as water holding capacity, color, and firmness (Huff-Lonergan et al., 2002; Boler et al., 2010) In the present study, loin pH at 1 d postmortem was moderately correlated to aged ventral loin color and aged loin chop color. This is supported by previous research (Huff-Lonergan et al., 2002) which also observed that ultimate loin pH was weakly correlated with aged loin color. However, the study by Huff-Lonergan et al. (2002) only aged loins for 2 d postmortem and therefore, may not be truly representative of the quality traits observed by the consumer. Another study, by Hamilton et al. (2003), also reported a relationship between pH and L* however, similar to the study by Huff-Lonergan et al. (2002) quality measurements were measured at approximately 2 d postmortem and most likely does not reflect the traits consumers will observe.

The correlation between early color with aged color is also supported by a relationship between early ventral a* and both aged ventral subjective color and aged chop subjective color. Huff-Lonergan et al. (2002) observed a strong correlation between early postmortem (2 d) L* and early postmortem (2 d) color. However, Huff-Lonergan et al. (2002) determined that correlations did not exist between early L* and aged color, so it is possible that over time, those correlations would become weaker. During aging, proteolysis can alter water holding capacity and color, therefore, quality traits may change with postmortem aging (Hwang et al., 2005).

Ultimately, the goal of selecting loins based on quality characteristics in the early postmortem period is to segregate loins based on expected eating quality.

Tenderness is often cited as the most important quality trait for consumer eating experience (Moeller et al., 2010). Thus, the correlation coefficient between early postmortem quality characteristics observable by packers and tenderness is important. While WBSF was weakly correlated with early pH and early L*, the majority of early postmortem quality traits did not correlate to aged tenderness in the present study. Previous work reported weak correlations between aged tenderness and early postmortem traits, such as marbling, but aged tenderness was not correlated with ultimate pH or color (Dilger et al., 2010) similar to the present study. Marbling is thought to be an important trait for pork tenderness. Moderate correlations between early ventral marbling and aged ventral marbling, early ventral marbling and aged chop marbling, and aged ventral marbling and aged chop marbling indicate that estimates of marbling on the ventral surface at early times postmortem are valid. But early ventral marbling estimates were not correlated with WBSF in either barrows or gilts. Rincker et al. (2008) reported that extractable lipid (range 0.76 to 8.09%) did not influence instrumental or sensory tenderness of pork loins cooked to a medium (71°C) degree of doneness. Likewise, Wilson et al. (2017) reported that extractable lipid (range 0.80 to 5.52%) explained less than 1% of the variation in sensory tenderness of pork loins cooked to a medium-rare degree of doneness (63°C).

Pork carcasses, unlike beef carcasses, are not routinely ribbed (cut between the 10th and 11th rib to expose the longissimus muscle) in the United States. Therefore, estimations of quality by packers is done on the ventral surface of a boneless loin after carcass fabrication. Consumers most often observe the cut surface of loin chops. However, most observations made on the ventral surface of both early and aged loins were not correlated with the corresponding observations made on the chop face of aged loin chops. Subjective chop color was the lone exception. This indicates that estimates of ventral quality, both early and aged, are not necessarily indicative of aged chop quality. The lack of correlation between ventral and chop measurements is troubling because it suggests that what is observed at the processing facility is not what is observed by consumers. That is potentially the result of variation within a loin (Van Oeckel and Warnants, 2003), but also that perception of color may be influenced by the direction of the muscle fibers during observation. When color was assessed on the ventral side of loins, the muscle fibers were oriented mostly perpendicular to the observer. In other words, the observer was viewing muscle fiber longitudinally. But when observed on the chop face, the cross-section of muscle fibers was visible to observers. This difference in fiber directionality could alter the perception of color between these two locations.

Compositional differences between barrows and gilts are well known and, in the current study, were similar to previous research (Friesen et al., 1994; Cisneros et al., 1996). Barrows had greater ending live weights than gilts with more back fat and greater extractable lipid, but gilts produced heavier Canadian back loins yielded a greater percent of estimated carcass lean compared to barrows (Friesen et al., 1994). Bruner et al. (1958) and Hale and Southwell (1967) also observed that barrows were heavier than gilts, but gilts were leaner, had a greater carcass yield, less backfat, and larger loin eye area. A more recent study by Cisneros et al. (1996) confirmed these differences between barrows and gilts, similar to the present study. There were minimal differences between barrows and gilts in regard to fresh meat quality. Loins from gilts were more firm than loins from barrows, had greater cooking loss, but did not differ in WBSF. Increased firmness in loins from gilts may be related to increase WHC, as demonstrated by DeVol et al. (1988). Previous reports have also failed to detect differences in tenderness between barrows and gilts (Cisneros et al., 1996; Latorre et al., 2004). Therefore, while sex does not affect tenderness, it may affect WHC and cooking loss.

It is not common at either commercial farms or slaughter facilities to segregate barrows and gilts. Therefore, when packers make assessments of quality, sex is not known. Because barrows and gilts differ in both the mean and variability of some quality and composition traits (Overholt et al., 2016), the hypothesis was that the relationships among early and aged quality characteristics may differ between barrows and gilts. Therefore, the second objective of this study was to determine if correlations between early postmortem loin quality characteristics and aged loin and chop quality characteristics differed between barrows and gilts.

In general, correlation coefficients between early and aged postmortem quality did not differ between barrows and gilts. However, there were 4 early postmortem quality characteristics that were correlated differently to aged quality traits between the 2 sexes. It is important to determine if these differences are significant and if sex should be accounted for when using early postmortem quality traits to predict aged quality. To that point, the independent slopes for both barrows and gilts were negative (as became lighter, pH was less) between early postmortem ventral lightness and aged ventral pH, but the correlation in barrows was moderately strong in barrows, but weak in gilts. Likewise, there was a moderately strong inverse correlation and a negative slope in barrows between early ventral lightness and aged ventral color (as loins became lighter instrumentally, they also became lighter visually), but no predictive ability of aged ventral color using early instrumental lightness in gilts. Early subjective color was positively, yet weak-

ly, correlated with aged ventral redness in barrows, but subjective color score was not related to aged redness scores in gilts. This indicates no predictive ability of aged redness scores in gilts and poor predictive ability of aged redness scores in barrows using early ventral color. Finally, early ventral firmness was not predictive of WBSF for either barrows or gilts, but the directionality of the correlations differed between barrows and gilts. This inconsistency between barrows and gilts was anticipated. Arkfeld et al. (2015) reported weak or no correlation between firmness and other meat quality traits. Overholt et al. (2016) reported greater variability in early subjective color scores of loins from gilts compared with loins from barrows. In most cases variability (a greater range) in the trait of interest increases the likelihood of a relationship being detected. However, if subjective color of gilts is more variable than subjective color of barrows and that variability is different from early and aged color, it is possible this explains the differences in the correlation coefficients of color scores between barrows and gilts with other quality traits.

Based on the results of the present study it may be possible to use early pH, L*, and a* as indicators of aged color. Additionally, early pH and L* may provide limited information regarding tenderness, but those correlations were weak. It should also be noted that while early ventral quality may be used to estimate aged ventral quality, data from this study suggest that early and aged ventral loin color may not be accurate estimators of aged chop color. Additionally, while there are differences between barrows and gilts in terms of quality characteristics, the relationship between early and aged quality did not differ between barrows and gilts. Thus, sex does not need to be accounted for when using early postmortem quality traits to predict aged quality.

LITERATURE CITED

Arkfeld, E. K., S. Mancini, B. Fields, A. C. Dilger, and D. D. Boler. 2015. Correlation of fresh muscle firmness with sensory characteristics of pork loins destined for a quality focused market. J. Anim. Sci. 93:5059–5072. doi:10.2527/jas.2015-9316

Boler, D. D., A. C. Dilger, B. S. Bidner, S. N. Carr, J. M. Eggert, J. W. Day, M. Ellis, F. K. McKeith, and J. Killefer. 2010. Ultimate pH explains variation in pork quality traits. J. Muscle Foods 21:119–130. doi:10.1111/j.1745-4573.2009.00171.x

Brewer, M. S., L. G. Zhu, B. Bidner, D. J. Meisinger, and F. K. McKeith. 2001. Measuring pork color: Effects of bloom time, muscle, pH and relationship to instrumental parameters. Meat Sci. 57:169–176. doi:10.1016/S0309-1740(00)00089-9

Bruner, W. H., V. R. Cahill, W. L. Robinson, and R. F. Wilson. 1958. Perfomance of barrow and gilt littermate pairs at the Ohio Swine Evaluation Station. J. Anim. Sci. 17:875–878. doi:10.2527/jas1958.173875x

CIE. 1978. Recommendations on uniform color spaces, color difference equations. Psychometric Color Terms. Paris: Commission Internationale de l'Eclairage. Supplement 2 of CIE Publication 15 (E-1.3.1) 1971. p. 8–12.

Cisneros, F., M. Ellis, F. K. McKeith, J. McCaw, and R. L. Fernando. 1996. Influence of slaughter weight on growth and carcass characteristics, commercial cutting and curing yields, and meat quality of barrows and gilts from two genotypes. J. Anim. Sci. 74:925–933. doi:10.2527/1996.745925x

DeVol, D. L., F. K. McKeith, P. J. Bechtel, J. Novakofski, R. D. Shanks, and T. R. Carr. 1988. Variation in composition and palatability traits and relationships between muscle characteristics and palatability in random sample of pork carcasses. J. Anim. Sci. 66:385–395. doi:10.2527/jas1988.662385x

Dilger, A. C., P. J. Rinker, J. M. Eggert, F. K. McKeith, and J. Killefer. 2010. Pork tenderness and postmortem tenderization: Correlations with meat quality traits and the impact of sire line. J. Muscle Foods 21:529–544. doi:10.1111/j.1745-4573.2009.00201.x

Friesen, K. G., J. L. Nelssen, J. A. Unruh, R. D. Goodband, and M. D. Tokach. 1994. Effects of interrelationship between genotype, sex, and dietary lysine on growth performance and carcass composition in finishing pigs fed either 104 or 127 kilograms. J. Anim. Sci. 72:946–954. doi:10.2527/1994.724946x

Hale, O. M., and B. L. Southwell. 1967. Differences in swine performance and carcass characteristics because of dietary protein level, sex, and breed. J. Anim. Sci. 26:341–344. doi:10.2527/jas1967.262341x

Hamilton, D. N., K. D. Miller, M. Ellis, F. K. McKeith, and E. R. Wilson. 2003. Relationships between the longissimus glycolytic potential and swine growth performance, carcass traits, and pork quality. J. Anim. Sci. 81:2206–2212. doi:10.2527/2003.8192206x

Holmer, S. F., and D. Sutton. 2009. Industry perspective on pork quality. Proc. Recip. Meat Conf. 62:1-3.

Huff-Lonergan, E., T. J. Baas, M. Malek, J. C. M. Dekkers, K. Prusa, and M. F. Rothschild. 2002. Correlations among selected pork quality traits. J. Anim. Sci. 80:617–627. doi:10.2527/2002.803617x

Hwang, I. H., B. Y. Park, J. H. Kim, S. H. Cho, and J. M. Lee. 2005. Assessment of postmortem proteolysis by gel-based proteome analysis and its relationship to meat quality traits in pig longissimus. Meat Sci. 69:79–91. doi:10.1016/j.meatsci.2004.06.019

Kenny, D. A. 1987. Testing measures of association. In: Statistics for the social and behavioral sciences. Little, Brown and Company (Canada) Limited. p. 270–291.

King, D. A., S. D. Shackelford, and T. L. Wheeler. 2011. Use of visible and near-infrared spectroscopy to predict pork longissimus lean color stability. J. Anim. Sci. 89:4195–4206. doi:10.2527/jas.2011-4132

Latorre, M. A., R. Lázaro, D. G. Valencia, P. Medel, and G. G. Mateos. 2004. The effects of gender and slaughter weight on the growth performance, carcass traits, and meat quality characteristics of heavy pigs. J. Anim. Sci. 82:526–533. doi:10.2527/2004.822526x

Lonergan, S. M., K. J. Prusa, E. Huff-Lonergan, and C. Yu. 2017. Prediction of pork quality using raman spectroscopy– NPB#15-078. http://research.pork.org/Results/ResearchDetail.aspx?id=2030. (Accessed 23 August, 2017.)

Lonergan, S. M., K. J. Stalder, E. Huff-Lonergan, T. J. Knight, R. N. Goodwin, K. J. Prusa, and D. C. Beitz. 2007. Influence of lipid content on pork sensory quality within pH classification. J. Anim. Sci. 85:1074–1079. doi:10.2527/jas.2006-413

Lusk, J., G. Tonsor, T. Schroeder, and D. Hayes. 2017. Consumer valuation of pork chop quality information– NPB#15-198. http://research.pork.org/FileLibrary/ResearchDocuments/15-198-SCHROEDER-MktEcon.pdf. (Accessed 23 August, 2017.)

Mancini, R. A., and M. C. Hunt. 2005. Current research in meat color. Meat Sci. 71:100–121. doi:10.1016/j.meatsci.2005.03.003

Martel, J., F. Minvielle, and L. M. Poste. 1988. Effects of crossbreeding and sex on carcass composition, cooking properties and sensory characteristics of pork. J. Anim. Sci. 66:41–46. doi:10.2527/jas1988.66141x

Moeller, S. J., R. K. Miller, K. K. Edwards, H. N. Zerby, K. E. Logan, T. L. Aldredge, C. A. Stahl, M. Boggess, and J. M. Box-Steffensmeier. 2010. Consumer perceptions of pork eating quality as affected by pork quality attributes and end-point temperature. Meat Sci. 84:14–22. doi:10.1016/j.meatsci.2009.06.023

NAMI (North American Meat Institute). 2014. NAMP Meat Buyer's Guide. 8th rev. ed. North American Meat Association, Washington, DC.

National Pork Producers Council (NPPC). 1991. Procedures to evaluate market hogs. 3rd ed. NPPC, Des Moines, IA.

National Pork Producers Council (NPPC). 1999. Official color and marbling standards. NPPC, Des Moines, IA.

Novakofski, J., S. Park, P. J. Bechtel, and F. K. McKeith. 1989. Composition of cooked pork chops– Effects of removing subcutaneous fat before cooking. J. Food Sci. 54:15–17. doi:10.1111/j.1365-2621.1989.tb08556.x

Overholt, M. F., E. K. Arkfeld, D. A. Mohrhauser, D. A. King, T. L. Wheeler, A. C. Dilger, S. D. Shackelford, and D. D. Boler. 2016. Comparison of variability in pork carcass composition and quality between barrows and gilts. J. Anim. Sci. 94:4415–4426. doi:10.2527/jas.2016-0702

Rincker, P. J., J. Killefer, M. Ellis, M. S. Brewer, and F. K. McKeith. 2008. Intramuscular fat content has little influence on the eating quality of fresh pork loins. J. Anim. Sci. 86:730–737. doi:10.2527/jas.2007-0490

Shackelford, S. D., D. A. King, and T. L. Wheeler. 2017. Prediction of pork loin quality and tenderness with the VQG pork loin grading camera– NPB#15-103. http://research.pork.org/FileLibrary/ResearchDocuments/15-103%20SHACKELFORD-USDA.pdf. (Accessed 23 August, 2017.)

Taylor, R. 1990. Interpretation of the correlation coefficient: A basic review. J. Diagn. Med. Sonogr. 6:35–39. doi:10.1177/875647939000600106

Van Oeckel, M. J., and N. Warnants. 2003. Variation of the sensory quality within the m. longissimus thoracis et lumborum of PSE and normal pork. Meat Sci. 63:293–299. doi:10.1016/S0309-1740(02)00085-2

Wilson, K. B., M. F. Overholt, C. M. Shull, C. Schwab, A. C. Dilger, and D. D. Boler. 2017. The effects of instrumental color and extractable lipid content on sensory characteristics of pork loin chops cooked to a medium–rare degree of doneness. J. Anim. Sci. 95:2052–2060. doi:10.2527/jas2016.1313