The effects of ultimate pH and color on sensory traits of pork loin chops cooked to a medium-rare degree of doneness

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ABSTRACT: The objective was to determine the effects of pH and color on sensory characteristics of boneless pork loin chops cooked to an internal endpoint temperature of 63 °C. Center cut loins (296 total) from barrows and gilts, 5 different sire lines, and a range in pH of 5.36 through 6.23 were used. Previously, ultimate pH was correlated with sensory characteristics of chops cooked to a medium (71 °C) degree of doneness. Additionally, increasing ultimate pH improved sensory tenderness and juiciness of loin chops cooked to a medium degree of doneness. However, in 2011, the United States Department of Agriculture Food Safety and Inspection Service reduced the recommended final internal cooking temperature of pork chops from 71 to 63 °C (followed by a 3-min rest). The effects of ultimate pH on sensory traits of pork chops cooked to a medium-rare (63 °C) degree of doneness are not known. Therefore, loins were categorized using historical categories based on ultimate pH: >5.95, $n = 22$; 5.80 to 5.95, $n = 75$; 5.65 to 5.80, $n = 102$; 5.50 to 5.65, $n = 91$; <5.50, $n = 6$. On 1-d postmortem, loins were evaluated for CIE instrumental L*, a*, b*, visual color, marbling, and subjective firmness. Then, loins were aged in vacuum packages at 4 °C until 16-d postmortem. After aging, loins were cut into 2.54-cm

thick chops, vacuum-packaged, and frozen until sensory or instrumental tenderness analysis. One chop was also used to determine extractable lipid. Chops were weighed, cooked to 63 °C, cooled to approximately 23 °C, weighed again to determine cook loss, and then evaluated for Warner–Bratzler shear force. Another chop was cooked to 63 °C internal temperature and served warm to trained panelists to determine sensory traits. Coefficients of determination (R^2) were calculated to determine the predictability of ultimate pH and instrumental color on sensory tenderness, juiciness, and flavor. A 1-way ANOVA and means separation test were used to determine specific differences among pH categories. Ultimate pH explained less than 5% of the variation in tenderness and less than 1% of the variation in juiciness or flavor. Furthermore, sensory tenderness did not differ ($P > 0.05$) among pH categories, except for chops with an ultimate pH > 5.95. Chops with a pH > 5.95 were at least 9.1% more tender ($P < 0.05$) than chops with a pH < 5.95. Visual and instrumental color were not predictive ($R^2 \leq 0.03$) of any sensory traits. Overall, pH does not influence sensory traits of pork chops cooked to medium-rare degree of doneness unless pH is at least 5.95.

Key words: color, degree of doneness, loin quality, pork, tenderness, ultimate pH

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INTRODUCTION

Tenderness and juiciness are important sensory traits that determine overall eating experience (Enfält et al., 1997). Ultimate pH was significantly correlated with both of these traits when pork

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chops were cooked to a medium (71 °C) degree of doneness (Huff-Lonergan et al., 2002). Increasing ultimate pH resulted in an increase in tenderness and juiciness scores for fresh pork loin chops cooked to 71 °C when evaluated by trained sensory panelists (Lonergan et al., 2007; Moeller et al., 2010). Visual color is also an important trait that affects consumer purchasing intent (Brewer et al., 2001). Consumers generally prefer darker-colored pork chops over lighter-colored chops (Mancini and Hunt, 2005). Ultimate pH affects the color of pork products. Darker-colored chops tend to have a greater ultimate pH, whereas lighter-colored chops tend to have a lesser ultimate pH (Monin and Sellier, 1985). Furthermore, chops with a lesser pH also have reduced water holding capacity (Huff-Lonergan et al., 2002) and tend to be less juicy. Therefore, increasing pH seems to be advantageous for both consumer purchase intent and overall eating experience.

In 2011, the United States Department of Agriculture (USDA) Food Safety and Inspection Service changed the recommended endpoint temperatures of whole muscle cuts of pork from 71 to 63 °C in order to maintain food safety, but improve sensory traits. Previous research has demonstrated that color and marbling have minimal impact on the sensory traits of pork chops cooked to 63 °C (Wilson et al., 2017). However, it is not known whether relationships between ultimate pH and sensory quality of pork chops already established in pork cooked to a medium degree of doneness persist in chops cooked to a medium-rare degree of doneness. Therefore, the objective was to determine the effects of ultimate pH and color on sensory characteristics of boneless pork loin chops cooked to an internal endpoint temperature of 63 °C. Because ultimate pH tends to increase water holding capacity and improve tenderness in pork cooked a medium degree of doneness, the hypothesis was that increasing ultimate pH from 5.36 to 6.23 would improve sensory tenderness and juiciness when chops were cooked to a medium-rare degree of doneness.

MATERIALS AND METHODS

Pigs were harvested at a federally inspected facility under the supervision of the USDA Food Safety and Inspection Service. Boneless loins were purchased from that facility and transported to the University of Illinois Meat Science Laboratory (Urbana, IL). No live animal interaction occurred during this study; therefore, no Institutional Animal Care and Use Committee approval was needed.

Background

Loins from approximately 600 barrows and gilts from 5 different sire lines mated to the same F1 female line were available for selection for this experiment. Pigs were raised under the same commercial conditions and transported approximately 450 km to a federally inspected commercial abattoir. Pigs were marketed in groups of 150 over a 2-wk period. Each pig was tattooed with a lot number upon arriving at the processing facility. Once at the facility, pigs were provided free access to water, but no access to feed. Pigs were immobilized via carbon dioxide and terminated by exsanguination. After evisceration, a sequential identification number was written on the shoulder of each carcass using a carcass crayon for traceability purposes.

Processing Facility Data Collection

Following commercial harvesting procedures, carcasses were blast-chilled for approximately 90 min and placed in a temperature equilibration carcass cooler for at least 16 h prior to fabrication. After chilling, carcasses were fabricated into primal cuts and loins were further fabricated into Canadian back loins (NAMP #414). Only loins from the left side were used for analysis in this study. Loins were evaluated for visual color (NPPC, 1999), visual marbling (NPPC, 1999), subjective firmness (NPPC, 1991), instrumental color, and ultimate pH immediately following fabrication with limited opportunity for oxygenation of myoglobin prior to evaluation. All measurements were evaluated on the ventral surface of the loin at approximately the area of the 10th rib. Visual and subjective measurements were evaluated by a single individual. Instrumental CIE lightness (L^*), redness (a^*), and yellowness (b^*) were measured with a Minolta CR-400 Chroma meter (Minolta Camera Co., Ltd., Osaka, Japan) using a C illuminant and 2° observer with an 8-mm aperture and calibrated using a white tile. Ultimate pH was measured using a Reed data logger fitted with a Hanna glass electrode (REED SD-230 Series pH/ORP Datalogger, 0.00 to 14.00 pH/0–199 mV; Hanna FC200B electrode). After 1-d postmortem procedures were complete, loins were weighed, vacuum-packaged, and transported on ice at approximately 4 °C to the University of Illinois Meat Science Laboratory.

Loin Selection

A subsample of 296 (target of 300 total) loins from the original candidate loins were selected to

fill a 3×5 matrix using 1-d postmortem ultimate pH and 1-d postmortem NPPC visual color score for trained sensory panel analysis (Table 1). There were no differences ($P = 0.39$) in Warner–Bratzler shear force (WBSF) among the 5 sire lines for the subpopulation of selected loins. Therefore, loins were pooled across sire line for all response variables. Ultimate pH categories were determined using the same categories described in Lonergan et al. (2007) and were as follows: >5.95 , $n = 22$; 5.80 to 5.95, $n = 75$; 5.65 to 5.80, $n = 102$; 5.50 to 5.65, $n = 91$; <5.50 , $n = 6$. Loins were categorized using the visual color guidelines provided by the National Pork Producers Council (1999) using half-score increments, where loins became darker with increasing color score in the following manner: 1.5 to 2.5, 3.0 to 3.5, and ≥ 4.0 . There were no loins within this population that had the combination of a color score ≥ 4.0 and an ultimate pH of <5.50 or a color score of 1.5 to 2.5 and an ultimate pH > 5.95 .

Aged Loin Quality Measurements

Whole boneless loins were allowed to age in vacuum bags until 16-d postmortem at 4 °C. After the aging period, packages were opened and loins were weighed in order to calculate purge loss. Oxygenation of the loins was allowed to occur for at least 20 min before quality evaluations took place. Final aged postmortem pH was measured on the ventral side of the longissimus dorsi muscle in the approximate location of the 10th rib using a Reed data logger fitted with a Hanna glass electrode calibrated at 4 °C (REED SD-230 Series pH/ORP Datalogger, 0.00 to 14.00 pH/0–199 mV; Hanna FC200B electrode). Visual color (NPPC, 1999), visual marbling (NPPC, 1999), and subjective firmness (NPPC, 1991) were evaluated by the same individual as in data collection at the processing facility. Instrumental CIE lightness (L^*), redness (a^*), and yellowness (b^*) were measured on the ventral side of each loin near the 10th rib following the same procedure used in data collection at the processing facility. After instrumental and visual quality evaluations, loins were sliced into

2.54-cm thick chops using a push-feed style Treif Puma slicer (Treif model 700 F; Treif, Oberlahr, Germany). The first 3 chops immediately posterior to the spinalis dorsi muscle were collected for further analysis in the following consecutive order: 1) extractable lipid and moisture content, 2) WBSF, and 3) trained sensory analysis. Chops designated for extractable lipid content were trimmed of all secondary muscles and subcutaneous fat. All chops were then vacuum packaged separately and stored at -20 °C until further analysis.

Proximate Analysis

Chops stored for analysis of moisture and extractable lipid were allowed to partially thaw, with great care taken to prevent loss of exudate such that any exudate was added to the chop and included in the homogenate. Samples were homogenized using a Cuisinart food processor (East Windsor, NJ). After homogenization, two 10-g samples from the homogenate were weighed and placed in a drying oven at 110 °C for at least 24 h. Samples were then weighed to determine moisture and washed multiple times in a mixture of chloroform and methanol for at least 24 h in the manner described by Novakofski et al. (1989). After extraction, samples were dried for at least 24 h before the lipid extracted weight was recorded.

Warner–Bratzler Shear Force

Samples designated for WBSF were allowed to thaw at 4 °C for at least 24 h prior to analysis. Chops were then individually weighed and cooked on a Farberware Open Hearth grill (model 455N; Walter Kidde, Bronx, NY) to an internal temperature of 63 °C (medium-rare degree of doneness). Chops were flipped half way through cooking when they reached an internal temperature of 31 °C. Internal temperature was monitored by using copper-constantan thermocouples (Type T, Omega Engineering, Stamford, CT, USA) placed in the geometrical center of each chop and connected to a digital scanning thermometer (model 92000-00,

Table 1. Number of chops per color-pH category combination

Variable		pH category ¹				
		>5.95	5.80 to 5.95	5.65 to 5.80	5.50 to 5.65	<5.50
Color ²	1.5 to 2.5	0	18	38	43	1
	3.0 to 3.5	16	53	50	45	5
	≥ 4.0	6	4	14	3	0

¹Ultimate pH collected 1-d postmortem on the ventral side of whole boneless loins.

² NPPC color using the 1999 standards, half point scale where 1 = palest color and 6 = darkest color.

Barnat Co, Barrington, IL). After cooking, chops were allowed to cool to room temperature and weighed again to determine cooking loss. Four cores measuring 1.25 cm in diameter were removed from each chop. Cores were cut at an angle that was parallel to the orientation of the muscle fibers. A Texture Analyzer TA.HD Plus (Texture Technologies Corp., Scarsdale, NY/Stable Microsystems, Godalming, UK) with a blade speed of 3.33 mm/s and a load cell capacity of 100 kg was used to shear each sample. WBSF values from each of the 4 cores were averaged to yield a single shear force value for each loin.

Trained Sensory Panel

Trained sensory panels consisted of 6 individuals that evaluated pork chop tenderness, juiciness, and pork flavor. Panelists were selected from a pool of experienced, trained students and faculty from the University of Illinois (Champaign-Urbana, IL). Before starting these panels, panelists were trained to evaluate pork chops for tenderness, juiciness, and pork flavor using the Sensory Guidelines from the American Meat Science Association (AMSA, 2015). Pork tenderness was standardized using 3 pork chops cooked to an internal temperature of 63, 71, or 80 °C, respectively. Pork juiciness was standardized by cooking a nonenhanced and an enhanced chop to an internal temperature of 71 °C. Pork flavor was standardized by cooking a pork blade steak to an internal temperature of 71 °C. As a group, panelist tasted each sample in order to determine a respective anchor. For this group of trained panelists, sensory tenderness scores explained 15% ($R^2 = 0.15$) of the variation in WBSF instrumental tenderness. The effectiveness of the University of Illinois trained sensory panel to detect differences in tenderness was less than

the 57% ($R^2 = 0.57$) previously reported by Wilson et al. (2017). However, this decrease in effectiveness could be explained by the lack of variation in WBSF values among pH categories (Table 2).

Chops were assigned to sensory sessions using an incomplete randomized block schedule of chops for each sensory panel, generated using the OPTEX procedure in SAS (SAS Inst., Inc., Cary, NC). Panelists were seated in breadbox-style stations under red lights to mask color differences. Panelists were given apple juice and an unsalted saltine cracker between each sample to use as a palate cleanser. A 15-cm unstructured line scale was used to evaluate tenderness, juiciness, and flavor (0 = extremely tough, extremely dry, no pork flavor; 15 = extremely tender, extremely juicy, and very intense pork flavor). Chops were allowed to thaw at least 24 h prior to cooking at approximately 4 °C. After thawing, chops were cooked to an internal endpoint temperature of 63 °C using the same Farberware Open Hearth grills used for WBSF analysis. Internal temperature was monitored using the same copper thermocouples mentioned previously for WBSF. After a 3-min rest period, all secondary muscles and subcutaneous fat were trimmed. Chops were cut into cubes using a 1- × 1-cm sample sizer prior to serving. No more than 2 sensory sessions occurred per day with up to 6 samples per session. Panels were held at least an hour apart in order to reduce panelist fatigue. The study consisted of 296 samples in 50 sessions over 87 d. Results from panelists were averaged for use in data analyses.

Statistical Analyses

Loin (296 total) served as the experimental unit in this study. Summary descriptive statistics were calculated using the Means procedure in

Table 2. Effects of ultimate pH on sensory traits of pork chops cooked to a medium-rare degree of doneness¹

Item	pH category ¹					SEM	P-value
	>5.95	5.80 to 5.95	5.65 to 5.80	5.50 to 5.65	<5.50		
Loins, <i>n</i>	22	75	102	91	6		
Sensory tenderness ²	10.59 ^a	9.67 ^b	9.51 ^b	9.46 ^b	9.47 ^b	0.29	< 0.01
Sensory juiciness ²	9.29	9.15	9.02	9.03	8.74	0.23	0.18
Sensory flavor ²	2.30	2.35	2.44	2.44	2.27	0.13	0.12
Cook loss, % ³	16.14	18.09	18.54	18.58	18.87	1.13	0.08
Warner–Bratzler shear force, kg ⁴	2.87	2.78	2.82	2.67	2.84	0.19	0.09

Least square means within a row lacking a common superscript are different ($P < 0.05$).

¹Ultimate pH collected 1-d postmortem on the ventral side of whole boneless loins.

²Sensory scores with a greater value represent a greater degree of tenderness, juiciness, or flavor.

³Cook loss was recorded immediately prior to cooking and after cooling to an internal temperature of approximately 23 °C.

⁴Warner–Bratzler shear force was collected on chops cooked to a final internal temperature of 63 °C and sheared at an internal temperature of approximately 23 °C.

SAS. Regression analyses were performed using the REG procedure in SAS to calculate coefficients of determination (R^2) between the dependent (tenderness, juiciness, flavor, and WBSF) and independent (ultimate pH, visual color, and instrumental color) variables. WBSF was used as an independent variable in a regression analysis to validate the trained sensory panel data. Additionally, the effects of ultimate pH and visual color on sensory characteristics, WBSF, and cook loss were analyzed using the MIXED procedure in SAS as a 1-way ANOVA. A multivariate model was fit using the repeated statement because of heterogeneous variances due to extreme differences in sample size among pH

and visual color categories. Significance was determined at $P < 0.05$ for all analyses.

RESULTS

Carcass Characteristics and Loin Quality

Hot carcass weights ranged from 80.81 to 123.49 kg in this population of pigs. In addition, loin muscle depth was between 45.5 and 85.6 mm, and fat depth ranged between 15.0 and 39.6 mm (Table 3). Ultimate pH ranged from 5.36 to 6.23, NPPC visual color scores ranged from 1.5 to 4.5,

Table 3. Population summary statistics for early (1 d) postmortem and aged (16 d) quality parameters and sensory characteristics

Item	Observations	Mean	SD	Minimum	Maximum
Carcass characteristics					
Hot carcass wt, kg	296	101.37	6.22	80.81	123.49
Loin muscle depth, mm	296	65.68	0.37	45.50	85.60
Fat depth, mm	296	23.39	0.28	15.00	39.60
1-d fresh quality traits					
Ultimate pH ¹	296	5.73	0.14	5.36	6.23
Visual color ²	296	2.95	0.54	1.50	4.00
Visual marbling ³	296	2.42	0.76	1.00	5.00
Subjective firmness ⁴	296	3.12	0.52	2.00	4.00
Lightness, L* ⁵	296	42.08	2.87	34.43	50.94
Redness, a* ⁵	296	9.08	1.69	4.50	13.20
Yellowness, b* ⁵	296	0.87	1.64	-2.75	5.49
16-d aged quality traits					
Final pH ⁶	296	5.70	0.13	5.46	6.25
Visual color ²	296	3.22	0.40	2.00	5.00
Visual marbling ³	296	2.28	0.66	1.00	4.50
Subjective firmness ⁴	296	3.16	0.43	2.00	5.00
Lightness, L* ⁵	296	46.62	3.35	35.56	53.43
Redness, a* ⁵	296	9.27	1.15	6.19	13.07
Yellowness, b* ⁵	296	4.58	1.62	-0.73	8.61
Cook loss, % ⁷	296	18.89	3.72	10.80	36.74
Extractable lipid, %	296	3.43	1.10	0.99	7.69
Warner–Bratzler shear force, kg ⁸	295	2.78	0.55	1.64	4.66
Sensory characteristics					
Tenderness ⁹	296	9.61	0.92	6.48	11.98
Juiciness ⁹	296	9.07	0.81	6.22	11.05
Flavor ⁹	296	2.40	0.29	1.70	3.75

¹Ultimate pH collected 1-d postmortem on the ventral surface of whole boneless loins.

²NPPC color using the 1999 standards, half point scale where 1 = visually palest and 6 = visually darkest.

³NPPC marbling using the 1999 standards where 1 = visually the least marbling and 6 = visually the most marbling.

⁴NPPC firmness using the 1991 standard where 1 = softest and 6 = firmest.

⁵L* measures darkness to lightness (greater L* indicates a lighter color), a* measures redness (greater a* value indicates a redder color), and b* measures yellowness (greater b* value indicates a more yellow color).

⁶Final pH collected 16-d postmortem on the ventral surface of whole boneless loins.

⁷Cook loss was recorded immediately prior to cooking and after cooling to an internal temperature of approximately 23 °C.

⁸Warner–Bratzler shear force was collected on chops cooked to a final internal temperature of 63 °C and sheared at an internal temperature of approximately 23 °C.

⁹Evaluated on a 15 point scale, where 0 = extremely tough, dry, or not flavorful and 15 = extremely tender, juicy, or flavorful.

and instrumental L^* values ranged from 34.43 to 50.94 (Table 3). Visual color and marbling scores ranged from 1.5 to 4.0 and 1.0 to 5.0, respectively, whereas subjective firmness scores ranged from 2.0 to 4.0 (Table 3). Additionally, trained sensory tenderness, juiciness, and flavor scores ranged from 6.48 to 11.98, 6.22 to 11.05, and 1.70 to 3.75, respectively (Table 3). Furthermore, the majority of loins fell in the intermediate ultimate pH categories (5.65 to 5.95) and achieved a NPPC visual color score between 3.0 and 3.5 (Table 1).

Ultimate pH and Color as Predictors of Sensory Traits

Ultimate pH explained 5% of the variation ($R^2 = 0.05$, $P < 0.001$) in trained sensory tenderness scores (Table 4). In addition, chops from loins in the most elevated pH category (pH > 5.95) were more tender ($P < 0.01$) when compared with those from the lower pH categories (Table 2). However, ultimate pH was not an effective predictor of trained sensory juiciness or flavor scores as it explained less than 1% ($R^2 < 0.01$; $P = 0.10$) of the variation in panelist scores (Table 4). Ultimate pH was also not predictive ($R^2 < 0.01$, $P = 0.34$) of WBSF.

Sensory traits, cook loss, and WBSF values did not differ among the 3 color categories (Table 5). In addition, NPPC visual color score explained less than 1% ($R^2 < 0.01$, $P = 0.83$) of the variation in sensory tenderness, juiciness, and flavor scores or WBSF and, therefore, was not an effective predictor of eating quality. Instrumental L^* was also not ($R^2 = 0.02$, $P < 0.05$) predictive of sensory tenderness scores. Additionally, instrumental L^* was not predictive of juiciness or flavor as it explained

less than 1% of the variation in panelist scores (Table 4). Furthermore, neither tenderness nor juiciness could be predicted using instrumental a^* as it explained less than 1% of the variation in panelist scores. Instrumental a^* was also not predictive ($R^2 = 0.01$, $P < 0.05$) of sensory flavor scores (Table 4). Finally, instrumental b^* explained 3% of the variation in sensory tenderness scores, but did not effectively predict ($R^2 < 0.01$) juiciness or flavor scores (Table 4).

The combination of ultimate pH, instrumental L^* , instrumental a^* , and instrumental b^* accounted for 11% ($R^2 = 0.11$, $P < 0.0001$) of the variation in sensory tenderness scores, but was not at all predictive of sensory juiciness or flavor scores ($R^2 \leq 0.01$, $P \leq 0.13$). Extractable lipid content was slightly predictive ($R^2 = 0.06$, $P < 0.001$) of sensory tenderness, but not of either sensory juiciness or flavor scores ($R^2 < 0.01$, $P = 0.08$) (Table 4). Therefore, the addition of extractable lipid to the model improved the predictability of tenderness. When extractable lipid was included along with predictor variables above, 14% ($R^2 = 0.14$, $P < 0.0001$) of the variation in sensory tenderness scores was accounted for. However, even with the addition of extractable lipid to the model, these variables are still not predictive of sensory juiciness or flavor scores ($R^2 \leq 0.01$, $P \leq 0.10$).

DISCUSSION

Previous research determined that ultimate pH is correlated with both sensory tenderness and juiciness in pork loin chops cooked to a medium degree of doneness (71 °C) (Huff-Lonergan et al., 2002). When chops were cooked to 71 °C, chops from loins with an ultimate pH above 5.95 tended

Table 4. Coefficient of determination (R^2) estimates between early postmortem loin ventral surface quality parameters and sensory tenderness, juiciness, and flavor

Independent variable	Tenderness		Juiciness		Flavor	
	R^2	P -value	R^2	P -value	R^2	P -value
Ultimate pH ¹	0.05	<0.001	<0.01	0.16	<0.01	0.10
Visual color ²	<0.01	0.94	<0.01	0.83	<0.01	0.84
Lightness, L^* ³	0.02	<0.05	<0.01	0.65	<0.01	0.63
Redness, a^* ³	<0.01	0.09	<0.01	0.78	0.01	0.04
Yellowness, b^* ³	0.03	<0.01	<0.01	0.98	<0.01	0.73
Warner–Bratzler shear force, kg ⁴	0.15	<0.001	<0.01	0.43	<0.01	0.55
Extractable lipid, %	0.06	<0.001	<0.01	0.29	0.01	0.08

¹Ultimate pH collected 1-d postmortem in the ventral surface of whole boneless loins.

²NPPC color using the 1999 standards, half point scale where 1 = visually palest and 6 = visually darkest.

³ L^* measures darkness to lightness (greater L^* indicates a lighter color), a^* measures redness (greater a^* value indicates a redder color), and b^* measures yellowness (greater b^* value indicates a more yellow color).

⁴Warner–Bratzler shear force was collected on chops cooked to a final internal temperature of 63 °C and sheared at an internal temperature of approximately 23 °C.

Table 5. Effects of visual color on sensory traits of pork chops cooked to a medium-rare degree of doneness¹

Item	Visual color category ¹			SEM	P-value
	1.5 to 2.5	3.0 to 3.5	≥ 4.0		
Loins, <i>n</i>	101	168	27		
Sensory tenderness ²	9.48	9.60	9.21	0.19	0.10
Sensory juiciness ²	9.03	9.14	8.78	0.17	0.07
Sensory flavor ²	2.40	2.43	2.38	0.05	0.53
Cook loss, % ³	19.08	18.93	17.99	0.96	0.53
Warner–Bratzler shear force, kg ⁴	2.84	2.73	2.88	0.11	0.15

¹NPPC color using the 1999 standards, half point scale where 1 = visually palest and 6 = visually darkest.

²Sensory scores with a greater value represent a greater degree of tenderness, juiciness, or flavor.

³Cook loss was recorded immediately prior to cooking and after cooling to an internal temperature of approximately 23 °C.

⁴Warner–Bratzler shear force was collected on chops cooked to a final internal temperature of 63 °C and sheared at an internal temperature of approximately 23 °C.

to have as much as a 5% reduction in cook loss when compared with those with an ultimate pH less than 5.95 (Lonergan et al., 2007). An increase in pH also resulted in significantly greater sensory tenderness and juiciness scores (Huff-Lonergan et al., 2002; Lonergan et al., 2007; Moeller et al., 2010). Furthermore, Torley et al. (2000) reported that cook loss was affected by both internal cooking temperature and pH. In the present study, loins with a pH of greater than 5.95 were also more tender ($P < 0.01$) and had a decreased cook loss ($P = 0.04$) when compared with those with a pH less than 5.95. The relationship between pH and tenderness is likely due to the influence pH has on water-holding capacity and, therefore, cook loss.

Unlike previous studies, results from this study indicate that there were no differences in sensory juiciness scores among the 5 pH categories ($P = 0.30$). The lack of variation in sensory juiciness scores is likely due to the decrease in internal cooking temperature. Reducing internal cooking temperature from 71 to 63 °C has the potential to reduce both cooking time and cook loss. Moeller et al. (2010) reported that cook loss decreases by as much as 3% when internal cooking temperature was reduced from 79.4 to 62.8 °C. In addition, studies by both Baublits et al. (2006) and Torley et al. (2000) reported as much as a 5% and 16% decrease in cook loss, respectively, as internal cooked temperature was decreased. This reduction in cook loss should result in a loin chop that is perceived as juicier. As such, it is not surprising that Rincker et al. (2008) reported as much as a 3-unit increase in sensory tenderness and juiciness scores as internal cooked temperature decreased from 80 to 62 °C when chops were evaluated by trained panel. Therefore, the lack of differences between pH categories in the present study suggests that ultimate

pH may not be an important factor in determining sensory juiciness scores when cooking to 63 °C due to minimal cooking loss of all chops.

Furthermore, in the current study, instrumental CIE lightness (L^*), redness (a^*), and yellowness (b^*) were not predictive of overall eating quality. Previously, instrumental L^* and b^* explained only 2% and 3%, respectively, of the variation in tenderness scores, but less than 1% of the variation in both juiciness and flavor scores (Wilson et al., 2017; Harsh et al., 2018). Instrumental a^* explained 1% of the variation in flavor scores, but less than 1% of the variation for both tenderness and juiciness. This was unexpected based on historical data that suggest darker-colored chops are expected to have a more favorable eating experience due to muscle fiber type and increased myoglobin concentration (Moody et al., 1980). Moody et al. (1980) reported that carcasses with a greater number of oxidative Type I fibers can positively influence the palatability characteristics of meat. Furthermore, in pork loin chops cooked to a medium degree of doneness, visual color is significantly ($P < 0.01$) correlated with sensory tenderness scores (Huff-Lonergan et al., 2002).

In the current study, the lack of variation in sensory tenderness and juiciness scores could be due to the consistent management practices and relatively limited genetic variation in the population. Therefore, subtle differences in transport, lairage, or chilling could explain the differences in pH. However, the results indicate that these potential differences do not appear to be great enough to affect eating quality. This is unlike Lonergan et al. (2007), which reported significant differences among pH categories for both tenderness and juiciness. These differences could be due to the diverse genetic background and management practices that were

utilized within the population of pigs used for the previously mentioned study. Furthermore, a study conducted by Wilson et al. (2017), which evaluated the effects of color and extractable lipid content on sensory traits of pork loin chops cooked to 63 °C, also reported that instrumental L* was poorly predictive ($R^2 = 0.01$; $P = 0.04$) of sensory tenderness scores, and not at all predictive of either juiciness or flavor scores. Similar to the current study, Wilson et al. (2017) reported that extractable lipid content explained no more than 2% ($R^2 = 0.02$, $P = 0.02$) of the variation in sensory tenderness and juiciness scores. In addition, Norman et al. (2003) evaluated the effects of pork loin color on instrumental tenderness and consumer acceptance. Loins from an unknown genetic line were divided into 3 categories using NPPC visual color standards and were as follows: NPPC visual color scores 1 and 2, NPPC visual color scores 3 and 4, and NPPC visual color scores 5 and 6. Instrumental L* means for each of the 3 categories were pale = 57.00, intermediate = 50.24, and dark = 45.54. The results indicated that there were no significant ($P > 0.05$) differences in tenderness among color categories when chops were cooked to 71 °C and evaluated using WBSF analysis. However, Norman et al. (2003) also reported that consumers rated the chops in the dark category as being significantly ($P < 0.05$) more juicy than those in both the intermediate and pale color categories. The lack of consistent results between these studies could also be due to internal endpoint cooking temperature as Norman et al. (2003) utilized “in-home” consumer testing. Therefore, internal endpoint temperatures may have been inconsistent and chops may have been cooked to a greater degree of doneness.

CONCLUSIONS

Based on these results, it is clear that many quality factors may affect the palatability traits of pork loin chops. Although the chops in the most elevated pH category (pH > 5.95) were nearly 10% more tender, ultimate pH explained only 5% of the variation in sensory tenderness scores and less than 1% of the variation in juiciness and flavor scores. In addition, instrumental color, at most, explained 3% of the variation in tenderness scores and 1% of the variation in flavor scores, but was not an effective predictor of juiciness. In conclusion, ultimate pH does not independently influence eating quality (tenderness, juiciness, and flavor) of boneless pork loin chops cooked to a medium-rare degree of doneness unless pH is at least 5.95.

SUPPLEMENTARY DATA

Supplementary data are available at *Journal of Animal Science* online.

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