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Meat Quality Attributes and Sensory Characteristics for Pork Tenderloins (*M. Psoas Major*)

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Abstract: The objective of this study was to determine the association between meat quality traits and sensory attributes of pork tenderloins. Meat quality traits (ultimate pH, instrumental color, cooking loss, Warner-Bratzler shear force [WBSF], and desmin degradation) and trained sensory attributes (tenderness, juiciness, and flavor) were evaluated for pork tenderloins from 103 pigs slaughtered on the same day in a commercial processing facility. Data were initially analyzed using the CORR procedure of SAS and correlations were considered significantly different from 0 at $P < 0.05$. The analysis revealed moderate correlation between several meat quality traits and sensory tenderness, including ultimate pH ($r = 0.36$), cooking loss ($r = -0.42$), and WBSF ($r = -0.47$). Only weak correlation ($r < 0.35$) was present between meat quality traits and sensory juiciness and sensory flavor. Data were then categorized into groups based on ultimate pH (low pH, $\text{pH} < 5.60$, $n = 16$; average pH, $5.60 \leq \text{pH} \leq 5.80$, $n = 70$; high pH, $\text{pH} > 5.80$, $n = 17$;) and WBSF values (tender, $\text{WBSF} < 2.5$ kg, $n = 25$; intermediate, $2.5 \text{ kg} \leq \text{WBSF} \leq 3.0$ kg, $n = 48$; tough, $\text{WBSF} > 3.0$ kg, $n = 30$). Data were analyzed using the GLIMMIX procedure of SAS with ultimate pH or WBSF category serving as the fixed effect and with linear regression modeling with the REG procedure of SAS, using sensory attributes as the dependent variables. These analyses revealed weak prediction but multicollinearity among ultimate pH and WBSF. Overall, while ultimate pH and WBSF influenced sensory attributes of pork tenderloins, future exploration for new measures of pork quality connecting biological mechanisms and eating experience would be beneficial for the pork industry.

Key words: pork quality, pork tenderloin, ultimate pH, shear force, sensory
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Introduction

Establishing relationships among quality traits and sensory attributes is important to advance consumer acceptance of pork, particularly for those of muscle cuts that have not been extensively studied. Pork tenderloins (muscle: *psoas major*) represent a relatively small proportion of total fresh pork consumption, yet are commonly marketed as whole muscle premium cuts. While the pork loin (muscle: *longissimus thoracis et lumborum*) comprises the largest market share for whole muscle cuts, the tenderloin is valued for its leanness, tenderness, superior water-holding capacity, and culinary versatility (Picardy et al., 2020; Market Report Analytics, 2025). Previous research suggested that pork tenderloins exhibited the lowest drip loss, lowest intramuscular fat content, lowest Warner-Bratzler shear force (WBSF) values, greatest sensory tenderness, and greatest sensory acceptance scores compared with the *longissimus thoracis, semitendinosus, triceps brachii, and gluteus medius* muscles (Wang et al., 2025).

Pork loins (muscle: *longissimus thoracis et lumborum*) and pork tenderloins (muscle: *psoas major*) have substantial differences in muscle fiber composition, energy metabolism, glycolytic potential, mitochondrial apoptosis, the rate and extent of pH decline, myofibrillar protein degradation, instrumental tenderness, and sensory traits (O'Sullivan et al., 2003; Lösel et al., 2013; Zhang et al., 2013; Guo et al., 2020;

Zhang et al., 2020; Wang et al., 2025). Specifically, Zhang et al. (2013) reported a lower proportion of oxidative muscle fibers and a greater proportion of glycolytic muscle fibers for the pork loin (type I = 0.94%; type IIA = 10.63%, type IIX = 13.33%; type IIB = 75.10%) compared with the pork tenderloin (type I = 3.65%; type IIA = 34.15%, type IIX = 20.62%; type IIB = 41.58%). Guo et al. (2020) reported similar differences in muscle fiber type proportions between the pork loin and the pork tenderloin while studying the developmental expression patterns of myosin heavy chain isoforms during the grow-finish period. Furthermore, the pork loin and the pork tenderloin have been shown to differ greatly during the early postmortem stage, where the pork tenderloin experiences a very rapid decline in postmortem pH. Zhang et al. (2013) reported pH = 5.88 for the tenderloin at 45 min postmortem compared with pH = 6.27 for the loin at 45 min postmortem; Wang et al. (2025) reported pH = 5.73 for the tenderloin at 1 h postmortem compared with pH = 6.13 for the loin at 1 h postmortem. These differences in muscle fiber type and early postmortem metabolism must be considered when using existing knowledge of the pork loin to make assumptions about the pork tenderloin. In general, the relationship between meat quality attributes—including ultimate pH (Bidner et al., 2004; Richardson et al., 2018), instrumental color (Norman et al., 2003; Wilson et al., 2017; Honegger et al., 2019), intramuscular lipid content (Lonergan et al., 2007; Cannata et al., 2010), and instrumental tenderness (Choe et al., 2015; Carlson et al., 2017)—and sensory attributes of pork loins (muscle: *longissimus thoracis et lumborum*) have been extensively studied. While the relationship between meat quality traits and sensory attributes of pork tenderloins has not been reported previously. Therefore, the objective of this study was to determine the association between meat quality traits and sensory attributes of pork tenderloins.

Materials and Methods

Approval from the Institutional Animal Care and Use Committee was not required because live animals were not used in this study. The sensory portion of the study was reviewed by the institutional review board at the Ohio State University, given the study number 2024E0962, and deemed exempt from full review.

Sample collection

A total of 103 pork tenderloin (muscle: *psoas major*) muscle cuts (Institutional Meat Purchase Specifications [IMPS] #415A; IMPS, 2014) were purchased from a commercial processor that uses electrical stunning and chilling, consisting of 20–24 h of exposure to ambient temperatures of approximately 2°C. All muscle cuts originated from the same slaughter and subsequent packaging days. Evaluations for fresh meat quality and instrumental texture analysis were carried out during 2 consecutive days, with 71 muscle cuts on the first day (8 d postmortem and 7 d post-packaging) and 32 muscle cuts on the second day (9 d postmortem and 8 d post-packaging). Each pork tenderloin was cut perpendicular to the ventral edge of the muscle into sections beginning at the posterior end (i.e., head end of the muscle), which resulted in a 5-cm thick section used for sensory analysis and a 10-cm thick section used for cooking loss and WBSF analysis. The remaining portion (*i.e.*, anterior/tail end of the muscle) was used for assessment of pH and instrumental color as well as for protein extraction. Following fresh meat quality evaluations, samples from the remaining portion were individually vacuum packaged and frozen at −80°C until protein extraction and further analysis took place. Pork chops for sensory analysis were individually vacuum packaged and preserved at −20°C until assessment, whereas those for WBSF analysis were cooked on the same day as the meat quality evaluations.

Meat quality assessment

Muscle pH was measured in duplicate in the center of the muscle (remaining portion of the muscle not used for sensory analysis or instrumental tenderness, i.e., anterior/tail end of the muscle) using a portable MPI pH meter (Meat Probes Inc., Topeka, Kansas, USA). The pH meter was calibrated with pH 4.01 and pH 7.00 buffers stored at refrigerated temperatures (≤ 4°C) before use. Instrumental L^* (lightness), a^* (redness), and b^* (yellowness) were measured on the cut surface of each pork tenderloin (following at least 30 min of blooming) using a calibrated, handheld Minolta CM-700d with D_{65} illuminance, 8° viewing angle, 10° observer, and an 8-mm aperture (Konica Minolta Sensing Inc., Osaka, Japan). Measurements for pH and instrumental color were conducted at 3 separate locations, and the average of these measurements was reported. Following pH and color evaluation, muscle samples of approximately 100 g were placed in sterile 15-mL plastic centrifuge tubes and then preserved at −80°C until protein extraction took place.

Samples (10-cm thick sections) used for cooking loss and WBSF analysis were weighed (to measure the raw weight for cooking loss), vacuum packaged in individual plastic bags, and cooked in a water bath which was set at 80°C (Precision general purpose water bath; Thermo Fisher Scientific, Waltham, Massachusetts, USA) for approximately 25 min to an internal endpoint cooking temperature of 71°C. Internal cooking temperature was monitored throughout cooking by inserting a digital temperature logger (ThermaQ, ThermoWorks, London, UK) with 2 thermocouples into the center of a non-study sample, which was of a similar weight and size when compared with study samples. Once the internal temperature reached the targeted endpoint cooking temperature, samples were immediately arranged in a single layer on a plastic tray and transferred to a 2 ± 1.5°C refrigerated room for a period of approximately 12 h. After 12 h of refrigerated storage, cooked samples were removed from the vacuum packages and reweighed. The percentage of weight difference between the initial raw weight and the cooked weight was calculated as cooking loss. The samples were cut perpendicular to the ventral edge into 3 sections of equivalent thickness (approximately 3 cm per section). For this study, only one of the 3 sections was used. Four cores without fat or connective tissue, parallel to muscle fiber orientation, were obtained from each cooked sample using a handheld coring device (1.25-cm diameter). Cores were sheared perpendicular to the fiber direction using a Warner-Bratzler shear attachment affixed to a TA-XT PlusC texture analyzer (Texture Technologies Corp., Hamilton, Massachusetts, USA). Pretest speed of 2.0 mm/s, test speed of 2.0 mm/s, post-test speed of 10.0 mm/s, and distance of 20 mm were used as the test-specific settings. The peak force (kg) required to shear through each core was recorded, and the average peak force of 4 cores was calculated for each sample.

Protein extraction was conducted following the procedure of Richardson et al. (2017) with a few modifications. Frozen samples were homogenized and powdered in liquid nitrogen, then approximately 0.15 g of the powdered sample was homogenized with 1 mL of whole muscle buffer (2% SDS wt/vol and 10 mM Sodium Phosphate, pH = 7.0) in a bead mill homogenizer (Fisherbrand Bead Mill 4 Homogenizer; Fisher Scientific International Inc., Pittsburgh, Pennsylvania, USA) at speed setting #2 for 200 s. The homogenate was then centrifuged at 3,220 × *g* for 15 min (Fisherbrand accuSpin Micro 17 microcentrifuge; Fisher Scientific International Inc.). Protein concentration of the supernatant was determined using a BCA Protein Assay Kit (Pierce Protein Research Products, Rockford, Illinois, USA). Samples were adjusted to a final protein concentration of 4.0 mg/mL by mixing 0.03 mL of β-mercaptoethanol, 0.25 mL of Laemmli sodium dodecyl sulfate SDS sample buffer tracking dye, and whole muscle buffer. Samples were then vortexed and placed on a heating block (Fisher Scientific IsoTemp heating block; Fisher Scientific International, Inc.) for 15 min at 50°C, followed by frozen storage at −80°C until further analysis occurred.

SDS-PAGE was used for running load checks to ensure proper protein concentrations were achieved. Protein samples (40 μg per well) were loaded into 4–12% Bis-Tris gels (Bolt 4–12% Bis-Tris PlusGels, 10-well; Invitrogen, Waltham, Massachusetts, USA). Gels were electrophoresed using Blot™ MES SDS running buffer (Invitrogen) and were then transferred to a PVDF blotting membrane with an iBlot 2 Western Blotting System (Invitrogen). Membranes were blocked using 5% nonfat dry milk in PBS-Tween solution for 1 h at room temperature and washed 3 times for 10 min each with PBS-Tween solution before transferring to an iBindTM Flex Western Device (Invitrogen). The membranes were incubated with mouse monoclonal anti-desmin IgG (Sigma-Aldrich D1022) as the primary antibody, and goat-anti-mouse IgG, HRP-linked antibody (ThermoFisher, A28177) as the secondary antibody. Both primary and secondary antibodies were diluted to 1:2000 in iBindTM Flex Solution. Blotting membranes were then washed with PBS-Tween solution 3 times before protein detection. Protein bands were detected using a western blotting chemiluminescent detection kit (Pierce ECL Western Blotting Substrate, Thermo Fisher Scientific). Immunoreactive bands were visualized using an iBright1500 imager (Invitrogen), and the area-defined density of each band was determined by iBright Analysis Software (Invitrogen). A nonstudy pork loin (*longissimus thoracis*) sample aged for 14 d postmortem was used as a consistent internal reference, which was loaded onto each gel to standardize protein band intensity measurements. The intensity of 55 kDa intact desmin, 42 kDa degraded desmin, and 38 kDa degraded desmin was quantified as a comparative ratio relative to the corresponding internal protein band on the same blot. All the samples were analyzed in duplicate across different blots, with a coefficient of variance less than 20% to ensure repeatable results, and the average results from the 2 blots were reported.

Sensory analysis

Trained sensory sessions consisted of individuals selected from a pool of students and staff from the Ohio State University. In total, 10 panelists were trained to evaluate pork tenderloins for tenderness, juiciness, and pork flavor during multiple training sessions. Tenderness and juiciness training was conducted by cooking pork tenderloins to internal endpoint temperatures of 63°C, 74°C, and 85°C using sous-vide cookers (Anova Precision Cooker; Anova Culinary; San Francisco, California, USA). Juiciness training consisted of cooking 2 pork tenderloins with or without pork broth created using pork bouillon cubes, with a broth dilution of 24 mg/mL (250 mL total) (Knorr brand, Unilever; Englewood Cliffs, New Jersey, USA) to an internal endpoint temperature of 74°C. Flavor training consisted of diluting pork bouillon cubes to 4 different dilutions (6 mg/mL, 12 mg/mL, 24 mg/mL, and 48 mg/mL) for panelists to evaluate the pork flavor differences. Additionally, a pork tenderloin and a pork blade steak were cooked to an internal endpoint temperature of 71°C to compare the pork flavor intensity. In the final training session, no tangible differences between the responses of tenderness, juiciness, and pork flavor from trained panelists were observed when presented with the same samples.

The 103 pork tenderloin samples were evaluated over 13 sessions. Each session included 7 or 8 study samples containing at least 2 samples from each of the 3 WBSF categories (categories described below in the statistical analysis section). Each sensory session was conducted by a six-member panel (selected from the ten-member group of trained panelists). Samples used for sensory evaluation were allowed to thaw for 24 h before each panel evaluation by placing the vacuum-packaged chops on a plastic tray in a single layer at refrigerated temperatures (approximately 4°C). Samples were placed in a water bath and cooked using a sous vide cooker (Anova Precision Cooker). Samples were clipped to the side of the water bath during cooking, and the sous vide cooker was positioned in the middle of the water bath to ensure uniform heat transfer rates for each sample. Samples were cooked in a water bath set to 71.5°C for approximately 1 h 10 min to reach an internal endpoint cooking temperature of 71°C. Internal temperature was monitored during cooking using a digital temperature logger (ThermaQ) with 2 thermocouples inserted into the center of the heaviest sample in each water bath. Following cooking, subcutaneous fat and silver skin were removed from each sample, and the remaining portion was cut into 1.5 cm × 1.5 cm × 1.5 cm cubes. Each panelist received 2 cubes from each of the study samples on a paper plate, and the standardized amount of time between the completion of cooking and serving was approximately 15 min. Panelists were seated in a classroom with one vacant seat separating each individual. Tenderness, juiciness, and flavor were measured on a 15-cm anchored scale, with anchor points set at 0, 7.5, and 15, respectively (0 = extremely tough, extremely dry, or no flavor and 15 = extremely tender, extremely juicy, or very intense flavor). Unsalted crackers and still water were provided to the panelists for palate cleaning between samples. Descriptive statistics were determined, and the average of the results from all 6 panelists was calculated for each pork tenderloin sample.

Statistical analysis

Each tenderloin sample ($n = 103$) served as an experimental unit. Summary statistics for ultimate pH, instrumental color, cooking loss, WBSF, and sensory variables were analyzed using the MEANS procedure of SAS v9.4 (SAS Institute Inc., Cary, North Carolina, USA). Pearson correlation coefficients between variables were determined using the CORR procedure of SAS. Correlations were considered weak at $|r| < 0.35$, moderate at $0.36 \leq |r| < 0.67$, and strong at $|r| \geq 0.68$ (Taylor, 1990). Multiple linear stepwise regression analysis was performed with the REG procedure with selection criteria of SLENTRY=0.15 to develop prediction equations for sensory attributes using meat quality traits and block (*i.e.*, day of evaluation; evaluations for fresh meat quality and instrumental texture analysis were carried out during 2 consecutive d) as independent variables. Simple linear regression with sensory attributes serving as the dependent variable and ultimate pH or WBSF serving as the independent variable was generated using the REG procedure of SAS.

Samples were classified into different categories based on ultimate pH and WBSF, respectively, using an in-situ design, where treatment assignments were not predetermined before the study. Groups based on ultimate pH were as follows: low pH, pH < 5.60, $n = 16$; average pH, $5.60 \leq \text{pH} \leq 5.80$, $n = 70$; high pH, pH > 5.80, $n = 17$. Groups based on WBSF values were as follows: tender, WBSF < 2.5 kg, $n = 25$; intermediate, 2.5 kg ≤ WBSF ≤ 3.0 kg, $n = 48$; tough, WBSF > 3.0 kg, $n = 30$. Normality was examined using the UNIVARIATE procedure of SAS, with consideration given to the Shapiro-Wilk test. Homogeneity of variance was evaluated using Levene's test, generated by the GLM procedure of SAS. All Levene's test values were nonsignificant ($P > 0.10$), indicating homogeneity of variances. The effects of ultimate pH and WBSF on meat quality traits and sensory attributes were analyzed as a randomized complete block design using the GLIMMIX procedure of SAS, with ultimate pH or WBSF category serving as the fixed effect and day of evaluation serving as the block (i.e., evaluations for fresh meat quality and instrumental texture analysis were carried out during 2 consecutive days). Least-squares means were determined using the LSMEANS statement, with a Tukey-Kramer adjustment used for the means separation. Differences for all analyses were considered significant at $P < 0.05$. Within each pH group, the prediction of sensory attributes using WBSF was determined using the REG procedure of SAS, and within each WBSF group, the prediction of sensory attributes using ultimate pH was determined using the REG procedure of SAS.

Results

Summary statistics and correlation analysis

Summary statistics provided baseline information for quality traits and sensory attributes of the pork tenderloins evaluated in this study (Table 1). Pearson correlation coefficients were presented in Table 2, and a number of significant correlation coefficients were present. Of note, sensory tenderness was significantly correlated with ultimate pH ($r = 0.36$; $P < 0.0001$), Minolta b^* ($r = -0.19$; $P = 0.05$), cooking loss ($r = -0.42$; $P < 0.0001$), WBSF ($r = -0.47$; $P < 0.0001$), and 42 kDa degraded desmin ($r = -0.29$; $P < 0.01$), sensory juiciness was significantly correlated with ultimate pH ($r = 0.25$; $P = 0.01$), Minolta a^* ($r = -0.21$; $P = 0.03$), Minolta b^* ($r = -0.21$; $P = 0.04$), cooking loss ($r = -0.26$; $P = 0.01$), and WBSF ($r = -0.25$; $P = 0.01$), and sensory flavor was significantly correlated with ultimate pH ($r = 0.23$; $P = 0.02$) and cooking loss ($r = -0.20$; $P = 0.04$).

Table 1. Summary statistics for fresh pork tenderloin quality traits and sensory attributes ($n = 103$).

	Mean	Std Dev	Minimum	Maximum
Ultimate pH	5.70	0.13	5.21	6.11
Lightness, Minolta L^*	49.08	3.14	41.19	56.50
Redness, Minolta a^*	7.44	1.84	2.67	12.17
Yellowness, Minolta b^*	12.93	1.46	9.53	16.85
Cooking Loss, %	19.31	2.19	11.95	25.76
WBSF, kg	2.79	0.38	1.89	3.64
Desmin[1]				
Intact (55 kDa)	0.39	0.70	0.01	3.72
Degraded (42 kDa)	0.33	0.25	0.02	1.40
Degraded (38 kDa)	2.64	1.16	0.04	5.95
Trained sensory attributes[2]				
Tenderness	8.66	1.45	5.60	12.00
Juiciness	7.14	1.68	3.10	11.30
Flavor	7.49	0.94	4.90	9.50

[1] Western blotting was used to compare intact desmin bands (55 kDa) and degraded desmin bands (42 kDa, 38 kDa) with the corresponding bands of a 14-d-aged pork loin sample as the reference; data represent the fold change from the reference sample.

[2] Evaluated on 15-point scale, where 0 = very tough, very dry, or no flavor and 15 = very tender, very juicy, or very flavorful.

Ultimate pH category analysis

Ultimate pH category significantly influenced ($P < 0.05$) several meat quality traits and sensory tenderness (Table 3). High pH (> 5.80) tenderloins had lower ($P < 0.05$) Minolta L^* values compared with average pH (5.60 to 5.80) tenderloins, both of which had lower ($P < 0.05$) Minolta L^* values compared with low pH (< 5.60) tenderloins. High pH (> 5.80) and average pH (5.60 to 5.80) tenderloins had lower ($P < 0.05$) Minolta b^* values compared with low pH (< 5.60) tenderloins. High pH (> 5.80) tenderloins had less ($P < 0.05$) cooking loss compared with average pH (5.60 to 5.80) and low pH (< 5.60) tenderloins. Minolta a* and WBSF did not differ ($P \geq 0.14$) among the ultimate pH categories.

The abundance of intact desmin (55 kDa) and 38 kDa degraded desmin was unaffected ($P \geq 0.47$) by ultimate pH category (Figure 1). However, low pH (< 5.60) tenderloins demonstrated greater ($P < 0.05$) abundance of 42 kDa degraded desmin than those in the average pH (5.60 to 5.80) or high pH (> 5.80) treatments. The variation of desmin degradation among different pH categories was likely driven by protease activity, which is influenced by pH. High pH (> 5.80) tenderloins had greater ($P < 0.05$) sensory tenderness scores compared with average pH (5.60 to 5.80) and low pH (< 5.60) tenderloins. Sensory juiciness ($P = 0.07$) and sensory flavor ($P = 0.36$) were not different among the pH categories.

WBSF category analysis

Most meat quality traits and sensory attributes were not influenced ($P \geq 0.13$) by WBSF categories (Table 4). The exceptions were WBSF value, 42 kDa degraded desmin, and sensory tenderness. The abundance of intact desmin (55 kDa) and 38 kDa degraded fragment was not influenced ($P \geq 0.17$) by WBSF category, whereas 42 kDa degraded desmin was less abundant ($P < 0.05$) for the tender category (WBSF < 2.5kg) compared with the tough category (WBSF > 3.0 kg) (Figure 2).

Table 2. Pearson correlation between quality traits and sensory attributes of pork tenderloin ($n = 103$).[1]

	Ultimate pH	Lightness, Minolta L*	Redness, Minolta a*	Yellowness, Minolta b*	Cooking Loss	WBSF	Intact Desmin (55 kDa)	Degraded Desmin (42 kDa)	Degraded Desmin (38 kDa)	Sensory Tenderness	Sensory Juiciness
Lightness, Minolta L*	**−0.47** (< 0.0001)										
Redness, Minolta a*	0.07 (0.49)	–0.19 (0.06)									
Yellowness, Minolta b*	**−0.41** (< 0.0001)	**0.62** (< 0.0001)	**0.42** (< 0.0001)								
Cooking loss	**−0.49** (< 0.0001)	**0.25** (0.01)	0.16 (0.11)	**0.29** (< 0.01)							
WBSF	**−0.21** (0.03)	0.10 (0.32)	**0.21** (0.04)	**0.21** (0.04)	**0.26** (0.01)						
Intact desmin (55 kDa)	0.17 (0.08)	−0.10 (0.34)	0.07 (0.48)	−0.02 (0.85)	−0.13 (0.18)	0.12 (0.23)					
Degraded desmin (42 kDa)	**−0.28** (< 0.01)	**0.29** (< 0.01)	0.19 (0.06)	**0.38** (< 0.01)	**0.37** (< 0.0001)	**0.32** (< 0.001)	0.13 (0.19)				
Degraded desmin (38 kDa)	−0.10 (0.31)	0.04 (0.67)	−0.10 (0.31)	< 0.01 (0.94)	0.03 (0.79)	−0.19 (0.06)	**−0.67** (< 0.0001)	**−0.25** (0.01)			
Sensory tenderness	**0.36** (< 0.0001)	−0.08 (0.40)	−0.10 (0.31)	**−0.19** (0.05)	**−0.42** (< 0.0001)	**−0.47** (< 0.0001)	− 0.08 (0.40)	**−0.29** (< 0.01)	0.12 (0.22)		
Sensory juiciness	**0.25** (0.01)	−0.02 (0.84)	**−0.21** (0.03)	**−0.21** (0.04)	**−0.26** (0.01)	**−0.25** (0.01)	0.08 (0.42)	−0.15 (0.13)	0.01 (0.93)	**0.54** (< 0.0001)	
Sensory flavor	**0.23** (0.02)	−0.01 (0.90)	−0.05 (0.65)	−0.12 (0.22)	**−0.20** (0.04)	−0.15 (0.14)	0.03 (0.73)	−0.01 (0.90)	0.09 (0.36)	**0.47** (< 0.0001)	**0.58** (< 0.0001)

[1] Upper row is the correlation coefficient between traits; bold values indicate significant correlations; P value for difference from zero provided in parentheses.

Table 3. The effect of ultimate pH categorization on fresh pork tenderloin quality, sensory characteristics, and desmin degradation.[1]

	Low pH (< 5.60) $n = 16$	Average pH (5.60 to 5.80) $n = 70$	High pH (> 5.80) $n = 17$	SEM	P Value
Ultimate pH	5.53^{c}	5.69^{b}	5.90^{a}	0.02	< 0.01
Lightness, Minolta L^*	51.80^{a}	48.98^{b}	46.67^{c}	0.70	< 0.01
Redness, Minolta a^*	7.25	7.39	7.89	0.46	0.56
Yellowness, Minolta b^*	13.91^{a}	12.92^{b}	12.27^{b}	0.40	< 0.01
Cooking loss, %	20.83^{a}	19.68^{a}	17.86^{b}	0.80	< 0.01
WBSF, kg	2.94	2.85	2.70	0.15	0.14
Desmin[2]					
Intact (55 kDa)	0.27	0.39	0.56	0.14	0.47
Degraded (42 kDa)	0.56^{a}	0.30^{b}	0.26^{b}	0.05	< 0.01
Degraded (38 kDa)	2.74	2.67	2.43	0.25	0.71
Trained sensory attributes[3]					
Tenderness	8.19^{b}	8.44^{b}	9.95^{a}	0.32	< 0.01
Juiciness	6.88	6.93	7.90	0.44	0.07
Flavor	7.29	7.46	7.74	0.24	0.36

[1] Superscripts within each row with different letters indicate significant differences ($P < 0.05$).

[2] Values are expressed as a relative ratio of band intensity compared to the corresponding bands of the reference samples.

[3] Evaluated on 15-point scale, where 0 = very tough, very dry, or no flavor and 15 = very tender, very juicy, or very flavorful.

SEM = standard error of mean.

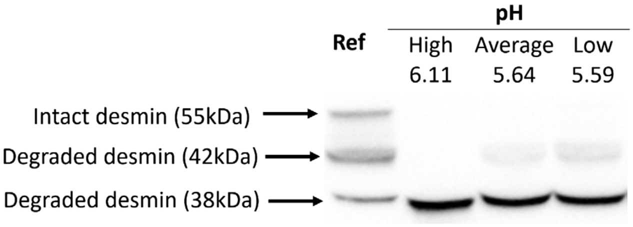

Figure 1. Representative western blot showing desmin degradation in pork *psoas major* muscle with varying pH categories. Intact bands (55 kDa) and degradation bands (42 kDa, 38 kDa) were compared to corresponding bands of a 14-d-aged pork loin sample (Ref). pH values are provided for the samples, and samples are labeled high/average/low depending on pH.

Prediction of sensory attributes using ultimate pH and WBSF

Multiple linear regression revealed low levels of prediction for sensory attributes when using all meat quality traits evaluated in this study as the independent variables (*data not included*). In summary, 35.3% of the variation for sensory tenderness was explained with WBSF (partial $R^2 = 0.22$; $P < 0.0001$), cooking loss (partial $R^2 = 0.10$; $P < 0.001$), block (partial $R^2 = 0.02$; $P = 0.08$), and ultimate pH (partial $R^2 = 0.02$; $P = 0.09$); 8.3% of the variation for sensory juiciness was explained with WBSF (partial $R^2 = 0.04$; $P = 0.04$), ultimate pH (partial $R^2 = 0.02$; $P = 0.10$), and Minolta a^* (partial $R^2 = 0.02$; $P = 0.13$); 5.6% of the variation for sensory flavor was explained with ultimate pH (partial $R^2 = 0.06$; $P = 0.02$).

Simple linear regression models were generated with ultimate pH serving as the independent variable and sensory attributes serving as the dependent variables (Figure 3). Low levels of prediction were reported for all models (13% of the variation in sensory tenderness was explained by ultimate pH, 7% of the variation in sensory juiciness was explained by ultimate pH, and 6% of the variation in sensory flavor was explained by ultimate pH). Interestingly, when the same linear regression models (ultimate pH serving as the independent variable and sensory attributes serving as the dependent variables) were generated within each WBSF category, the tough category (WBSF > 3.0 kg) explained 20% of the variation in sensory tenderness and the tender WBSF category (WBSF < 2.5 kg) explained 19% of the variation in sensory juiciness and 23% of the variation in sensory flavor (Table 5).

Linear regression models were generated with WBSF serving as the independent variable and sensory attributes serving as the dependent variables (Figure 4). Low levels of prediction were reported for all models (22% of the variation in sensory tenderness was explained by WBSF, 6% of the variation in sensory juiciness was explained by WBSF, and 2% of the variation in sensory flavor was explained by WBSF). Interestingly, when the same linear regression models (WBSF serving as the independent variable and sensory attributes serving as the dependent variables) were generated within each pH category, the low pH

Table 4. The effect of Warner-Bratzler shear force categorization on fresh pork tenderloin quality, sensory characteristics, and desmin degradation.[1]

	Tender (< 2.5 kg) *n* = 25	Intermediate (2.5 to 3.0 kg) *n* = 48	Tough (> 3.0 kg) *n* = 30	SEM	*P* Value
WBSF, kg	2.32^{c}	2.77^{b}	3.25^{a}	0.04	< 0.01
Ultimate pH	5.72	5.69	5.67	0.04	0.36
Lightness, Minolta L^*	48.82	48.99	49.42	0.63	0.76
Redness, Minolta a^*	6.99	7.40	7.88	0.37	0.20
Yellowness, Minolta b^*	12.83	13.00	13.22	0.42	0.63
Cooking loss, %	19.02	19.65	19.97	0.9	0.25
Desmin[2]					
Intact (55 kDa)	0.31	0.38	0.47	0.12	0.70
Degraded (42 kDa)	0.22^{b}	0.33^{ab}	0.42^{a}	0.04	0.01
Degraded (38 kDa)	2.98	2.65	2.40	0.22	0.17
Trained sensory attributes[3]					
Tenderness	9.59^{a}	8.59^{b}	8.01^{b}	0.27	< 0.01
Juiciness	7.54	7.19	6.67	0.35	0.16
Flavor	7.82	7.39	7.35	0.2	0.13

[1] *n* = 103 pork tenderloin muscles; superscripts within each row with different letters indicate significant differences ($P < 0.05$).

[2] Values are expressed as a relative ratio of band intensity compared to the corresponding bands of the reference samples.

[3] Evaluated on 15-point scale, where 0 = very tough, very dry, or no flavor and 15 = very tender, very juicy, or very flavorful.

SEM = standard error of mean.

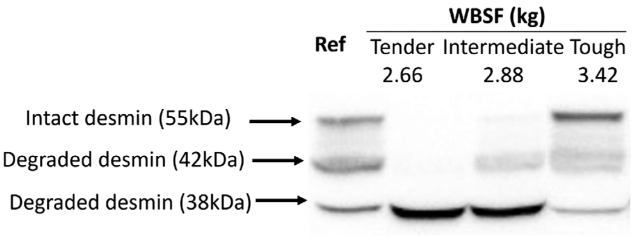

Figure 2. Representative western blot showing desmin degradation in pork *psoas major* muscle with varying Warner-Bratzler shear force (WBSF) category. Intact bands (55 kDa) and degradation bands (42 kDa, 38 kDa) were compared to corresponding bands of a 14-d-aged pork loin sample (Ref). Warner-Bratzler shear force values (kg) are provided for the samples, and samples are labeled tender/intermediate/tough depending on WBSF.

category (< 5.60) explained 39% of the variation in sensory tenderness (Table 6).

The improved prediction ability of sensory attributes within the WBSF and pH categories implies that multicollinearity exists among ultimate pH and WBSF, which may warrant further investigation in the pork tenderloin, as well as other muscles throughout the pork carcass.

Discussion

Quality traits and sensory attributes were at similar values in the current study as reported by other studies evaluating the pork tenderloin (Warner et al., 1993; Barkley et al., 2023; Wang et al., 2025). It has been shown that the pork tenderloin (muscle: *psoas major*) has unique properties in terms of muscle fiber composition, energy metabolism, glycolytic potential, mitochondrial apoptosis, the rate and extent of pH decline, myofibrillar protein degradation, instrumental tenderness, and sensory traits (O'Sullivan et al., 2003; Lösel et al., 2013; Zhang et al., 2013; Guo et al., 2020; Zhang et al., 2020; Wang et al., 2025). Zhang et al. (2020) reported that although tenderloins exhibited greater mitochondrial apoptotic factors compared with loins, such as increased mitochondrial membrane permeability, caspase-3 activity, and Ca^{2+} concentration, tenderloins demonstrated more intact desmin, less troponin-T degradation, and lower levels of autolyzed calpain-1 compared with loins. In addition, Wang et al. (2025) demonstrated that the tenderloin experiences limited proteolytic changes during aging, particularly in comparison with the loin. These findings may provide support that mitochondrial apoptosis-mediated proteolysis is muscle-specific, and the tenderloin is truly unique in its metabolic properties. Provided with the muscle-specific nature of proteolysis, myofibrillar protein degradation for tenderloins is likely influenced by alternative pathways that may not favor a higher ultimate pH over a lower ultimate pH, such as the caspase system and other proteolytic enzyme systems.

Results from the current study indicated that high pH tenderloins (> 5.80) were darker (lower Minolta L^*), less yellow (lower Minolta b^*), had lower levels of cooking loss, had numerically greater levels of intact

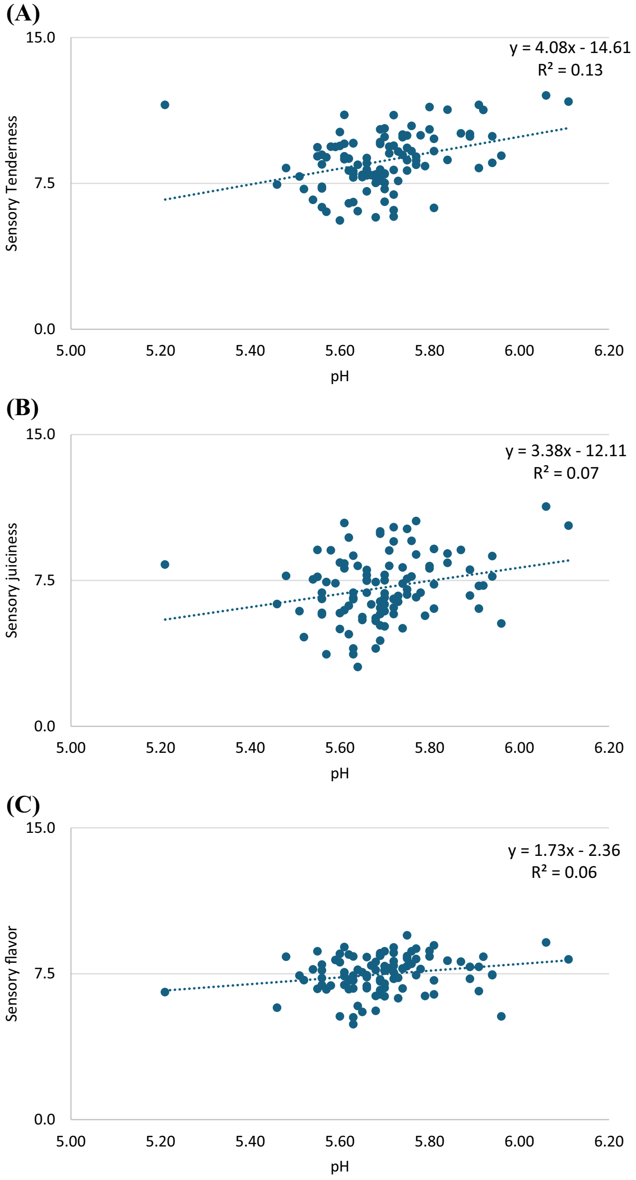

Figure 3. Prediction of sensory tenderness (Figure 3A), sensory juiciness (Figure 3B), and sensory flavor (Figure 3C) using pH as the independent variable. Tenderness, juiciness, and flavor were assessed using a trained sensory panel and measured on a 15-cm anchored scale, with anchor points set at 0, 7.5, and 15, respectively (0 = extremely tough, extremely dry, or no flavor and 15 = extremely tender, extremely juicy, or very intense flavor).

Table 5. Prediction of sensory attributes using ultimate pH as the independent variable, within the Warner-Bratzler shear force categories for pork tenderloins.[1]

	Tender (< 2.5 kg) *n* = 25	Intermediate (2.5 to 3.0 kg) *n* = 48	Tough (> 3.0 kg) *n* = 30
Sensory tenderness			
R^2	0.09	0.08	**0.20**
Intercept	–3.97	–9.60	**–27.11**
Estimated slope	2.37	3.19	**6.20**
Model *P* value	0.16	0.06	**0.01**
Sensory juiciness			
R^2	**0.19**	0.01	0.02
Intercept	**–20.17**	0.10	–6.39
Estimated slope	**4.84**	1.25	2.30
Model *P* value	**0.03**	0.56	0.42
Sensory flavor			
R^2	**0.23**	< 0.01	0.08
Intercept	**–6.90**	7.49	–6.89
Estimated slope	**2.57**	–0.02	2.51
Model *P* value	**0.02**	0.99	0.13

[1] Significant ($P < 0.05$) contribution of ultimate pH to each trait was identified by a significant R^2 and estimated slope (shown in bold).

desmin, lower levels of degraded desmin, and had improved sensory attributes compared with low pH tenderloins (< 5.60). The association of high pH levels with greater water-holding capacity and improved sensory attributes has been previously reported for the pork loin (Lonergan et al., 2007; Richardson et al., 2018; Moeller et al., 2010). Previous studies, including Miller et al. (2020) and Warner et al. (2021), have postulated that the improved water-holding capacity, associated with greater ultimate pH, not only decreases cooking loss but may also dilute the structural effect of proteins during mastication, resulting in a perception of more tender pork to sensory panelists. While most previous research has not elucidated the 42 kDa degraded desmin band, 55 kDa intact desmin and 38 kDa degraded desmin have been extensively reported in pork loin studies. Bee et al. (2007) reported greater abundance of intact desmin and lower levels of 76 kDa calpain-1 in low pH (pH < 5.7 at 3 h postmortem) pork loins compared with high pH (pH > 6.0 at 3 h postmortem) pork loins. Yin et al. (2014) reported greater abundance of intact desmin and lower levels of 76 kDa calpain-1 in pale, soft, and exudative pork loins compared with red, firm, and nonexudative pork loins. Zuber et al. (2021) reported that loins with a low ultimate pH (5.38 to 5.45 at 14 d postmortem) had a greater abundance of intact desmin throughout the aging period compared with loins with a normal ultimate pH (5.53 to 5.67 at 14 d postmortem). All of which suggests a faster rate of pH decline for pork loins during the early postmortem period is associated with earlier calpain-1 autolysis and less desmin degradation throughout the aging period. However, in the current study, pork tenderloins with a greater ultimate pH (> 5.80) had numerically greater levels of intact desmin and lower levels of degraded desmin compared with pork tenderloins with low ultimate pH (< 5.60). This warrants further investigation, particularly provided

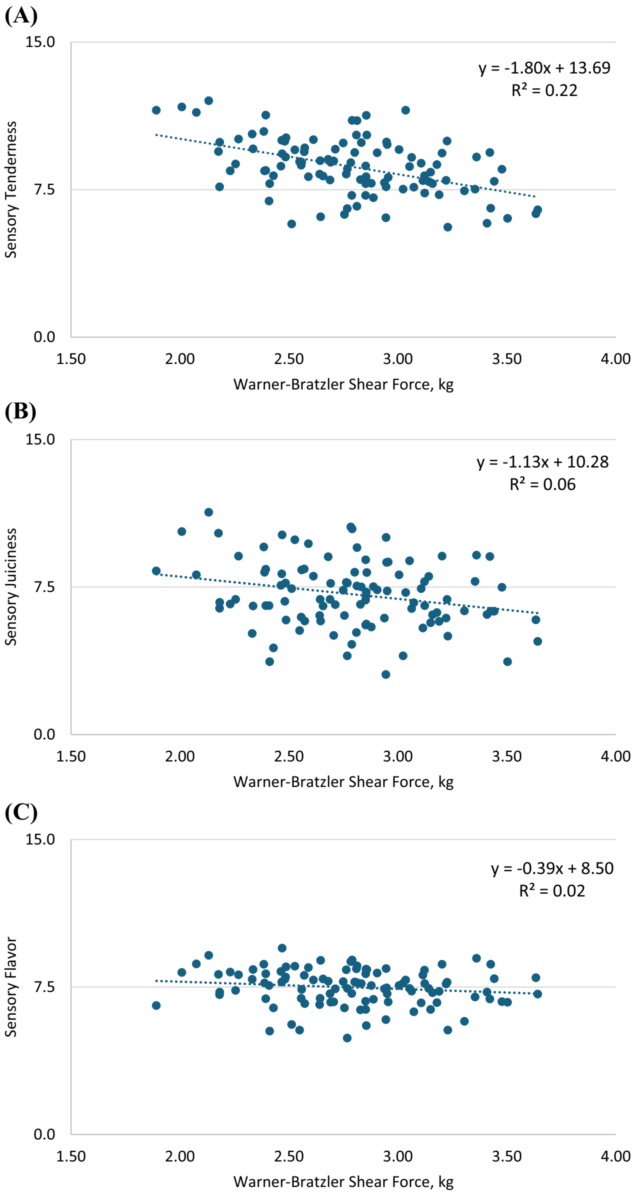

Figure 4. Prediction of sensory tenderness (Figure 4A), sensory juiciness (Figure 4B), and sensory flavor (Figure 4C) using Warner-Bratzler shear force as the independent variable. Tenderness, juiciness, and flavor were assessed using a trained sensory panel and measured on a 15-cm anchored scale, with anchor points set at 0, 7.5, and 15, respectively (0 = extremely tough, extremely dry, or no flavor and 15 = extremely tender, extremely juicy, or very intense flavor).

Table 6. Prediction of sensory attributes using Warner-Bratzler shear force as the independent variable, within the pH categories for pork tenderloins.[1]

	Low pH (< 5.60) *n* = 16	Average pH (5.60 to 5.80) *n* = 70	High pH (> 5.80) *n* = 17
Sensory tenderness			
R^2	**0.39**	**0.16**	0.12
Intercept	**14.17**	**12.71**	13.65
Estimated slope	**−2.02**	**−1.51**	−1.44
Model *P* value	**0.01**	**< 0.001**	0.18
Sensory juiciness			
R^2	0.08	0.04	0.08
Intercept	9.62	9.66	11.23
Estimated slope	−0.94	−0.95	−1.23
Model *P* value	0.28	0.11	0.28
Sensory flavor			
R^2	0.02	0.04	< 0.01
Intercept	6.58	9.12	7.66
Estimated slope	0.24	−0.58	< 0.01
Model *P* value	0.61	0.08	1.00

[1] Significant ($P < 0.05$) contribution of Warner-Bratzler shear force to each trait was identified by a significant R^2 and estimated slope (shown in bold).

that the water-holding capacity and sensory attributes were improved in tenderloins with greater levels of intact desmin and lower levels of degraded desmin (i.e., the high pH group compared with the low pH group).

In the current study, most meat quality traits and sensory attributes were not influenced by the WBSF categories. One of the exceptions was 42 kDa degraded desmin, which was greater for the tough category (WBSF > 3.0 kg) compared with the tender category (WBSF < 2.5 kg). The degradation of desmin, which integrates myofibrils with surrounding organelles and provides interlinkages for myofibrils at the Z-line, has consistently been associated with the reduced instrumental tenderness (Wheeler et al., 2002; Melody et al., 2004; Schulte et al., 2020). Carlson et al. (2017) reported that loins with low star probe values exhibited lower abundance of intact desmin and greater abundance of 38 kDa degraded desmin compared with samples with high star probe values. Schulte et al. (2020) documented that the abundance of intact desmin in the low star probe loins decreased by 67% from 1 to 21 d of postmortem aging, while the abundance of intact desmin decreased by 30% for the high star probe pork loins during the aging period. Despite the variation in desmin degradation, Schulte et al. (2020) also reported greater marbling score, longer sarcomere length, greater abundance of metabolic, regulatory, and mitochondrial-associated proteins, and lower abundance of stress response proteins for loins with high star probe values compared with those with low star probe values. Their results suggested that the differences in tenderness of loins were also influenced by their glycolytic metabolism capabilities. Similarly, in the current study, variation of tenderness for tenderloins may be attributed not only to the differences in desmin degradation, but also to the variation of proteolysis of other myofibrillar proteins, sarcomere length, the sarcoplasmic proteome, and other metabolic intricacies specific to the tenderloin muscle. In particular, the early postmortem metabolic processes for the tenderloin muscle, including mitochondrial membrane permeability, mitochondrial lipid peroxidation, and proteolytic enzyme activity beyond that of the calpain system, should be further explored.

Conclusion

This study indicates that ultimate pH and WBSF influenced sensory attributes of pork tenderloins, but with relatively low levels of prediction when evaluated with linear regression. Collectively, the meat quality traits measured in this study—including WBSF, ultimate pH, cooking loss, instrumental color, and desmin degradation—only accounted for approximately 35% of the variation in sensory tenderness, approximately 8% of the variation in sensory juiciness, and approximately 6% of the variation in sensory flavor. Similar to the pork loin (muscle: *longissimus thoracis et lumborum*), the current meat quality traits that are measured provide weak to moderate prediction of sensory attributes for the pork tenderloin (muscle: *psoas major*); however, differences in proteolytic activity during the early postmortem and aging periods may be present between the pork loin and the pork tenderloin and warrants further investigation. Research connecting biological mechanisms and eating experience is essential if a quality-based merit system is to be established in the pork industry. This research highlights the need to identify new quality traits to improve the predictive accuracy of sensory attributes and establish quality specifications for pork tenderloins, as well as the need to use muscle-specific approaches when evaluating pork quality and eating experience.

Conflict of Interest

The authors declare no conflicts of interest.

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Author Contribution

Yifei Wang: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing.

Jacqueline Bush: Investigation

Benjamin M. Bohrer: Conceptualization, Data curation, Methodology, Investigation, Supervision, Funding acquisition, Project administration, Writing – review & editing.

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