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Trained sensory perception of pork eating quality as affected by fresh and cooked pork quality attributes and end-point cooked temperature

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ABSTRACT

The present study evaluated individual and interactive influences of pork loin ($n = 679$) ultimate ph (pH), intramuscular fat (IMF), Minolta L^* color (L^*), Warner-Bratzler shear force (WBSF), and internal cooked temperatures (62.8 °C, 68.3 °C, 73.9 °C, and 79.4 °C) on trained sensory perception of palatability. Logistical regression analyses were used, fitting sensory responses as dependent variables and quality and cooked temperature as independent variables, testing quadratic and interactive effects. Incremental increases in cooked temperature reduced sensory juiciness and tenderness scores by 3.8% and 0.9%, respectively, but did not influence sensory flavor or saltiness scores. An increase of 4.9 N in WBSF, from a base of 14.7 N (lowest) to 58.8 N (greatest) was associated with a 3.7% and 1.8% reduction in sensory tenderness and juiciness scores, respectively, with predicted sensory tenderness scores reduced by 3.55 units when comparing ends of the WBSF range. Modeled sensory responses for loins with pH of 5.40 and 5.60 had reduced tenderness, chewiness, and fat flavor ratings when compared with responses for loins with pH of 5.80 to 6.40, the range indicative of optimal sensory response. Loin IMF and L^* were significant model effects; however, their influence on sensory attributes was small, with predicted mean sensory responses measurably improved only when comparing 6% and 1% IMF and L^* values of 46.9 (dark) when compared with 65.0 (pale). Tenderness and juiciness scores, were related to a greater extent to loin WBSF and pH, and to a lesser extent to cooked temperature, IMF and L^*.

1. Introduction

Fresh meat quality is a term that encompasses several factors including wholesomeness, healthfulness, visual properties, and palatability. All of these factors can be influenced by various antemortem factors including transport (Leheska, Wulf, & Maddock, 2002), feeding, and exercise strategies (Rosenvold et al., 2001), as well as postmortem strategies including variation in carcass suspension (Moller, Kirkegaard, & Vestergaard, 1987; Moller & Vestergaard, 1986). However, at the commercial level, from the farm through the packing plant, there are no standard procedures utilized to assure consistency, resulting in extensive variation in muscle quality properties that influence pork eating satisfaction. Because variation in fresh pork quality continues to exist at the retail level, it is important to take a fundamental look at the combination of quality attributes observed in pork products and determine their influence on eating quality. Through the use of trained sensory methods, an assessment of the influence of individual and combinations of quality attributes can be assessed. Utilization of these findings will help define expectations with regard to the ability of consumers to differentiate among levels of a given attribute, identify individual or combinations of quality attributes to target for improvement, and potentially establish quality targets for the pork industry. Therefore, the objective of the present study was to evaluate the potential independent and interactive influences of commonly measured pork quality indicators (loin color, pH, intramuscular fat, and shear force) on trained sensory panel perception of pork eating quality across four cooked temperatures. To achieve this objective, commercially derived loins were selected to capture and test the variation in and combinations of pork quality present in the US pork industry.

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2. Materials and methods

2.1. Loin selection criteria

Loins utilized ($n = 679$) represented a subset of loins collected ($n = 1120$) within three U.S. commercial packing facilities ($n = 228$, 228, and 223 loins per plant). By design, loins used were selected to represent the normal range of industry observed values and selected with the statistical ability to test main and interactive effects of fresh pork quality measurements (Minolta L^* (L^*), ultimate pH (pH), and intramuscular fat percentage (IMF)) on sensory panel measures of palatability. Post-collection, loins were placed into three-dimensional subclasses based on L^* (3.9 unit increments), pH (0.10 unit increments) and IMF (1% increments). Loins chosen for sampling were selected, to the extent possible, to create a uniform distribution for each individual quality measurement.

2.2. Loin quality assessment

Whole, boneless loins were collected on the fabrication line at approximately 24 h postmortem. Using the size of the *spinalis dorsi* muscle as an anatomical indicator, the loin was cut at approximately the 7th rib, and the cut surface was allowed to "bloom" for 10 min. Loin pH was measured using a portable pH meter (HI98240, Hanna Instruments, Italy) equipped with a glass-tipped pH probe (FC201D, Hanna Instruments, Italy) placed in the center on the exposed 7th rib loin surface and inserted approximately 1 cm under the cut surface. After "bloom", loin color was measured on the 7th rib loin surface using a Minolta Colorimeter (CR-310, 50 mm diameter orifice, 10° standard observer, D^{65} light source, calibrated against a white tile; Minolta Company, Ramsey, New Jersey), recording L^*.

A 1.25 cm-thick section of loin was cut immediately posterior to the 7th rib location, subcutaneous fat and connective tissue removed, and the muscle used for subsequent assessment of moisture and fat amounts using the air-dry oven and Soxhlet ether extraction methods (AOAC, 2007), respectively. Approximately 2 g of powdered sample from each chop was added to dried, pre-weighed thimbles (filter paper #1, Whatman®, Maidstone, England), and weights were recorded. Analysis of the samples was performed in triplicate. The samples were dried in a convection oven at 100 °C for 18–24 h then removed and placed in a dessicator for cooling. Weights were taken and recorded to determine percent moisture. Samples were placed in a Soxhlet apparatus and refluxed with petroleum ether for approximately 18 h. Samples were removed and placed under a hood to allow ether to evaporate and then placed in a convection oven for approximately 12 h. Samples were removed and placed in a dessicator until cooled to room temperature. Weights were taken and recorded to determine percent fat (IMF) in each sample.

Following quality assessment, whole loins were weighed and individually vacuum-sealed for storage and transportation. Loins were transported under refrigeration to The Ohio State University Meat Science Laboratory, Columbus, OH, where the loins were stored and aged at 2 °C for a minimum of 7 and maximum of 10 d postmortem, with processing occurring on the Friday following the previous sampling week.

An additional factor included in the present study, but not reported in this manuscript, was a comparison between enhanced and non-enhanced pork loins with similar 24 h fresh pork quality parameters. Although the focus of the present manuscript is a study of trained sensory panel perceptions regarding non-enhanced pork, the procedures involved in loin selection and trained sensory panel evaluation portions of the study require provision of a brief description of collection procedures for the enhanced product. Briefly, within one packing plant, sampling numbers were doubled and loins were classified based on quality parameters and paired. Pairs of similar quality loins were then randomly assigned to enhancement or non-enhancement. Enhancement was completed using needle injection. Final loin target inclusion rates were: 10% pump rate, 2.5% potassium lactate, 0.35% sodium phosphate, and 0.35% salt.

2.3. Loin processing

After aging, loins were removed from their package and weighed to assess loin purge loss. Loins were then tempered in a freezer (−28.8 °C), creating a slightly frozen surface, and sliced, beginning at the anterior end, into 12, 2.54 cm-thick chops. Four chops per loin were then randomly assigned to three experimental groups (consumer sensory evaluation, trained sensory evaluation, or Warner-Bratzler Shear Force (WBS) assessment) and, within each experimental group, to one of four end-point cooked temperatures (62.8 °C, 68.3 °C, 73.9 °C, or 79.4 °C). While previous research (Hansen, Hansen, Aaslyng, & Byrne, 2004) described longitudinal variation in loin sensory tenderness measures, randomization of chops to experimental group and within experimental group to a cooked temperature end-point avoided confounding of chop location with L^*, pH, and IMF measurements obtained only at the 7th rib location. Following allocation, chops were individually packaged using a roll-stock machine and frozen at −28.8 °C until used within their respective experimental group.

2.4. Warner-Bratzler shear force

Warner-Bratzler shear force chops were weighed prior to and after thawing to assess thaw purge. Chops were cooked using a clam-style cooker (George Foreman grill) to the designated internal cooked temperature. Internal temperature (Digi-sense, Model # 277653 or equivalent) was monitored by copper constant thermocouples (Digi-sense, K-type probe, 30.48 cm × 1.016 cm diameter, Code 93631-11 or equivalent) inserted into the geometric center of each chop. Chops were removed from the grill at their designated temperature, recording cooking time, temperature, and cooked weight. Cook loss was measured using pre- and post-cooked weights. Chops were cooled for four hours to approximately 22.2 °C prior to tenderness assessment. Six, 1.27 cm diameters cores were removed from each chop parallel to the longitudinal orientation of the muscle fibers. Each core was sheared with a Warner-Bratzler shearing device (Model TA.XT2^{plus} Texture Technologies, Scarsdale, New York) with a probe travel distance of 40 mm from the base, a pre-test speed of 5 mm/s, a test speed of 3.33 mm/s and a post-test speed of 20 mm/s.

2.5. Trained sensory panel evaluation procedures

Trained sensory panel testing was conducted at Texas A&M University and Iowa State University to accommodate the large number of chops ($n = 3616$). Prior to initiation of the sensory testing, cross-training of panelists was conducted; in addition, panel location was included in statistical modeling to account for location differences in responses. Testing required approximately 83 d of testing within each sensory panel location. Loins were sorted within packing plant of origin based on quality classification and were alternately assigned to a trained sensory panel location in an attempt to establish a near uniform representation of quality variation within each panel location. The four chops within a loin, each representing a cooked temperature, were tested in the same panel location. Chops were sampled within cooking session to represent two or more plants, two or more temperatures, and both enhanced and non-enhanced without regard for variation in quality parameters.

Sensory panels consisted of five individuals evaluating ~24 samples per test day with a balanced representation of non-enhanced chops from the three packing plants and enhanced product (not reported in this manuscript) from one packing plant. Panelists were provided a warm-up sample for panel calibration prior to each testing session. Cooked temperature was random within a given trained panel testing session. Chops were cooked using the method described previously for assessment of WBSF to the target internal temperature. Cooked yield, cook time, and final temperature were recorded only in the Texas A&M taste panel. Immediately after cooking, chops were cut into 1.27 cm width × 1.27 cm length × 2.54 cm height cubes with two cubes placed in serving boats representing a sample for each trained panelist.

Samples were served under red incandescent lighting to minimize sample color variation due to differing end-point temperatures and or quality attributes. Panelists cleansed their pallet prior to the first and between samples with an unsalted, saltine cracker and distilled water. The trained sensory ballot consisted of five questions measured on a 10-point categorical intensity scale. The questions were: Juiciness Level (JL), 1 = Dry and 10 = Juicy; Tenderness Level (TL), 1 = Tough and 10 = Tender; Chewiness Level (CL), 1 = Not Chewy and 10 = Very Chewy; Cooked Pork Fat Flavor (FF), 1 = None and 10 = Intense; Saltiness, 1 = None and 10 = Intense. Within the Texas A&M panel, Cooked Pork Lean Flavor (LF) was evaluated whereby, 1 = None and 10 = Intense. Saltiness was included as descriptive attribute for the purpose of comparing non-enhanced and enhanced product. Saltiness level arithmetic (1.16) and model predicted mean responses (1.01) presented are reflective of $\geqslant$98% of sensory responses being a ‘1’ on the 10-point scale when assessing only non-enhanced loins.

2.6. Statistical analyses

The present study was designed for analysis using regression procedures. Data were analyzed using ordered logistical regression through STATA software (StataCorp, LP, College Station, TX) and the output parameters summarized using CLARIFY V 2.1 (Tomz, Wittenberg, & King, 2003). Dependent variables included trained sensory responses to ballot questions for chops representing non-enhanced loins only and representing product derived from three packing plants. Preliminary models tested the continuous independent variables cooked temperature, pH, IMF, L^*, and WBSF as linear and quadratic effects, and the two-way interactions among independent variables were tested. Plant of origin and trained sensory panel were included as independent effects. Model solutions were used to estimate mean response levels and predicted trained sensory response proportions for, and encompassing the range of, each independent variable in the regression model. Correlation statistics were used to describe linear relationships among variables of interest.

3. Results and discussion

Descriptive statistics for fresh pork loin quality attributes, WBSF tenderness at each end-point cooked temperature, and mean trained sensory panel responses for each panel are presented in Table 1. Classification and sorting procedures utilized in the study appear to have adequately partitioned loins among the trained panels as mean, standard deviation and ranges evaluated were very similar across the two trained panels. Small differences were observed in mean responses across the panels for nearly all questions, justifying the inclusion of panel effects in statistical models. Pork FF mean levels were very near 2 on the 10-point scale, with sensory panelists realistically using scores of 1, 2 or 3, with very few scores between 4 and 7 on the 10-point scale. Salt Level mean response was near 1 (none), which was expected given that the chop samples were served without any flavor adding ingredients.

A summary of significant ordered logistical regression model effects for all dependent trained sensory variables is provided in Table 2. For all dependent variables, the final models included independent effects of cooked temperature, IMF, pH, Minolta L^*, and WBSF regardless of significance levels within the model because these factors were the primary design-focused attributes. In the final statistical models for JL and FF, the quadratic pH effect was not significant and was therefore removed prior to estimating response means. A major finding of the present study was that interactions among independent variables were not observed for the trained responses tested, and with the exception of loin pH, no quadratic effects were observed. The large sample size allowed for very small differences among some independent variables to be statistically significant over the range tested, resulting in differences that may be of limited practical value. Instances where small differences were significant have been identified.

Analyses reported within the present study do not indicate interactions among quality measurements, implying that there is no evidence of statistical dependencies among the independent quality measurement variables as they relate to sensory panel assessment of eating quality: nor, with the exception of quadratic pH responses for some sensory traits, did the analyses of quality measures evaluated appear to provide discernable threshold levels whereby sensory perception of eating quality characteristics was either markedly improved or reduced. Of note, the report of results reflect independent effects of incremental changes in a specific independent variable while maintaining all other model effects at their respective mean values.

Correlations (Table 3) describing linear relationships among trained sensory measurements and between sensory responses and pork quality attributes observed reflect moderate relationships between JL and TL ($r = 0.53$), CL ($r = -0.43$) and LF ($r = 0.38$). Tenderness Level was highly, negatively correlated with CL ($r = -0.71$) indicating tougher pork was also chewier, a relationship that was expected to exist as both attributes reflect a panel’s attempt to evaluate meat structure. Of the relationships between sensory attributes and pork quality measures, the largest correlations were observed with pH in relation to JL ($r = 0.21$) and TL ($r = 0.29$) and for WBSF in relation to JL ($r = -0.23$), TL ($r = -0.41$), and CL ($r = 0.29$), indicating loins with greater pH and lower WBSF were rated by sensory panelists as more juicy and tender, as well as less chewy. Direction of the correlations between L^* and sensory attributes indicate that greater L^* (paler) was associated with drier, tougher and chewier pork.

3.1. Temperature effects

Panelists were able to detect measurable and significant reductions in JL ratings as cooked temperature increased (Table 4). Incrementally, mean JL responses declined by 0.38 units for each 5.5 °C increase in cooked temperature, and the proportion of panelists responses predicted to be $\geqslant$7 on the 10-point scale were reduced from 46.3% at 62.5 °C to 20% when cooked temperature was 79.4 °C. Heymann, Hedrick, Karrasch, Eggeman, and Ellersieck (1990) also identified a reduction in juiciness scores (from 5.4 to 4.2 on a 9-point scale) when cooked temperature of pork roasts increased from 60 to 80 °C. The reduction in JL responses is consistent with an observed significant increase in the percentage cook loss (9.54 ± 0.17% at 62.8 °C, 9.93 ± 0.17% at 68.3 °C, 10.98 ± 0.17% at 73.9 °C, and 12.50 ± 0.17% at 79.4 °C) as cooked temperature increased. Baublits, Meullenet, Sawyer, Mehaffey, and Saha (2006) and Torley, D’Arcy, and Trout (2000) reported that pork loin chops

Table 1
Characterization of loin quality attributes and trained sensory response variables for loins served in trained sensory preference testing studies.

Trait	Panel 1				Panel 2			
	N	Mean	Std. dev.	Range	*N*	Mean	Std. dev.	Range
Ultimate pH	330	5.76	0.24	5.35–6.50	349	5.77	0.24	5.34–6.48
Minolta L^*	330	52.77	4.42	40.9–65.4	349	52.87	4.15	41.74–64.40
Minolta a^*	330	17.50	1.37	11.7–21.0	349	17.37	1.40	11.80–20.90
Minolta b^*	330	5.09	1.36	1.93–10.60	349	5.19	1.38	2.05–9.40
NPPC color[a], 1–6	330	3.13	1.04	1–5	349	3.12	0.99	1–5
Intramuscular fat (%)	330	3.01	1.41	0.49–6.93	349	3.11	1.34	0.43–6.86
NPPC Marbling[b], 1–6	330	2.43	1.27	1–6	349	2.61	1.27	1–6
Loin purge loss (%)	227	1.95	1.94	−4.05–10.62	349	1.96	1.88	−1.77–8.20
Warner-Bratzler Shear (N)								
Cooked temperature at:								
62.8 °C	329	24.9	5.9	12.6–48.1	349	24.2	5.7	12.3–48.7
68.3 °C	333	26.5	8.0	13.7–66.9	343	25.3	6.8	12.1–63.6
73.9 °C	326	27.2	7.7	12.1–59.6	351	26.8	7.4	13.0–68.6
79.4 °C	327	28.4	8.7	14.9–62.6	348	27.9	7.9	14.3–63.0
Sensory response variables[b]								
Juiciness Level at:								
62.8 °C	1687	7.28	1.52	2–10	1695	6.45	1.61	1–10
68.3 °C	1668	7.07	1.51	2–10	1690	5.97	1.72	1–10
73.9 °C	1667	6.73	1.54	1–10	1689	5.41	1.88	1–10
79.4 °C	1691	6.44	1.55	1 – 10	1688	4.81	1.84	1–10
Tenderness Level at:								
62.8 °C	1686	7.32	1.42	2–10	1695	6.88	1.80	1–10
68.3 °C	1670	7.29	1.45	3–10	1690	6.58	1.84	1–10
73.9 °C	1669	7.19	1.50	2–10	1689	6.33	1.87	1–10
79.4 °C	1690	6.95	1.50	1–10	1688	6.12	1.81	1–10
Chewiness Level at:								
62.8 °C	1686	1.91	1.10	1–10	1695	2.84	1.33	1–9
68.3 °C	1668	1.88	1.11	1–9	1690	3.03	1.44	1–10
73.9 °C	1666	1.88	1.19	1 – 9	1689	3.22	1.56	1–10
79.4 °C	1689	1.99	1.32	1–10	1688	3.33	1.62	1–10
Fat Flavor Level at:								
62.8 °C	1686	1.53	0.62	1–7	1695	1.99	0.85	1–6
68.3 °C	1667	1.48	0.60	1–5	1690	1.98	0.83	1–6
73.9 °C	1667	1.47	0.57	1–5	1689	1.96	0.82	1–6
79.4 °C	1688	1.44	0.59	1–6	1688	1.98	0.80	1–7
Salt Level at:								
62.8 °C	1683	1.16	0.39	1–4	1695	1.01	0.17	1–7
68.3 °C	1665	1.15	0.39	1–6	1690	1.01	0.19	1–6
73.9 °C	1666	1.17	0.46	1–7	1689	1.01	0.15	1–6
79.4 °C	1686	1.16	0.42	1–7	1688	1.01	0.12	1–4
Lean Flavor Level at[c]:								
62.8 °C	1687	5.69	1.13	1–8	–	–	–	–
68.3 °C	1668	5.71	1.11	1–8	–	–	–	–
73.9 °C	1669	5.70	1.15	1–8	–	–	–	–
79.4 °C	1691	5.72	1.17	1–8	–	–	–	–

[a] National Pork Producers Council (NPPC) 2000 color and marbling standards.

[b] Trained sensory responses measured on a 10-point, end-anchored scale (1 = extremely dry, tough, not chewy, none, none, and none, respectively; and 10 = juicy, tender, very chewy, intense, intense, and intense, respectively).

[c] Trained sensory characteristic measured in only one trained sensory panel.

Table 2
Ordered logistical regression model effects and significance levels for trained sensory eating quality response variables.[a]

	Trained sensory response					
	Juiciness Level	Tenderness Level	Chewiness Level	Fat Flavor Level	Lean Flavor Level[b]	Salt Level
Model effect						
Cooked temperature	0.000	0.000	0.813	0.014	0.222	0.854
Intramuscular fat (%)	0.000	0.000	0.000	0.000	0.000	0.000
pH	0.000	0.000	0.000	0.000	0.003	0.001
Quadratic pH	NS[c]	0.000	0.000	0.000	NS[c]	0.002
Minolta L^*	0.000	0.000	0.000	0.000	0.000	0.000
Warner-Bratzler Shear, N	0.000	0.000	0.000	0.005	0.029	0.311

[a] Packing plant of loin origin and trained sensory panel (two panels used) destination effects were accounted for in ordered logistic regression models.

[b] Trained sensory characteristic measured in only one trained sensory panel.

[c] NS = not significant, effect removed from the final model.

Table 3
Phenotypic correlations between trained sensory response variables and pork loin quality indicator traits ($n = \sim13{,}685$ responses across two trained panels).

Item	Trained sensory response					
	Juiciness Level	Tenderness Level	Chewiness Level	Fat Flavor Level	Lean Flavor Level[a]	Salt Level
Tenderness Level	0.53					
Chewiness Level	−0.43	−0.70				
Fat Flavor Level	−0.02	0.01	0.13			
Lean Flavor Level	0.38	0.26	−0.41	−0.12		
Salt Level	0.07	0.03	0.01	0.13	0.02	
Intramuscular fat (%)	0.05	0.03	−0.03	0.09	0.03	NS
Minolta L^*	−0.14	−0.15	0.10	−0.01	−0.06	0.07
pH	0.21	0.29	−0.16	0.14	0.07	−0.02
Warner-Bratzler Shear (N)	−0.23	−0.41	0.29	−0.09	NS	NS

[a] Trained sensory characteristic measured in only one trained sensory panel.

cooked to greater internal temperatures had more cook loss, resulting in a greater loss of meat juices. Bertram, Aaslyng, and Andersen (2005) reported that the reduction in juiciness when comparing pork loin cooked temperatures of 75 vs. 62 °C was ascribed to changes in the size of the pores confining the myofibrillar water together with an expulsion of water; however, in this study cook loss percentages averaged 24.3% with a range from 9.0% to 38.1%. The findings of the present study concur with previously reported research and verify the detrimental impact of greater cooked temperature on juiciness of pork loin, but it appears that the mean and variation in cook loss across experiments was quite different, likely due to variation in cooking methods.

Predicted mean sensory responses for TL, observed across the cooked temperatures evaluated, were near 6.50 on the 10-point scale with >47% of responses predicted to be ⩾7 on the 10-point scale which is indicative of a slightly favorable assessment of the tenderness for the pork evaluated in the present study. Increasing cooked temperature from 62.8 to 79.4 °C resulted in a 0.27 unit (2.7%) reduction in the predicted mean TL rating, a change reflective of a small, yet significantly negative influence that greater end-point cooked temperatures have on pork tenderness ratings. Wood, Nute, Fursey, and Cuthbertson (1995) reported a much greater (12.5%, 1 unit) reduction in tenderness score on an 8-point scale as cooked temperature increased from 65 to 80 °C, whereas Bertram et al. (2005) reported 3.1 (~20.7%) and 3.2 unit (21.3%) reductions in loin tenderness on a 15-point non-structured line scale at 3 and 6 d aging times, respectively, supporting the direction of change noted in the present study, but representing much greater effects. The magnitude of impact may be related to the different cooking methodologies used in previous studies. Cooked temperature had no impact on the CL, a measure of sustained tenderness, in the present study.

Pork FF was not measurably influenced by cooked temperature. This finding may be a function of the distribution of sensory observations where ⩾96% of ratings were ⩽3 or may be a function of the relatively limited amount of cook loss observed at each end-point cooked temperature allowing fat flavor to be consistent across cooked temperatures. Lean Flavor predicted mean levels were near 4.70 in the present study and, similar to FF, were not changed across the range of cooked temperatures evaluated. Wood et al. (1995) suggested that cooked temperature influenced sensory flavor intensity and that pork cooked to 80 °C would be more flavorful than pork cooked to 72.5 °C or 65 °C end-point temperatures, but also reported that pork cooked to 72.5 °C would be adequately juicy and more tender than pork cooked to 80 °C, but more flavorful than chops cooked to 65 °C. As lean flavor intensity is the specific flavor of pork, and Wood et al. (1995) evaluated a combined flavor attribute, differences in results may simply be due to attributes measured.

3.2. Intramuscular fat effects

Increasing loin IMF by 1% improved predicted sensory TL ratings by only 0.23 (Table 5) across the 1–6% range evaluated, representing a relatively small influence of IMF on perception of tenderness by panelists. At IMF levels of 1% and 6%, 50.7% and 57.4% of sensory responses were predicted to be ⩾7 on the 10-point scale, respectively. One potential factor influencing the relationship between IMF and TL in the present study is the 7–10 day aging period for the fresh loin. Brewer, Zhu, and McKeith (2001) previously reported a 1 unit improvement in tenderness scores measured on a 5-point scale when comparing IMF levels of <1% with IMF of ⩾3.5%, while Rincker, Killefer, Ellis, Brewer, and McKeith (2008)

Table 4
Predicted[a] mean trained sensory panel responses for the assessment of pork loin eating quality at four end-point cooked temperatures.

Variable[b]	Sig.	Cooked temperature (°C)			
		62.8	68.3	73.9	79.4
Juiciness Level	0.000	6.24	5.86	5.48	5.09
Tenderness Level	0.000	6.68	6.59	6.50	6.41
Chewiness Level	NS	3.05	3.05	3.05	3.05
Fat Flavor Level	0.014	1.99	1.97	1.96	1.94
Lean Flavor Level	NS	4.68	4.71	4.72	4.74
Saltiness	NS	1.01	1.01	1.01	1.01

[a] Modeled effects with independent variables loin pH, quadratic loin pH, intramuscular fat percentage, Minolta L^* color, and Warner-Bratzler Shear force at their respective mean values, and after adjustment for packing plant of origin and trained sensory panel effects.

[b] Trained sensory responses measured on a 10-point, end-anchored scale (1 = extremely dry, tough, not chewy, none, none, and none, respectively; and 10 = juicy, tender, very chewy, intense, intense, and intense, respectively).

Table 5
Predicted[a] mean trained sensory panel responses for the assessment of pork loin eating quality at six loin intramuscular fat percentage levels.

Variable[b]	Sig.	Intramuscular fat (%)					
		1	2	3	4	5	6
Juiciness Level	0.000	5.45	5.56	5.67	5.78	5.88	5.99
Tenderness Level	0.000	6.45	6.50	6.55	6.59	6.64	6.68
Chewiness Level	0.000	3.13	3.09	3.05	3.01	2.97	2.94
Fat Flavor Level	0.000	1.88	1.92	1.96	2.00	2.05	2.09
Lean Flavor Level	0.000	4.46	4.59	4.71	4.82	4.94	5.06
Saltiness	0.000	1.01	1.01	1.01	1.01	1.01	1.01

[a] Modeled effects with independent variables cooked temperature, loin pH, quadratic loin pH, Minolta L^* color, and Warner-Bratzler Shear force at their respective mean values, and after adjustment for packing plant of origin and trained sensory panel effects.

[b] Trained sensory responses measured on a 10-point, end-anchored scale (1 = extremely dry, tough, not chewy, none, none, and none, respectively; and 10 = juicy, tender, very chewy, intense, intense, and intense, respectively).

reported that intramuscular fat content had little influence on the eating quality of fresh pork loin chops. In agreement with the observed tenderness-IMF relationship, increasing IMF resulted in only a very slight reduction in the predicted mean response for CL, whereby increasing IMF from 1% to 6% only improved CL by 0.19 units total. Predicted mean responses for JL increased by ~0.11 units for each 1% increase in IMF, proving valuable when comparing the ends of the IMF range but of limited value when comparing 1% incremental increases in IMF.

The association between intramuscular fat and flavor attributes was significant, but the effects were small. This was most likely at least partially due to a clustering of sensory responses near the lower, less intense, end of the evaluation scale. Increasing IMF in 1% increments improved the predicted mean Fat Flavor response by only 0.04 units and totaled ~0.21 units when comparing 1% with 6% IMF chops. Predicted mean LF increased by ~0.12 response units for each 1% increase in IMF and totaled ~0.60 unit improvement for a chop with 6% IMF when compared with 1% IMF. Fernandez, Monin, Talmont, Mourot, and Lebret (1999a) in a study outlining two experiments, reported that increasing IMF had a positive relationship on consumer perception of texture and taste up to levels of 3.5% and 3.25%, respectively. In a companion manuscript assessing sensory characteristics of the loin, Fernandez, Monin, Talmont, Mourot, and Lebret (1999b) reported a trend for favorable influence of increased IMF on flavor ($P = 0.09$) and tenderness ($P = 0.055$) within the first experiment and significant improvements in juiciness and flavor scores with an increase in IMF within the second experiment. They concluded that increased IMF had a favorable effect on sensory attributes, but the effects were experiment dependent.

3.3. Ultimate pH effects

The effects of ultimate pH are reported in 0.20 unit increments across the range of pH evaluated. Ultimate pH was a primary factor influencing sensory responses, and predicted mean sensory scores were consistently less favorable for loins with pH values of ⩽5.60 (Table 6). Sensory responses improved as pH increased to the upper end (pH = 6.40) of the pH range evaluated, suggesting trained panelist perceptions were optimized at a loin pH near 6.40.

Increasing pH by 0.20 units improved predicted mean JL responses (Table 6) by 0.23 scale units and resulted in a 1.12 unit juicier rating for a chop with a 6.40 pH (mean = 6.38) when compared with a chop from a loin with a pH of 5.40 (mean = 5.26). When comparing the distribution of sensory responses across the range of pH values, 23.1% of responses were predicted to be ⩾7 on the 10-point scale at a loin pH of 5.4 with the percentage increasing to 50.3% of responses at a loin pH of 6.40. Lonergan et al. (2007) reported juiciness ratings increased from 2.9 to 3.3 on a 10-point scale when comparing pork chops with a pH of <5.50 to chops with a pH of >5.95, an effect that was in agreement with, but of a slightly smaller magnitude, than observed in the present study.

Ultimate pH of the loin was also highly related to sensory ratings for TL with predicted mean responses increasing in a quadratic manner as loin pH increased. Increasing pH across the measured range of 5.40–6.40 resulted in an increase in the predicted mean response from 6.14 up to 7.54 units. The quadratic effect of loin pH changed the magnitude of incremental increases in predicted mean responses. As pH increased from the least to the greatest level, predicted sensory responses increased, for example, a shift in pH from 5.40 to 5.60 (0.14 unit increase) had a lesser effect when compared with a shift from 5.60 to 5.80 (0.22 unit increase) or 6.00 to 6.20 (0.35 unit increase). Panelists clearly viewed chops from loins with greater pH as being more tender as 79.6% of responses were predicted to be ⩾7 at a loin pH of 6.40 compared with 41.3% at a loin pH of 5.40 across the 10-point assessment scale. Predicted mean chewiness ratings declined (less chewy) in a quadratic manner as pH increased, an effect reflecting improved perception of chewiness when pH increased. Observed relationships between pH and TL and chewiness indicate the significant influence of pH on textural attributes of pork, which have been reported previously (Huff-Lonergan et al., 2002). Increased ultimate pH has been shown to be related to increased water-holding capacity (Bidner, Ellis, Witte, Carr, & McKeith, 2004; Leheska et al., 2002); therefore, it is reasonable to hypothesize that the increased water-holding capacity of high pH pork dilutes the structural effect of proteins during mastication resulting in a perception of more tender, less chewy pork. In the present study, the positive influence of pH on sensory measures of texture were more pronounced at a pH > 6.00.

Predicted mean responses were greater for Fat Flavor for loin pH values of greater than 5.80 when compared with means at loin pH values of 5.60 and 5.40. Loins with pH values of 6.00 and greater had similar predicted mean responses for Fat Flavor. Fat flavor is the fat specific flavor in pork. Panelists were provided cooked pork fat as a reference point for a 10 on the scale and ground pork patties containing less than 5% fat (3 on the scale) to 30% fat (6–7 on the scale) were used to scale panelists on cooked pork fat flavor. The increased level of fat flavor detected in pork chops with high pH most likely was due to greater water-holding capacity of high pH pork. Greater water-holding capacity of pork at a higher pH may have allowed for a reduction in both fat and moisture loss during cooking. Pork Fat Flavor was not highly correlated with other sensory attributes (Table 3) indicating that panelists were independently evaluating pork FF. In contrast with pork FF results, as loin pH increased LF ratings declined slightly (−0.27 units) when observed across the 5.40–6.40 range evaluated. These findings indicate that greater pH levels allow for increased expression of fat flavor profiles when viewed by the trained panel and conversely that LF was expressed to a lesser extent in chops from loins with a greater pH.

3.4. Warner-Bratzler shear effects

Sensory responses for the direct assessments of TL and CL as well as the associated responses for JL and LF were consistently less favorable as WBSF of the cooked chops increased (Table 7). Tougher pork was clearly identified by the panel and rated lower. As well, tougher pork created a negative association with the panel's perception of juiciness and lean flavor while having little or no influence on fat flavor.

Table 6
Predicted[a] mean trained sensory panel responses for the assessment of pork loin eating quality at six loin pH levels.

Variable[b]	Sig.	pH					
		5.40	5.60	5.80	6.00	6.20	6.40
Juiciness Level	0.000	5.26	5.49	5.72	5.94	6.16	6.38
Tenderness Level	0.000	6.14	6.28	6.50	6.78	7.13	7.54
Chewiness Level	0.000	3.15	3.17	3.12	3.01	2.85	2.64
Pork Fat Flavor Level	0.000	1.70	1.89	2.06	2.18	2.26	2.29
Pork Lean Flavor Level	0.003	4.81	4.76	4.70	4.65	4.60	4.54
Saltiness	0.001	1.01	1.01	1.01	1.01	1.01	1.01

[a] Modeled effects with independent variables cooked temperature, intramuscular fat percentage, Minolta L^* color, and Warner-Bratzler Shear force at their respective mean values, and after adjustment for packing plant of origin and trained sensory panel effects.

[b] Trained sensory responses measured on a 10-point, end-anchored scale (1 = extremely dry, tough, not chewy, none, none, and none, respectively; and 10 = juicy, tender, very chewy, intense, intense, and intense, respectively).

Table 7
Predicted[a] mean trained sensory panel responses for the assessment of pork loin eating quality at loin Warner-Bratzler Shear force levels.

Variable[b]	Sig.	Warner-Bratzler shear (N)									
		14.7	19.6	24.5	29.4	34.3	39.2	44.1	49.0	53.9	58.8
Juiciness Level	0.000	6.10	5.92	5.74	5.56	5.37	5.19	5.00	4.82	4.63	4.45
Tenderness Level	0.000	7.46	7.08	6.70	6.31	5.91	5.50	5.09	4.69	4.29	3.91
Chewiness Level	0.000	2.39	2.64	2.93	3.25	3.59	3.97	4.37	4.80	5.23	5.69
Pork Fat Flavor Level	0.005	1.99	1.98	1.97	1.96	1.94	1.93	1.92	1.90	1.89	1.88
Pork Lean Flavor Level	0.029	5.30	5.05	4.81	4.56	4.32	4.07	3.82	3.58	3.31	3.08
Salt Level	0.311	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01

[a] Modeled effects with independent variables cooked temperature, loin pH, quadratic loin pH, intramuscular fat percentage, and Minolta L^* color at their respective mean values, and after adjustment for packing plant of origin and trained sensory panel effects.

[b] Trained sensory responses measured on a 10-point, end-anchored scale (1 = extremely dry, tough, not chewy, none, none, and none, respectively; and 10 = juicy, tender, very chewy, intense, intense, and intense, respectively).

At approximately the average WBSF (24.5 N) the predicted mean response was 6.70 units on the 10-point scale, a rating that increased to 7.46 when panelists assessed chops with the lowest WBSF (14.7 N). However, increasing WBSF by 4.9 N resulted in a reduction in the predicted mean TL ratings by approximately 0.37 units for each incremental increase, reaching a point where the mean predicted response dropped to below 5.0 at a WBSF value of 49.0 N and reached less than 4.0 on the 10-point scale when WBSF reached 58.8 N. Graphically, the impact of WBSF level on the percentage of sensory responses across the response surface (Fig. 1) is evident in relation to the shift in response curves to the lower end of response scale as WBSF increased. Using a rating of greater than 7 as a favorable response criterion, 77.8% of responses met the criteria if WBSF was 14.7 N, 57.9% of responses met the criteria at average WBSF of the pork (~24.5 N) and only 4.9% of responses met the criteria when WBSF was 58.8 N. Chewiness ratings followed a similar, unfavorable trend as TL ratings, whereby chops were chewier as WBSF increased across the range evaluated.

Incremental increases in WBSF resulted in a 0.18 unit decrease in the predicted mean response for chop Juiciness resulting in a mean Juiciness rating of 6.10 for the most tender chops (WBSF = 14.7 N) and 4.45 for the toughest chops (WBSF – 58.8 N). Fat flavor was not influenced by WBSF level, but LF was greater for chops with lower WBSF. Incrementally increasing WBSF by 4.9 N resulted in a 0.25 unit reduction in sensory ratings for LF. These results indicate that tougher chops, as defined by WBSF, were drier and had less cooked pork lean flavor. As chops with greater WBSF levels included chops that were tough due to a variety of factors (e.g. inherently tough, low pH, cooking to a high degree of doneness) the relationships between WBSF, juiciness, and pork LF were not strong (Table 3), although the statistical analysis indicated a small effect.

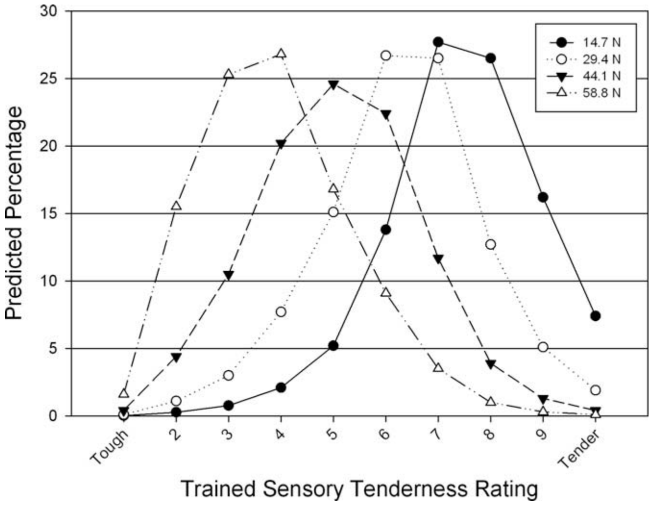

Fig. 1. Illustration of the change in predicted percentage of trained sensory ratings for tenderness at loin Warner-Bratzler shear force levels.

3.5. Minolta L^* effects

Sensory assessments of pork eating quality characteristics were influenced by Minolta L^* levels. This is in contrast to the consumer portion of the present study (data not shown) where L^* did not contribute to variation in consumer perceptions of eating quality (Moeller et al., 2010). The contrast in results may be a function of the increased precision with which trained panels are able to differentiate slight differences in sensory attributes that were present within the fresh pork color classes assessed. For illustration purposes, the Minolta L^* values used to estimate predicted mean responses were chosen to approximately reflect subjective visual color scores (National Pork Producers Council, 2000) collected in the data set and similar statistical results when subjective color score was substituted for L^* in ordered logistical regression models. Accordingly, L^* values of 61.9 and 65.0 closely represent a visual color score of 1 (pale pinkish gray to white), an L^* of 57.9 represents a visual color score of 2 (grayish pink), an L^* of 53.9 represents a visual color score of 3 (reddish pink), an L^* of 49.9 represents a visual color score of 4 (dark reddish pink), and an L^* of 46.9 represents a visual color score of 5 (purplish red) or 6 (dark purplish red).

When assessing the influence of L^* color on predicted mean trained panel ratings (Table 8), greater loin L^* (values of 61.9 and

Table 8
Predicted[a] mean trained sensory panel responses for the assessment of pork loin eating quality at designated loin Minolta L^* levels.

Variable[b]	Sig.	Minolta L^*					
		46.9	49.9	53.9	57.9	61.9	65.0
Juiciness Level	0.000	5.86	5.76	5.64	5.51	5.38	5.28
Tenderness Level	0.000	6.63	6.59	6.53	6.48	6.42	6.36
Chewiness Level	0.000	2.90	2.97	3.08	3.18	3.29	3.38
Pork Fat Flavor Level	0.000	1.86	1.91	1.99	2.06	2.14	2.20
Pork Lean Flavor Level	0.000	4.97	4.83	4.67	4.50	4.32	4.19
Salt Level	0.000	1.00	1.01	1.01	1.01	1.02	1.03

[a] Modeled effects with independent variables cooked temperature, loin pH, quadratic loin pH, intramuscular fat percentage, and Warner-Bratzler Shear force at their respective mean values, and after adjustment for packing plant of origin and trained sensory panel effects.

[b] Trained sensory responses measured on a 10-point, end-anchored scale (1 = extremely dry, tough, not chewy, none, none, and none, respectively; and 10 = juicy, tender, very chewy, intense, intense, and intense, respectively).

65.0) measurements were consistently associated with unfavorable responses, particularly when compared with chops derived from loins with L^* values of $\leqslant$49.9 (darker color). When comparing the ends of the L^* range evaluated, JL, TL, and LF predicted means were reduced by 0.58, 0.27, and 0.78 units, respectively, on the 10-point scale, while CL increased (unfavorable) by 0.48 units on the same measurement scale. Norman, Berg, Heymann, and Lorenzen (2003) reported that consumer perceptions of pork loins classified as 5 or 6 on the NPPC scale (NPPC, 2000) were improved for liking of juiciness when compared with visual color classifications of 4 or less, but no differences were observed across classifications for overall liking or liking of flavor, while visual classification influences on liking of tenderness were inconsistent across the color spectrum.

Within the context of the present study, increasing cooked temperature had the most pronounced negative influence on juiciness ratings and only a small negative influence on tenderness ratings, suggesting that a reduction in the recommended end-point cooked temperature for pork will improve juiciness but have little impact on tenderness or flavor-related attributes. Of the objective measures assessed, a change in WBSF had the greatest influence on sensory attributes, whereby small incremental increases (4.9 N) in WBSF were reflected in large incremental, non-favorable changes in mean ratings for tenderness, chewiness, and juiciness ratings, indicating that WBSF, while not perfectly correlated with sensory attributes, may be the most important predictor of palatability.

The quadratic effect of loin pH on ratings for tenderness, chewiness, and fat flavor indicated the adverse impact of loins with pH values of 5.40 and 5.60 on sensory ratings, while also suggesting that increasing pH will continue to improve sensory ratings, albeit in a smaller magnitude, as pH increases from 5.80 to 6.40. Based on data from the present study, systems that reduce the frequency of low pH ($\leqslant$5.60 pH), and increase the proportion of loins with pH > 5.80 will greatly improve tenderness, juiciness, and fat flavor ratings of pork chops.

Chops from loins that had relatively large amounts of intramuscular fat (6%) or from dark loins (Minolta L^* = 46.9 units) were rated more favorably for juiciness, tenderness, chewiness and flavor attributes; however, the favorable response observed was of practical value when comparing with the opposite end of the respective range, rather than when describing small incremental changes in a given trait.

4. Conclusions

When assessing the results of the present study in total, shear force was the best indicator trait for assessing sensory properties of pork chops, followed by loin pH. Given that trained sensory panelists were able to clearly differentiate among levels of tenderness and pH, the expectation is that consumers may respond to the variation in a similar manner, albeit potentially not to the same extent; therefore, tenderness and pH, together or individually, appear to be very important attributes when defining palatability. Methods to identify tough pork prior to distribution and or processes to enable production of more tender pork are necessary to improve the eating quality of pork. Current industry efforts geared toward measurement of loin pH likely have value and are best suited toward efforts to increase the mean level of loin pH upward in an effort to improve eating quality.

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