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Consumer perceptions of pork eating quality as affected by pork quality attributes and end-point cooked temperature

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ABSTRACT

The study evaluated the interactive and individual effects of fresh pork loin ($n = 679$) ultimate pH (pH), intramuscular fat (IMF), Minolta L^* color (L^*), Warner–Bratzler shear force (WBS), and four cooked temperatures (62.8 °C, 68.3 °C, 73.9 °C, and 79.4 °C) on consumer ($n = 2280$) perception of eating quality ($n = 13,265$ observations). Data were analyzed using ordered logistical regression. Predicted mean responses were consistently near or under five on the 1–8-point end-anchored scale, indicating a neutral perception of pork eating quality regardless of fresh quality or cooked temperature. Responses improved as IMF and pH increased and WBS decreased, whereas L^* did not contribute significantly to variation in responses. Increasing IMF resulted in a very small incremental improvement in responses, but was of practical size only when comparing the least (1%) to the greatest (6%) levels. Loin pH and WBS were primary contributors to consumer perceptions, whereby an incremental increase in pH (0.20 unit) and decrease in WBS (4.9 N) resulted in a 4–5% reduction in the proportion of consumers rating pork as $\geqslant 6$ (favorable) on the 8-point scale. No interactions between quality and temperature effects were observed. Increased cooked temperature was negatively ($P < 0.05$) associated with Overall-Like and Tenderness ratings, but the incremental effect was small. Juiciness-Like and Level responses decreased by 0.50 units as temperature increased across the range. Consumer responses favor pork with lower WBS, greater pH and IMF, and pork cooked to a lower temperature.

1. Introduction

Increasing per capita consumption is a challenge in a competitive market place where the needs and expectations of the consumer contribute significantly to the choice among alternative protein sources. Palatability or eating quality, a culmination of taste, flavor, juiciness, and tenderness, is an important factor that influences choice of protein sources at the consumer level.

Previous research indicated overall consumer acceptability of pork was first related to tenderness, followed by flavor intensity, and then by level of juiciness (Enfalt, Lundstrom, Hansson, Lundeheim, & Nystrom, 1997) and an additional report indicated that consumer perception of juiciness improved for darker colored pork loin chops (Norman, Berg, Heymann, & Lorenzen, 2003). The relationships between quality attributes that influence palatability appear to vary across studies as Brewer, Zhu, and McKeith (2001) reported that as marbling increased from less than 1% to approximately 3.5%, tenderness scores increased, while, in contrast, van Laack, Stevens, and Stalder (2001) reported there was no significant relationship between intramuscular fat level and tenderness and Rincker, Killefer, Ellis, Brewer, and McKeith (2008) reported intramuscular fat level of pork chops had little impact on eating quality in consumer and trained sensory panels. Many of the previous research reports utilized pork derived from either breed or genetic line specific samples and or sampling that represented only a portion of variation present within the pork quality parameters commonly measured within the pork industry, potentially limiting their ability to effectively test for interactions and or threshold levels for pork quality factors that may influence a consumer's perception of pork palatability.

Therefore, the objective of the present study was to evaluate the potential independent and interactive influences of commonly measured pork quality indicators, including loin color, pH, intramuscular fat, and cooked pork shear force on consumer perceptions of pork eating quality across four cooked temperatures

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through the use of commercially derived loins that were selected to capture the variation in and combinations of pork quality attributes present in US pork.

2. Materials and methods

2.1. Loin selection criteria

Loins ($n = 679$) were selected in nearly equal proportions ($n = 228$, 228, and 223 loins, respectively) within three commercial US pork packing facilities based on 24 h ultimate pH (pH), marbling score, and Minolta L^* (L^*) color. Loins were collected during fall and spring months across plants with a total of 20 days of in-plant selection. Sampling was designed to assess the overall variation for each trait observed in the pork industry and to evaluate the combination of pork quality traits in biologically feasible, three-dimensional combinations such that the influence of an individual trait and the potential interactive effects among traits that influence consumer responses could be estimated. Chemically derived intramuscular fat (IMF) was used in final loin classification in substitution for marbling score. A $3 \times 3 \times 3$ classification arrangement of pH, IMF, and L^* was used to initially create a near uniform representation of quality combinations for subsequent sensory and mechanical tenderness evaluation. Briefly, the initial classification criteria were: loin pH, <5.5, 5.5–5.8, and >5.8; loin L^*, >55, 49–55, and <49; loin IMF, <2.0, 2.0–4.0, and >4.0%. Due to the strong negative correlation between L^* and pH, loins with greater pH and greater L^*, as well as lesser pH and lesser L^* were not considered biologically representative and these classes were not sampled. Final classification for identification of loins used in the study involved creation of subclasses defined by 0.10 ph, 1% IMF, and 3.9 L^* increments to establish the opportunity to more uniformly test combinations of pork quality attributes.

2.2. Loin quality assessment

Whole, boneless loins were collected along 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) inserted approximately 1 cm under the cut surface and placed in the center on the exposed 7th rib loin surface. After bloom, loin color was measured on the exposed 7th rib loin surface using a Minolta Colorimeter (CR-310, 50 mm diameter orifice, 10° standard observer, D^{65} light source; Minolta Company, Ramsey, New Jersey), recording L^*, a^* and b^* values. Subjective visual color and marbling scores were collected by one of two trained personnel using a 1 to 6 scale as outlined by the National Pork Producer Council (NPPC, 2000). A 1.25 cm-thick section of loin was cut immediately posterior to the 7th rib exposed location, subcutaneous fat and connective tissue removed, and the remaining muscle sample packaged for assessment of IMF by the ether extract method using AOAC (2007) procedures.

For the IMF sample, moisture and fat amounts were attained by the air-dry oven and Soxhlet ether extraction methods, 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 desiccator 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 placed in a convection oven for approximately 12 h. Samples were removed and placed in a desiccator until cooled to room temperature. Weights were taken and recorded to determine percent fat in each sample.

Loins were weighed and individually vacuum sealed for storage and transportation. All 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 7–10 days. Loin processing and slicing occurred on the Friday following the previous sampling week.

2.3. Loin processing

After aging, loins were removed from their package and weighed to assess loin purge loss. Loins were then tempered at −28.8 °C, creating a slightly frozen surface to allow for uniform slicing. Beginning at the anterior end, loins were sliced into 12, 2.54 cm-thick chops. Chops were subsequently randomly assigned to one of three designated end-points: (1) consumer sensory evaluation, (2) trained sensory evaluation, or (3) Warner–Bratzler shear force (WBS) assessment. Within each destination, chops were randomly assigned to one of four end-point cooked temperatures (62.8 °C, 68.3 °C, 73.9 °C, or 79.4 °C). Random assignment of chops to a destination and cooked temperature end-point was designed to avoid potential confounding of chop location within the loins with the classification criteria pork quality data collected at the ~ 7th rib location on each loin. Allocated chops were individually packaged using a roll-stock machine and frozen at -28.8 °C until further evaluated within their respective designated assignment.

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 temperature. Internal temperatures (Digi-sense, Model # 277653 or equivalent) were monitored by copper constant thermocouplers (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 with cooking time, temperature, and cooked weight recorded. Cook loss was measured using pre- and post-cooked weights. Chops were cooled for 4 h to approximately 22.2 °C prior to shear force assessment. Six, 1.27 cm diameter 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 was 3.33 mm/s and a post-test speed of 20 mm/s.

2.5. Consumer evaluation procedures

Consumer taste panels were conducted in three cities; Chicago IL, Philadelphia, PA, and Sacramento, CA. Consumer recruitment was conducted via telephone interview. Recruitment parameters included: primary household grocery shoppers, females aged 25–49, annual household income of $30,000+, and presence of children under 16 in the household. Male pork consumers were included in this study with a target representation of 35–40% of the total respondents. All respondents were regular pork consumers. Within a city, 760 consumers were secured for a total of 2280 consumers polled. Consumer evaluations occurred over a two week period in each city, with 20 consumers in each testing session and 38 sessions conducted per city. Sessions were approximately 45 min in length.

Consumers were provided samples from eight different chops with five different consumers assessing each chop. Chops were assigned to sessions using the following criteria: (1) each consumer was provided non-enhanced samples representing two chops from each packing plant (three plants represented) to balance for plant of origin, (2) each consumer was provided samples from two chops that had been enhanced (data not reported in this manuscript), (3) chops were randomly assigned across cooked temperature and quality classification within each plant, and (4) serving order was randomized across the eight chops assigned to a group of five respondents.

Chops were cooked using the method described previously for assessment of WBS to their respective target internal temperature. Cooking yield, cook time, and final temperature were recorded. Immediately after cooking, chops were cut into 1.27 cm width × 1.27 cm length × 2.54 cm height cubes. A consumer sample represented two cubes provided in a serving boat.

Samples were served under red incandescent lighting to minimize sample color differences due to differing end-point cooked temperatures. Consumers were asked to cleanse their pallet prior to the first and between samples with an unsalted, saltine cracker and distilled water. The consumer ballot consisted of seven questions measured on an 8-point, end-anchored scale with the consumer marking the box of their choice. Following the ballot order, the questions were: Overall-Like/Dislike, 1 = Dislike Extremely and 8 = Like Extremely; Juiciness-Like/Dislike, 1 = Dislike Extremely and 8 = Like Extremely; Level of Juiciness, 1 = Extremely Dry and 8 = Extremely Juicy; Tenderness Like/Dislike, 1 = Dislike Extremely and 8 = Like Extremely; Level of Tenderness, 1 = Extremely Tough and 8 = Extremely Tender; Flavor Like/Dislike, 1 = Dislike Extremely and 8 = Like Extremely; Level of Flavor, 1 = Extremely Bland or No Flavor and 8 = Extremely Flavorful. The final ballot question asked: How likely would you be to purchase this sample if it were available at a reasonable price in your area? Likelihood of Purchase response options were: Definitely Would Not Buy, Probably Would Not Buy, May or May Not Buy, Probably Would Buy, and Definitely Would Buy, which were labeled for data analyses as numbers 1–5, respectively.

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 consumer responses to ballot questions representing product derived from three packing plants and only six of the eight chop samples consumed by panelists. Preliminary models tested the continuous independent variables cooked temperature, pH, IMF, L^*, a^*, b^*, WBS, as linear and quadratic effects, and the two-way interactions among independent variables were tested. Plant of origin and city of testing were included as independent effects. A linear covariate for the temperature deviation of observed cooked temperature from the designated treatment temperature was tested in all analyses and found not significant but was maintained in all final models to correctly assess temperature effects. Plant of origin and both a^* and b^* color values were not significant effects and were removed from final models. Model solutions were used to estimate predicted mean response levels and predicted consumer response proportions for, and encompassing the range of, each independent variable in the regression model. The influence of cooked temperature on shear force was analyzed using a standard mixed model with a fixed effect of temperature and a random effect for plant of origin. Correlation statistics were used to describe linear relationships among variables of interest.

3. Results and discussion

Descriptive statistics for fresh pork loin quality attributes, WBS tenderness at each end-point cooked temperature, and arithmetic mean consumer responses are presented in Table 1. Loins were selected to capture the range and combination of attribute values; therefore, the values in Table 1 are not expected to represent an industry average. Model effects and significance levels are presented in Table 2 for all dependent consumer variables and are included to provide a clear understanding of the final ordered logistical models used in the study. A major finding of the present study was that interactions among independent variables were not observed, nor were quadratic effects of independent variables found to be significant. The large sample population size likely contributed to statistically significant effects that resulted in relatively small changes in mean responses when assessed across the range of a given independent variable. Interpretation of results in relation to the practical value of the effect for each significant effect observed will be provided. The data from the present study, designed to assess and test loin quality indicators in combinations, indicate that the impact of the individual quality indicators on consumer acceptability measures were linear within the context of the modeled effects. In addition, a lack of quality measurement interactions implies that responses for a given quality indicator were not dependent on the level of another independent variable evaluated, nor was there evidence to support threshold levels for a given independent variable in relation to their respective influence on consumer perception of eating quality attributes. Therefore, results of analyses reported in the present study reflect independent effects of incremental changes in a specific independent variable while maintaining all other model effects at their respective mean values.

Table 1
Characterization of pork loin quality attributes and consumer response variables for loin chops served in consumer preference testing sessions.

Trait	*n*	Mean	Std. Dev.	Range
Ultimate pH	679	5.76	0.23	5.34–6.50
Minolta L^*	679	52.82	4.28	40.91–65.4
Minolta a^*	679	17.42	1.38	11.70–21.02
Minolta b^*	679	5.14	1.34	1.93–10.6
NPPC Color[a], 1–6	679	3.13	1.01	1.00–5.00
Intramuscular fat, %	678	3.06	1.37	0.43–6.93
NPPC Marbling[a], 1–6	679	2.52	1.27	1.00–6.00
Loin purge loss, %	679	1.97	1.92	−4.05–10.62
Warner–Bratzler shear, N				
Cooked temperature				
62.8 °C	678	24.6	5.9	12.4–48.7
68.3 °C	676	25.9	7.5	12.1–67.1
73.9 °C	677	27.0	7.6	12.2–68.7
79.4 °C	675	28.2	8.3	14.3–63.1
Consumer response variables[b]				
Overall Dislike/Like	13,190	4.84	1.87	1–8
Juiciness Dislike/Like	13,232	5.15	1.89	1–8
Juiciness-Level	13,235	5.07	1.91	1–8
Tenderness Dislike/Like	13,237	4.92	1.97	1–8
Tenderness-Level	13,239	4.87	1.95	1–8
Flavor Dislike/Like	13,234	4.47	1.92	1–8
Flavor-Level	13,242	4.21	1.94	1–8
Likelihood of Purchase[c]	13,183	2.90	1.21	1–5

[a] National Pork Producers Council (NPPC) 2000 color and marbling standards.
[b] Consumer responses measured on an 8-point, end-anchored scale; 1 = Most unfavorable, 8 = Most favorable.
[c] Consumer responses measured on a 5-point scale; 1 = Definitely Would Not Buy, 5 = Definitely Would Buy.

Table 2
Ordered logistical regression model effects and significance levels for consumer pork loin eating quality response variables[a].

Model effect	Consumer response							
	Overall-Like	Juiciness-Like	Juiciness-Level	Tenderness-Like	Tenderness-Level	Favor-Like	Flavor-Level	Likelihood of Purchase
Cooked temperature	0.025	0.000	0.000	0.000	0.000	0.556	0.063	0.000
Intramuscular fat	0.000	0.001	0.010	0.018	0.049	0.049	0.000	0.000
pH	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Minolta L^*	0.650	0.303	0.237	0.246	0.122	0.838	0.102	0.224
Warner–Bratzler shear	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

[a] Packing plant of loin origin and differences among consumer test cities are accounted for in the ordered logistic regression.

Table 3
Phenotypic correlations between consumer pork loin eating quality response variables[a] (n = ∼13,220 responses).

Item	Consumer response variable						
	Overall-Like	Juiciness-Like	Juiciness-Level	Tenderness-Like	Tenderness-Level	Flavor-Like	Flavor-Level
Juiciness-Like	0.75	–					
Juiciness-Level	0.65	0.87	–				
Tenderness-Like	0.73	0.75	0.70	–			
Tenderness-Level	0.68	0.71	0.71	0.92	–		
Flavor-Like	0.79	0.63	0.54	0.62	0.58	–	
Flavor-Level	0.71	0.57	0.52	0.55	0.53	0.88	–
Likelihood of Purchase[b]	0.78	0.64	0.58	0.68	0.65	0.75	0.70

[a] Consumer responses measured on an 8-point, end-anchored scale; 1 = Most unfavorable, 8 = Most favorable.
[b] Consumer responses measured on a 5-point scale; 1 = Definitely Would Not Buy, 5 = Definitely Would Buy.

Of note, across all consumer response variables, loin Minolta L^*, a^* and b^* and subjective visual color measurements were not significant model effects indicating that in the presence of the other model effects, loin color attributes did not contribute significantly to variation in consumer responses. However, the effect of L^* was maintained in all models for consistency of reporting results across traits and because the original project design included fresh pork color as a primary selection criteria for assessment of pork eating quality.

A summary of correlations (Table 3) among consumer response variables indicates that relationships between 'Like' and 'Level', respectively for tenderness (r = 0.92), juiciness (r = 0.87) and flavor (r = 0.88) were strong and that consumers were consistently assessing perception of 'Like' and 'Level' for each attribute evaluated. As expected, the observed strong relationships between 'Like' and 'Level' measures within an attribute were directly reflected in similar statistical ordered logistic regression model relationships; therefore, primary summary and discussion regarding results are generally limited to either 'Like' or 'Level' response in the subsequent paragraphs. Relationships between consumers rating of Overall-Like were strongest in relation to Tenderness-Like (r = 0.73), Flavor-Like (r = 0.79) and Likelihood of Purchase (r = 0.78) and somewhat weaker with respect to Juiciness-Level (r = 0.65). Moderate relationships (r = 0.52–0.63) were observed between the consumer's perceptions of Flavor-Like or Level when compared with Tenderness (Like or Level) and Juiciness (Like or Level) ratings. Interestingly, the strongest relationship between consumer responses for Likelihood of Purchase were with the observed responses for pork Flavor-Like (r = 0.75).

Table 4
Predicted[a] mean consumer pork loin eating quality responses measured at designated loin end-point cooked temperatures.

Variable[b]		Cooked temperature, °C			
	Sig.	62.8	68.3	73.9	79.4
Overall-Like	0.025	4.97	4.93	4.90	4.87
Juiciness-Like	0.000	5.43	5.28	5.13	4.97
Juiciness-Level	0.000	5.45	5.23	5.01	4.79
Tenderness-Like	0.000	5.10	5.00	4.91	4.82
Tenderness-Level	0.000	5.06	4.94	4.83	4.71
Flavor-Like	0.556	4.56	4.55	4.54	4.54
Flavor-Level	0.063	4.35	4.32	4.29	4.26
Likelihood of Purchase[c]	0.000	3.01	2.97	2.93	2.89

[a] Modeled effects with independent variables loin pH, intramuscular fat percentage, Minolta L^* color, and Warner–Bratzler Shear force at their respective mean values, and after adjustment for the city where consumer testing was conducted.
[b] Consumer responses measured on an 8-point, end-anchored scale; 1 = Most unfavorable, 8 = Most favorable.
[c] Consumer responses measured on a 5-point scale; 1 = Definitely Would Not Buy, 5 = Definitely Would Buy.

3.1. Cooked temperature effects

Table 4 describes the predicted mean responses for each consumer response variable at the four end-point cooked temperatures. Predicted mean responses for consumer variables on the 8-point response scale were very close to or near a rating of five with the exception of Pork Flavor-Level which was closer to a rating of 4.0. The predicted mean ratings, across the end-point cooked temperatures, were marginal with respect to consumer perception of eating quality attributes for the pork served. Cooked temperature effects were of practical significance for responses to the consumer's ratings of Juiciness-Like and Level and Tenderness-Like and Level where incremental (5.5 °C) increases in cooked temperature resulted in observable (−0.16 to −0.09 unit) reductions in the consumer's response rating. Temperature effects, while significant for the response to the question of Overall-Like, were not of a magnitude that was informative, representing only a 0.10 unit decrease in consumer response from the least to greatest cooked temperature. Bryhni et al. (2003) concur with our date whereby the reported consumers overall liking was greatest when pork was cooked to 65 °C when compared with 80 °C and also indicated that elevated pH_{24h} and a 65 °C cooked temperature resulted in a more sweet and tender meat.

Cooked temperature did not influence Flavor-Like or Level ratings in the present study which is supported by research (Prestat, Jensen, McKeith, & Brewer, 2002) for non-enhanced pork loins cooked at 70 or 80 °C. Of note, predicted mean responses for

Flavor-Like and Level were also consistently less than mean consumer responses for the remaining eating quality assessment variables at each cooked temperature evaluated. Likelihood of Purchase results were reflective of observed trends for eating quality attribute responses, with consumers responding on average in a very neutral or non-committal manner and showing only a small incremental (0.12 unit) reduction in predicted response as cooked temperature increased across the full range.

3.2. Intramuscular fat effects

Predicted mean consumer responses, represented at 1% increments for IMF, are presented in Table 5. Consumer mean responses increased in a significant linear fashion for all consumer variables across the range of IMF evaluated, but the observed favorable increase in mean responses as IMF increased were of limited practical value for juiciness- and tenderness-related attributes even when comparing the 1% and 6% IMF levels. The observed improvement in mean responses for Overall-Like (+0.30), Flavor Like (+0.36), and Flavor-Level (+0.41) appear to be of practical value at the consumer level only when comparing the greater predicted mean responses at 6% IMF with the lowest predicted mean response at 1% IMF. Results suggest that to have a measurable influence at the consumer level, IMF levels of 5–6% would improve pork flavor, but contribute very little or have no influence on consumer perceptions of juiciness or tenderness attributes. These findings tend to support recent research by Rincker et al. (2008) who reported IMF had no practical impact on eating quality of pork chops; however, pork produced for specific niche or targeted markets that cater to and promote pork flavor may benefit from a system that can supply highly marbled pork loins. Increasing IMF improved the consumer responses for Likelihood of Purchase, and the effect, while significant, was small with mean responses centered on neutrality, again offering insight that the consumer attitudes toward the pork served were somewhat indifferent.

3.3. Ultimate pH effects

The effects of incremental increases in ultimate pH from a base of 5.40 to the upper level of 6.40 on predicted mean consumer responses (Table 6) demonstrate considerable differentiation in consumer responses and more pronounced effects across the pH range for all consumer response criteria. In particular, for Juiciness and Tenderness-Like and Level, mean responses increased a full unit on the 8-point scale when moving from the least to greatest pH. Ultimate pH is related to water holding capacity (Aberle, Forrest, Gerrard, & Mills, 2001) and cook loss (Lonergan et al., 2007) which supports the observation that the consumers rated pork with greater ultimate pH more favorably for Juiciness-Like and Level. Predicted mean responses for Overall-Like and Flavor-Like increased across the range by approximately 0.5 units indicating consumers rated pork with greater pH more favorably than the baseline 5.40 ultimate pH level. When viewed across all consumer response variables, the results of the present study suggest ultimate pH has a large influence on consumer perceptions of pork eating quality and that the industry can expect reduced consumer satisfaction for products that are near an ultimate pH of 5.40 and incremental improvements in juiciness, tenderness, and flavor attributes as pH increases incrementally up to 6.40. Supporting this finding is the significant, linear increase in a consumer's rating for Likelihood of Purchase when ultimate pH increased from 5.40 to 6.40. As indicated by Rosenvold and Andersen (2003) in a review of factors influencing pork quality, there is still a significant fundamental need to understand the role of glycogen and the forms of glycogen as they relate to improving pork quality and palatability. Variation in pH observed and tested in the present study suggests that methods to increase ultimate pH of the pork loin will improve consumer perception of the product.

Table 5
Predicted[a] mean consumer pork loin eating quality responses reported at designated pork loin intramuscular fat percentages.

Variable[b]	Intramuscular fat, %					
	1	2	3	4	5	6
Overall-Like	4.79	4.85	4.91	4.97	5.03	5.09
Juiciness-Like	5.14	5.16	5.20	5.24	5.28	5.32
Juiciness-Level	5.06	5.09	5.12	5.15	5.18	5.21
Tenderness-Like	4.90	4.93	4.96	4.99	5.02	5.05
Tenderness-Level	4.84	4.86	4.88	4.91	4.93	4.96
Flavor-Like	4.40	4.47	4.54	4.62	4.69	4.76
Flavor-Level	4.13	4.22	4.30	4.38	4.46	4.54
Likelihood of Purchase[c]	2.86	2.90	2.95	2.99	3.03	3.07

[a] Modeled effects with independent variables loin cooked temperature, pH, Minolta L* color, and Warner–Bratzler Shear force at their respective mean values, and after adjustment for the city where consumer testing was conducted.
[b] Consumer responses measured on an 8-point, end-anchored scale; 1 = Most unfavorable, 8 = Most favorable.
[c] Consumer responses measured on a 5-point scale; 1 = Definitely Would Not Buy, 5 = Definitely Would Buy.

Table 6
Predicted[a] mean consumer pork loin eating quality responses reported at designated pork loin pH levels.

Variable[b]	pH					
	5.40	5.60	5.80	6.00	6.20	6.40
Overall-Like	4.69	4.81	4.94	5.07	5.19	5.31
Juiciness-Like	4.84	5.04	5.24	5.43	5.62	5.81
Juiciness-Level	4.71	4.94	5.16	5.38	5.59	5.80
Tenderness-Like	4.59	4.79	4.99	5.19	5.39	5.58
Tenderness-Level	4.47	4.70	4.93	5.15	5.37	5.59
Flavor-Like	4.37	4.47	4.57	4.66	4.76	4.86
Flavor-Level	4.20	4.26	4.31	4.37	4.43	4.49
Likelihood of Purchase[c]	2.82	2.89	2.96	3.03	3.10	3.17

[a] Modeled effects with independent variables loin cooked temperature, intramuscular fat percentage, Minolta L* color, and Warner–Bratzler Shear force at their respective mean values, and after adjustment for the city where consumer testing was conducted.
[b] Consumer responses measured on an 8-point, end-anchored scale; 1 = Most unfavorable, 8 = Most favorable.
[c] Consumer responses measured on a 5-point scale; 1 = Definitely Would Not Buy, 5 = Definitely Would Buy.

3.4. Warner–Bratzler shear effects

The relationship between WBS and consumer perceptions of pork eating quality clearly indicate that as WBS increased, consumer ratings decreased in a sizable, significant manner (Table 7). Tenderness-Like and Level, when directly compared to mechanical measurement of a chop from the same loin cooked to a same degree of doneness, showed that consumer ratings averaged 5.0 or greater when WBS was ⩽24.5 N, averaged greater than 4.0 when WBS was ⩽39.2 N, and had average ratings near 3.0 when WBS reached 58.8 N. Correlations between WBS and consumer rating for Tenderness-Like ($r = -0.27$) and Tenderness-Level ($r = -0.29$) were only moderate in the present data set, but were indicative of the decline in consumer ratings as WBS increased. With regard to tenderness attributes of non-enhanced pork loin, the ability to achieve an average response that was one full unit on the favorable side of response scale (5) required a WBS level of ⩽24.5 N which is similar to the mean WBS of the non-enhanced pork cooked at 62.8° C in the present study. A very similar pattern of reduced consumer response means in relation to an increase in WBS was observed for

Table 7
Predicted[a] mean consumer pork loin eating quality responses reported at designated pork loin Warner–Bratzler shear force levels.

Variable[b]	Warner–Bratzler shear, *N*									
	14.7	19.6	24.5	29.4	34.3	39.2	44.1	49.0	53.9	58.8
Overall-Like	5.36	5.10	4.99	4.80	4.61	4.41	4.22	4.03	3.83	3.64
Juiciness-Like	5.69	5.49	5.28	5.07	4.86	4.64	4.42	4.21	3.99	3.77
Juiciness-Level	5.63	5.42	5.21	4.99	4.77	4.54	4.32	4.10	3.87	3.66
Tenderness-Like	5.64	5.36	5.07	4.78	4.48	4.18	3.89	3.60	3.32	3.06
Tenderness-Level	5.61	5.31	5.01	4.69	4.38	4.07	3.77	3.47	3.19	2.92
Flavor-Like	4.86	4.73	4.60	4.47	4.33	4.20	4.07	3.94	3.81	3.68
Flavor-Level	4.57	4.46	4.35	4.23	4.12	4.01	3.90	3.79	3.68	3.57
Likelihood of Purchase[c]	3.23	3.11	2.99	2.88	2.76	2.64	2.52	2.41	2.30	2.19

[a] Modeled effects with independent variables loin cooked temperature, pH, intramuscular fat percentage, and Minolta L^* color at their respective mean values, and after adjustment for the city where consumer testing was conducted.
[b] Consumer responses measured on an 8-point, end-anchored scale; 1 = Most unfavorable, 8 = Most favorable.
[c] Consumer responses measured on a 5-point scale; 1 = Definitely Would Not Buy, 5 = Definitely Would Buy.

Overall-Like, Juiciness-Like and Juiciness-Level, whereby loins with WBS of less than 24.5 N provided an average consumer response of ⩾5 and incremental 4.9 N increases in WBS resulted in sizable reductions in predicted mean responses.

Predicted mean responses for Flavor-Like and Level ratings at each WBS level were generally less, having means of less than 5 on the 8-point scale. Increasing WBS in 4.9 N increments reduced mean consumer response for Flavor-Like and Level to a lesser degree when compared with tenderness and juiciness attributes. The observed results were consistent with respect to consumer perceptions of flavor being very neutral and also suggesting that flavor and tenderness relationships are weak in the present study. Correlations between WBS and consumer Flavor-Like ($r = -0.13$) and Flavor-Level ($r = -0.12$) were generally low, validating the weak relationship between mechanical tenderness and consumer perception of pork flavor characteristics.

The decrease in the mean for Likelihood of Purchase as WBS increased reinforces the consumer's negative perception of tough pork and challenges the pork industry to address tenderness in any efforts to increase consumer satisfaction. As well, the large incremental changes in consumer responses across the eating quality attributes in reflection of changes in WBS that are observed in the present study provide strong evidence that tenderness is the primary contributor to a consumer's perception of non-enhanced pork loin eating quality.

3.5. Patterns of consumer response

To better describe the impact of incremental changes in consumer responses for the set of independent pork quality indicators evaluated in the present study, the authors chose to look closely at the predicted proportions of consumer responses that were six or greater on the eight-point scale. Predicted probability data supplied in Table 8 summarize each consumer response variable and the modeled impact of incremental changes in cooked temperature, IMF, pH and WBS on proportions of responses that meet the criteria. A response level of six or greater represents a numerically positive eating experience and assessing this segment of consumer responses may more clearly indicate where opportunities exist to improve pork eating quality. Incremental changes described reflect the range and commonly measured, quality attribute specific, increments utilized in the industry and reflect the proportionate change in the percentage of consumers predicted to scoring pork ⩾6 on the 8-point scale.

Consumer responses for Overall-Like, a culmination of juiciness, tenderness and flavor attributes, indicated that as cooked temperature of the chop increased, the proportion of consumers rating pork as ⩾6 decreased only marginally (~1% per each per 5.5 °C) and the predicted response would likely be of practical value only when comparing the ends (62.8 °C and 79.4 °C) of the cooked temperature range evaluated. In contrast, incremental increases in cooked temperature had a large influence on consumer responses to Juiciness-Like and Level where >50% of consumers rated pork as ⩾6 when cooked temperature was 62.8 °C followed by a proportionate decrease of 3.7–5.2% when cooked temperature increased incrementally by 5.5 °C. The data clearly indicate that increased cooked temperature reduced juiciness, likely due to the increased moisture loss associated with the greater cooking time and cooked temperature. Increasing cooked temperature reduced the proportion of consumers rating pork ⩾6 for both Tenderness-Like and Level at a magnitude intermediate (−2.1% to −2.5%) to responses for Overall-Like and Juiciness-Like. Cooked temperature had no impact in the present study on Flavor-Like or Level.

The influence of incremental (1%) changes in IMF on proportions of consumers rating pork as ⩾6 were considerably small, ranging from 0.6% per 1% IMF for tenderness attributes up to 1.6% per 1% IMF for Flavor-Level, effects that would only be useful when comparing the extremes of the 6% range evaluated in the present study. The small influence of IMF on consumer responses was also reflective of the very small correlations, ranging from 0.02 to 0.05, between IMF and individual consumer response variables and would support the findings of Rincker et al. (2008) who reported no influence of IMF on consumer or trained sensory attributes.

Ultimate pH and WBS in the present study were moderately and inversely correlated ($r = -0.29$) indicating that as pH increased WBS values tended to decrease. While a correlation of this magnitude is not strong and may not imply cause and effect, the impact of both pH and WBS, as described previously in relation to mean responses, suggests that this relationship has value if pH, collected at ~24 post harvest, were used as one of a potential set of indicators that might be used to predict cooked product WBS or tenderness. The inverse relationship was also evident when assessing consumer responses at varying levels of ultimate pH and WBS. Favorable (greater) ultimate pH and WBS (lesser) levels were clearly associated with a greater proportion of consumers rating pork as ⩾6 for all consumers attributes evaluated. Each incremental (4.9 N) increase in WBS resulted in a 4% decline in the proportion of consumer responses that were ⩾6 in relation to their Overall-Like of the product, reducing the proportion of consumers from 52.6% at 14.7 N to less than 20% responding at a level ⩾6 when WBS reached 58.8 N and representing a very tough pork product. As ultimate pH increased in 0.2 unit increments, the proportion of consumer ratings predicted to be ⩾6 for Overall-Like increased by approximately 3% from a predicted base of 36.4% (pH 5.40) to a level of 51.3% (pH 6.40) for consumers ratings.

Table 8
Frequencies of predicted consumer pork loin eating quality response levels observed across pork quality measures of intramuscular fat, ultimate pH, and Warner–Bratzler shear force and representing four cooked temperatures.

Consumer response[a]	Increment	Range	Predicted percentage of consumers rating pork ⩾6 (8-point scale)		Average% improvement in consumer rating per increment
Independent variable			% at minimum of the range	% at maximum of the range	
Overall Dislike/Like					
Cooked temperature	5.5 °C	62.8–79.4 °C	42.8	40.5	−1.0
Intramuscular fat	1.0%	1.0–6.0%	38.8	45.8	1.4
Ultimate pH	0.20 units	5.40–6.40	36.4	51.3	3.0
Warner–Bratzler shear	4.9 N	14.7–58.8 N	52.6	17.4	4.0
Juiciness Dislike/Like					
Cooked temperature	5.5 °C	62.8–79.4 °C	54.8	43.8	−3.7
Intramuscular fat	1.0%	1.0–6.0%	47.4	52.1	1.0
Ultimate pH	0.20 units	5.40–6.40	40.7	64.1	4.7
Warner–Bratzler shear	4.9 N	14.7–58.8 N	61.3	20.2	4.2
Juiciness-Level					
Cooked temperature	5.5 °C	62.8–79.4 °C	55.2	39.6	−5.2
Intramuscular fat	1.0%	1.0–6.0%	45.8	49.5	0.7
Ultimate pH	0.20 units	5.40–6.40	37.9	63.9	5.2
Warner–Bratzler shear	4.9 N	14.7–58.8 N	59.7	18.4	4.6
Tenderness Dislike/Like					
Cooked temperature	5.5 °C	62.8–79.4 °C	46.7	40.2	−2.1
Intramuscular fat	1.0%	1.0–6.0%	42.1	45.6	0.6
Ultimate pH	0.20 units	5.40–6.40	35.4	58.2	4.6
Warner–Bratzler shear	4.9 N	14.7–58.8 N	59.5	11.4	5.3
Tenderness-Level					
Cooked temperature	5.5 °C	62.8–79.4 °C	45.1	37.4	−2.5
Intramuscular fat	1.0%	1.0–6.0%	40.0	42.2	0.6
Ultimate pH	0.20 units	5.40–6.40	32.2	57.8	5.1
Warner–Bratzler shear	4.9 N	14.7–58.8 N	58.4	9.3	5.5
Flavor Dislike/Like					
Cooked temperature	5.5 °C	62.8–79.4 °C	34.5	34.0	−0.2
Intramuscular fat	1.0%	1.0–6.0%	31.1	38.9	1.5
Ultimate pH	0.20 units	5.40–6.40	30.6	41.0	2.1
Warner–Bratzler shear	4.9 N	14.7–58.8 N	41.1	18.8	2.5
Flavor-Level					
Cooked temperature	5.5 °C	62.8–79.4 °C	31.6	29.9	−0.6
Intramuscular fat	1.0%	1.0–6.0%	27.5	35.6	1.6
Ultimate pH	0.20 units	5.40–6.40	28.7	34.4	1.1
Warner–Bratzler shear	4.9 N	14.7–58.8 N	36.2	18.4	2.0

[a] Consumer responses measured on an 8-point, end-anchored scale; 1 = Most unfavorable, 8 = Most favorable.

Juiciness-Like and Level, attributes that contribute to the perception of Overall-Like, were influenced to a greater extent by incremental changes in pH and WBS. The percentage of consumer responses for Juiciness-Like that were predicted to be ⩾6 reached >60% at pH levels of 6.40 and greater than 59% when WBS values were 14.7 N. Similar to the observation for Overall-Like, incremental increases of 4.9 N for WBS reduced the predicted proportion of consumer responses that were ⩾6 × 4.2%, whereas for each 0.20 increase in ultimate pH, the proportion of consumer responses that were ⩾6 increased 4.7% and 5.2% for Juiciness-Like and Level, respectively.

Relationships between a consumer's perception of tenderness and WBS, a mechanical estimate of expected consumer tenderness, were very pronounced in the present study. Predicted proportions of consumers rating pork Tenderness-Like and Level at ⩾6 were as large as 59.5% when the WBS values were equal to 14.7 N, but were reduced dramatically (∼5.5%) for each incremental (4.9 N) increase in WBS as illustrated in Fig. 1. Consumers clearly disliked pork with greater WBS values and rated it accordingly. These results were in accordance with Verbeke, Van Oeckel, Warnants, Viaene, and Boucque (1999) who suggested that there was significant variation in the proportion of unacceptable levels for taste, juiciness, and tenderness, and in particular a very strong variability in pork tenderness ratings from consumers. The challenge for the pork industry is determining where along the scale of WBS a product is deemed to be too tough as well as identifying a reliable method to assess tenderness in a pre-cooked, pre-purchase state that may allow product sorting and or price differentiation.

In the present study, as ultimate pH increased from 5.4 to 6.4 the predicted proportion of consumer responses that were ⩾6 for Tenderness-Like and Level increased by ∼23% to a level where nearly 58% of consumers would respond favorably (⩾6 response) for pork with a pH of 6.40. Patterns of predicted consumer responses for Juiciness-Like (Fig. 2) and Level were similar to the relationship observed between pH and consumer perceptions of Tenderness-Like and Level. When ultimate pH of pork was 5.40, consumers proportionately rated Juiciness-Like and Level on the less desirable end of the scale, and as pH was incrementally increased, the predicted proportion of consumers rating juiciness of pork as ⩾6 increased by 4.7% (Like) and 5.2% (Level) for each 0.20 unit pH increase. While achieving an industry level ultimate pH of 6.4 would likely be very difficult, pH levels of 5.80 and 6.00 were predicted to improve the proportions of consumers rating Juiciness-Like and Level at ⩾6 by nearly 10% and 15%, respectively, when compared to an ultimate pH of 5.40.

Focusing on the proportion of consumers rating Likelihood of Purchase (Table 9) as 'Probably Would Buy' or 'Definitely Would Buy' (scores of 4 or 5 on the 5-point scale), data would suggest

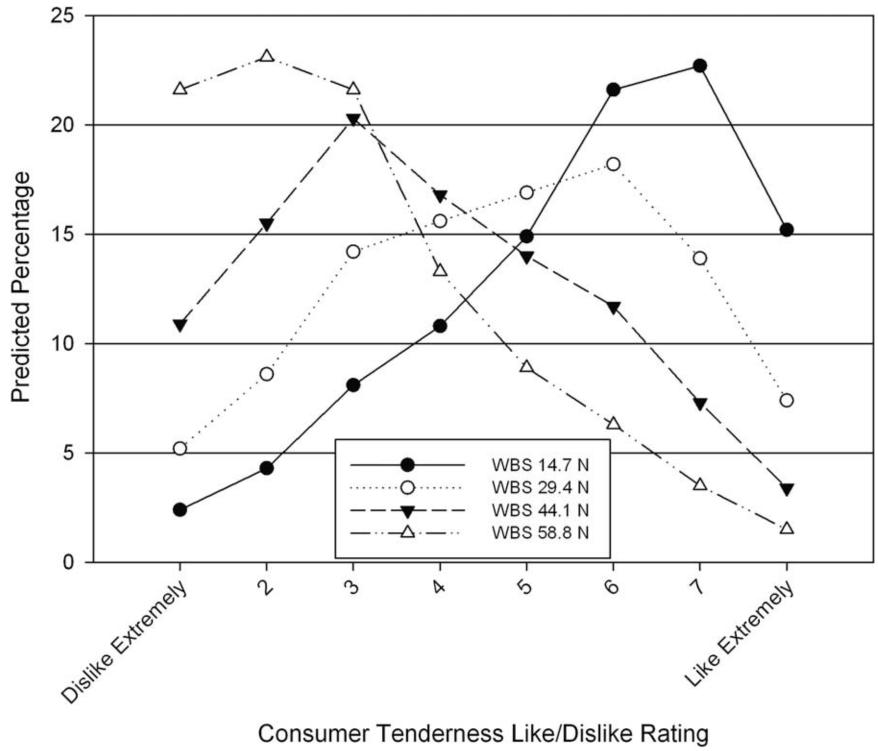

Fig. 1. Predicted percentages of consumer responses for assessment of tenderness Like/Dislike in relation to the level of pork loin Warner–Bratzler shear force (N).

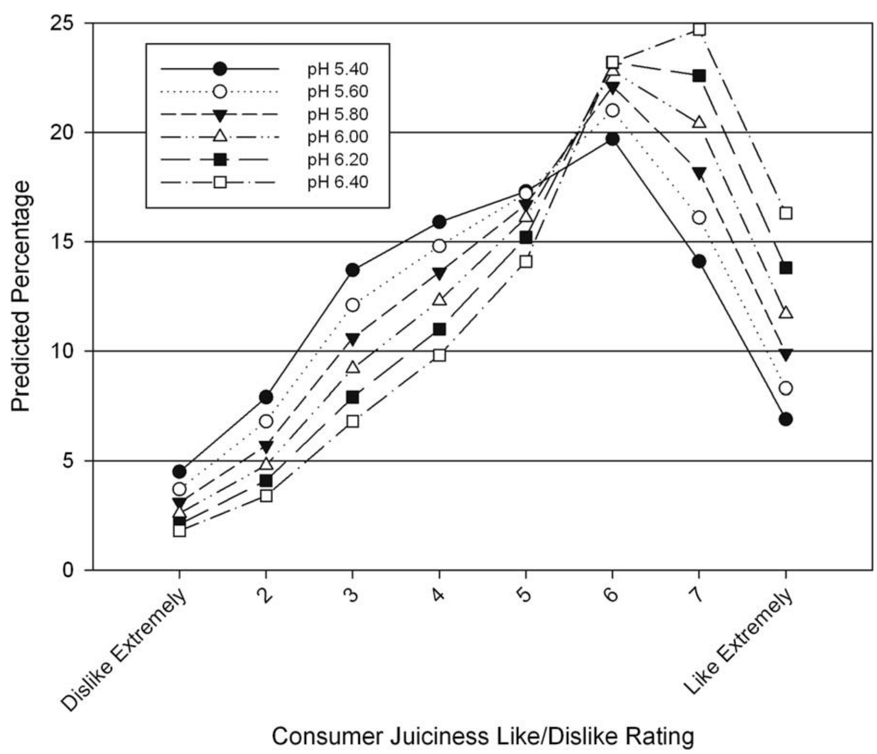

Fig. 2. Predicted percentage of consumer responses for assessment of Juiciness-Like/Dislike in relation to the ultimate pH of pork loins.

and support results (Tables 6 and 7) that indicated the consumers are principally influenced by pH and WBS level and to a lesser extent by cooked temperature and IMF levels. Very tough pork had a very low Likelihood of Purchase. Pork with an average WBS (~29 N) in the present study was predicted to achieve only a 34.3% of consumers rating pork as Probably Would Buy or Definitely Would Buy. These findings support the influences of pH and WBS on consumer assessments of eating quality previously described and provide evidence for a very neutral to slightly negative overall perception of non-enhanced pork in general.

Table 9
Frequencies of predicted consumer responses to likelihood of purchase[a] observed across pork quality measures of intramuscular fat, ultimate pH, and Warner–Bratzler shear force and representing four cooked temperatures.

Consumer Response Independent Variable	Increment	Range	Predicted Percentage of Consumers Responding: Probably Would Buy or Definitely Would Buy the Pork		Average% improvement in consumer rating per increment
			% at minimum of the range	% at maximum of the range	
Likelihood of purchase					
Cooked Temperature	5.5 °C	62.8–79.4 °C	36.5	32.4	−1.4
Intramuscular Fat	1.0%	1.0–6.0%	31.5	38.8	1.5
Ultimate pH	0.20 units	5.40–6.40	30.3	42.2	2.4
Warner–Bratzler shear	4.9 N	14.7–58.8 N	44.5	14.0	3.4

[a] Consumer responses measured on a 5-point scale; 1 = Definitely Would Not Buy, 5 = Definitely Would Buy.

4. Conclusions

Consumer perceptions of pork eating quality were greatly influenced by and reflective of differences in fresh pork ultimate pH and cooked pork Warner–Bratzler shear force in the present study with significant, but smaller influences with respect to the level of loin intramuscular fat and end-point cooked temperature. The absence of significant interactions among quality indicators and between quality indicators and end-point temperature in the present data set suggests that, for non-enhanced pork loin, consumer's perceptions of eating quality (flavor, tenderness, juiciness, overall desirability) would be optimized in a fresh pork loin with greater pH and IMF, lower cooked WBS, and a chop that is cooked to a lesser degree of doneness.

Of general concern to the swine industry is the near neutral to unfavorable mean responses for consumer's perceptions of non-enhanced pork eating quality. This finding may reflect a significant industry challenge when pork competes with alternative protein sources for market share. Continued focus on production efficiency, carried out through improved genetics, nutrition, and facilities and necessitated by a requirement of financial sustainability, will likely provide obstacles to rapid improvement in non-enhanced pork eating quality. In concert with a production efficiency requirement, the findings of this consumer-focused study strongly suggest that additional research efforts that focus on the biological mechanisms that influence pork pH and tenderness are needed to improve pork palatability. In addition, identification of strategies for pork-chain intervention strategies to improve pork quality characteristics that influence consumer perception of non-enhanced pork is necessary to improve consumer demand.

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