Food Sci. Biotechnol. Vol. 18, No. 2, pp. 307 ~ 311 (2009)

Food Science and Biotechnology

# Comparison of Postmortem Meat Quality and Consumer Sensory Characteristic Evaluations, According to Porcine Quality Classification

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**Abstract** This study examined variations in postmortem meat quality characteristics and consumer sensory evaluations of different pork quality classes in fresh and cooked meat. Pale, soft, and exudative (PSE) meat had the highest drip loss, lightness, and the lowest $pH_{24\ hr}$ whereas dark, firm, and dry (DFD) meat showed the opposite results. When the fresh meat was evaluated by consumer panelists, they could only distinguish the PSE class of meat and it scored lowest in overall acceptability. However, the panelists did not consider cooked PSE or DFD pork to be unacceptable overall, indicating that consumers cannot distinguish the quality of cooked pork.

**Keywords:** pork quality class, postmortem meat quality, consumer sensory evaluation, pig

## Introduction

Despite a great deal of effort to reduce unacceptable meat, it remains a significant issue for the meat industry. Pale, soft, and exudative (PSE) meat results from extremely fast glycolysis during the early postmortem period and causes a rapid decline in muscle pH and a high carcass temperature due to the rapid production and accumulation of lactate (1-4). The combination of low muscle pH and high carcass temperature leads to poor postmortem pork quality with increased light reflectance and decreased water holding capacity (WHC) and in the end, a paler surface and higher drip loss as compared to normal meat (5). In contrast, dark, firm, and dry (DFD) meat occurs when muscle glycogen is depleted as a result of preslaughter chronic stress and, consequently, reduced lactate formation (6). Consequently, DFD meat has abnormally high pH, an undesirable dark color, as well as a susceptibility to spoilage (7). Therefore, such characteristics of PSE and DFD meat are unattractive and discriminated against by consumers when they purchase fresh meat via visual appearance.

Meat quality can be defined as a combination of various properties of fresh and processed meat. These properties include sensory and technical characteristics, such as color, WHC, cooking losses, and texture (8). Among the sensory characteristics, eating quality, which refers to the flavor, tenderness, and juiciness of meat, has long been regarded as the most critical characteristic because it influences repeat purchases (9). The sensory characteristics of pork can be affected by many factors such as breed, carcass weight, gender, diet, genetic variation, biochemical changes that occur during further processing, slaughtering and cooling routines, maturation, and cooking methods (10-14). Therefore, postmortem pork quality characteristics affect the final eating quality of the cooked meat (11).

Although several studies have investigated the effects of postmortem meat quality, particularly the PSE condition, on the eating quality of pork, the results remain controversial. Studies show there are no significant differences in eating quality among different pork quality classes (14-16). However, Livisay *et al.* (7), Topel *et al.* (16), Kauffman *et al.* (18), and Warriss *et al.* (19) showed that consumer panelists scored PSE chops significantly lower in palatability than red, firm, and non-exudative (RFN) or DFD meat. Moreover, Franck *et al.* (20) reported that the cooked pork meat sector is severely handicapped by major quality defects due to PSE. Whether eating quality is affected by the quality status of meat, namely meat of good quality or with abnormal characteristics, is still unclear. Therefore, the objective of this study was to measure the variations in postmortem meat quality characteristics and evaluate consumer sensory appeal for fresh and cooked meat of different pork quality classes.

## Materials and Methods

**Animals and muscle samples** A total of 113 commercial crossbred pigs were used in this study. The treatment conditions were the same for the animals before and after slaughter (such as the feeding system and environmental conditions). The pigs were slaughtered during the winter period using electrical stunning. The abattoir used the traditional scald-singe process. At 45 min postmortem, a total of 113 samples were taken from the *longissimus dorsi* muscles at the 8th *thoracic vertebra* to analyze muscle pH at 45 min ($pH_{45\ min}$) postmortem. After 24 hr of chilling, the pork loins (9-13th *thoracic vertebra*) were collected to analyze the meat quality characteristics and sensory traits of the fresh meat. Sample for the cooked meat sensory evaluation were frozen and stored at –20°C (21).

**Meat quality measurements** All experiments for evaluating

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Received April 3, 2008; Revised September 16, 2008;
Accepted October 9, 2008

meat quality were done in 3 times, and the average of triplicate measurements was recorded. The muscle $pH_{45\ min}$ and $pH_{24\ hr}$ of postmortem samples were measured directly using a spear-type pH meter (IQ150; IQ Instrument, San Diego, CA, USA). The meat color was assessed at 24 hr postmortem using a Minolta chromameter (CR-300; Minolta Camera Co., Osaka, Japan) after exposing the meat surface to the air for 30 min at 4°C. The results are expressed as Commission International de l'Eclairage (CIE) lightness ($L^*$), redness ($a^*$), and yellowness ($b^*$) values. The drip loss was measured in accordance with the method described by Honikel (22). The muscle samples were classified based on drip loss and lightness into 4 classes (23):

Pale, soft, and exudative (PSE): drip loss>6.0%, $L^*>50$
Reddish-pink, soft, and exudative (RSE): drip loss> 6.0%, $L^*\leq 50$
Reddish-pink, firm, and non-exudative (RFN): drip loss 6.0%, $L^*\leq 50$
Dark, firm, and dry (DFD): drip loss<2.0%, $L^*<43$.

Filter-paper fluid uptake (FFU) was also measured according to the method of Kauffman *et al.* (24). Pork samples from each classification were cooked to a final core temperature of 71°C, and cooking losses were estimated by weighing the samples before and after cooking (25). Warner-Bratzler shear force (WBS), an indicator of meat tenderness, was determined using an Instron Universal Testing Machine (Model 1011; Instron Corp., Norwood, MA, USA) equipped with a Warner-Bratzler shearing device. Six cores (1.27 cm diameters), parallel to the longitudinal orientation of the muscle fibers, were taken from each steak. The samples were sheared perpendicular to the long axis of the cores. Protein solubility was measured as an indicator of the level of protein denaturation, and measured in accordance with the method described by Joo *et al.* (23).

**Consumer sensory evaluation** A total of 48 pork eating consumers (20-40 ages, 22 females and 26 males) were used, consisting mainly of student and staff members from Korea University, to evaluate sensory quality of a total of 113 pork samples. The sensory evaluation consisted of 2 sessions: one to visually evaluate the attributes of the fresh pork, and a second to evaluate all of the sensory attributes of the cooked pork. The samples were labeled with individual 3-digit random numbers and served one at a time in random order. The panelists used 9-point scales with word anchors at the extreme ends (27), with the exception of the National Pork Producers Council (NPPC) color and marbling scores (28). The fresh-pork sensory traits were assessed 24 hr postmortem after the samples (28 mm thick) were exposed to air for 30 min at 4°C to allow for complete bloom prior to being presented to the panelists. Subjective measures for color (1=pale pinkish-gray to white; 6=dark purplish-red) and marbling [1=1.0% intramuscular fat (IMF); 10=10% IMF] were evaluated according to NPPC (27). The panelists also visually evaluated moisture (1=very dry; 9=very moist) as well as the color, appearance, and overall acceptability (1=very unacceptable; 9=very acceptable) of the fresh pork.

Samples for the cooked meat sensory evaluation were thawed overnight at 4°C and cut into segments approximately 25 mm thick. The steaks were roasted in an oven (MCS312CF4; Electrolux, Stockholm, Sweden) at 180°C, turned every 3 min, and cooked to an internal temperature of 71.1°C, which was measured using a thermometer with a handheld probe (TES-1300; TES Electrical Electronic Co., Taipei, Taiwan). The cooked steaks were cut into $10\times10\times25\ mm^3$ pieces, placed on a white plastic tray covered with aluminum foil, and served immediately to each panelist. The cooked samples were evaluated for color (1=very unacceptable; 9=very acceptable), appearance (1=very unacceptable; 9=very acceptable), flavor (1=very unacceptable; 9=very acceptable), taste (1=very unacceptable; 9=very acceptable), juiciness (1=very dry; 9=very juicy), tenderness (1=very tough; 9=very tender), and overall acceptability (1=very unacceptable; 9=very acceptable).

**Statistical analysis** The data were classified into 4 groups (PSE, $n$=36; RSE, $n$=24; RFN, $n$=43; DFD, $n$=10) based on drip loss and lightness. After classification, the general linear model (GLM) procedure (29) was performed to identify the association between groups and traits using SAS software (Cary, NC, USA). For the consumer sensory evaluation, the model was: $y_{ijk}=\mu+T_i+S_j+A_k+e_{ijk}$, where $y_{ijk}$ is the observation; $\mu$ is the general mean; $T_i$ is the fixed effect of the quality class $i$; $S_j$ is the fixed effect of sex $j$; $A_k$ is the fixed effect of age $k$; and $e_{ijk}$ is the random error. When significant differences were detected, the mean values were separated by the probability difference (PDIFF) option. The results are presented as least-squares means for each group, together with the standard errors.

## Results and Discussion

**Postmortem meat quality characteristics** The significantly different meat quality traits and protein solubility among the pork quality classes were shown in Table 1. The PSE group had the significantly lowest muscle $pH_{45\ min}$ ($p<0.001$) and a significantly lower muscle $pH_{24\ hr}$ than the RFN or DFD groups (5.63 vs. 5.71 vs. 5.93, respectively, $p<0.001$). The DFD group had the darkest surface, lowest drip loss, and FFU; whereas the PSE group had the lightest surface, highest drip loss, and the most exudate on filter paper ($p<0.001$). The RFN and RSE groups had similar lightness characteristics, but they were significant differences in drip loss (4.11 vs. 7.13%, $p<0.001$) and FFU (29.86 vs. 37.12 mg, $p<0.001$). These results implied that the RSE group had weaker WHC than the RFN group.

The high rate of pH decline and/or a low ultimate pH result in muscle protein denaturation (30) which has a major impact on meat quality parameters, such as meat color and WHC (4). The total and myofibrillar protein solubility of the PSE group was the lowest among the meat quality classes and that of the DFD group showed the opposite tendency ($p<0.001$). Sarcoplasmic protein solubility of the PSE group was significantly lower than the other groups ($p<0.001$), but there were no significant differences between the RSE and the DFD groups. These results imply that the PSE group had a high level of protein denaturation due to the rate and extent of glycolysis, which lead to a tendency for pale color and diminished WHC.

**Consumer sensory evaluations for fresh meat** The PSE

**Table 1. Comparison of meat quality measurements for different pork quality classes**

| | Pork quality class[1] | | | | Levels of significance[2] |
|---|---|---|---|---|---|
| | PSE | RSE | RFN | DFD | |
| **Meat quality traits** | | | | | |
| Muscle pH$_{45\ min}$ | 5.96$^{c}$ (0.03)[3] | 6.13$^{b}$ (0.04) | 6.19$^{b}$ (0.03) | 6.42$^{a}$ (0.06) | *** |
| Muscle pH$_{24\ hr}$ | 5.63$^{c}$ (0.02) | 5.64$^{c}$ (0.07) | 5.71$^{b}$ (0.01) | 5.93$^{a}$ (0.03) | *** |
| Lightness ($L$*) | 53.41$^{a}$ (0.35) | 47.92$^{b}$ (0.43) | 47.48$^{b}$ (0.32) | 41.28$^{c}$ (0.63) | *** |
| Redness ($a$*) | 6.81$^{b}$ (0.20) | 6.48$^{b}$ (0.24) | 6.62$^{b}$ (0.18) | 8.04$^{a}$ (0.36) | *** |
| Yellowness ($b$*) | 3.71$^{a}$ (0.14) | 2.65$^{b}$ (0.17) | 2.56$^{b}$ (0.13) | 1.75$^{c}$ (0.25) | *** |
| Drip loss (%) | 7.85$^{a}$ (0.21) | 7.13$^{b}$ (0.26) | 4.11$^{c}$ (0.19) | 1.17$^{d}$ (0.38) | *** |
| Filter-paper fluid uptake (mg) | 45.42$^{a}$ (1.90) | 37.21$^{b}$ (2.32) | 29.86$^{c}$ (1.73) | 14.48$^{d}$ (3.43) | *** |
| **Protein solubility (mg/g)** | | | | | |
| Total protein | 155.6$^{c}$ (3.06) | 180.8$^{b}$ (3.75) | 179.5$^{b}$ (2.80) | 214.0$^{a}$ (5.54) | *** |
| Myofibrillar protein | 92.63$^{c}$ (3.21) | 108.9$^{b}$ (3.93) | 109.7$^{b}$ (2.94) | 136.5$^{a}$ (5.80) | *** |
| Sarcoplasmic protein | 62.93$^{b}$ (2.17) | 71.90$^{a}$ (2.66) | 69.74$^{a}$ (1.99) | 77.48$^{a}$ (3.93) | *** |

[1] PSE: pale, soft, and exudative; RSE: red, soft, and exudative; RFN: red, firm, and non-exudative; DFD: dark, firm, and dry.
[2] ***$p<0.001$.
[3] Standard error of least-square means; $^{a\text{-}d}$Least-square means with different superscripts in the same row differ significantly ($p<0.05$).

**Table 2. Comparison of fresh meat sensory traits for different pork quality classes**

| | Pork quality class[1] | | | | Levels of significance[2] |
|---|---|---|---|---|---|
| | PSE | RSE | RFN | DFD | |
| NPPC[3] color score | 1.86$^{c}$ (0.08)[4] | 2.38$^{b}$ (0.10) | 2.40$^{b}$ (0.07) | 4.02$^{a}$ (0.15) | *** |
| NPPC marbling score | 1.47$^{c}$ (0.10) | 1.88$^{b}$ (0.12) | 1.98$^{b}$ (0.09) | 2.66$^{a}$ (0.18) | *** |
| Moisture | 6.23$^{a}$ (0.10) | 5.78$^{b}$ (0.28) | 5.41$^{c}$ (0.09) | 5.70$^{bc}$ (0.07) | *** |
| Color | 4.66$^{c}$ (0.15) | 6.07$^{a}$ (0.18) | 6.16$^{a}$ (0.13) | 5.50$^{b}$ (0.26) | *** |
| Appearance | 5.03$^{b}$ (0.12) | 5.62$^{b}$ (0.14) | 6.05$^{a}$ (0.11) | 6.02$^{a}$ (0.21) | *** |
| Overall acceptability | 4.72$^{b}$ (0.14) | 5.78$^{a}$ (0.17) | 6.02$^{a}$ (0.13) | 5.51$^{a}$ (0.25) | *** |

[1] PSE: pale, soft, and exudative; RSE: red, soft, and exudative; RFN: red, firm, and non-exudative; DFD: dark, firm, and dry.
[2] *** $p<0.001$.
[3] National Pork Producers Council.
[4] Standard error of least-square means; $^{a\text{-}c}$Least-square means with different superscripts in the same row differ significantly ($p<0.05$).

pork received the lowest NPPC color score ($p<0.001$), whereas the DFD pork received the highest rating as was expected from the results for lightness (Table 2). Color is one of the most important meat characteristic for consumers because it influences their perception of the appearance and attractiveness of pork (31). Other studies have shown significantly lower subjective color scores for PSE pork (32,33), and those for DFD pork as higher than those of acceptable pork (34). According to Flores *et al.* (11), there was no difference among PSE, RFN, and DFD pork for IMF. However, in this study, NPPC marbling scores were lowest in the PSE pork and highest in the DFD pork ($p<0.001$). Candek-Potokar *et al.* (33) also observed that subjective marbling scores were lower in PSE meat, likely because its paleness may have indicated to consumers that the lean portions were fat; however, the DFD meat showed the opposite effect.

The PSE pork was judged as significantly more moisture than the other pork quality classes ($p<0.001$), and these results corresponded to those of the objective measures for moisture such as FFU and drip loss. The WHC of pork is influenced by many factors. Specifically, myosin denaturation may cause unacceptable exudation in terms of drip loss in PSE pork (35). Thus, fresh PSE muscle has a lower percentage of bound water than normal muscle (34). The color acceptability scores of the PSE and DFD pork were significantly lower than those of the RSE and RFN pork ($p<0.001$). This is consistent with the results of Fox *et al.* (32) who reported that PSE meat showed lower color acceptability than normal meat and Viljoen *et al.* (6) who found that DFD meat scored lower than acceptable meat. Although the colors of both the PSE and DFD pork were undesirable, the panel regarded the DFD pork as significantly more acceptable ($p<0.001$), and the RFN and DFD pork ranked higher than the PSE and RSE pork for acceptability of appearance ($p<0.001$). This result suggests that consumers find excessive exudation unacceptable.

O'Neill *et al.* (36) reported that pale-colored pork that exudes juices into the package and is unable to maintain a proper shape is unattractive to consumers. Also, it was concluded that consumers prefer marbled to unmarbled pork (37). Our results corresponded with these findings as the PSE class was significantly the least acceptable pork quality class (16,37). Topel *et al.* (16) found that normal pork was preferred over both PSE and DFD pork, but we found no significant differences between RFN and DFD pork. Therefore it is unknown whether PSE is a key consumer determinant of fresh pork sensory quality.

**Table 3. Comparison of cooked meat sensory traits, cooking loss, and Warner-Bratzler shear force (WBS) for different pork quality classes**

| | Pork quality class[1] | | | | Levels of significance[2] |
|---|---|---|---|---|---|
| | PSE | RSE | RFN | DFD | |
| **Cooked meat sensory traits** | | | | | |
| Color | 5.86$^{a}$ (0.10)[3] | 6.05$^{a}$ (0.12) | 5.96$^{a}$ (0.09) | 4.96$^{b}$ (0.18) | *** |
| Appearance | 5.74$^{a}$ (0.11) | 5.84$^{a}$ (0.13) | 5.79$^{a}$ (0.10) | 4.95$^{b}$ (0.19) | ** |
| Flavor | 5.26$^{bc}$ (0.08) | 5.47$^{ab}$ (0.09) | 5.55$^{a}$ (0.07) | 4.99$^{c}$ (0.13) | *** |
| Taste | 4.92 (0.10) | 5.26 (0.12) | 5.21 (0.09) | 4.92 (0.18) | NS |
| Juiciness | 5.29 (0.15) | 5.19 (0.18) | 5.62 (0.14) | 5.46 (0.28) | NS |
| Tenderness | 5.56 (0.15) | 5.05 (0.18) | 5.22 (0.13) | 5.15 (0.27) | NS |
| Overall acceptability | 5.17 (0.10) | 5.28 (0.13) | 5.40 (0.09) | 5.04 (1.89) | NS |
| **Cooked meat quality traits** | | | | | |
| Cooking loss (%) | 28.46$^{a}$ (0.82) | 26.52$^{ab}$ (1.01) | 24.32$^{b}$ (0.75) | 27.86$^{a}$ (1.45) | ** |
| WBS (N) | 43.95$^{b}$ (0.08) | 40.13$^{b}$ (1.61) | 38.47$^{bc}$ (1.28) | 51.74$^{a}$ (2.58) | *** |

[1] PSE: pale, soft, and exudative; RSE: red, soft, and exudative; RFN: red, firm, and non-exudative; DFD: dark, firm, and dry.

[2] NS=not significance; **$p<0.01$; ***$p<0.001$.

[3] Standard error of least-square means; $^{a-c}$ Least-square means with different superscripts in the same row differ significantly ($p<0.05$).

**Consumer sensory evaluation of cooked meat** The sensory attributes of the cooked pork are presented according to meat quality class in Table 3. In contrast to the sensory evaluation results for the fresh pork (Table 2), the cooked DFD pork was significantly more unacceptable than any of the other pork quality classes in terms of color ($p<0.001$) and appearance ($p<0.01$). Norman *et al.* (38) reported that pork samples with lower NPPC color scores were perceived to be brighter. However, color acceptability was not significantly different between the PSE, RSE, and RFN pork in our study.

The PSE and DFD pork scored significantly lower in terms of flavor acceptability than the RFN pork ($p<0.001$); however, there was no significant difference between the PSE and DFD pork. This is consistent with results by Topel *et al.* (16) who reported that normal pork scored higher in flavor. However, Bennett *et al.* (34), as well as Searcy *et al.* (15), found no significant differences in flavor among PSE, DFD, and normal pork; and DFD pork had better flavor than PSE pork in a study by Kauffman *et al.* (18). The taste acceptability scores were also not significantly different among the different pork quality classes. This is in agreement with others (6,17,39), but in disagreement with low WHC scored low in taste (15).

Because of capillary force, it is difficult for water to remain entrapped within protein structures, so cooking loss is presumed to be generated by protein denaturation during cooking (40). According to Huff-Lonergan *et al.* (41), cooking losses correlate to juiciness, which is a major factor in terms of meat preference (40). However, we found no differences in juiciness among the pork quality classes, although significant differences were observed for cooking loss ($p<0.01$) (Table 3). These results agree with other studies (11,15,16), but disagree with those presented PSE pork as having the lowest level of juiciness and DFD pork as being the juiciest (18,34).

Among sensory quality traits, tenderness is considered the most crucial factor determining overall meat acceptability (9). According to Flores *et al.* (11), tenderness depends on the degree of proteolytic breakdown within myofibrillar proteins as well as on the concentration of marbling. Numerous studies (16,32) indicate there are large variations in tenderness among the different pork quality classes. Some researchers found that PSE pork was more tender than normal or DFD pork (34), and Livisay *et al.* (7) reported that both PSE and DFD pork scored higher in tenderness than normal pork. In contrast, PSE pork was judged as less tender than normal and DFD pork (16), and DFD pork was tender than RFN (14) or PSE pork (18). However, our panel found no differences in tenderness among the pork classes although the WBS values of the DFD class were significantly higher than those of the other classes ($p<0.001$) (Table 3), thus supporting the findings of Searcy *et al.* (15) and Toldra and Flores (17).

The overall acceptability of cooked pork is evaluated by considering all sensory quality attributes, and Maltin *et al.* (9) reported that tenderness, flavor, and juiciness are regarded as the 3 most important traits in determining the eating quality of meat. In the current study, no significant differences were found in tenderness and juiciness. The overall acceptability of the pork quality classes did not significantly differ in the current study and this finding agrees with the conclusions of Toldra and Flores (17).

In conclusion, consumers could only distinguish the fresh PSE class and it was scored the lowest in overall acceptability. In terms of cooked meat, consumers were not able to perceive PSE or DFD pork when making their overall decision for acceptability. These results suggest that the consumer cannot distinguish the quality of cooked pork.

## Acknowledgment

This work was supported by the Agricultural R&D Promotion Center (Korea).

## References

1. Briskey EJ. The etiological status and associated studies of pale, soft, and exudative porcine musculature. Adv. Food Res. 13: 89-178 (1964)

2. Asghar A, Pearson AM. Influence of ante- and postmortem treatments on muscle composition and meat quality. Adv. Food Res. 26: 53-61 (1980)
3. Choi YM, Ryu YC, Kim BC. Influence of myosin heavy- and light chain isoforms on early postmortem glycolytic rate and pork quality. Meat Sci. 76: 281-288 (2007)
4. Choe JH, Choi YM, Lee SH, Shin HG, Ryu YC, Hong KC, Kim BC. The relation between glycogen, lactate content and muscle fiber type composition, and their influence on postmortem glycolytic rate and pork quality. Meat Sci. 80: 355-362 (2008)
5. Freise K, Brewer S, Novakofski J. Duplication of the pale, soft, and exudative condition starting with normal postmortem pork. J. Anim. Sci. 83: 2843-2852 (2005)
6. Viljoen HF, de Kock HL, Webb EC. Consumer acceptability of dark, firm and dry (DFD) and normal pH beef steaks. Meat Sci. 61: 181-185 (2002)
7. Livisay SA, Xiong YL, Moody WG. Proteolytic activity and calcium effect in dark-firm-dry and pale-soft-exudative meat. Lebensm. -Wiss. Technol. 29: 123-128 (1996)
8. Van der Wal PG, Engel B, Hulsegge B. Causes for variation in pork quality. Meat Sci. 46: 319-327 (1997)
9. Maltin CA, Warkup CC, Matthews KR, Grant CM, Porter AD, Delday MI. Pig muscle fibre characteristics as a source of variation in eating quality. Meat Sci. 47: 237-248 (1997)
10. Risvik E. Sensory properties and preferences. Meat Sci. 36: 67-77 (1994)
11. Flores M, Armero E, Aristoy MC, Toldra F. Sensory characteristics of cooked pork loin as affected by nucleotide content and post-mortem meat quality. Meat Sci. 51: 53-59 (1999)
12. Shin HG, Choi YM, Nam YJ, Lee SH, Choe JH, Jeong DW, Kim BC. Relationships among instrumental tenderness parameters, meat quality traits, and histochemical characteristic in porcine *longissimus dorsi* muscle. Food Sci. Biotechnol. 17: 965-970 (2008)
13. Park BY, Park KM, Kim JH, Cho SH, Kim NK, Song MJ, Lee CS, Cho IK, Choe HS, Ryu KS, Hwang IH. Free amino acids, collagen solubility, and meat quality in pork (*Longissimus* muscle of Yorkshire) as a function of chiller temperature and aging. Food Sci. Biotechnol. 17: 26-30 (2008)
14. Waje C, Kim MY, Nam KC, Jo C, Kim DH, Lee JW, Kwon JH. Effect of irradiation on the color, microbiological quality, and sensory attributes of frozen ground beef, pork, and chicken after 6 months at −6°C. Food Sci. Biotechnol. 17: 212-215 (2008)
15. Searcy DJ, Harrison DL, Anderson LL. Palatability and selected related characteristics of three types of roasted porcine muscle. J. Food Sci. 34: 486-489 (1969)
16. Topel DG, Miller JA, Berger PJ, Rust RE, Parrish Jr FC, Ono K. Palatability and visual acceptance of dark, normal, and pale colored porcines M. *longissimus*. J. Food Sci. 41: 628-630 (1976)
17. Toldra F, Flores M. The use of muscle enzymes as predictors of pork meat quality. Food Chem. 69: 387-395 (2000)
18. Kauffman RG, Russell RL, Greaser ML, The 1998 UW-AS-305 Class. Using pork to teach students quality variations and how they are measured. J. Anim. Sci. 77: 2574-2577 (1999)
19. Warriss PD, Brown SN, Pasciak P. The colour of the adductor muscle as a predictor of pork quality in the loin. Meat Sci. 73: 565-569 (2006)
20. Franck M, Figwer P, Godfraind C, Poirel MT, Khazzaha A, Ruchoux MM. Could the pale, soft, and exudative condition be explained by distinctive histological characteristics? J. Anim. Sci. 85: 746-753 (2007)
21. Sakata R, Oshida T, Morita H, Nagata Y. Physico-chemical and processing quality of porcine M. *longissimus dorsi* frozen at different temperatures. Meat Sci. 39: 277-284 (1995)
22. Honikel KO. Evaluation and Control of Meat Quality in Pigs. Nijhoff Publishers, Dordrecht, Netherlands. pp. 129-142 (1987)
23. Joo ST, Kauffman RG, Kim BC, Park GB. The relationship of sarcoplasmic and myofibrillar protein solubility to colour and water-holding capacity in porcine *longissimus* muscle. Meat Sci. 52: 291-297 (1999)
24. Kauffman RG, Eikelenboom G, Van der Wal PG, Merkus BG, Zaar M. The use of filter paper to estimate drip loss of porcine musculature. Meat Sci. 18: 191-200 (1986)
25. Honikel KO. Reference methods for the assessment of physical characteristics of meat. Meat Sci. 49: 447-457 (1998)
26. Gornall AG, Bardawill CJ, David MM. Determination of serum-protein by means of the biuret reaction. J. Biol. Chem. 177: 751-766 (1949)
27. Meilgaard M, Civille GV, Carr BT. Sensory Evaluation Techniques. CRC Press, Inc., Boca Ranton, FL, USA. pp. 211-222 (1991)
28. NPPC. Pork composition and quality assessment procedures. National Pork Producers Council, Des Moines, IA, USA (2000)
29. SAS Institute, Inc. SAS User's Guide. Statistical Analysis Systems Institute, Cary, NC, USA (2001)
30. Henckel P, Karlsson A, Oksbjerg N, Petersen JS. Control of post mortem pH decrease in pig muscles: Experimental design and testing of animal models. Meat Sci. 55: 131-138 (2000)
31. Tan FJ, Morgan MT, Ludas LI, Forrest JC, Gerrard DE. Assessment of fresh pork color with color machine vision. J. Anim. Sci. 78: 3078-3085 (2000)
32. Fox JD, Wolfram SA, Kemp JD, Langlois BE. Physical, chemical, sensory, and microbiological properties and shelf life of PSE and normal pork chops. J. Food Sci. 45: 786-790 (1980)
33. Candek-Potokar M, Zlender B, Lefaucheur L, Bonneau M. Effects of age and/or weight at slaughter on *longissimus dorsi* muscle: Biochemical traits and sensory quality in pigs. Meat Sci. 48: 287-300 (1998)
34. Bennett ME, Bramblett VD, Aberle ED, Harrington RB. Muscle quality, cooking method, and aging vs. palatability of pork loin chops. J. Food Sci. 38: 536-538 (1973)
35. Kuo CC, Chu CY. Quality characteristics of Chinese sausages made from PSE pork. Meat Sci. 64: 441-449 (2003)
36. O'Neill DJ, Lynch PB, Troy DJ, Buckley DJ, Kerry JP. Effects of PSE on the quality of cooked hams. Meat Sci. 64: 113-118 (2003)
37. Wachholz D, Kauffman RG, Henderson D, Lochner JV. Consumer discrimination of pork color at the market place. J. Food Sci. 43: 1150-1152 (1978)
38. Norman JL, Berg EP, Heymann H, Lorenzen CL. Pork loin color relative to sensory and instrumental tenderness and consumer acceptance. Meat Sci. 65: 927-933 (2003)
39. Van Oeckel MJ, Warnants N. Variation of the sensory quality within the m *longissimus thoracis* et *lumborum* of PSE and normal pork. Meat Sci. 63: 293-299 (2003)
40. Aaslyng MD, Bejerholm C, Ertbjerg P, Bertram HC, Andersen HJ. Cooking loss and juiciness of pork in relation to raw meat quality and cooking procedure. Food Qual. Prefer. 14: 277-288 (2003)
41. Huff-Lonergan E, Baas TJ, Malek M, Dekkers JC, Prusa K, Rothschild MF. Correlations among selected pork quality traits. J. Anim. Sci. 80: 617-627 (2002)