

PROCESSING AND PRODUCTS

Characteristics of Pale, Soft, Exudative Broiler Breast Meat

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ABSTRACT The objective of the study was to characterize pale breast meat, compare it with normal colored breast meat, and determine whether it should be considered pale, soft, and exudative (PSE). Characteristics of 20 normal and 20 pale broiler breasts, obtained at a commercial slaughter plant, were evaluated. Compared with normal meat, the pale breast meat had a significantly ($P < 0.05$) lower pH (5.7 vs. 5.9), higher color L* value (60.0 vs. 55.1), higher drip loss (1.34 vs. 0.87%), lower marinade uptake (31.2 vs. 44.3%), and lower cooking yields (95.2 vs. 105.8%). Protein solubility in pale samples was slightly ($P < 0.05$) lower than in normal samples, which suggests increased protein denaturation in the pale breasts. Correlations between pH and L* value ($r = -0.76$), pH and

marinade uptake ($r = 0.64$), sarcoplasmic protein solubility and L* value ($r = -0.71$), and sarcoplasmic protein solubility and moisture uptake ($r = 0.66$) and cooking yield ($r = 0.66$) were significant ($P < 0.05$). Correlations between total protein solubility and moisture uptake or cooking yields were not significant. The low ultimate pH of pale breast muscle appears to be the main determinant of its low water-holding capacity (WHC). This lower pH was unrelated to a higher lactate concentration or glycolytic potential of the pale muscle. Further research is needed to determine the causes of the low pH and possible measures to increase the pH (and functionality) of pale broiler breast muscle. Because the pale breast muscle has a low WHC, it can be considered PSE.

(Key words: pale, soft, exudative; protein denaturation; pH; water-holding capacity; color)

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INTRODUCTION

In pork, the existence of pale, soft, exudative (PSE) quality was recognized decades ago (Wismer-Pedersen, 1959; Lawrie, 1960; Bendall and Swatland, 1988). More recently, there have been reports on PSE quality in poultry products (Barbut, 1993; Sosnicki, 1995); however, details on characteristics and causes of PSE in broiler breast meat are not available.

The PSE condition in pork is reported to be the result of denaturation of proteins, caused by attainment of a low pH while the carcass is still warm (Bendall and Swatland, 1988). This situation may occur through rapid glycolysis, a particularly low ultimate pH, slow chilling, or various combinations of these factors. It is assumed that PSE in broiler breast meat is comparable to PSE in pork (Barbut, 1998). The seasonal variation in the incidence of PSE in broiler breast meat (Barbut, 1998) strongly supports this assumption. The PSE-quality turkey is comparable to PSE-quality pork in that it is pale and has poor processing characteristics (Sosnicki, 1995; Pietrzak et al., 1997). The PSE turkey seems different from PSE pork in that drip losses from fresh meat are not affected by the condition

(A. Sosnicki, 1999, PIC USA, Franklin, KY 42135, personal communication).

The incidence of PSE-quality broiler breast meat varies from 2 to 20%, depending on the environmental conditions (Vimini, 1996; Barbut, 1998). Yet, there is little information on the characteristics of PSE-quality broiler breast meat. Data from Barbut (1998) indicate that paleness and poor water-holding capacity (WHC) may be related to (or caused by) a low ultimate pH. In pork, correlation coefficients between pH, color, and WHC are low (War-riss and Brown, 1987; Van Laack et al., 1994; Warner, 1994). The PSE condition in pork and turkey is primarily a result of protein denaturation (Offer and Knight, 1988; Warner, 1994; Pietrzak et al., 1997). It is not known whether protein denaturation is the cause of paleness and poor WHC in broiler breast meat.

To effectively prevent the occurrence of PSE-quality broiler breast meat, it is necessary to understand the cause of this condition. The objective of this study was to characterize pale broiler breast meat and to determine whether it should be considered PSE.

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Abbreviation Key: PSE = pale, soft, and exudative; WHC = water-holding capacity.

MATERIALS AND METHODS

Materials

Butterflied chicken breasts were collected at a commercial slaughter plant. Breasts were deboned at approximately 6 h postmortem. Based upon visual evaluation of color, plant personnel selected pale and normal samples. The selected samples were packed in styrofoam boxes with ice packs and transported overnight to the university laboratory. At 1 d postmortem, the breasts were sampled. Color was assessed at the thickest part of the ventral surface, in the middle of the cranial section of the pectoralis muscle. Subsequently, one lobe of each butterflied breast was sampled for drip loss, pH, and sarcomere length. The other lobe was ground and used for measurement of pH, protein solubility, and WHC. The remaining ground meat was frozen until analysis of lactate concentration and glycolytic potential.

Methods

Color. Color was measured with a Minolta surface spectrophotometer (model CM-508d, SCI setting, illuminant D65 and viewing angle 2°).² Breasts were exposed to air for at least 30 min at 15 C before color measurement. Color L*, a*, and b* values at three locations of the thickest part of the ventral surface in the middle of the cranial section of the pectoralis muscle were averaged and recorded.

pH. Two procedures for pH measurement were used: the direct probe method and the slurry method. In both procedures, pH was measured with an Orion pH meter (model 250A³) equipped with a spear-shaped Mettler-Toledo combination pH electrode.⁴ In the direct probe method, the probe was inserted into the center of the muscle, 0.5 to 1 cm below the surface of the muscle. For the slurry method, 1 g of ground meat was blended with 10 mL deionized water (Stewart et al., 1984), and the pH of the solution was assessed. Results of the two procedures were similar, and only values obtained with the slurry method are reported.

Drip Loss. A cored sample, 4 cm in diameter, of the cranial section of the pectoralis muscle was collected and weighed. Subsequently, the core was suspended from a steel wire hook attached to the lid of a 1-L polymethylene pentene jar. Samples were stored at 2 ± 2 C for 48 h. After 48 h, samples were reweighed, and drip loss was calculated.

Sarcomere Length. Parallel to the muscle fiber, five samples (2 mm thick and 1 cm long) were cut from different locations across the center of the breast muscle. Sam-

ples were fixed and processed, and sarcomere length was assessed as described by Koolmees et al. (1986).

Protein Solubility. Protein solubility was used as an indicator of protein denaturation. For sarcoplasmic protein solubility, 2 g of ground meat was homogenized with 20 mL 0.03 M K-phosphate, pH 7.4. After overnight storage at 2 ± 2 C, the homogenate was filtered through Whatman No. 1 filter paper. The protein concentration of the filtrate was assessed using the biuret procedure (Gornall et al., 1949), with bovine serum albumin used as standard.

For measurement of total protein solubility, 1 g ground meat was homogenized in 0.05 M K-phosphate 0.55 M KI, pH 7.4. Homogenates were stored, filtered, and analyzed for protein as described for the sarcoplasmic proteins.

Moisture Uptake and Cooking Yield. Exactly 6 g ground breast meat was weighed into a 50-mL plastic test tube. After addition of 10 mL 3.5% NaCl solution, the tube was capped and shaken vigorously for 15 s. The suspensions were incubated at 25 C for 30 min and were centrifuged (15 min, 3,000 × g). Subsequently, the supernatant was discarded, the tube was thoroughly drained, weight of tube and pellet was assessed, and moisture uptake was calculated as follows:

$$\frac{[(\text{weight pellet} + \text{tube}) - \text{weight tube} - 6.00]}{6.00} \times 100$$

= moisture uptake.

After weighing, the tubes were recapped loosely and incubated for 20 min at 80 C. Following this cooking, the juices were poured off, the tubes were thoroughly drained and weighed, and cooking yield was calculated as follows:

$$\frac{[(\text{weight pellet} + \text{tube}) - \text{weight tube}]}{6.00} \times 100$$

= cooking yield (%).

SDS-PAGE. An SDS-PAGE of the myofibrillar fraction was performed to determine the presence of phosphorylase, a sarcoplasmic protein that becomes insoluble when denatured (Warner, 1994). Two grams ground meat was homogenized in 20 mL "rigor buffer" (75 mM KCl, 5 mM KPO₄, 2 mM EGTA, and 2 mM MgCl₂; pH 7.2). The homogenate was centrifuged at 1,000 × g for 15 min at 2 C. Subsequently, the supernatant was poured off, and the pellet was resuspended in rigor buffer and centrifuged. This process was repeated four times. The final pellet was resuspended in 0.0625 M Tris, pH 6.8, and protein concentration was assessed (Gornall et al., 1949). The homogenate was mixed with sample buffer and analyzed on 12% acrylamide gels (Fritz et al., 1989).

The density of phosphorylase and actin bands was determined with a laser densitometer.⁵ To obtain a measure of the amount of phosphorylase present in the myofibrillar fraction, the ratio of phosphorylase:actin was calculated.

²Minolta, Ramsey, NJ 07446.

³Orion, Boston, MA 01915-6199.

⁴Mettler-Toledo Process Analytical Inc., Wilmington, MA 01887.

⁵GelScan XL version 2, Pharmacia LKB Biotechnology, Uppsala, Sweden.

Glycolytic Potential. Glycogen, glucose, glucose-6-phosphate, and lactate concentrations were determined as described by Monin et al. (1987). Glycolytic potential, expressed in micromoles lactate per gram of meat, was calculated as follows:

$$\{[2 \times (\text{glucose} + \text{glucose-6-phosphate} + \text{glycogen}) + \text{lactate}\} = \text{glycolytic potential.}$$

Statistical Analysis. To evaluate differences between normal and pale samples, data were analyzed using PROC MIXED (SAS Institute, 1996). PROC CORR (SAS Institute, 1996) was used to analyze linear correlations between factors.

RESULTS AND DISCUSSION

The physical and biochemical characteristics of normal and pale samples are included in Table 1. Normal and pale breasts were different in pH, L* value, a* value, drip loss, moisture uptake, cooking yield, and protein solubility. In pale samples, the pH was 0.26 units lower and the L* value was 4 units higher than in normal samples. These results are consistent with earlier observations in turkeys (Van Hoof, 1979; Barbut, 1993, 1996, 1997) and broilers (Barbut, 1998).

Moisture uptake and cooking yields were lower ($P < 0.01$) in pale vs. normal muscles. Cooking loss is a very important characteristic for the processing industry, because water retention is a main point of profit. Barbut (1993) found a 9% difference in cooking loss from dark and pale turkey samples.

Differences in drip loss from pale and normal breasts were significant ($P < 0.01$) but small. Drip loss during storage was measured. At the time that meat was sampled, the breasts had been stored for approximately 18 h after slaughter. During transport and storage, the muscle may have lost some of its moisture. Thus, drip losses might have been lower if the muscle had been sampled immediately after deboning.

TABLE 1. Meat quality characteristics of pale and normal colored broiler breast meat (n = 20)

Quality characteristic	Pale	Normal	SE
pH	5.70 ^b	5.96 ^a	0.04
L*value	60.0 ^a	55.1 ^b	0.5
a*value	1.2 ^b	2.2 ^a	0.2
b*value	9.6	9.6	0.3
Drip loss, %	1.34 ^a	0.87 ^b	0.16
Moisture uptake, %	31.9 ^b	44.3 ^a	1.8
Cooking yield, %	95.2 ^b	105.8 ^a	1.4
Sarcomere length, μm	1.74	1.77	0.04
Protein solubility, mg/g			
Sarcoplasmic protein	44 ^b	50 ^a	1
Total protein	210 ^b	217 ^a	2
Phosphorylase:actin	0.14	0.15	0.02
Lactate, $\mu\text{mol/g}$	89	87	2
Glycolytic potential, $\mu\text{mol/g}$	101	97	2

^{a,b}Means within a row without a common superscript differ significantly ($P < 0.05$).

TABLE 2. Pearson correlation coefficients (r) among various quality parameters of chicken breast muscle (n = 40)

	pH	L* value	Moisture uptake (%)	Cooking yield (%)
pH	1			
L* value	-0.76***	1		
Moisture uptake	0.71***	-0.74***	1	
Cooking yield	-0.65***	-0.63***	-0.68***	1
Protein solubility				
Sarcoplasmic	0.45**	-0.71***	0.66***	0.44**
Total	NS ^a	-0.31*	NS	NS

^aNS = not significant.

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

Compared with drip losses from PSE pork (>6%; Warner, 1994), the drip losses from pale broiler breast meat were low. The isoelectric point of the major water-binding protein, myosin, is 5.3 (Offer and Knight, 1988). At this pH, water binding will be minimal. In PSE pork, the pH is close to 5.4 (Warner, 1994), whereas in the pale chicken from the present study, the pH was 5.7, i.e., further away from the isoelectric point. The difference in ultimate pH of PSE pork and pale broiler meat may explain the relatively low drip loss from pale broiler breast meat.

The main determinants of WHC of meat are pH and protein denaturation (Offer and Knight, 1988). Differences in protein solubility, a measure of protein denaturation, of normal and pale breast meat are small but significant ($P < 0.05$); protein solubility of pale samples is lower, indicating more protein denaturation, than that of normal samples (Table 1). In PSE vs. normal pork, differences in protein solubility are higher than those found in pale vs. normal broiler breast meat; in PSE pork total protein solubility may be as low as 90 vs. 200 mg/g in normal pork (Warner, 1994). The lack of a significant correlation between total protein solubility and WHC parameters (Table 2) suggests that denaturation does not contribute to low WHC of pale breast meat. A correlation between sarcoplasmic protein solubility and WHC has been observed before (Scopes, 1964; Lopez-Bote et al., 1989; Van Laack et al., 1994; Warner et al., 1997); however, at present this does not seem to be a causal relationship. The main determinants of WHC are the myofibrillar proteins rather than the sarcoplasmic proteins (Offer and Knight, 1988).

In PSE pork, solubility of myofibrillar and sarcoplasmic proteins is highly correlated with different measures of WHC, such as drip loss and moisture uptake (Bendall and Wismer-Pedersen, 1962; Bendall and Swatland, 1988; Offer and Knight, 1988; Warner, 1994). However, in so-called red, soft, exudative pork, protein solubilities are comparable to those of normal pork (Warner, 1994). The only difference between normal pork and red, soft, exudative pork is the presence of phosphorylase in the myofibrillar fraction of red, soft, exudative pork (Warner et al., 1997). Pietrzak et al. (1997) also found phosphorylase in the myofibrillar fraction of PSE turkey. The presence of

the sarcoplasmic protein phosphorylase in the myofibrillar fraction indicates loss of solubility, which is a result of denaturation. Although not directly related to concentration, density of protein bands on an SDS gel is a measure of the amount of protein present. The ratio of phosphorylase:actin was determined to assure that differences in band density were not due to differences in sample load rather than due to actual differences in the amount of precipitated phosphorylase. Actin is not degraded by proteolytic enzymes and is resistant to denaturation. Thus, the amount of actin present in the sample is directly related to the sample load. Pale and normal samples contained similar quantities of phosphorylase in the myofibrillar fraction (Table 1), indicating that protein denaturation in pale and normal samples was similar.

Sarcomere length has been associated with WHC; shorter sarcomeres result in a lower WHC (Honikel et al., 1986). Sarcomere length of pale and normal samples did not differ (Table 1) and cannot explain differences between WHC of pale and normal samples.

After slaughter, the substrates glycogen, glucose, and glucose-6-phosphate are converted to lactate. Meat with a lower ultimate pH (the pale breast) may be expected to contain more lactate than meat with a higher pH. However, as can be seen in Table 1, lactate concentrations in normal and pale breast muscle were similar. Lactate values of the present study are similar to those reported by others (Grey et al., 1974; Grey and Jones, 1974; Lee et al., 1979). The correlation of pH with lactate concentration was not significant.

It is generally assumed that the ultimate pH of meat is dependent on glycogen concentration at the time of slaughter. Assessment of glycogen concentration in the living muscle is difficult and yields inaccurate results because, upon stimulation caused by sampling, glycogen is rapidly converted to lactate. Rather than assessing glycogen concentration, so-called glycolytic potential can be measured (Monin et al., 1987). Glycolytic potential is the sum of carbohydrates that may be converted to lactate, plus lactate. In an anaerobic situation (as in the postmortem muscle), glycolytic potential will be constant. Glycolytic potential of pale and normal samples was not significantly different (Table 1). The correlation coefficient of pH with glycolytic potential was significant but low, -0.32 , indicating that variation in glycolytic potential cannot explain the differences in pH.

Low pH of pale samples could not be explained by a higher lactate concentration or higher glycolytic potential. Thus, it appears doubtful that feed deprivation before slaughter (to reduce glycolytic potential) will prevent or limit the occurrence of pale samples. Based upon correlation coefficients (Table 2), it appears that pH is a major determinant of color L^* value, moisture retention, and cooking yield. Further research on the cause of low pH of pale muscle will provide indications for prevention of occurrence of pale broiler breast meat.

In pork and beef, rapid glycolysis, resulting in a low pH and high temperature, causes myofibrillar protein denaturation (Offer and Knight, 1988). Thus, lack of myo-

fibrillar protein denaturation in pale samples may be interpreted as an indication that pale samples are not associated with a rapid postmortem glycolysis. However, in recent studies we found that myofibrillar protein from broiler breast muscle was highly resistant to denaturation (R. Van Laack, unpublished data). Detailed studies on the relationships between postmortem glycolysis, ultimate pH, and incidence of PSE are needed before we can effectively control and improve broiler breast meat quality.

CONCLUSIONS

In conclusion, pale broiler breast meat has a low WHC and, thus, should be called PSE. Pale, soft, exudative broiler breast meat appears different from PSE in turkey and pork, in that protein denaturation does not seem to be the main cause of paleness and low WHC. The ultimate pH of PSE broiler breast meat is lower than the pH of normal breast meat and appears to be the main determinant of its paleness and low WHC. Thus, procedures that limit pH decline or increase pH of PSE to that of normal meat during processing may be effective in reducing the incidence and improving functionality of PSE broiler breast meat.

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