Properties of broiler breast meat with pale color and a new approach for evaluating meat freshness in poultry processing plants

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ABSTRACT The current trend in monitoring meat quality is to move the quality measurements from the laboratory to the processing line. To provide better meat quality control in the commercial poultry processing plants, we evaluated the quality of broiler breast meat samples, observing different colors, and assessed their freshness using a Torrymeter. Different colors were classified based on the mean ± standard deviation of lightness (**L***) values in 1,499 broiler breast fillets: Dark (L* < 56), normal (56 ≤ L* ≤ 62), and pale (L* > 62). To characterize the differences between the pale and normal color groups, we evaluated additional fillets for meat quality traits. Changes in meat quality during storage were also evaluated. The L* and Torrymeter values (freshness values) allowed us to distinguish between the pale and normal meat samples. Normal and pale fillets showed a significant difference in pH, Torrymeter values, and water-holding capacity ($P < 0.001$). The L* values were significantly correlated with cook and drip loss ($P < 0.01$) and were higher (paler, +1.2 L* unit) at 72-h postmortem than at 4-h postmortem. Torrymeter values were correlated with cook loss ($P < 0.05$) and pH ($P < 0.001$), and significantly decreased with the increase in storage period ($P < 0.001$). These results suggest the applicability of the Torrymeter, a fast and non-destructive device, in distinguishing stale and fresh breast fillets. With its portability and simplicity, the Torrymeter is expected to be a valuable tool to estimate meat freshness. Especially, the use of Torrymeter for evaluating pale breast fillets may allow easy identification and separation of fillets according to their pale, soft, and exudative properties in commercial poultry processing lines.

Key words: broiler breast fillet, quality evaluation methods, color, freshness, Torrymeter

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INTRODUCTION

Worldwide poultry meat production and consumption have increased rapidly over the past decades, and the poultry industry has seen tremendous changes in consumption patterns (Barbut et al., 2008; Magdelaine et al., 2008; Petracci et al., 2009). As the consumption of processed products has dramatically increased, consumers are more attentive to several qualities of meat, such as the color, texture (tenderness), and drip loss, which were relatively unimportant when most poultry was sold as whole carcasses (Barbut et al., 2008). Pale, soft, and exudative meat (**PSE**) has been a growing concern in the poultry industry (Woelfel et al., 2002). Characteristics of PSE-like chicken breast meat are paleness, low water holding capacity (**WHC**), and increased cook and drip loss (Barbut et al., 2005). Among meat qualities, higher lightness (**L***) values are reportedly associated with lower muscle pH and WHC, which results in increased cook and drip loss, and decreased tenderness (Qiao et al., 2001; Petracci et al., 2004). Therefore, meat color can be utilized as a valuable indicator of meat quality for further processing and marketing (Barbut, 1997; Owens et al., 2000; Woelfel et al., 2002).

Poultry meat is more perishable than meat from other livestock, such as beef or pork. Therefore, measuring freshness is essential for meat quality assurance in

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poultry processing plants. High quality is a critical factor for the modern poultry processing industry. Functional and sensory properties of poultry meat are closely related to its storage and processing. Meat quality control needs to be implemented to improve the sensory characteristics and functional properties of meat samples, and decrease economic losses, as well as improve the effectiveness of the poultry industry. Meat quality evaluation is traditionally achieved using physical and chemical methods. Some of these methods are time-consuming, laborious, destructive, and costly, and require lengthy sample preparation. Furthermore, laboratory evaluation methods are not practical for commercial poultry processing plants. For the fast and early detection of quality-related parameters, the current trend in monitoring meat quality is to move the quality measurements from the laboratory to the processing line.

The Torrymeter is a device used to determine the freshness of meat or fish by measuring modifications in the electrical properties of tissues (Lougovois et al., 2003; Đorđević et al., 2006). It has been used by many researchers to measure the freshness of fish products since the first commercial version appeared in 1970 (Burt et al., 1976; Storey and Mills, 1976). The changes in dielectric properties of muscle are closely related to meat spoilage rates (Duflos et al., 2002). A high correlation between the Torrymeter values and sensory attributes has been reported for several fish (Hoffmann, 1981). However, the Torrymeter has rarely been applied to measure the freshness of poultry meat (Jung et al., 2011; Sujiwo et al., 2018); therefore, less data on the relationship between Torrymeter values and storage period are available for poultry meat. Furthermore, to the best of our knowledge, there is little information available regarding the relationship between Torrymeter values and other meat qualities such as pH, color, and WHC. Especially, the use of Torrymeter for evaluating pale breast fillets may allow easy identification and separation of fillets according to their pale, soft, and exudative properties in commercial poultry processing lines. To our knowledge, this study is the first to estimate the L* distribution of chicken breast meat in Korean poultry processing plants and compare the meat quality characteristics between pale and normal meat. Hence, herein, we evaluated the change in L*, pH, and Torrymeter values in chicken breast meat during storage and presented the use of the Torrymeter as an indicator of meat freshness.

MATERIALS AND METHODS

Sample Collection

The sampling was performed at three major slaughterhouses located in 2 geographic areas (Gyeonggi and Chungcheong) in South Korea. High broilers (1,251 −1,450 g/carcass, 32−35 days old) were transported from farms to the slaughterhouse. The broilers were hung on shackles and killed by severing the right carotid artery and the jugular vein in a single cut. The broilers were left to bleed for 3 min and then scalded at 62°C for 75 s, mechanically de-feathered at 60°C for 30 s and eviscerated. The carcasses were then chilled in an immersion cooler with pre-chilled water at 4°C for 45 min. Broiler breast fillets were randomly collected from the deboning line in processing plants about 2 to 3 h postmortem (**PM**).

L* Values of Breast Fillets

The L* values of 1,499 broiler breast fillets were measured 4 and 24 h PM, respectively. According to Petracci et al. (2004), the limiting L* values classifying meat color are determined based on the means ± standard deviations (**SDs**) of L* values obtained 24 h PM as follows: Dark, L* < mean - SD; normal, mean - SD ≤ L* ≤ mean + SD; and pale, L* > mean + SD. The cut-off L* value of the pale group was determined as L* = mean + SD.

Meat Quality Measurements

To characterize PSE-like chicken breast fillets, we collected additional breast fillets and placed them into pale or normal color groups based on the cut-off L* value. Meat quality was evaluated through 2 independent experiments. The meat quality characteristic values of each breast fillet were expressed as the average of three replicates. In each experiment, breast fillets were individually packed in a sealed polyethylene package and stored in a cold room at 4°C. The fillets were maintained at 2 to 4°C throughout the experiments. The L*, pH, and Torrymeter measurements were performed in the processing plants and fillets were transported to the laboratory to analyze meat attributes, such as WHC, shear loss, and protein quality.

First, the L*, pH, and Torrymeter values of 130 broiler breast fillets were measured and 115 samples (normal, 76; pale, 39) were selected for drip loss and cook loss analysis. After measuring drip loss, the fillet samples were used to determine cook loss. Among the fillets used for the analysis of cook loss, 63 samples were used to analyze the shear force values.

Second, 86 broiler breast fillets were sampled and stored at 4°C for 72 h to assess the variations in meat attributes with storage time. Precisely 24 h PM, a slice (approximately 20 g) was removed from the caudal end of each fillet to analyze protein solubility, and the remainder of the muscle was used to assess the effect of storage time. The L*, pH, and Torrymeter values were measured 4, 24, 48, and 72 h PM as most retails in Korea adopt 2 d for the best shelf life.

Meat Quality Characteristics

- **Color.** The color was measured on the dorsal (bone side) surface in areas free of visible color defects, bruises, or blood spots. The color was determined via a Minolta Chroma Meter CR-400 (Minolta Co., Osaka, Japan) with illuminant C

using the CIE (1978) system color profile of lightness, redness, and yellowness. The colorimeter was calibrated throughout the study using a standard white ceramic tile.

- **pH.** Muscle pH was directly measured in the cranial, dorsal side of each breast fillet using a portable pH meter equipped with a penetration electrode (pH*K21, NWK - Technology GmbH Co., Landsberg, Germany). The pH electrode was calibrated using pH 4.00 and 6.88 buffer solutions at room temperature.
- **Torrymeter.** Freshness was measured using a Torrymeter (Torrymeter Distell Freshness Meter, Distell Co., Scotland, UK). The measuring electrodes were placed onto the dorsal surface of each fillet according to the manufacturer's instructions (Distell, 2010, http://www.distell.com). Muscle freshness was recorded with fresher samples, which yielded higher values, ranging from 0 (advanced decomposition) to 16 (very fresh).
- **Drip loss.** For drip loss measurements, about 100 g of each fillet was weighed at the time of collection, individually packed in a sealed polyethylene package, and stored in a cooler at 4°C overnight. After 24 h, the exudation on the surface of the muscle was removed, and the fillets were reweighed. The weight loss, expressed as the percentage of initial weight, was regarded as drip loss (Honikel, 1998) and expressed as follows: Drip loss (%) = [(final weight − initial weight)/(initial weight)] × 100.
- **Cook loss.** For cook loss measurements, about 80 g of fillet sample was vacuum-packed and cooked at 80°C to a core temperature of 75°C. During cooking, the core temperature was recorded using a portable needle-tipped thermometer (GT-309, Giltron, New Taipei, Taiwan). The samples were then equilibrated to room temperature and reweighed. Cook loss was determined by calculating the weight loss during cooking as a percentage of the weight before cooking and was expressed as follows: Cook loss (%) = [(final weight − initial weight)/(initial weight)] × 100.
- **Shear force.** Instrumental analysis of texture was performed after cooking vacuum-packed samples in 80°C water to an internal temperature of 75°C. Samples were then cooled to room temperature before testing. Three 10 × 10 × 20 mm^3 blocks were cut from each muscle, with the long axis parallel to the muscle fiber and sheared perpendicularly using a TMS-touch texture analyzer (Food Technology Co., Sterling, VA). The average force of the three pieces was regarded as the shear force and was expressed in kilogram-force (**kgf**). Muscle toughness was recorded as the force required to shear the muscle fibers, with tougher (less tender) samples giving high values.
- **Protein solubility.** Samples were collected 24 h PM to determine protein characteristics and immediately frozen and stored at −18°C until analysis. Protein solubility was measured using the method described by Joo et al. (1999). Exactly 1 g of muscle sample was minced and homogenized with 10 mL of 0.025 M potassium phosphate buffer (pH 7.2) to determine the sarcoplasmic protein solubility. Total protein solubility was determined by homogenizing 1 g of muscle sample with 20 mL of 1.1 M potassium iodide in 0.1 M potassium phosphate buffer (pH 7.2). The homogenates were stored overnight at 4°C. The following day, the homogenates were centrifuged at 1,500 *g* for 20 min, and the protein concentration in the supernatant was determined using the Biuret method (Gornall et al., 1949).

Statistical Analysis

Results were reported as the means ± SDs. The data were analyzed using one-way ANOVA in SPSS (version 15, SPSS, Chicago, IL). Differences between group means were determined using the Tukey's Honestly Significant Difference test at a significance level of $P < 0.05$. Pearson correlations were used to test for correlation among the test variables.

RESULTS

L* Value Distribution

The L* value of 1,499 breast fillets showed normal distribution (data not shown). The overall L* value range in the study population ranged from 48.28 (dark) to 68.63 (pale). The mean L* value was 58.73, and the SD was 2.82. Based on the means and SDs of the L* value distribution, broiler breast fillets were classified into 3 color groups: Dark (L* < 55.91), normal (55.91 ≤ L* ≤ 61.55), and pale (L* > 61.55). Practically, L* = 56 and L* = 62 were adopted as color group boundaries: Dark (L* < 56, 15.08 %), normal (56 ≤ L* ≤ 62, 73.51 %), and pale (L* > 62, 11.41%, Table 1). L* = 62 was established as the cut-off value for the pale group in Korea (dark, L* < 56; normal, 56 ≤ L* ≤ 62; pale, L* > 62).

Comparison of the Meat Quality Characterization of the Pale and Normal Meat Samples

The physical and biochemical characteristics of the normal and pale groups are presented in Table 2. There was a significant difference between the muscle pH ($P < 0.001$) of the meat samples of different colors. The normal and

Table 1. Classification of 1,499 broiler breast fillets based on lightness (L*) values at 24 h postmortem (L* < 56; 56 ≤ L* ≤ 62; and L* > 62) and distribution of L* values among meat samples with different colors.

	Frequency	
Classification criteria	n	(%)
Dark (L* < 56)	226	15.08
Normal (56 ≤ L* ≤ 62)	1,102	73.51
Pale (L* > 62).	171	11.41
Total	1,499	100

L*: lightness values of meat.

Table 2. Physicochemical characteristics of normal and pale broiler breast fillets.

Quality characteristic	Meat color group	
	56 ≤ L* ≤ 62 Normal	L* > 62 Pale
[1]pH	5.90[a] ± 0.02	5.80[b] ± 0.02
[1]Torrymeter	10.40[a] ± 0.31	9.19[b] ± 0.51
[1]Drip loss (%)	0.72[a] ± 0.06	1.24[b] ± 0.12
[1]Cook loss (%)	20.09[a] ± 0.36	23.91[b] ± 0.54
[2] Shear force	2.87[a] ± 0.31	2.73[a] ± 0.24
[3]Total extractable protein (mg/g)	13.51[a] ± 0.19	12.95[a] ± 0.23
Sarcoplasmic protein (mg/g)	8.50[a] ± 0.13	8.50[a] ± 0.17
Myofibrillar protein (mg/g)	5.13[a] ± 0.22	4.45[b] ± 0.11

pH, lightness (L*), and Torrymeter values were collected at 24 h postmortem; mean ± SEM.
[1]n = 115 (normal, 76; pale, 39).
[2]n = 63 (normal, 24; pale, 39).
[3]n = 20 (normal, 10; pale, 10).
[a,b]Means within a row with different superscript letters differ significantly ($P < 0.001$).

pale meat samples also showed significant differences ($P < 0.001$) in drip and cook loss, the characteristic used for evaluating WHC. The relationship between L* and WHC is presented in Figures 1 and 2. Each point represents the average loss at each L* value unit. The drip and cook loss increased as each incremental L* value (L* unit) increased.

Interestingly, there was a significant difference ($P < 0.001$) between the Torrymeter measurements of the pale and normal meat samples (Table 2). However, the meat samples with different colors did not show a significant difference ($P > 0.05$) with regard to the shear values, which indicate meat texture (Table 2). The results of protein solubility, as an index of protein denaturation, are shown in Table 2. There were no significant differences between the total protein fraction and sarcoplasmic protein fraction of the meat samples with different colors, whereas the solubility of myofibrillar proteins was considerably lower in the pale meat samples than in the normal meat samples ($P < 0.05$).

Change of Meat Qualities (L*, pH, Torrymeter Values) During the Storage Period

Breast meat characteristics during the storage period up to 72 h PM, are presented in Table 4. Breast fillets (n=86, normal and pale color group combined) exhibited higher ($P < 0.01$) L* values 24, 48, and 72 h PM (61.55, 61.91, and 62.03, respectively) than those obtained 4 h PM (60.34). There was no significant difference in the pH of the various meat samples throughout the storage period. On the contrary, the Torrymeter enabled the powerful discrimination of the samples at each time point (4, 24, 48, and 72 h PM). The Torrymeter values decreased significantly ($P \leq 0.001$) with

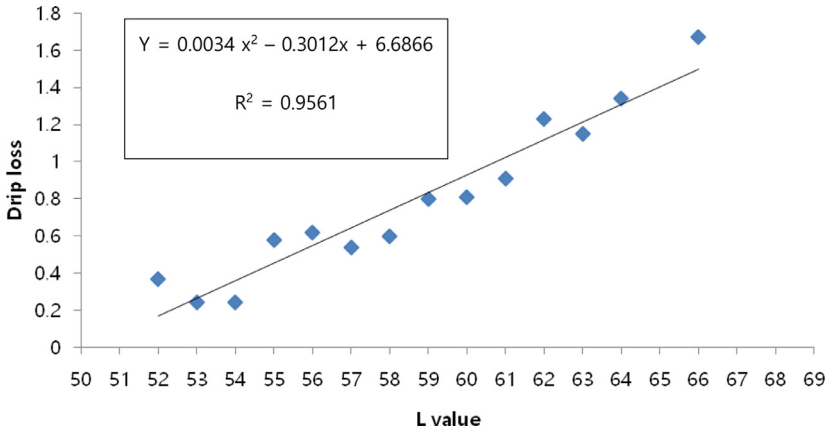

Figure 1. The relationship between lightness values (L*) and drip loss of broiler breast meats (n = 115). Each point represents the average drip loss at each L* value unit (one increment of L* value) ranging from 53 to 66. Drip loss increased as each incremental L* value (L* unit) increased. L*, lightness.

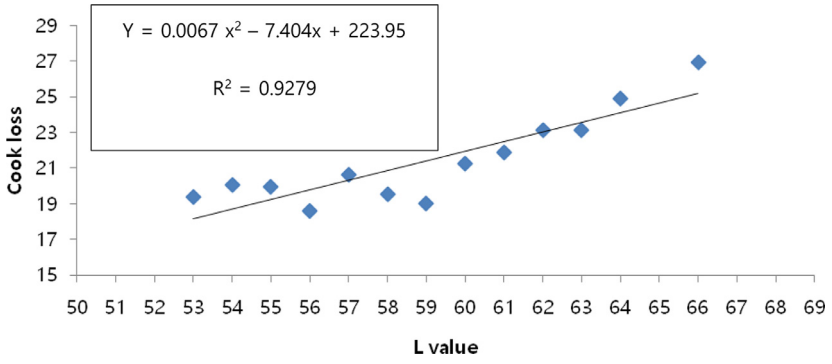

Figure 2. The relationship between lightness values (L*) and cook loss of broiler breast meats (n = 115). Each point represents the average cook loss at each L* value unit (one increment of L* value) ranging from 53 to 66. Cook loss increased as each incremental L* value (L* unit) increased. L*, lightness.

Table 3. Pearson correlation coefficients among various quality parameters of breast meats (n = 115).

Parameter	pH	Torrymeter	Drip loss	Cook loss
L*	−0.44***	−0.21*	0.41**	0.57***
pH	-	0.34***	−0.44***	−0.36***
Torrymeter	-	-	−0.43***	−0.23*
Drip loss	-	-	-	0.47***

*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.

the increase in storage time and showed a greater change than pH or color, which was useful in estimating the storage time of poultry meats.

DISCUSSION

Here, we presented the overall range of L* values in major broiler processing plants in Korea. To our knowledge, this study is the first to estimate the L* distribution of chicken breast meat in Korean poultry processing plants and compare the meat quality characteristics between pale and normal meat. Considerable variation was detected in the L* values, and therefore, breast fillets could be classified according to the L* values. The mean L* value (L* = 58.73) was considerably higher than those (L* = 47.10−52.04) reported by previous studies for meat samples from other countries (Barbut, 1997; Bianchi et al., 2006; Lesiów et al., 2007). The L* value range of pale meat samples established in previous studies (Barbut, 1997; Qiao et al., 2001; Woelfel et al., 2002; Petracci et al., 2004) was included for the dark meat samples analyzed herein. This might be due to differences in experimental variables and conditions. The L* values can vary according to the broiler strain, slaughter age, post-slaughter holding temperature, and broiler processing plant (Woelfel et al., 2002). In Korea, broilers are usually slaughtered when they are about 5 wk old, which is much quicker than the case for those investigated in North America or Europe, which are slaughtered at the age of 7 to 8 wk (Smith et al., 2002; Petracci et al., 2004; Berri et al., 2005; Bianchi et al., 2006). Wilkins et al. (2000) also reported that the muscles of older broilers usually have greater pigment concentration, and consequently, a darker appearance.

This study also provides important information regarding the relationship among different meat quality characteristics of broiler muscles. In the present study, breast meat lightness 24 h PM was negatively correlated with pH (R = −0.44, $P < 0.001$), and positively correlated with cook loss (R = 0.57, $P < 0.001$) and drip loss (R = 0.41, $P < 0.01$; Table 3). The correlation between L* values and drip loss was similar to that reported by Allen et al. (1998) (R = 0.437, $P < 0.01$). Barbut (1993) also reported that the L* values of poultry breast muscle are positively correlated with cook loss, which is consistent with our findings.

The significant differences ($P < 0.001$) in WHC between the meat samples with different colors and the correlations between the L* value and WHC (R = 0.57, cook loss) suggested that the L* values could be used to predict meat characteristics. These results generally agree with those reported previously (Barbut, 1997; Wilkins et al., 2000; Qiao et al., 2001).

Shear values were significantly correlated with pH (R = −0.548, $P < 0.001$); however, the meat samples with different colors showed no significant difference ($P > 0.05$) with regard to the shear values (Table 2), which is consistent with the results of previous studies (Fletcher, 1999; Petracci et al., 2004). Fletcher (1995) observed no significant differences in shear values among breast muscles with different L* values. In the present study, the pH of pale meat did not approach the isoelectric point (5.4−5.5) of myofibrillar proteins (Lawrie, 2006) and consequently, did not seem to affect the meat texture largely. When the pH of the meat is above the isoelectric point, water molecules are tightly bound, causing more light to be absorbed by the muscle (Kauffman and Marsh, 1987; Cornforth, 1994). The differences of WHC between the pale and normal meat samples might be explained based on the myofibrillar protein solubility (Table 2). Previous reports found that the denaturation of myofibrillar proteins (major water-binding proteins such as myosin and actin) significantly contributes to the WHC of meat (Hamm, 1986; Wismer-Pedersen, 1987; Offer and Knight, 1988). The present results agree with those of Barbut et al. (2005), who demonstrated that light-colored broiler breast meat has significantly lower salt-soluble protein content than dark, firm, and dry meat. Pietrzak et al. (1997) reported lower myosin solubility in PSE meat, compared with myofibrils from normal turkey meat, and suggested that irreversible myosin insolubility is decisive in the development of PSE meat. Although the correlations between myofibrillar solubility and color were weaker, we

Table 4. Change of meat quality parameters in broiler breast fillets during storage at 4°C.

	Meat quality parameters (n = 86)					
	Normal color group (n = 47)			Pale color group (n = 39)		
PM(h)	L*	pH	Torrymeter	L*	pH	Torrymeter
4	$58.57^{a} \pm 0.29$	$5.86^{a} \pm 0.02$	$13.99^{a} \pm 0.26$	$62.47^{a} \pm 0.32$	$5.85^{a} \pm 0.04$	$14.04^{a} \pm 0.24$
24	$59.69^{b} \pm 0.21$	$5.85^{a} \pm 0.03$	$11.66^{b} \pm 0.32$	$63.79^{b} \pm 0.21$	$5.75^{b} \pm 0.03$	$11.11^{b} \pm 0.48$
48	$60.32^{b} \pm 0.21$	$5.90^{a} \pm 0.02$	$8.06^{c} \pm 0.46$	$63.84^{b} \pm 0.18$	$5.78^{ab} \pm 0.03$	$7.89^{c} \pm 0.57$
72	$60.42^{b} \pm 0.20$	$5.90^{a} \pm 0.02$	$5.40^{d} \pm 0.45$	$63.98^{b} \pm 0.21$	$5.79^{ab} \pm 0.03$	$5.63^{d} \pm 0.53$

L*, lightness. Values are presented as the mean ± SEM.
[a-d]Means within a column followed by different superscript letters differ significantly ($P \leq 0.05$).

thought that the denaturation of myofibrillar proteins affected the pale color in PSE-like breast samples to some degree.

In the present study, the L* values of breast fillets (n=86, normal and pale color group combined) significantly increased during the initial 24 h of storage ($P \leq 0.01$, 60.34 vs. 61.55 at 4 and 24 h PM, respectively), indicating that their color could continue to change during the first 24 h PM. Meanwhile, the change in L* values was not significant after 24 h PM (Table 4). The significant differences in L* values between the samples obtained 4 and 24 h PM are similar to those reported in studies by Petracci and Fletcher (2002) and Garcia et al. (2010). Petracci and Fletcher (2002) reported that breast muscle color changed dramatically during the first 4 h of processing and continued to change until up to 24 h PM at a slower rate. These results indicate that color assessment of breast meat should be estimated at least 24 h PM because the lightness of breast meat may increase during the initial 24 h PM. Meanwhile, we observed no significant differences in pH throughout the storage period (Table 4), which may be attributed to the rapid development of rigor mortis (≤30 min PM). Change of meat quality characteristics during the storage period was evident based on the Torrymeter values. Based on the present results, the Torrymeter values were closely associated with the freshness of broiler breast meats, as indicated in the previous studies (Jung et al., 2011; Sujiwo et al., 2018). Accordingly, it seems plausible to utilize the Torrymeter for predicting the freshness of broiler breast meat. Torrymeter values were correlated with pH ($R = 0.34$, $P < 0.001$, Table 3) and drip loss ($R = -0.43$, $P < 0.001$, Table 3), suggesting its use in estimating broiler breast meat quality.

It is reported that the permittivity and conductivity of meat decrease with an increase in the degree of spoilage (Lougovois et al., 2003). The Torrymeter determines changes in the dielectric properties of tissues by detecting the signals after sending low electric currents (under 1 mA) through the samples (Duflos et al., 2002). Although the Torrymeter has not yet been sufficiently exploited for poultry meat assessment, the results suggest that it may be utilized as a simple, nondestructive method for the assessment of the freshness of broiler breast meat during storage in the poultry processing industry. Even though the Torrymeter averages are different between normal and pale meat (Table 2), it seems unlikely that the separation is adequate for consistent separation of these groups (Table 4).

In conclusion, this study presented the difference in meat quality via color and demonstrated the use of a Torrymeter in estimating the freshness of chicken breast meat. Combining different measurement devices (Chroma Meter and Torrymeter) may help in differentiating fillets with PSE properties in commercial poultry processing lines. Owing to its straightforward and rapid use, the Torrymeter is expected to be valuable for routine quality control in the poultry industry, especially in identifying the freshness of poultry meat. However, its applicability as an indicator of meat freshness remains to be verified through further studies in many other poultry processing plants.

DISCLOSURES

The authors declare that they have no conflicts of interest.

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