The Effect of Broiler Breast Meat Color on pH, Moisture, Water-Holding Capacity, and Emulsification Capacity

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ABSTRACT The relationship between broiler breast meat color and pH, moisture content, water-holding capacity (WHC), and emulsification capacity (EC) was investigated. In each of three replicate trials, fillets were collected from three different commercial processing plants according to breast meat lightness (L*) values as follows: lighter than normal (light, L* > 53), normal (48 < L* < 53), and darker than normal (dark, L* < 46). Color values of lightness (L*), redness (a*), and yellowness (b*) were measured at 0 and 24 h after collection. Fillets were then ground and homogenized prior to determining color, pH, moisture, WHC, and EC of the ground meat. There was a significant difference among the three color groups (light, normal, and dark) in L*, a*, pH, WHC, and EC. The L* values of whole raw breast fillets had significant negative correlation coefficients with ground meat EC (−0.9237), pH (−0.9610), and a* (−0.6540). Emulsification capacity had significant positive correlations with pH (0.9572) and water-holding capacity (0.7080). WHC had significant correlations with a* (0.8143), moisture (−0.7647), and pH (0.7963). Lighter-than-normal meat was associated with low pH, high moisture, low EC, and low WHC. These results indicate that wide differences in raw breast meat color exist and that these differences may be used by poultry further processors as an indicator of fillets with altered functional properties.

(Key words: broiler breast meat, meat quality, color, water-holding capacity, emulsification capacity)

INTRODUCTION

Color is an important quality attribute that influences consumer acceptance of many food products, including poultry meat. Consumers will often reject products in which the color varies from the expected normal appearance. Birren (1963) pointed out that color is everywhere and that psychological responses to color, as they relate to appetite, are considered important to processors and consumers. Consequently, color is often used to determine economic value of food.

Color defects of raw and cooked poultry meat have been a problem for the poultry industry for many years. Color defects such as the pale, soft, and exudative (PSE)-like condition reported primarily in turkey breast meat as well as the occurrence of pink to red discolorations in otherwise fully cooked poultry meat products are well documented and have recently been reviewed by Froning (1995). Recent research reports have shown rather dramatic color variations occurring in the production of boneless and skinless raw breast meat (Barbut, 1997; Fletcher, 1999a). Barbut (1997) reported that the occurrence of PSE meat in broiler chickens ranged from 0 to 28% in seven different flocks. A grocery store survey of 1,000 boneless, skinless, broiler breast fillet packages showed that approximately 7% of the multiple-fillet packages had one or more fillets that were significantly different in color, either lighter or darker, than the other fillets in the same package (Fletcher, 1999a).

Several researchers have demonstrated a significant relationship between raw breast meat color and raw meat pH (Barbut, 1993; Boulianne and King, 1995, 1998; Allen et al., 1997; Fletcher, 1999b). Barbut (1993) reported that lightness (L*) had the highest correlation of the L*, a*, b* color values with PSE-like conditions. Allen et al. (1998) compared the difference between light- and dark-colored fillets in pH, marination pick-up, and shelf life, and found that dark, high-pH broiler breast meat had reduced shelf life but higher marination pick-up.

Although color variations and their related problems occur in the poultry industry, they tend to be sporadic, inconsistent in severity, and are often not well described. A thorough understanding of the difference in quality properties related to color is important for further processing to reduce the potential negative impact of meat color variation on further processed products. The pur-
pose of this project was to characterize the relationship of lighter-than-normal, normal, and darker-than-normal broiler breast meat on the functional and physical properties of the meat.

**MATERIALS AND METHODS**

**Sample Collection and Color Measurement**

A total of 704 lighter-than-normal (light), normal, and darker-than-normal (dark) colored skinless, boneless broiler breast fillets were collected over three replicate trials (weeks) from three different processing plants on day of slaughter. Fillets in each color group were selected by determining the L* value using a reflectance colorimeter in the deboned breast meat packaging area of the plants as follows: lighter than normal, L* > 53, normal, 48 < L* < 53, darker than normal, L* < 46. Samples were placed in polyethylene bags by color group, packed on ice, and transported to the laboratory.

Immediately upon arrival in the lab, the complete CIE system color profile of lightness (L*), redness (a*), and yellowness (b*) was measured on individual fillets in each color group. Color was measured on the cranial, medial surface (bone side) in an area free of obvious color defects (bruises, blood spots, or surface discolorations). Measurements were made on the medial surface to avoid breast fillet surface discolorations due to possible over scalding. Fillets were then held overnight at 4 C, and the color was determined again on each fillet. Fillets were then trimmed of excess fat, combined by color group (approximately 25 fillets), chopped, and thoroughly mixed using a meat cutter for 4 min at 4 C. Color of the ground meat was determined using a pH meter calibrated at pH 4.0 and 7.0.

**pH**

The pH of ground meat was determined in triplicate using a modification of the iodoacetate method initially described by Jeacocke (1977). Approximately 2.5 g of ground breast meat was homogenized in 25 mL of an iodoacetate solution (5 mM sodium iodoacetate, 150 mM potassium chloride, and the pH adjusted to 7.0 with potassium hydroxide) for 30 s, and the pH of the homogenate was determined using a pH meter calibrated at pH 4.0 and 7.0.

**Moisture**

Meat moisture was determined in triplicate using the vacuum-oven method (method 24.002) according to the Association of Official Analytical Chemists (AOAC, 1984). The ground meat samples were dried for 48 h in a vacuum-oven (23 kPa) at 98 C and cooled to room temperature in a desiccator prior to taking final weights.

**Water-Holding Capacity**

Water-holding capacity (WHC) was estimated by determining expressible juice using a modification of the filter paper press method described by Wierbicki and Deatherage (1958) as follows. A meat sample weighing between 200 and 400 mg was placed on a 11 cm diameter filter paper between plexiglass plates and pressed at 2,000 psi for 1 min. The outline area of the expressible juice and the meat film was traced, and the two areas were determined using a compensating polar planimeter. Expressible juice, as a percentage, was calculated as follows:

\[
\text{expressible juice %} = \left( \frac{100 \times (\text{total juice area} - \text{meat film area})}{\text{water/square inch filter paper}} \right) \times \frac{\text{total moisture (mg) of original sample (sample wt in (mg) } \times \% \text{ moisture)}}{2,000 \text{ psi for 1 min}}
\]

Higher expressible juice percentage is related to decreased WHC.

**Emulsification Capacity**

The method of Swift et al. (1961) was used to measure emulsification capacity. A 10-g ground meat sample was blended with 75 mL cold 1 M NaCl solution at high speed for 1 min. An 8-g aliquot of the homogenate was transferred to another blender jar with 45 mL cold, 1 M NaCl solution and was mixed for an additional 10 s at low speed. Corn oil mixed with 0.3 g Sudan III was first added in a 50-mL aliquot. The blender was run at high speed, and additional oil was added at 1.0 mL/s until the solution changed phases. As evidenced by a viscosity change, a darkening color, and an audible change in motor speed. The total amount of oil used was recorded and was used to express emulsification capacity (EC) as the amount of oil (mL) needed to effect the phase change.

**Statistical Analysis**

The experimental design was a 3×3×3 for color group (lighter-than-normal, normal, and darker-than-normal), processing plant, and replication (n = 27). The main effects of color group, plant and replication, and their first level interactions were analyzed using the ANOVA option of the general linear models procedures of SAS software (SAS Institute, 1988). The main effects and interactions were tested using residual experimental error (color × plant × replication, degrees of freedom = 8). When color group and plant or replication interactions were significant, that interaction was used as the error term to determine color group significance. Means were separated using the Duncan’s multiple-range test option (SAS Insti-
Grinding and compositing the breast meat samples also resulted in different reflective properties of the meat such that, although the treatment groups were still different from each other, the absolute lightness values were no longer in the L* collection range.

The Pearson correlation coefficients and probabilities between the values for 0 and 24 h and ground meat color are presented in Table 2. The L*, a*, and b* correlations between the 0 and 24 h samples were all highly significant and were 0.93 or higher. However, the correlations between the 0 h and ground, or the 24 h and ground samples, were less highly significant and exhibited correlation coefficients between 0.45 to 0.63.

These results indicated that selection of the breast fillets based on L* values resulted in a clear and consistent differentiation of the three color groups at 0 and 24 h postmortem. The differences in the absolute color values and the differences in correlations between intact fillet color at 0 or 24 h and the ground samples indicated that grinding substantially changed the light reflectance properties of the meat. For this reason, subsequent analyses and correlation of functional properties to meat color will be based on the 0 and 24 h intact fillet color values and not on the ground meat color values.

The physical and functional properties of muscle pH, moisture, expressible juice, and emulsification capacity

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**RESULTS AND DISCUSSION**

The color values of L*, a*, and b* of the lighter-than-normal (light), normal, and darker-than-normal (dark) whole fillets on day of collection (0 h), after holding the fillets for 24 h at 4 C (24 h) and following grinding and homogenization (ground) are presented in Table 1. All three of the individual color group values, L*, a*, and b*, were significantly different from each other at 0 h and were very close to the L* collection values used for treatment identification in the plant (light > 53, normal 48 to 53, dark < 46). After storage for 24 h at 4 C, all of the color values (L*, a*, and b*) increased, were still significantly different by color group, and were still in the L* collection ranges. The color values, L*, a*, and b* of the ground and composited sample groups also increased, compared to the 0 and 24 h samples. The differences for L* and a* were still significantly different across color groups, but the difference between the normal and light group for yellowness was no longer significant.

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**TABLE 1. Color lightness (L*), redness (a*), and yellowness (b*) means and standard error of the means of darker-than-normal (dark), normal, or lighter-than-normal (light) chicken breast meat at 0 and 24 h postcollection and following grinding**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Group</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 hour</td>
<td>Dark</td>
<td>43.47 ± 0.25a</td>
<td>4.93 ± 0.28a</td>
<td>3.68 ± 0.16a</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>49.72 ± 0.08b</td>
<td>3.34 ± 0.24b</td>
<td>4.34 ± 0.25b</td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td>55.22 ± 0.16c</td>
<td>2.78 ± 0.16c</td>
<td>4.87 ± 0.25c</td>
</tr>
<tr>
<td>24 hour</td>
<td>Dark</td>
<td>45.68 ± 0.22c</td>
<td>5.4 ± 0.21c</td>
<td>4.18 ± 0.20c</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>51.32 ± 0.31b</td>
<td>4.09 ± 0.17b</td>
<td>5.06 ± 0.21b</td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td>55.95 ± 0.22c</td>
<td>3.42 ± 0.09c</td>
<td>5.56 ± 0.23c</td>
</tr>
<tr>
<td>Ground</td>
<td>Dark</td>
<td>57.83 ± 0.27c</td>
<td>5.01 ± 0.27c</td>
<td>9.05 ± 0.21b</td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>62.07 ± 0.54b</td>
<td>4.38 ± 0.22b</td>
<td>9.68 ± 0.25a</td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td>64.34 ± 0.60a</td>
<td>3.75 ± 0.17c</td>
<td>9.55 ± 0.14a</td>
</tr>
</tbody>
</table>

**TABLE 2. Pearson correlation coefficients and probabilities of broiler breast meat lightness (L*), redness (a*), and yellowness (b*) at 0 and 24 h postcollection and after grinding (G)**

<table>
<thead>
<tr>
<th></th>
<th>L*, 0 h</th>
<th>a*, 0 h</th>
<th>b*, 0 h</th>
<th>L*, G</th>
<th>a*, G</th>
<th>b*, G</th>
</tr>
</thead>
<tbody>
<tr>
<td>L*, 0 h</td>
<td>0.2979</td>
<td>-0.615</td>
<td>0.4559</td>
<td>0.678</td>
<td>-0.855</td>
<td>0.9839</td>
</tr>
<tr>
<td></td>
<td>0.1312</td>
<td>0.0006</td>
<td>0.0169</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0101</td>
</tr>
<tr>
<td>a*, 0 h</td>
<td>-0.479</td>
<td>0.6324</td>
<td>-0.258</td>
<td>-0.711</td>
<td>0.9384</td>
<td>-0.827</td>
</tr>
<tr>
<td></td>
<td>0.0115</td>
<td>0.0004</td>
<td>0.1934</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>b*, 0 h</td>
<td>0.6162</td>
<td>-0.472</td>
<td>0.2429</td>
<td>0.9295</td>
<td>-0.678</td>
<td>0.5867</td>
</tr>
<tr>
<td></td>
<td>0.0006</td>
<td>0.0129</td>
<td>0.2222</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0013</td>
</tr>
<tr>
<td>L*, 24 h</td>
<td>0.3136</td>
<td>-0.654</td>
<td>0.4863</td>
<td>0.6672</td>
<td>-0.856</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.1112</td>
<td>0.0002</td>
<td>0.0101</td>
<td>0.0001</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>a*, 24 h</td>
<td>-0.41</td>
<td>0.6262</td>
<td>-0.197</td>
<td>-0.735</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0337</td>
<td>0.0005</td>
<td>0.324</td>
<td>0.0001</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>b*, 24 h</td>
<td>0.6298</td>
<td>-0.583</td>
<td>0.4271</td>
<td>0.0004</td>
<td>0.0014</td>
<td>0.0263</td>
</tr>
<tr>
<td></td>
<td>0.0402</td>
<td>0.1839</td>
<td>0.1085</td>
<td>0.0001</td>
<td>0.0001</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
Correlations between color, pH, moisture, and WHC are presented in Table 3. The pH values of the lighter-than-normal, normal, and darker-than-normal groups were 5.81, 5.96, and 6.23, respectively, and were significantly different from each other. The moisture content of the lighter-than-normal meat was 76.72% and was significantly greater than the normal (76.35%) or darker-than-normal fillets (76.23%) that were not different from each other. Water-holding capacity, reported as percentage expressive juice, was 51.73% for the light samples, 43.77% for the normal samples, and 38.50% for the dark samples, all of which were significantly different from each other. For EC, the darker-than-normal meat required 83.07 mL of oil compared to 81.09 and 79.69 mL for the normal and light samples, respectively, all of which were significantly different from each other. For EC, the darker-than-normal meat required 83.07 mL of oil compared to 81.09 and 79.69 mL for the normal and light samples, respectively, all of which were significantly different from each other. The moisture content of the light meat was 5.81, 5.96, and 6.23, respectively, and were significantly different from each other. Water-holding capacity, reported as percentage expressive juice, was 51.73% for the light samples, 43.77% for the normal samples, and 38.50% for the dark samples, all of which were significantly different from each other. For EC, the darker-than-normal meat required 83.07 mL of oil compared to 81.09 and 79.69 mL for the normal and light samples, respectively, all of which were significantly different from each other.

The Pearson correlation coefficients and probabilities of broiler breast fillet lightness (L*), redness (a*), and yellowness (b*) at 0 h and 24 h postcollection and ground meat pH, moisture (H2O), water-holding capacity (WHC), and emulsification capacity (EC) are presented in Table 4. There were highly significant negative correlations between 0 h lightness values and pH (−0.9632), WHC (−0.8929), and EC (−0.9300) and significant positive correlations between 0 h redness values and pH (0.8809), WHC (0.7868), and EC (0.8108). Yellowness correlations were also significant for pH (−0.7436), WHC (−0.7200), and EC (−0.6863). There were no significant correlations between breast meat color and moisture. The correlations between the 24 h color values and functional properties were similar to the 0 h values. There were significant positive correlations between EC and pH (0.9572), EC and WHC (0.7868), and WHC and pH (0.7963) and a negative correlation between WHC and moisture (−0.7647).

The relationship between muscle pH, color, and meat quality in red meat species is well established (Dutson, 1983). As noted earlier, the relationship between poultry meat color and pH has also been well documented, but the relative influence on poultry meat quality is not as well established as in red meat species. Van Hoof (1979) and Barbut (1993) suggested that apparent pale color in turkey meat is associated with lower pH and is similar to the PSE condition in pork meat. Fletcher (1999a) reported that extremes of light and dark poultry breast fillets showed corresponding differences in muscle pH, and Allen et al. (1998) reported on differences in color extremes on functional properties similar to those for PSE- and dark, firm, and dry-like conditions in red meat.

Although the moisture content of the light meat was significantly greater than the moisture content in the normal and dark fillets, there were no significant correlations between pH and moisture content, 0 h color values and moisture, 24 h color values and moisture (P = 0.0428). Because higher pH is generally more associated with higher meat moisture content, these results were not expected. Boulianne and King (1995 and 1998) reported no differences in moisture content from pale or dark chicken breast meat. Although the values were significant, the difference between the light and dark samples was only

<table>
<thead>
<tr>
<th>Group</th>
<th>pH</th>
<th>Moisture (%)</th>
<th>WHC (%)</th>
<th>EC (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark</td>
<td>6.23 ± 0.02a</td>
<td>76.23 ± 0.12b</td>
<td>38.50 ± 1.56b</td>
<td>83.07 ± 0.32a</td>
</tr>
<tr>
<td>Normal</td>
<td>5.96 ± 0.03b</td>
<td>76.35 ± 0.11b</td>
<td>43.77 ± 1.84b</td>
<td>81.09 ± 0.37b</td>
</tr>
<tr>
<td>Light</td>
<td>5.81 ± 0.02c</td>
<td>76.72 ± 0.08c</td>
<td>51.73 ± 1.84c</td>
<td>79.69 ± 0.40c</td>
</tr>
</tbody>
</table>

*Means within column with differing superscripts are significantly different (P < 0.05).
0.5%. Other than as a possible statistical artifact, the authors offer no other explanation.

The significant differences in WHC, reported as expressible juice, between three color groups are similar to those reported by Barbut (1997), who indicated that breast muscle samples with lightness values >49 had poor WHC and were classified as PSE meat. Similar results for turkey were also reported by Barbut (1996) and Pietrzak et al. (1997). These results are expected because the relationship between WHC and muscle pH is well established (Judge et al., 1989).

Trautman (1964) indicated that porcine prerigor, salt-soluble proteins produced an emulsion more stable than that observed from post-rigor, salt-soluble proteins. The influence of rigor development on muscle pH and emulsification capacity in bovine meat was reported by Acton and Saffle (1969). These authors reported that prerigor meat had higher pH and superior EC. Similar results for rigor status, pH, and EC in turkey meat was reported by Froning and Neelakantan (1971).

The combination of significant differences in lightness, redness, pH, WHC, and EC between the three color groups and the highly significant correlations between color group, muscle pH, and functional properties indicate that breast meat color, especially for extremes in lightness and darkness, can be used as a possible indicator of functional properties. These results agree with previously reported research showing strong relationships between muscle pH and its effect on both color and functional properties. Although minor differences in color may have little relationship to these parameters, processors may wish to use color extremes as a means to segregate those fillets that could contribute to variations in functionality and reduced product uniformity.

ACKNOWLEDGMENTS

This study was supported in part by funds provided by the U.S. Poultry and Egg Association (Research Project No. 429) and by state and Hatch funds allocated to the Georgia Agricultural Experiment Station. The authors also express their appreciation to Reg Smith for his technical assistance.

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