Incidence of Pectoralis Major Turkey Muscles with Light and Dark Color in a Portuguese Slaughterhouse

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ABSTRACT

Turkey meat and processed products are very popular in Portugal. However, no studies have been made to assess turkey meat quality. The main objective of this study was to evaluate the quality of turkey breast meat in a Portuguese slaughterhouse, differentiating it to obtain better industrial management, performance, and consumer contentment. Nine hundred and seventy-seven male turkeys (from 16 to 20 wk old) from different flocks (BUT 9 and BIG 6) were evaluated to assess meat quality. Turkeys were slaughtered on different days, electrically stunned (225 V/3 s), and scalded in a vertical water bath at 81°C/5 min. On the slaughter line, the pH and temperature were measured on the pectoralis muscle 15 min post-mortem. The carcasses were fast-cooled in a tunnel (−2°C/2 m/s/90% RH) for 2 h and kept in a refrigeration chamber (0°C/85% RH) until deboning (approximately 24 h post-mortem). Color and pH 24 h post-mortem (pH24) were measured on the pectoralis major muscle after carcass deboning. Pectoralis major muscles were selected according to criteria used by Barbut (1996) and drip loss, cooking loss, and total pigments analysis were performed on 67 different sliced meat samples. Muscles classified by pH decline rate, called rapid glycolytic, did not present final quality characteristics that could relate them with pale, soft, and exudative- (PSE) like meat, because there was no relationship between pH 15 h postmortem and lightness (L*), drip loss, or cooking loss. The differences, founded on physicochemical characteristics within pectoralis major muscles, allowed us to establish a criteria of turkey meat quality for dark and PSE-like meat, with L* ≤ 44 and pH24 ≥ 5.8 and L* ≥ 50 and pH24 < 5.8, respectively. Based on criteria, the studied population presented 8.1% of carcasses with PSE-like muscles and 12.1% with dark muscles. The association of pH24 and L* as criteria classification can be useful to classify turkey meat quality.

Key words: poultry meat, turkey, color, pH, meat quality

INTRODUCTION

The identification and classification of pale, soft, and exudative- (PSE) like poultry meat, particularly turkey, has been referred to by several authors (Froning et al., 1978; Barbut, 1996, 1997; Santé et al., 1998; Owens et al., 2000) and has been considered a problem for the industry, leading to economic loss. Barbut (1996) used a fast-color measuring system CIELAB to evaluate the occurrence of PSE in young turkey breast meat, detecting, in some study flocks, 18 to 34% of breasts with a lightness (L*) > 50 and 6 to 17% with L* > 51. Owens et al. (2000) registered a PSE-like meat frequency of 41% in turkeys, using as criteria an L* value higher than 53. This color parameter presented a significant correlation with pH (r = −0.71, P < 0.01) and with the water-holding capacity evaluated by cooking loss (r = 0.70, P < 0.01; Barbut, 1993). Despite the establishment of a relationship among the analyzed parameters, including extreme cases of meat quality (pale and dark meat), proposals for criteria have only been based on L* parameters for meat with PSE-like characteristics. Other meat selection and classification criteria, based on glycolytic potential of fiber muscles and pH decline rates, have also been suggested for the identification of exudative meat (Malenica et al., 2002).

Boulianne and King (1995, 1998) studied biochemical properties related to the occurrence of pale and dark color in broiler breast muscles and concluded that pale meat presented a lower concentration of hemic pigments due to losses during carcass cooling and storage, but they did not present any explanation for the emergent dark meat. Today, turkey meat is commercialized under a modified atmosphere package or is processed in cooked products such as cooked ham, patties, or sausages. Deviations from “normal” meat quality cause industrial economic repercussions. The PSE-like meat is less appropriate to be used in cooked products and requires formula correction to maintain the best meat product processing yields. Dark color meat has a shorter shelf life, as found by Allen et al. (1997, 1998), and causes adverse effects in the color

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of processed products (Fletcher et al., 2000) and on consumer acceptability.

Color, pH, drip loss, and cooking loss are the main reference methods applied as tools for quality assurance of processing meat operations, assessment of effectiveness of production, and processing treatments, as well as for characterizing muscles and meat quality (Honikel, 1998).

Because Portugal has an important level of turkey meat production and a high consumption index for turkey meat, the aim of this study was to evaluate the quality of turkey breast meat in a Portuguese slaughterhouse with a quality system implemented in accordance with ISO 9001:2000 (International Organization for Standardization, 2000). To achieve a criteria for quality classification of meat and to obtain the best performance and acceptability for consumers and industries, a study into the relationship between objective breast muscle color and physicochemical parameters was undertaken to evaluate meat quality.

MATERIALS AND METHODS

Collection, Selection, and Physicochemical Evaluation of Samples

The sampling was performed on different working days from a population of 10,414 male turkeys (BUT 9 and BIG 6; 16 to 20 wk old), corresponding to 22 different flocks, which were identified and recorded by the slaughterhouse. All birds were slaughtered in identical conditions, electrically stunned with a current of 205 to 225 V during approximately 2 s, bled, scalded in a vertical bath with a temperature of 82.8°C/2 m·s⁻¹/90% RH) for 2 h and kept in a refrigeration chamber (0°C/85% RH) until deboning (approximately 24 h postmortem). Color and pH 24 h postmortem (pH₂₄) were measured on the pectoralis major muscles after carcass deboning. Pectoralis muscles were selected according to Barbut (1996) criteria (L* ≥ 50), and drip loss, cooking loss, and total pigments analysis were evaluated on 67 different sliced breast meat samples.

Physicochemical Analysis

**pH Determination.** The pH was measured directly on the pectoralis major muscle with a portable pH meter (HI9023, Hanna Instruments, Padova, Italy) equipped with a pH electrode (FC 230B, Hanna Instruments). Each value was an average of 3 determinations on the muscle.

**Temperature Determination.** Temperature measurements were made directly on the pectoralis major muscle with a temperature probe (HI7669/2 w, Hanna Instruments) connected to a temperature meter (HI9023, Hanna Instruments).

**Color.** The color was evaluated on the internal side of the pectoralis major muscle with a Minolta Colourimeter CR-300 (Minolta Co., Osaka, Japan) using the L*, redness (a*), and yellowness (b*) coordinates (CIELAB color system). Each value resulted from the arithmetic mean of 9 determinations. Chroma and hue (h) were calculated according to the following formulas: Chroma = (a²+b²)¹/² and h = tan⁻¹(b/a) (Hunt et al., 1991; Minolta Co., 1991).

**Drip Loss.** Samples were individually packed and stored at 0°C for 3 d. Drip was evaluated as the loss of weight during this time relative to the initial weight and was expressed in a percentage (Honikel, 1998).

**Cooking Loss.** Samples were weighed, vacuum-packed, and cooked at 85°C for 15 min. (Honikel, 1998; Sante et al., 1998) with an internal end point temperature of 82.2 ± 0.9°C. After being cooled to 0°C, meat samples were weighed again; the loss of weight was expressed as a percentage.

**Total Pigments Analysis.** Pigments were extracted from 10 g of a homogenized meat sample within a solution of acetone (40 mL), HCL (1 mL), and water (2 mL) according to Hornsey (1956). The meat was macerated, and after 1-h pause, the solution was filtrated. In an ultraspec 2000 UV/Visible Spectrophotometer (Amersham Pharmacia Biotech, Buckinghamshir, UK), the filtrate ab-

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### Table 1. Physicochemical parameters evaluated in pectoralis major muscles from turkey carcasses

<table>
<thead>
<tr>
<th>Item</th>
<th>pH₁₅</th>
<th>Temp₁₅</th>
<th>pH₂₄</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>Hue</th>
<th>Chroma</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>974</td>
<td>930</td>
<td>970</td>
<td>977</td>
<td>977</td>
<td>977</td>
<td>977</td>
<td>977</td>
</tr>
<tr>
<td>Mean</td>
<td>6.47</td>
<td>41.78</td>
<td>5.83</td>
<td>46.80</td>
<td>5.49</td>
<td>–1.84</td>
<td>354.52</td>
<td>5.84</td>
</tr>
<tr>
<td>SEM</td>
<td>0.01</td>
<td>0.03</td>
<td>0.003</td>
<td>0.09</td>
<td>0.03</td>
<td>0.03</td>
<td>1.37</td>
<td>0.03</td>
</tr>
<tr>
<td>SD</td>
<td>0.24</td>
<td>0.88</td>
<td>0.11</td>
<td>2.82</td>
<td>0.91</td>
<td>0.78</td>
<td>42.76</td>
<td>0.93</td>
</tr>
<tr>
<td>Range</td>
<td>1.49</td>
<td>8.9</td>
<td>0.85</td>
<td>19.99</td>
<td>7.88</td>
<td>4.91</td>
<td>359.99</td>
<td>7.79</td>
</tr>
<tr>
<td>Minimum</td>
<td>5.61</td>
<td>38.50</td>
<td>5.50</td>
<td>35.38</td>
<td>1.26</td>
<td>–4.22</td>
<td>0.00</td>
<td>1.79</td>
</tr>
<tr>
<td>Maximum</td>
<td>7.10</td>
<td>43.90</td>
<td>6.19</td>
<td>55.38</td>
<td>9.14</td>
<td>0.69</td>
<td>359.99</td>
<td>9.58</td>
</tr>
<tr>
<td>Percentiles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>6.32</td>
<td>41.30</td>
<td>5.76</td>
<td>45.12</td>
<td>4.90</td>
<td>–2.32</td>
<td>359.59</td>
<td>5.21</td>
</tr>
<tr>
<td>50</td>
<td>6.49</td>
<td>41.80</td>
<td>5.83</td>
<td>46.95</td>
<td>5.40</td>
<td>–1.85</td>
<td>359.66</td>
<td>5.72</td>
</tr>
<tr>
<td>75</td>
<td>6.65</td>
<td>42.33</td>
<td>5.89</td>
<td>48.75</td>
<td>5.97</td>
<td>–1.34</td>
<td>359.74</td>
<td>6.39</td>
</tr>
</tbody>
</table>

*1 pH₁₅ = pH 15 min postmortem; Temp₁₅ = temperature 15 min postmortem; pH₂₄ = ph 24 h postmortem; L* = lightness; a* = redness; and b* = yellowness.
Table 2. Pearson’s correlation coefficients among quality parameters of pectoralis major muscles from turkey carcasses

<table>
<thead>
<tr>
<th>Physico-chemical parameters</th>
<th>pH15</th>
<th>Temp15</th>
<th>pH24</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>Hue</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH15 Pearson’s correlation</td>
<td>1</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>n</td>
<td>974</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Temp15 Pearson’s correlation</td>
<td>—0.303**</td>
<td>1</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>n</td>
<td>927</td>
<td>927</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>pH24 Pearson’s correlation</td>
<td>0.125**</td>
<td>0.025</td>
<td>1</td>
<td>—</td>
<td>—</td>
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<td>—</td>
</tr>
<tr>
<td>n</td>
<td>965</td>
<td>918</td>
<td>970</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>L* Pearson’s correlation</td>
<td>0.068*</td>
<td>—0.081*</td>
<td>—0.303**</td>
<td>1</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>n</td>
<td>972</td>
<td>925</td>
<td>970</td>
<td>977</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>a* Pearson’s correlation</td>
<td>—0.292**</td>
<td>0.147**</td>
<td>—0.139**</td>
<td>—0.482**</td>
<td>1</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>n</td>
<td>972</td>
<td>925</td>
<td>970</td>
<td>977</td>
<td>977</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>b* Pearson’s correlation</td>
<td>0.131**</td>
<td>—0.076*</td>
<td>—0.185**</td>
<td>0.380**</td>
<td>—0.157**</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>n</td>
<td>972</td>
<td>925</td>
<td>970</td>
<td>977</td>
<td>977</td>
<td>977</td>
<td>—</td>
</tr>
<tr>
<td>Hue Pearson’s correlation</td>
<td>0.073*</td>
<td>—0.029</td>
<td>0.042</td>
<td>—0.031</td>
<td>—0.114**</td>
<td>—0.317**</td>
<td>1</td>
</tr>
<tr>
<td>n</td>
<td>972</td>
<td>925</td>
<td>970</td>
<td>977</td>
<td>977</td>
<td>977</td>
<td>977</td>
</tr>
<tr>
<td>Chroma Pearson’s correlation</td>
<td>—0.310**</td>
<td>0.152**</td>
<td>—0.077**</td>
<td>—0.545**</td>
<td>0.967**</td>
<td>—0.391**</td>
<td>—0.066*</td>
</tr>
<tr>
<td>n</td>
<td>972</td>
<td>925</td>
<td>970</td>
<td>977</td>
<td>977</td>
<td>977</td>
<td>977</td>
</tr>
</tbody>
</table>

1 pH15 = pH 15 min postmortem; Temp15 = temperature 15 min postmortem; pH24 = pH 24 h postmortem; L* = lightness; a* = redness; and b* = yellowness.

* Significant correlations to P < 0.05; ** significant correlations to P < 0.01.

The sorbance was measured at a 640-nm wavelength. The absorbance value obtained was multiplied by the factor value 17.18, and the concentration of total hemic pigments was expressed in milligrams of myoglobin per gram of meat.

**Statistical Analysis**

Descriptive statistical treatment of data was performed with SPSS 11.5 for Windows (SPSS Inc., Chicago, IL); histograms were made for the parameters analyzed in the sampling population. Pearson’s correlation analysis was performed for relationship evaluation of analytical parameters. Data were subjected to ANOVA using 1-way ANOVA. When F-test was significant, the least significant difference test was performed to multiple comparisons of means.

**RESULTS AND DISCUSSION**

The pH15 and Temp15 values in the pectoralis major muscles of turkey carcasses sampled are presented in Table 1. The mean internal muscle temperature was within the range of those observed on the pectoralis major after 20 min postmortem by Pietrzak et al. (1997). After carcass cooling, there was a decrease in pH in the muscles (24 h postmortem) to 5.83 ± 0.11, with a variation from 5.50 to 6.19.

From color parameters evaluated on the pectoralis major muscle in the turkey carcasses (Table 1), a* values were

Table 3. Pearson’s correlation coefficients among total pigments, drip loss, cooking loss and pH, temperature, and color parameters from turkey carcass pectoralis major muscles

<table>
<thead>
<tr>
<th>Physicochemical parameters</th>
<th>pH15</th>
<th>Temp15</th>
<th>pH24</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>Hue</th>
<th>Chroma</th>
<th>Total pigment</th>
<th>Drip loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pigment</td>
<td>—0.197</td>
<td>0.100</td>
<td>—0.026</td>
<td>—0.219</td>
<td>0.398**</td>
<td>—0.220</td>
<td>0.007</td>
<td>0.575**</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td>n</td>
<td>67</td>
<td>60</td>
<td>67</td>
<td>67</td>
<td>67</td>
<td>67</td>
<td>67</td>
<td>69</td>
<td>69</td>
<td>—</td>
</tr>
<tr>
<td>Drip loss</td>
<td>—0.096</td>
<td>—0.144</td>
<td>—0.059</td>
<td>0.042</td>
<td>—0.131</td>
<td>—0.002</td>
<td>—0.093</td>
<td>—0.050</td>
<td>—0.092</td>
<td>1</td>
</tr>
<tr>
<td>n</td>
<td>66</td>
<td>59</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>68</td>
<td>68</td>
<td>68</td>
</tr>
<tr>
<td>Cooking loss</td>
<td>—0.124</td>
<td>—0.048</td>
<td>—0.376**</td>
<td>0.356**</td>
<td>—0.044</td>
<td>0.347**</td>
<td>—0.175</td>
<td>—0.206</td>
<td>—0.188</td>
<td>—0.152</td>
</tr>
<tr>
<td>n</td>
<td>66</td>
<td>59</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>68</td>
<td>68</td>
<td>68</td>
</tr>
</tbody>
</table>

1 pH15 = pH 15 min postmortem; Temp15 = temperature 15 min postmortem; pH24 = pH 24 h postmortem; L* = lightness; a* = redness; and b* = yellowness.

* Significant correlations to P < 0.05; ** significant correlations to P < 0.01.
higher, and b* values were lower than those reported by Fernandez et al. (2002) in females from the BUT turkey line (a* = 3.7 to 2.8 and b* = 5.4 to 5.1) but similar to those obtained by El Rammouz et al. (2004). The differences in a* and b* values for turkey meat in the present study, when compared with the above authors, could be related to variations in slaughter method, animal sex, and diet (Mercier et al., 1998; Ranken, 2000).

Drip-loss values (1.28%, minimum of 0.36%; maximum of 4.74%) from 67 pectoralis major muscle samples were similar to those found by Molette et al. (2003) in turkey meat. However, the mean cooking losses in sampled turkey meat (17.83%, minimum of 11.15%; maximum of 25.85%) were higher.

Pearson’s correlation coefficients among pH15, Temp15, pH24, L*, a*, b*, hue, and chroma obtained from a population of 977 samples are presented in Table 2. Significant correlations were observed between pH15 and the other physicochemical parameters characterizing turkey meat quality. The most significant coefficients were established with Temp15 (r = −0.303, P < 0.01) and with chroma (r = −0.310, P < 0.01), but the level of association was low for both cases. Only 9% of pH15 variability was explained by Temp15 and vice versa, and meat color saturation (chroma) was explained in only 9% of cases by the variability in pH15.

The pH24 had a negative correlation with L* (r = −0.303, P < 0.01). Other factors may cause this color variation, because the relationship between pH24 and L* explains only approximately 9% of the variability. The correlations between pH24 and L* found by El Rammouz et al. (2004) were similar to those, but Barbut (1993) and Fletcher (1999) found higher associations between these 2 parameters. The higher association values presented by these authors result from turkey meat samples with a higher L* value associated to a lower pH than those found in the present study.

There was a significant correlation (P < 0.01) between L* and a*, b*, and chroma parameters. When the L* increased, turkey meat had less a* and more b* (Table 2).

The coefficient correlations among the quality parameters analyzed on line and total pigments, drip loss, and cooking loss from 67 turkey breast samples are presented in Table 3. Significant correlations among total pigments and a* value (r = 0.398, P < 0.001) and chroma (r = 0.575, P < 0.01) were observed. These relationships show that different chemical myoglobin states (oxygenation, oxidation, and reduction) and different concentrations of total pigments are factors influencing meat L* values (Boulianne and King, 1995, 1998; Gašperlin et al., 2000). Besides there being correlations between pH15 and Temp15 and also between pH24 and L* value in turkey meat (Table 2), there was no relationship between these parameters and drip loss (Table 3). In fact, 60.6% of carcasses had pectorals major muscles with a pH24 value equal to or above 5.8 (Figure 1, panel A). The pH24 mean value was far from the myosin isoelectric point (pH = 5.3), and there was less release of water, bound to the lateral protein chains (Fennema, 1977; Hamm, 1981). However, a significant correlation (Table 3) was reported between meat

<table>
<thead>
<tr>
<th>Item</th>
<th>pH15 ≤ 6.2</th>
<th>pH15 &gt; 6.2</th>
<th>F-value</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>n = 144</td>
<td>n = 830</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH15</td>
<td>6.07 ± 0.01</td>
<td>6.54 ± 0.01</td>
<td>907.328</td>
<td>***</td>
</tr>
<tr>
<td>Temp15</td>
<td>42.28 ± 0.06</td>
<td>41.69 ± 0.03</td>
<td>63.221</td>
<td>***</td>
</tr>
<tr>
<td>pH24</td>
<td>5.79 ± 0.01</td>
<td>5.83 ± 0.00</td>
<td>19.275</td>
<td>***</td>
</tr>
<tr>
<td>L*</td>
<td>46.17 ± 0.22</td>
<td>46.91 ± 0.10</td>
<td>8.431</td>
<td>**</td>
</tr>
<tr>
<td>a*</td>
<td>6.20 ± 0.09</td>
<td>5.38 ± 0.03</td>
<td>114.207</td>
<td>***</td>
</tr>
<tr>
<td>b*</td>
<td>−2.05 ± 0.08</td>
<td>−1.80 ± 0.03</td>
<td>13.342</td>
<td>***</td>
</tr>
<tr>
<td>Hue</td>
<td>347.18 ± 5.51</td>
<td>355.77 ± 1.30</td>
<td>4.938</td>
<td>*</td>
</tr>
<tr>
<td>Chroma</td>
<td>6.59 ± 0.09</td>
<td>5.71 ± 0.03</td>
<td>123.522</td>
<td>***</td>
</tr>
</tbody>
</table>

1pH15 = pH 15 min postmortem; Temp15 = temperature 15 min postmortem; pH24 = pH 24 h postmortem; L* = lightness; a* = redness; and b* = yellowness; mean ± SEM.

*Significantly different at P < 0.05; **significantly different at P < 0.01; and ***significantly different at P < 0.001.

<table>
<thead>
<tr>
<th>Item</th>
<th>pH15 ≤ 6.2</th>
<th>pH15 &gt; 6.2</th>
<th>F-value</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>n = 11</td>
<td>n = 56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH15</td>
<td>6.03 ± 0.03</td>
<td>6.55 ± 0.03</td>
<td>64.376</td>
<td>***</td>
</tr>
<tr>
<td>Total pigments (mg/g)</td>
<td>0.65 ± 0.08</td>
<td>0.58 ± 0.03</td>
<td>1.162</td>
<td>NS</td>
</tr>
<tr>
<td>Drip loss (%)</td>
<td>1.53 ± 0.36</td>
<td>1.24 ± 0.09</td>
<td>1.087</td>
<td>NS</td>
</tr>
<tr>
<td>Cooking loss (%)</td>
<td>18.43 ± 1.41</td>
<td>17.73 ± 0.46</td>
<td>0.316</td>
<td>NS</td>
</tr>
</tbody>
</table>

1pH15 = pH 15 min postmortem; NS = P > 0.05; mean ± SEM.

**Significantly different at P < 0.001.
cooking loss and pH24 (r = −0.376, P < 0.01) and also with L* value (r = 0.356, P < 0.01), indicating that paler and lower pH turkey meat had higher cooking loss values (less water-holding capacity). These 2 parameters, pH24 and L*, together could contribute to a better PSE-like meat discrimination, because, separately, each parameter only explained 14 and 13%, respectively, of meat cooking loss variability.

The distribution of pH15 values in pectoralis major muscles shows that the rate of pH decline was faster in some muscles than in others, and it was possible to establish a cutoff point in the population distribution when pH15 was 6.2 (data not shown). According to several authors, the rate of rigor mortis development in muscles and pH decline in meat induces defects in turkey meat, as well as in pork (Santé et al., 1991; Dransfield and Sosnicki, 1999; Fernandez et al., 2002). The value pH15 equal to 6.2 found in our study population was also chosen by Malenica et al. (2002) as a criteria for muscle classification related to pH decline, but it does not coincide with Santé et al. (1991) and Pietrzak et al. (1997), for whom a pH value lower than 5.8 after 5 to 30 min postmortem indicated rapid glycolytic (RG) muscles. Therefore, according to pH limit criteria, 15% of carcasses were found to have RG muscles with pH15 ≤ 6.2 (rapid decline of pH).

The mean and SE of physicochemical characteristics are displayed in Table 4, with significant differences between RG and slow glycolytic (SG) muscle groups. Rapid glycolytic muscles have a higher temperature (42.28°C), as expected from the significant negative correlation (r = −0.303, Table 2) obtained between pH15 and Temp15. The data confirms the relationship between the rate of biochemical modifications in muscle postmortem and temperature, an indicator of heat production (Lawrie, 1998). According to several authors (Warriss and Brown, 1987; Monin, 1988; Fernandez et al., 2002; Santos et al., 1996; Zhu and Brewer, 2002; Molette et al., 2003), the rate and extension of pH decline, when muscle temperature is still high, can promote denaturation of myofibrillar and sarcoplasmic proteins and, consequently, leads to an increase in light reflection and low water-holding capacity, characteristics of PSE meat. However, our results are in disagreement with the referred authors, because in the RG muscle group, despite a low pH24, the L* and b* values were lower, and the a* value was higher than those registered in the SG muscle group (Table 4). Although a higher mean temperature was associated with a lower pH15, Pearson’s coefficient correlation between pH15 and L* was very low (P < 0.05, Table 2), little explaining the variability observed in the L* parameter. In fact, SG muscles could also have high L* values, as shown in Table 4. Rathgeber et al. (1999) observed that RG muscles were not differentiated from normal muscles because they presented the same L* values after 24 h postmortem but had higher a* values. Malenica et al. (2002) stated that higher L* values were not associated with lower pH values measured at 20 min postmortem. They found similar L* values in muscles classified as RG and SG.

The Pearson correlations obtained between color parameters and pH15 confirmed the values found in the RG population (lower L*, higher a* and chroma). The pH24 was significantly lower (P < 0.001, Table 4) in the RG

<table>
<thead>
<tr>
<th>Classification criteria</th>
<th>Frequency</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L* ≤ 44</td>
<td>151</td>
<td>15.4</td>
</tr>
<tr>
<td>44 &lt; L* &lt; 50</td>
<td>707</td>
<td>72.4</td>
</tr>
<tr>
<td>L* ≥ 50</td>
<td>119</td>
<td>12.2</td>
</tr>
<tr>
<td>Total</td>
<td>977</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Table 6. Classification of 977 pectoralis major samples based on lightness (L*) values (L* ≤ 44; 44 < L* < 50; and L* ≥ 50) and distribution in quality color meat groups.
According to Rathgeber et al. (1999), SG muscles also inhibited glycolysis, not explaining all the variability of values founded. Warriss (1982) stated that muscles with a lower initial pH also have a lower pH 20 min postmortem, found that the group with the lower pH 20 min postmortem had a lower ultimate pH. However, in the present study, significant coefficient correlation between pH15 and L* values were too low (Table 2), not explaining all the variability of values founded. According to Rathgeber et al. (1999), SG muscles also can reach very low pH24 values. The rate of pH decline depends mainly on the postmortem rate that ATP hydrolyzes, whereas the pH decline extension depends on the amount of glycogen in the muscle at the time of animal slaughtering (Lawrie, 1998).

Drip loss and cooking loss in the RG group were slightly higher (Table 5), although no relationship among pH15, drip loss, and cooking loss had been observed (Table 3). Warriss (1982) stated that the relationship between pH 45 min postmortem and drip loss in pork was biphasic, reporting no significant effect on drip loss when pH was lower than 6.1, whereas for the above pH, the relationship was significant. Malenica et al. (2002) recorded drip loss differences in RG and SG turkey muscles, but they did not find any significant difference related to cooking loss between both muscle groups. Rathgeber et al. (1999) did not observe any influence of the rate of glycolysis in turkey meat cooking loss, in contrast to results reported by Fernandez et al. (2002). These authors stated that turkey breast meat with a rapid pH decline presented a low industrial yield and higher drip loss in packaged cooked products.

In this study, the muscle groups classified by pH15, mainly the RG muscles, did not present final quality characteristics that could relate them to PSE meat (pale meat with low water-holding capacity). There was no relationship between pH15 and L*, drip loss, and cooking loss, so, the classification method based only on pH15 was insufficient to discriminate among different turkey meat quality groups. This contradicts the recommendations of Malenica et al. (2002), who stated that measuring pH 20 min postmortem is a useful and practical method for predicting the water-holding capacity of turkey meat.

The distribution of the L* parameter in the population presented a normal curve (Figure 1, panel B). Adopting the methodology of Barbut (1993, 1997) for meat-quality evaluation by using the L* parameter, and according to the distribution of this parameter in the study population, a cutoff point was observed when L* > 50 and when L* ≤ 44. It was considered that approximately 12% of the population presented pectoralis major muscles with a L* ≤ 44, 15% presented muscles with a L* > 50, and 15% presented muscles with a L* ≥ 44, corresponding to darker meat (Table 6).

<table>
<thead>
<tr>
<th>Item</th>
<th>L* ≤ 44</th>
<th>44 &lt; L* ≤ 50</th>
<th>L* ≥ 50</th>
<th>F-value</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (V)</td>
<td>221.64a</td>
<td>218.96b</td>
<td>219.66b</td>
<td>14.809</td>
<td>***</td>
</tr>
<tr>
<td>Resting time (h)</td>
<td>3.24a</td>
<td>2.19b</td>
<td>1.94b</td>
<td>16.100</td>
<td>***</td>
</tr>
<tr>
<td>Scalding temperature (°C)</td>
<td>82.32b</td>
<td>82.75b</td>
<td>82.82b</td>
<td>6.988</td>
<td>***</td>
</tr>
<tr>
<td>Carcass weight (kg)</td>
<td>6.45</td>
<td>6.47</td>
<td>6.50</td>
<td>1.916</td>
<td>NS</td>
</tr>
<tr>
<td>pH15</td>
<td>41.86</td>
<td>41.79</td>
<td>41.64</td>
<td>2.471</td>
<td>NS</td>
</tr>
<tr>
<td>pH24</td>
<td>5.88b</td>
<td>5.83b</td>
<td>5.76b</td>
<td>51.923</td>
<td>***</td>
</tr>
<tr>
<td>L*</td>
<td>42.12</td>
<td>47.06b</td>
<td>51.18b</td>
<td>1.287796</td>
<td>***</td>
</tr>
<tr>
<td>a*</td>
<td>6.20b</td>
<td>5.45b</td>
<td>4.91b</td>
<td>86.966</td>
<td>***</td>
</tr>
<tr>
<td>b*</td>
<td>-2.20a</td>
<td>-1.86b</td>
<td>-1.23a</td>
<td>58.761</td>
<td>***</td>
</tr>
<tr>
<td>Hue</td>
<td>354.89</td>
<td>354.58</td>
<td>353.71</td>
<td>0.028</td>
<td>NS</td>
</tr>
<tr>
<td>Chroma</td>
<td>6.65b</td>
<td>5.79b</td>
<td>5.10b</td>
<td>118.151</td>
<td>***</td>
</tr>
</tbody>
</table>

**Means within a row with different superscript letters are significantly different.
1*pH15 = pH 15 min postmortem; Temp15 = temperature 15 min postmortem; pH24 = ph 24 h postmortem; L* = lightness; a* = redness; and b* = yellowness; NS = P > 0.05; mean ± SEM.
**Significantly different at P < 0.01.

---

Table 7. Physicochemical postmortem characteristics (mean and SEM) of pectoralis major muscles from turkey carcass (n = 977) color groups L* ≤ 44; 44 < L* ≤ 50; and L* ≥ 50

<table>
<thead>
<tr>
<th>Item</th>
<th>L* ≤ 44</th>
<th>44 &lt; L* ≤ 50</th>
<th>L* ≥ 50</th>
<th>F-value</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td>n = 151</td>
<td>n = 707</td>
<td>n = 119</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage (V)</td>
<td>221.64a</td>
<td>218.96b</td>
<td>219.66b</td>
<td>14.809</td>
<td>***</td>
</tr>
<tr>
<td>Resting time (h)</td>
<td>3.24a</td>
<td>2.19b</td>
<td>1.94b</td>
<td>16.100</td>
<td>***</td>
</tr>
<tr>
<td>Scalding temperature (°C)</td>
<td>82.32b</td>
<td>82.75b</td>
<td>82.82b</td>
<td>6.988</td>
<td>***</td>
</tr>
<tr>
<td>Carcass weight (kg)</td>
<td>6.45</td>
<td>6.47</td>
<td>6.50</td>
<td>1.916</td>
<td>NS</td>
</tr>
<tr>
<td>pH15</td>
<td>41.86</td>
<td>41.79</td>
<td>41.64</td>
<td>2.471</td>
<td>NS</td>
</tr>
<tr>
<td>pH24</td>
<td>5.88b</td>
<td>5.83b</td>
<td>5.76b</td>
<td>51.923</td>
<td>***</td>
</tr>
<tr>
<td>L*</td>
<td>42.12</td>
<td>47.06b</td>
<td>51.18b</td>
<td>1.287796</td>
<td>***</td>
</tr>
<tr>
<td>a*</td>
<td>6.20b</td>
<td>5.45b</td>
<td>4.91b</td>
<td>86.966</td>
<td>***</td>
</tr>
<tr>
<td>b*</td>
<td>-2.20a</td>
<td>-1.86b</td>
<td>-1.23a</td>
<td>58.761</td>
<td>***</td>
</tr>
<tr>
<td>Hue</td>
<td>354.89</td>
<td>354.58</td>
<td>353.71</td>
<td>0.028</td>
<td>NS</td>
</tr>
<tr>
<td>Chroma</td>
<td>6.65b</td>
<td>5.79b</td>
<td>5.10b</td>
<td>118.151</td>
<td>***</td>
</tr>
</tbody>
</table>

**Means within a row with different superscript letters are significantly different.
1*pH15 = pH 15 min postmortem; Temp15 = temperature 15 min postmortem; pH24 = ph 24 h postmortem; L* = lightness; a* = redness; and b* = yellowness; NS = P > 0.05; mean ± SEM.
**Significantly different at P < 0.01.

---

Table 8. Physicochemical postmortem characteristics (mean and SEM) of pectoralis major muscles from turkey carcass (n = 67) color groups L* ≤ 44; 44 < L* ≤ 50; and L* ≥ 50

<table>
<thead>
<tr>
<th>Item</th>
<th>L* ≤ 44</th>
<th>44 &lt; L* ≤ 50</th>
<th>L* ≥ 50</th>
<th>F-value</th>
<th>Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pigments (mg/g)</td>
<td>0.72a</td>
<td>0.53b</td>
<td>0.56b</td>
<td>5.777</td>
<td>**</td>
</tr>
<tr>
<td>Drip loss (%)</td>
<td>1.19</td>
<td>1.24</td>
<td>1.40</td>
<td>0.391</td>
<td>NS</td>
</tr>
<tr>
<td>Cooking loss (%)</td>
<td>16.95b</td>
<td>16.67b</td>
<td>19.93b</td>
<td>6.751</td>
<td>**</td>
</tr>
</tbody>
</table>

**Means within a row with different superscript letters are significantly different (P < 0.001).
1*L* = lightness; NS = P > 0.05; mean ± SEM.
**Significantly different at P < 0.01.
Regarding Tables 7 and 8, the 3 meat categories classified according to the L* parameter presented significant differences for pH24, a*, b*, chroma (P < 0.001), total pigments, and cooking loss mean values (P < 0.05). The paler meat (51.18) had the lower pH24 (5.76), whereas the darker meat (42.12) had the highest pH24 (5.88). Several authors, in previous studies, noted a relationship between meat color and pH (Allen et al., 1998; Fletcher, 1999; Fletcher et al., 2000; Qiao et al., 2001). In addition, it has also been reported that darker-colored poultry meat presented a higher pH, although no explanation was advanced for this fact (Boulianne and King, 1998; Fletcher, 1999; Fletcher et al., 2000; Qiao et al., 2001).

The fact that no significant differences were observed in the pH15 of these characterized groups supports the idea that the rate of pH decline had no influence on meat quality differences observed at 24 h. This is in agreement with Santé et al. (1996), who reported that the rate of glycolysis does not explain the variation of color found after 24 h in turkey meat, although this type of muscle is already characterized by a high rate of glycolysis, presenting rigor mortis after 2 h.

No significant differences in total pigment concentration were apparent between the muscles classified as paler and as intermediate color. The paler color was not related to a lower total pigment concentration, thereby disagreeing with the statements of Boulianne and King (1995). The paler color, in association with a lower pH24 (5.77 ± 0.02), may result from increased light reflection from the meat’s surface (Fennema, 1977; Pietrzak et al., 1997; Zhu and Brewer, 2002). In contrast, total pigment concentration in darker muscles was significantly higher. This higher concentration of pigments in dark turkey muscles, also reported by Boulianne and King (1998) on broilers, could be explained by bleeding deficiencies. However, because this meat presented a higher pH, the bleeding will not be the only factor explaining the darker meat. Other factors, such as O2 diffusion rate, oxygenation of myoglobin, and an increase in mitochondria activity, can also explain darker meat when the pH is higher (Faustman and Cassens, 1990; Lanari and Cassens, 1991; Lawrie, 1998; Gašperlin et al., 2000). This can justify our higher values (P < 0.05) found for a* and chroma in dark meat compared with the other meat groups.

Moreover, turkeys in lairage for a longer resting time and stunned with an electric current of higher voltage also having a lower weight (Table 7) could be exhausted, and this could induce darker meat. According to Quinn et al. (1998), potentially stressful environments caused by increased environmental temperature are rapidly reached in <1 h after unloading birds. Warriss et al. (1999) stated that glycolytic potential could be smaller with less extension of pH decline due to bird exhaustion. More recently, El Rammouz et al. (2004) observed correlations between glycolytic potential and ultimate pH (r = −0.44, P < 0.01), L* (r = 0.39, P < 0.01), b* value (r = 0.51, P < 0.01), and cooking loss (r = 0.28, P < 0.01).

With regard to the pH24 mean value of different meat categories, it is to be expected that there will be differences in water-holding capacities. However, the differences observed in drip loss were not significant, although there was a higher drip loss in meat with lower pH value. According to Santé et al. (1996) and van Laack et al. (2000), PSE-like turkey meat seems to be different from PSE pork meat with respect to drip loss, because fresh turkey meat is not influenced by this quality condition.

The group with a higher carcass weight presented a lower pH24 and a higher L* (Table 7). These findings disagree with results reported by Fernandez et al. (2002), who observed that birds with a lower weight were in the lower pH group. In spite of Temp15 being similar in the 3 muscle color groups, different weights of carcasses and muscle conformation could also emphasize the effect of cooling conditions on meat quality. Heavier weighted and also better breast muscle yield carcasses have higher probability to develop PSE meat characteristics (McKee and Sams, 1998; Offer, 1991; Pietrzak et al., 1997; Rathgeber et al., 1999; Updike et al., 2005).

In the pale and lowest-pH meat (pH24 = 5.76 ± 0.01), a higher cooking loss value was observed (Table 8; 19.93%, P < 0.01). This category of meat color registered a significant difference of 3% in cooking loss compared with the other meat categories. Dark meat presented cooking loss values of 16.95%, which were not significantly different from results observed in meat with intermediate color. This suggests that meat with a pH24 higher than 5.8 does not present a significant difference in water-holding capacity (evaluated by cooking loss), irrespective of its color. Because there was meat with pH higher than 5.8 that was pale without being exudative or without high cooking loss, as was observed by the range of L*, pH24, and cooking loss values, the inclusion of the pH24 parameter was considered an important criteria for classifying PSE meat (pale and exudative). According to this criteria (Table 9), 7.6% of samples were not classified in any category because they were pale with a pH higher than 5.8 and a higher water-holding capacity, or they were dark with a pH lower than 5.8 and a lower water-holding capacity. However, 8.1% of pectoralis major muscles from turkey carcasses were classified as PSE meat, a lower pH and high

### Table 9. Classification of 977 pectoralis major samples according to lightness (L*) and pH 24 h postmortem (pH24; L* ≤ 44 and pH24 ≥ 5.8; 44 < L* < 50; L* ≥ 50 and pH24 < 5.8) and distribution in quality color groups

<table>
<thead>
<tr>
<th>Criteria classification</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>L* ≤ 44 and pH24 ≥ 5.8</td>
<td>118</td>
</tr>
<tr>
<td>44 &lt; L* &lt; 50</td>
<td>706</td>
</tr>
<tr>
<td>L* ≥ 50 and pH24 &lt; 5.8</td>
<td>79</td>
</tr>
<tr>
<td>Samples not classified</td>
<td>74</td>
</tr>
<tr>
<td>Total</td>
<td>977</td>
</tr>
</tbody>
</table>

FRAQUEZA ET AL. 1998
cooking loss), and 12.1% presented darker meat with higher total pigment content and pH higher than 5.8. This dark meat was not different from meat classified as intermediate color in relation to cooking loss.

In conclusion, muscles classified by pH decline rate, RG, did not present final quality characteristics that could relate them with PSE-like meat, because no relationship was established between pH15 and L*, drip loss, or cooking loss. The association between pH24 and L* value, as was established between pH15 and L*, drip loss, or cooking loss, can be useful for a better assessment of turkey meat quality. The physicochemical characteristic differences found within pectoralis major muscles allowed us to establish a criteria of turkey meat quality, differentiating dark meat and PSE-like meat with L* ≤ 44 and pH24 ≥ 5.8 and L* ≥ 50 and pH24 ≤ 5.8, respectively. This can be used by the industry to improve meat quality management and processing. Based on our criteria, the studied population presented 8.1% of carcasses with PSE-like breasts and 12.1% with dark breast muscles.

ACKNOWLEDGMENTS

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REFERENCES


