DYNAMIC COLOUR CHANGES DEPENDING ON THE TEMPERATURE INSIDE THE FINAL BEEF PRODUCT IN A PROCESS OF FRYING AND GRILLING

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Abstract

Four different beef muscles (PM, SM, LTL, TB) were examined. These muscles were fried or grilled. Each muscle was observed at various internal temperatures: 60°C, 65°C, 70°C, and 75°C. At each temperature level, a measurement of colour was taken using a Minolta Chroma Meter CR-400 in a L*a*b* system. The values of the parameters L*, a*, and b* were measured on a cross-section sample (two areas) after cutting perpendicular to the fibres at the middle of its height. Area I was located at the central part of the steak with a diameter of 2 cm. Area II was located at a distance of 1 cm from the edge of the steak. From the results obtained, the difference in colour values between areas was noted. The results indicated that area I was lighter and redder in comparison to area II. The values of parameters L* and a* recorded in the first area were higher in comparison with the values from the second region, indicating that the sample in the area I was lighter and redder than in the area II at the outside of the sample. There was a large variation in the colour of the two areas. It was observed that for all sampled fried muscles, the highest difference in lightness (ΔL*) between the two test areas was obtained at a heat treatment temperature of T= 65°C inside the sample. With grilling the highest value for overall difference in colour between areas was from samples heated to a final temperature of T=60 °C.

Key words: beef, thermal treatment, colour, L*a*b* system.

Numerous investigations have studied colour changes in beef during the cooking process. (5, 7, 9, 10, 13). In the case of beef, and especially culinary beef, its colour, in addition to tenderness, is one of the most important parameters that affect the consumer's decision to buy (6). Consumers consider the correct meat colour to be bright red, because it is an indicator of freshness and safety. Beef colour depends on myoglobin. Myoglobin is the water-soluble haeme protein that stores oxygen and undergoes changes due to oxygenation (oxymyoglobin) and by heat treatment (oxidation) to metmyoglobin. This beef protein when heated at 55°C starts the second transformation from oxymyoglobin to denatured metmyoglobin. This gives the meat its "cooked meat colour". The rate of denaturation to metmyoglobin depends on the level of heat applied. Research has shown that the process peaks at temperature ranging between 75°C and 80°C. It was also shown that there are differences in the rate of the change also due to the age of the animal from which the meat was taken. Kołczak (9, 10) indicates that there is a more "rapid browning" of meat obtained from older animals. The colour change is due to the change in the haeme myoglobin protein and is an important indicator of doneness of meat. Brewer and Novakofski (3) describe the differing characteristics (including colour) of meat when heated to different levels. The American Meat Science Association produced illustrations to indicate levels of doneness from "very rare" to "very well done" (11). These clearly demonstrate the colour transformation through varying degrees from "cherry red" to pink and then to brown. Colour of beef depends primarily on the meat surface myoglobin concentration, but also on its surface structure, chemical status, and pH. During the heat treatment process, three forms of myoglobin are transformed and degraded as a consequence of a change affecting meat colour (5). With the animal age, meat is characterised by a rapid browning during heat treatment in comparison to meat obtained from young animals (9, 10). Heating muscles of normal pH 5.3-5.7 (and pigments: myoglobin, metmyoglobin, and oxymyoglobin) causes the formation of gray pigment of cooked meat. The appearance of this pigment depends on the internal temperature of heat-treated material (7). Colour is also closely correlated to consumer perceptions of eating quality. Colour can
indicate the degree of tenderness, hardness, and has implications in flavour. Sensory measurements can be compared and substituted by subjective instrument measurements when the scale and range of colour changes have been recorded during this process. In addition, Biller and Wierzbicka (1) have noted that errors may occur when relying on sensory measurement methods alone. Instrumental colour measurement provides a simple method of categorising and predicting a range of cooked and raw meat characteristics including its eating quality.

This study records the dynamics of colour change resulting from a range of heat treatments in two cooking processes. The results obtained are part of a wider study on the quality characteristics of beef being conducted by the research team.

The purpose of the work was analysis of the dynamics of colour changes depending on the final temperature inside various muscles of beef subjected to the processes of frying and grilling.

**Materials and Methods**

The following four bovine muscles were used in the study:  *M. psoas major* – PM, *M. semimembranosus* - SM, *M. longissimus thoracis et lumborum* – LTL, and *M. triceps brachii* – TB.

These muscles were removed from carcasses 48 h after slaughter, and then vacuum packed for 5 d. The samples were frozen at -25°C and stored at -18°C until the analysis. Before experimentation, the samples were thawed at 2°C ±1°C for 24 h. After thawing, the muscles were divided into samples measuring 7.5 x 7.5 x 2.5 cm. These were left in a refrigerator for 30 min for a short process of oxygenation (blooming).

Heat was applied until an internal temperature: of 60°C, 65°C, 70°C, and 75°C was reached. The *M. psoas major, M. semimembranosus, M. longissimus dorsi et lumborum* and *M. triceps brachii* were fried whereas the *M. longissimus thoracis et lumborum* and *M. Semimembranosus* were grilled. The frying process was performed using an electric pan (Küppersbusch) that maintained the temperature at 220°C until the target product temperature was reached inside the sample. The samples were turned every 2 min. Grilling was done using an electric contact grill. The temperature of the upper and lower plates was maintained at 230°C.

Instrumental colour coordinates measurement was conducted using a Minolta CR-400 chromameter in a L*a*b* system and illuminant D65, 2° standard observer. The diameter of the measuring head was 8 mm. The device was calibrated on a white standard tile (*L* = 98.45, *a* = -0.10, *b* = -0.13). The values of colour parameters *L* (lightness), *a* (redness), and *b* ( yellowness) were measured from a cross section perpendicular to the steaks’ cut fibres orientation in the centre of its height. The cross section of the sample was divided into two areas from which values *L*, *a*, and *b* were recorded. Measurement were taken at five locations in area I - the middle part of the steak with a diameter of 2 cm. Measurements were taken from eight locations in area II – at a distance of 1 cm from the edge of the steak - (Fig. 1).

From the data obtained, colour differences were calculated for *L*, *a*, and *b* (1, 2, 3) between each area:

\[
\Delta L = |L_i - L_f| \\
\Delta a = |a_i - a_f| \\
\Delta b = |b_i - b_f|
\]

and this was also used to determine an overall steak colour difference for each cross-sectional area for each sample (4):

\[
\Delta E_{II} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}
\]

Measurements were taken from samples at differing final internal temperatures to determine dynamic changes of colour in these two areas for the different muscles subjected to each treatment.

**Results and Discussion**

Table 1 summarises the mean values obtained by measurement of colour parameters *L*, *a*, and *b* within samples, for *M. psoas major, M. semimembranosus, M. longissimus dorsi et lumborum, and M. triceps brachii* when fried and grilled at different temperatures. Results were recorded from two areas (I and II). For the LTL muscle subjected to frying, higher values of colour parameters *L* and *a* in the area I were found. It indicated that the samples were brighter and redder in the area located in the central part of steak. For 60°C, 65°C, and 70°C, higher values of the colour parameter *b* in comparison with the region II were demonstrated in the area I. Only at 75°C inside the sample of LTL muscle, similar values of parameter *b* in both areas of measurement were observed.
In the case of PM muscle fried to 60°C, 70°C, and 75°C, similar lightness values (L*) were recorded in both areas and for 65°C, the sample was lighter in the area II (higher values parameter L*). Values of the a* colour parameter for all PM muscle samples subjected to frying were higher in the area I, which means that these samples were in this place more red than near the edge of the cross-sectional sample. For 65°C, values of the parameter a* increased in comparison with other samples. Frying SM muscles was characterised by higher values of parameters L* and a* in the area I in comparison with the area II (the samples were lighter and redder). This relationship was also observed for the TB muscle subjected to frying at 60°C, 65°C, 70°C, and 75°C. LTL and SM muscles were subjected to grilling at 60°C, 65°C, 70°C, and 75°C inside the samples. It was found that the values of parameters L* and a* measured in the area I, were higher in comparison with the values from the second region (in the area I samples were lighter and redder than in the area II). There was a significant difference in the values between parameter a* I and a* II of samples grilled. These results were strongly differentiated in terms of colour in the areas.

García-Segovia et al. (5) studied the effect of heat treatment temperature (60-80°C) on the colour of beef steaks obtained from *M. longissimus thoracis et lumbarum*. They found, as in this study, that the values of the parameter a* decrease with increasing final temperature inside the sample. Yancey et al. (13) studied the effects of different methods of heat treatment on the colour of steaks from *M. longissimus thoracis et lumbarum*, depending on the final temperature achieved inside the sample. They found that the colour values depend on the final temperature inside the steak, which has also been confirmed in the present study. The values of colour parameters a* decreased as the temperature increased, and for 65.5°C, 71.1°C, and 76.6°C and the values obtained were 18.2, 14.9, and 12.2, respectively. These results are very similar to those presented in this article. Lightness (L*) values obtained for these temperatures were 59.1, 58.4, and 57.9, respectively, and were consistent with the results obtained for SM muscles subjected to grilling. Differences in colour of

### Table 1

Mean values of colour parameters L*, a* and b* measured in two areas of the samples after heat treatment – frying (fr) and grilling (gr).

<table>
<thead>
<tr>
<th>muscle/type of treatment</th>
<th>T/°C</th>
<th>L* I</th>
<th>L* II</th>
<th>a* I</th>
<th>a* II</th>
<th>b* I</th>
<th>b* II</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTL/fr</td>
<td>60°C</td>
<td>53.21±1.12</td>
<td>52.82±0.99</td>
<td>22.97±0.75</td>
<td>20.11±0.84</td>
<td>15.92±0.28</td>
<td>15.45±0.46</td>
</tr>
<tr>
<td>LTL/fr</td>
<td>65°C</td>
<td>55.94±1.08</td>
<td>53.85±1.15</td>
<td>17.34±1.00</td>
<td>13.65±0.94</td>
<td>15.52±0.56</td>
<td>14.73±0.77</td>
</tr>
<tr>
<td>LTL/fr</td>
<td>70°C</td>
<td>56.91±1.43</td>
<td>55.38±1.52</td>
<td>10.98±0.62</td>
<td>9.91±0.57</td>
<td>15.85±0.48</td>
<td>14.02±0.74</td>
</tr>
<tr>
<td>LTL/fr</td>
<td>75°C</td>
<td>57.13±1.23</td>
<td>56.22±1.17</td>
<td>10.92±0.98</td>
<td>10.33±0.77</td>
<td>13.17±0.93</td>
<td>13.30±0.66</td>
</tr>
<tr>
<td>PM/fr</td>
<td>60°C</td>
<td>54.65±0.95</td>
<td>54.85±0.89</td>
<td>21.36±0.83</td>
<td>22.07±0.79</td>
<td>13.30±0.68</td>
<td>13.48±0.90</td>
</tr>
<tr>
<td>PM/fr</td>
<td>65°C</td>
<td>55.44±1.13</td>
<td>57.09±1.42</td>
<td>11.85±0.96</td>
<td>10.63±0.84</td>
<td>13.57±0.74</td>
<td>13.54±0.27</td>
</tr>
<tr>
<td>PM/fr</td>
<td>70°C</td>
<td>57.91±1.12</td>
<td>57.18±1.36</td>
<td>9.81±0.60</td>
<td>8.70±0.45</td>
<td>13.74±0.51</td>
<td>14.11±0.45</td>
</tr>
<tr>
<td>PM/fr</td>
<td>75°C</td>
<td>57.65±0.83</td>
<td>57.27±0.99</td>
<td>8.91±0.27</td>
<td>8.61±0.11</td>
<td>13.45±0.28</td>
<td>12.70±0.50</td>
</tr>
<tr>
<td>SM/fr</td>
<td>60°C</td>
<td>57.14±0.01</td>
<td>56.24±1.04</td>
<td>19.74±0.94</td>
<td>16.28±0.88</td>
<td>13.50±0.83</td>
<td>12.59±1.02</td>
</tr>
<tr>
<td>SM/fr</td>
<td>65°C</td>
<td>58.11±1.46</td>
<td>55.55±1.72</td>
<td>16.59±1.18</td>
<td>10.31±1.39</td>
<td>13.43±0.77</td>
<td>13.03±0.38</td>
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<tr>
<td>SM/fr</td>
<td>70°C</td>
<td>56.99±1.28</td>
<td>56.25±1.36</td>
<td>11.94±1.02</td>
<td>8.80±0.82</td>
<td>12.68±0.48</td>
<td>12.80±0.67</td>
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<tr>
<td>SM/fr</td>
<td>75°C</td>
<td>53.62±1.14</td>
<td>53.00±1.33</td>
<td>8.06±0.90</td>
<td>7.82±0.63</td>
<td>13.27±0.85</td>
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<tr>
<td>TB/fr</td>
<td>60°C</td>
<td>58.22±1.08</td>
<td>57.32±1.13</td>
<td>18.52±0.97</td>
<td>14.73±0.85</td>
<td>15.72±0.33</td>
<td>16.82±0.47</td>
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<tr>
<td>TB/fr</td>
<td>65°C</td>
<td>57.41±0.97</td>
<td>56.18±1.11</td>
<td>21.19±1.25</td>
<td>15.45±1.00</td>
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<td>52.89±1.80</td>
<td>8.93±0.79</td>
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<td>12.88±0.52</td>
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<td>LTL/gr</td>
<td>60°C</td>
<td>55.77±0.96</td>
<td>53.69±1.03</td>
<td>19.66±0.88</td>
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<td>12.83±0.55</td>
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<td>13.69±0.92</td>
<td>12.60±0.37</td>
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<td>70°C</td>
<td>55.16±1.42</td>
<td>53.58±1.36</td>
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<td>60°C</td>
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<td>54.37±0.88</td>
<td>20.56±1.36</td>
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<td>13.41±0.99</td>
<td>12.28±0.65</td>
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<td>SM/gr</td>
<td>65°C</td>
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<td>13.04±0.76</td>
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</tr>
</tbody>
</table>
the steak cross section, depending on the final temperature were consistent with results obtained by Hunt et al. (8), who found that the denaturation of myoglobin increases with an increase in the temperature from 55°C to 80°C. In contrast, the study of Bowers et al. (2) demonstrated that the interior of steaks from M. longissimus dorsi becomes lighter (higher L* values of the coefficient) with increasing temperature, and colour parameters a* and b* did not change until the temperature reached 75°C within the tested samples.

Effects of internal final temperature of fried and grilled muscle samples on the lightness difference ΔL*, redness difference Δa*, and overall difference ΔE* are shown in Figs 2, 3, and 4, respectively.

For all studied fried muscles difference in lightness (ΔL*) for two test areas was the highest at 65°C (Fig. 2). For LTL fried muscle at 70°C, ΔL* was 1.53, which shows an apparent difference in lightness of the studied areas. For other fried muscles, the obtained values were: ΔL*<1, which implies that the difference in brightness between the investigated areas was not noticeable to an observer. After the grilling process, the biggest differences in lightness ΔL* were observed for samples heated to 60°C (Fig. 2). ΔL* values decreased with increasing final internal temperature. For the internal final temperature of 75°C, the lowest value of ΔL*<1 was observed, which implies that the difference in lightness between the investigated areas was not noticeable to an observer. At 70°C, differences in colour (ΔL*> 1) between the two studied areas were observed.

For grilled SM to internal temperature of 60°C, the differences in lightness were larger in comparison to the samples of grilled LTL. For grilling and frying to 75°C, there was little difference in the ΔL* between muscles.

The most pronounced differences in the values of the parameter a* between the research areas were observed for muscle fried to 65°C in the geometrical centre (Fig. 3). Only fried PM had the lowest values Δa* during heat treatment at all used internal temperatures. The highest value of Δa* at 65°C was observed for the SM muscle, and then for TB, LTL, and PM (6.28, 5.75, 3.69, and 1.22, respectively).

The smallest differences in Δa* were found for samples fried to 75°C of inside temperature. These values were <1, which indicates that the consumer does not notice the difference in the colour. After the grilling to the internal temperature of 60°C, differences in Δa* were the greatest for both LTL and SM muscles. Δa* values decreased with increasing final temperature inside the grilled product.

Frying to the final temperature of 65°C resulted in the highest values of ΔE* in all studied muscles (Fig. 4). For SM and TB muscles, these values were 6.80 and 5.91, respectively, which indicates that the consumer has the impression of two different colours. From the temperature of 60°C, the ΔE* values increased, then decreased, and at 75°C reached a value close to 1 for LTL muscle and <1 for other muscles.

When frying to the internal temperature of 60°C, practically the whole cross-section was of red colour (which corresponded to the degree of doneness "very rare"), at 65°C, there were red and "gray" areas, which corresponded to the degree of doneness "medium rare". For the internal temperature of 70°C, reduction of the ΔE* value was observed, which indicates a smaller difference in colour between the areas of measurement - the degree of doneness was "medium". For the internal temperature of 75°C, the difference in the colour inside samples showed a "well" degree of doneness.

After grilling process, the highest values of overall difference in colour were observed for samples heated to the internal temperature of 60°C, then the ΔE* values decreased with the increase in final internal temperature.
It has been found that $\Delta E*$ values for temperatures of 60°C, 65°C, and 70°C were higher for grilled SM muscle in comparison with the LTL muscle.

In conclusion, the process of heat treatment causes denaturation of the myoglobin, which begins at 55°C, and at 75-80°C this process is most intense. In the process of thermal treatment of beef, all three forms of myoglobin are transformed and degraded, which affects meat colour. Choosing the right treatment of meat is very important in determining final quality of product. The thermal processes used in this work – frying and grilling, and internal temperature influence the dynamics of colour changes of beef.

For all investigated fried muscles, the differences in lightness ($\Delta L*$), redness ($\Delta a*$), and in overall colour ($\Delta E*$) for the two tested areas were the greatest in the case of conducting the heat treatment to the internal temperature of 65°C – degree of doneness – "medium rare".

For all grilled muscles, the differences in lightness ($\Delta L*$), redness ($\Delta a*$), and overall colour ($\Delta E*$) for two tested areas were the greatest in the case of conducting the heat treatment to the internal temperature of 60°C – degree of doneness – "rare".

On cross-section of the bovine muscle samples heated to the internal temperature of 70°C and 75°C, the smallest differences in colour for the two studied areas were found.

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**References**