Bone darkening: A study of surface cooling and slicing of pork loin

Bone marrow oxidation of industrial prepackaged pork chops causes bone darkening during storage. This discoloration causes poor sales in supermarkets. As the addition of antioxidant is not authorized, IFIP engineers modulated the conditions for surface cooling and slicing bone-in loin. Four conditions of surface cooling and three of slicing (blade type and sharpness) were tested. The change in color of the bones was then monitored for 11 days by sensory evaluation and colorimetric measurements. The results identified optimum surface cooling conditions for pork loin: cooling at −5 °C for 2 hours. Changing slicing conditions had no effect on the frequency of the defect. A validation phase in an industrial cutting plant showed that optimum surface cooling yielded 100% marketable pork chops after 4 days of storage, 95% at day 6 and 84% at day 8.
**Introduction**

To optimize their stability and visual appeal, controlled-atmosphere packaging has become the norm for industrial prepackaged meat products retailed in supermarkets. This packaging method is designed to oxygenate muscle myoglobin to give it an attractive color when being bought, and to add carbon dioxide to slow bacterial growth. The drawback of these gas mixtures is that they favor oxidation, in particular at the surface of bone marrow. After four days storage, retail distributors observe a highly adverse discoloration or darkening of bone. This discoloration of part of the product can deter purchasers. Bone darkening is due to the oxidation of the hemoglobin contained in the bone marrow. Deep freezing has been found to worsen this effect (Nicolalde et al. 2005 and 2006): the formation of crystals on rapid chilling (surface cooling step) may denature pigment molecules and spoil the color of the product. In addition, the solubility of oxygen in tissues such as bone marrow will be reduced at low temperatures, hindering the oxygenation of hemoglobin, which will turn from red to brown.

**Materials and methods**

Further to work done by IFIP in 2009 to investigate the origin of bone darkening, and identify the causative processes, our work carried out in 2014 sought technical and operational solutions that could be directly transposed to the meat industry.

After an initial survey phase addressing the main actors in the French pork butchery sector marketing pork chops, four surface cooling conditions were crossed with three slicing conditions in an experimental design. The experiments were conducted in two phases, the first at IFIP’s experimental unit at Romillé (Ille-et-Vilaine, Brittany) to determine the optimum surface cooling and slicing conditions, and the second (validation phase) in a real production setting in an industrial plant to validate the conditions identified in the first phase.

The meat products studied came from pigs slaughtered on D−2, cut up on D−1, and stiffened, sliced and packed on D0. All the chops studied were individually sealed (OPE 1000C / GUELT) under modified atmosphere (70% O₂ and 30% CO₂).

In the first experimental phase, four conditions of surface cooling were tested: 1 (control, −25 °C/45 minutes), 2 (−15 °C/1 h 15 min), 3 (−10 °C/1 h 45 min) and 4 (−5 °C/2 h). The surface cooling conditions were crossed with three slicing conditions: 1 (new micro-serrated LAN blade), 2 (new TOM blade), and 3 (worn TOM blade).

In the second experimental phase in industrial operation, three surface cooling conditions, control (−25 °C/45 minutes), −15 °C/1 h 15 min and −5 °C/2 h were crossed with a newly sharpened blade on a continuous-mode slicer.
Results and discussion

Study of surface cooling

Surface cooling is meant to make the loin stiffer to allow even slicing of chops and a clean cut. The recommendations of the TREIF Company (European meat cutting specialist) specify that the core of the loin to be cut should be close to 0 °C, and that the surface down to a depth of 15 mm should be between −2 °C and −3 °C. Chilling kinetics in the different surface cooling conditions were determined using temperature sensors placed in the ambient air, and on the surface and in the core of the loin (Photo 1). Two examples of stiffening conditions for bone-in loin are shown in Figure 1.

Table 1 gives the temperatures measured at the loin core and surface after surface cooling. According to the different scenarios applied, the temperature gradient between the core and the surface of the product ranged widely. We found that a gradual, mild chilling scenario generated a shallow temperature gradient between the core and the surface: 1.3 °C (−5 °C/2 h) against 9.5 °C for the control surface cooling (−25 °C/45 minutes). The coldest surface cooling scenario (−25 °C) caused the core temperature to drop to −8 °C; surface cooling at −10 °C and −5 °C left the meat surface at about −2 °C.

Table 1. Temperatures measured at the end of surface cooling

<table>
<thead>
<tr>
<th></th>
<th>-25°C 45 min</th>
<th>-15°C 1h15</th>
<th>-10°C 1h45</th>
<th>-5°C 2h</th>
</tr>
</thead>
<tbody>
<tr>
<td>T at loin core</td>
<td>1.5 °C</td>
<td>0.9 °C</td>
<td>-0.4 °C</td>
<td>-0.7 °C</td>
</tr>
<tr>
<td>T at loin surface</td>
<td>-8 °C</td>
<td>-3.9 °C</td>
<td>-2.2 °C</td>
<td>-2 °C</td>
</tr>
<tr>
<td>Surface core gradient</td>
<td>9.5 °C</td>
<td>4.8 °C</td>
<td>1.8 °C</td>
<td>1.3 °C</td>
</tr>
</tbody>
</table>

In the light of these measurements, we see that the scenarios at −10 °C and −5 °C came close to the temperature recommendations specified by the TREIF Company for optimum slicing. The scenario at −15 °C also came close to these values, but with a lower surface temperature of about −4 °C. The control scenario (−25 °C/45 minutes) generated core and surface temperatures far from those recommended for slicing, much lower at the surface and higher at the core.

The sensory evaluation of the bones was carried out by a panel of five persons from IFIP. This panel met periodically as shown in Table 2 to monitor the same packaged meat portions. As an illustration, the two photos below (Photos 3 & 4) show the changes over time in two packaged pork chops.

Comparison of the four surface cooling conditions (Table 2) reveals significant differences (p < 0.0001) on all the
Bone darkening: a study of surface cooling and slicing of pork loin

Observation days. Chi-squared tests carried out with SAS were also significant two by two except for D8 between surface cooling at −10 °C and at −15 °C. Consistent with our work of 2009, the more intense the surface cooling treatment, the sooner bone darkening appeared. The control surface cooling (−25 °C) generated 61% of noncompliant products at D6, whereas surface cooling at −5 °C generated only 2%. At D8, 84% of the controls were deemed noncompliant by the panel, while surface cooling at −5 °C generated 16% of rejects. Given that most buying is done from supermarket shelves between D4 and D6, surface cooling at −25 °C will generate more unsold products than mild or intermediate surface cooling. At D8 there was no statistically significant difference between products stiffened at −10 °C and at −15 °C.

Changes in bone color were measured with a chromameter. According to C.R. Raines et al. (2006) the ratio a*/b* can serve as a measure of discoloration. The variation of this ratio describes the darkening of the bones: the smaller the ratio, the greater the spoilage.

At D11, the ratio a*/b* was 1.09 for the control surface cooling (−25 °C) and 1.45 for the mildest surface cooling (−5 °C). This measure of discoloration was consistent with visual observations: the surface cooling at −25 °C lost 0.80 points between the day of packaging and the deadline of consumption (DLC), against 0.60 points for 2 hours at −5 °C. The time course of the ratio a*/b* confirmed the impact of the intensity of the cold treatment on bone darkening. The SAS Proc GLM procedure confirmed that there was a significant evolution (p < 0.0001) of the discoloration measure between D0 and the DLC for these surface cooling scenarios.

Study of slicing

As regards the effects of slicing conditions, no statistically significant effect covering the whole period of storage was observed by the panel or measured by the chromameter. The chi-squared test showed that at D6, slicing with blade 1 (new LAN) was different from slicing with blade 2 (new TOM) and blade 3 (worn TOM) for surface cooling at −25 °C (Figure 4). By contrast, at D11 the chi-squared test was no longer significant between the three slicing conditions with surface cooling at −25 °C. The chi-squared test also shows that at D6, the three slicing scenarios were different, whereas at D11 the test no longer showed any significant difference from surface cooling at −15 °C.
Bone darkening: a study of surface cooling and slicing of pork loin

Photos 3. Time course of a pork loin stiffened at −25 °C for 45 minutes and sliced with a new LAN blade

Photos 4. Time course of a pork loin stiffened at −5 °C for 2 h and sliced with a new TOM blade

Figure 4. Influence of cold-surface cooling and slicing at D6
The conclusion of this statistical treatment is that the type of blade and its sharpness did not affect the frequency of bone darkening defects. Whether the same blade was new or worn did not change the number of darkened bones in storage. However, the type of blade did affect the evenness and cleanness of the cut. The worn blade gave a less even slice, with chops of more variable thickness.

Validation of optimum conditions in industrial operation

In this second phase of our work, our purpose was to validate the optimum conditions of surface cooling found in the first phase. To specify a control surface cooling condition for comparison, the surface cooling at −25 °C for 45 minutes was kept. The mild surface cooling at −5 °C for 2 h was also selected as it was found best by all the panel members at all the storage dates. We added surface cooling at −15 °C for 1 h 15 min, because although it scored less highly than surface cooling at −10 °C for 1 h 45 min, it offered the advantage of greater speed and so promised a gain in production time.

During this work, surface cooling cycles were performed using a mechanical chilling cell used routinely in production. Chilling kinetics for the loins in the surface cooling conditions tested were obtained using temperature sensors placed in the ambient air, and at the surface and core of the meat. Surface cooling kinetics for bone-in loins are shown in Figure 5.

During the validation step for the slicing conditions in industrial operation, we used a continuous mode slicer with a freshly sharpened fully micro-serrated blade.

Comparison of temperatures after cryogenic and mechanical surface cooling showed that the products were colder at both core and surface with cryogenic chilling for an equivalent exposure time (Table 4). This suggests that the hemoglobin at the surface of the bone marrow was less strongly impacted with mechanical chilling.

By D6 the control surface cooling at −25 °C generated 54% of noncompliant products. By contrast, 82% and 95% of the products were compliant after surface cooling at −15 °C and −5 °C, respectively. The results obtained in industrial operation were thus in full agreement with those we obtained using a cryogenic chilling cell at IFIP.

Comparison of the three surface cooling conditions (Table 5) shows significant differences (p < 0.0001) on all the observation days. The chi-squared tests were also significant two by two except for Day 4 between surface cooling at −15 °C and at −5 °C and Day 11 between surface cooling at −25 °C and at −15 °C. The results obtained in industrial operation were thus in full agreement with those we obtained using a cryogenic chilling cell at IFIP.

The conclusion of this statistical treatment is that the type of blade and its sharpness did not affect the frequency of bone darkening defects. Whether the same blade was new or worn did not change the number of darkened bones in storage. However, the type of blade did affect the evenness and cleanness of the cut. The worn blade gave a less even slice, with chops of more variable thickness.

Validation of optimum conditions in industrial operation

In this second phase of our work, our purpose was to validate the optimum conditions of surface cooling found in the first phase. To specify a control surface cooling condition for comparison, the surface cooling at −25 °C for 45 minutes was kept. The mild surface cooling at −5 °C for 2 h was also selected as it was found best by all the panel members at all the storage dates. We added surface cooling at −15 °C for 1 h 15 min, because although it scored less highly than surface cooling at −10 °C for 1 h 45 min, it offered the advantage of greater speed and so promised a gain in production time.

During this work, surface cooling cycles were performed using a mechanical chilling cell used routinely in production. Chilling kinetics for the loins in the surface cooling conditions tested were obtained using temperature sensors placed in the ambient air, and at the surface and core of the meat. Surface cooling kinetics for bone-in loins are shown in Figure 5.

During the validation step for the slicing conditions in industrial operation, we used a continuous mode slicer with a freshly sharpened fully micro-serrated blade.
and −5 °C. Figure 6 shows the visible differences between the types of surface cooling during meat storage.

**Conclusion**

The findings of this study are in perfect agreement with our earlier results and are consistent with the literature.

We show that high intensity chilling applied to stiffen bone in pork loins favors the oxidation of hemoglobin present at the surface of the bone marrow. The formation of crystals during rapid chilling denatures pigment molecules, spoiling the color of the product. In addition, the solubility of oxygen in tissues such as bone marrow falls at low temperature, slowing the oxygenation of the hemoglobin, which turns from red to brown.

The observations of the expert panel were statistically confirmed by instrument measurements. The ratio $a^*/b^*$ was correlated with a faster degradation of bone color in chops cut from loins that were most intensely stiffened, compared with those from loins that had undergone the mildest surface cooling conditions.

The optimum surface cooling conditions found here were −5 °C for 2 h (Table 6).

This surface cooling procedure yielded loins with a surface temperature of −1.4 °C and a core temperature of −0.4 °C. Under these surface cooling conditions, the panel found that 95% and 84% of the final prepackaged chops were fit for sale at D6 and D8 respectively.

As regards slicing conditions, no statistically significant effect covering the whole storage period was observed by the panel or recorded instrumentally. The blade type and its sharpness affected the cleanness and evenness of slicing, but not the frequency of bone darkening.

**Table 6. Results after surface cooling in industrial operating conditions**

<table>
<thead>
<tr>
<th></th>
<th>-25°C</th>
<th>-15°C</th>
<th>-5°C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time</strong></td>
<td>45 min</td>
<td>1 h 15 min</td>
<td>2 h</td>
</tr>
<tr>
<td><strong>T at core</strong></td>
<td>−1.5 °C</td>
<td>0.8 °C</td>
<td>−0.4 °C</td>
</tr>
<tr>
<td><strong>T at surface</strong></td>
<td>−8 °C</td>
<td>−2.1 °C</td>
<td>−1.4 °C</td>
</tr>
<tr>
<td><strong>Gradient</strong></td>
<td>9.5 °C</td>
<td>2.9 °C</td>
<td>1.0 °C</td>
</tr>
<tr>
<td><strong>Percentage of products fit to sell on D4</strong></td>
<td>93%</td>
<td>99%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Percentage of products fit to sell on D6</strong></td>
<td>46%</td>
<td>82%</td>
<td>95%</td>
</tr>
<tr>
<td><strong>Percentage of products fit to sell on D8</strong></td>
<td>28%</td>
<td>47%</td>
<td>84%</td>
</tr>
<tr>
<td><strong>Percentage of products fit to sell on D11</strong></td>
<td>14%</td>
<td>13%</td>
<td>63%</td>
</tr>
</tbody>
</table>
Our results have been validated in industrial operating conditions, and so can be directly transposed to a butchery line. The conditions we specify should allow a significant reduction in the frequency of bone darkening in controlled-atmosphere packaged pork chops.

Acknowledgments

We thank FRANCEAGRIMER for funding this research, and the Companies TREIF, AIR LIQUIDE, GUELT, LINPAC, and FORM’PLAST for their help.

References

• Bieche C, Noircissement des os : évaluation des facteurs de risques chez le veau de boucherie. Compte rendu d'étude France Agrimer (juin 2012)

How to cite