Relationship between water mobility and distribution and sensory attributes in pork slaughtered at an age between 90 and 180 days

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Received 11 September 2006; received in revised form 26 February 2007; accepted 5 March 2007

Abstract

Water mobility and distribution were measured in M. longissimus dorsi from 41 pigs slaughtered at an age of 90, 140, 161 or 182 days using low-field proton NMR relaxometry, and in order to investigate the impact on sensory attributes, a sensory evaluation of the pork was performed in parallel. The sensory evaluation demonstrated a significant effect of slaughter age on juiciness of the meat, and a final juiciness score of 8.4, 7.7, 7.2 and 7.8 was obtained for meat from 90, 140, 161 and 182-day old pigs, respectively. The NMR measurements revealed that the higher juiciness in meat slaughtered at an age of 90 days could be ascribed to a longer relaxation time of the extramyofibrillar water, corresponding to more mobile water, in the fresh meat of 90-day old pigs compared with the older pigs. In the cooked meat the higher juiciness of meat from 90-day old animals could be ascribed to a more homogenous distribution of the myofibrillar water compared with meat from older pigs. In contrast, the NMR measurements showed no effects that could explain the higher juiciness in meat from pigs slaughtered at an age of 182 days compared with meat from pigs slaughtered at an age of 140 or 161 days. Possibly the increase in juiciness when the age at slaughter is increased from 161 to 182 days should be ascribed to an increase in intramuscular fat content, which was not evident in the NMR measurements.

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Keywords: Meat; Juiciness; NMR; T2 relaxation; Myofibrillar water; Heavy pigs; Slaughter age; Slaughter weight

1. Introduction

Pork quality is affected by several factors including genotype and slaughter conditions. While a live slaughter weight of approximately 100 kg is the standard in Danish pork production, production of so-called heavy pigs that are slaughtered around a live weight of 120 kg also takes place. Moreover, recently a niche production of piglets slaughtered at a live weight of around 30 kg has been introduced (Danish Crown, 2006). The effects of varying the slaughter live weight in the range between 100 and 160 kg on growth performance, carcass characteristics and meat quality traits have been investigated (Candek-Potokar, Zlender, Lefaucheur, & Bonneau, 1998; Correa et al., 2001, 2003; Bertram, Dønstrup, Karlsson, & Andersen, 2006; Fisher, Lindner, Judas, & Höreth, 2006; Latorre, Lázaro, Valencia, Medel, & Mateos, 2004; Monin et al., 1999), while studies of the effect of varying the slaughter weight between 70 and 100 kg are more rare (Beattie, Weatherup, Moss, & Walker, 1999). In relation to meat quality the most pronounced effect of slaughter weight reported in these studies was on colour attributes. However, a sensory evaluation also revealed a significant effect of slaughter weight on juiciness (Fisher et al., 2006). In addition, some of the studies have also reported effects of slaughter weight on the water content of the meat (Beattie et al., 1999; Candek-Potokar et al., 1998; Fisher et al., 2006). Nevertheless, there is limited knowledge of how slaughter weight affects water mobility and distribution in the meat, which are decisive for meat quality attributes related to water-holding capacity (WHC) (Bertram et al., 2001, 2003; Bertram, Dønstrup, Karlsson, & Andersen, 2006).
animals. The animals were anaesthetised with 80% CO₂ Foulum. The same slaughter procedure was used for all. distanced at the experimental abattoir at Research Centre of the last rib. WHC was determined using the bag method stored at /C0 for 3 days at 4°C. Sub-samples of 5 and 20 cm, which were vacuum-packed, was cut from each animal. This piece was divided into two dorsi starting from the last rib and in the posterior direction of the meat.

2. Materials and methods

2.1. Animals and sampling

The study included a total of 41 pigs. All animals were crossbreeds of Hampshire/Duroc boars crossed with Landrace/Yorkshire sows. Eight pigs were slaughtered at an age of 90 days, 12 pigs were slaughtered at an age of 140 days, 12 pigs were slaughtered at an age of 161 days, while the remaining nine pigs were slaughtered at an age of 182 days; the minimum, maximum and mean live weights for the different ages are reported in Table 1. All pigs were slaughtered at the experimental abattoir at Research Centre Foulum. The same slaughter procedure was used for all animals. The animals were anaesthetised with 80% CO₂ for 3 min. After cutting and exsanguinations, the animals were scalced at 62 °C for 3 min.

Twenty-four hour postmortem, 25 cm of M. longissimus dorsi starting from the last rib and in the posterior direction was cut from each animal. This piece was divided into two sub-samples of 5 and 20 cm, which were vacuum-packed, stored for 3 days at 4 °C and subsequently frozen and stored at −20 °C until NMR and sensory analyses, respectively.

WHC and pH was determined on the contra lateral muscle of the meat. The NMR relaxation measurements were performed on a Maran Benchtop Pulsed NMR Analyzer (Resonance Instruments, Witney, UK) with a resonance frequency for protons of 23.2 MHz. The NMR instrument was equipped with an 18 mm variable temperature probe. Prior to measurements the 5-cm samples were thawed overnight at 4 °C. From each 5-cm sample, two sub-samples (approximately 4 cm along the fibre direction and 1 × 1 cm in cross-sectional area) were cut, weighed (weight 1) and placed in cylindrical glass tubes for the NMR measurements. The samples were tempered in a 25 °C water bath for 15–20 min prior to measurement. Transverse relaxation (T₂) was measured at 25 °C using the Carr–Purcell–Meiboom–Gill sequence (CPMG), and measurements were performed with a T-value (time between 90° pulse and 180° pulse) of 150 μs using a repetition delay of 3 s, and data were acquired as the amplitude of every second echo (to avoid influence of imperfect pulse settings) in a train of 4096 echoes as an average of 16 repetitions. After T₂ relaxation measurements on the fresh samples, the samples were cooked in a water bath at 68 °C for 20 min, subsequently tempered in a 25 °C water bath, lightly dabbed and weighed (weight 2), and the T₂ relaxation measurements were repeated. Cooking losses were calculated from weights 1 and 2.

The obtained T₂ relaxation decays were analysed using distributed exponential fitting analysis (Menon, Rusinko, & Allen, 1991) by means of in-house-made scripts in Matlab.

2.3. Sensory analysis

A trained sensory panel of eight assessors was used. All assessors came from the area around Roskilde and were familiar with pork assessments. They had all received a basic training in sensory assessments in accordance with ISO 4121, ASTM-MNL 13, DIN 10964. The sensory analysis was conducted as four sessions with 10–11 samples per session. At session 1, two loins of 90-day old pigs and three loins of each of the others age groups were analysed. At sessions 2, 3 and 4, two loins of 90 and 180 days, respectively, and three loins of the other two groups were analysed. The meat was sliced in 2 cm chops and fried on a frying pan at 155 °C until an end point temperature of 68 °C measured with a thermometer with a handheld probe (Testo 926, Testoterme, Buhl and Bundsoe, Virum, Denmark) was reached. The chops were turned every 2 min during frying.

Table 1

<table>
<thead>
<tr>
<th>Live weight (kg)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 days (n = 8)</td>
<td>38.6</td>
<td>54.3</td>
<td>45.3</td>
</tr>
<tr>
<td>140 days (n = 12)</td>
<td>82.1</td>
<td>112.4</td>
<td>96.5</td>
</tr>
<tr>
<td>161 days (n = 12)</td>
<td>77.7</td>
<td>152.7</td>
<td>120.9</td>
</tr>
<tr>
<td>182 days (n = 9)</td>
<td>114.8</td>
<td>157.0</td>
<td>145.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Carcass weight (kg)</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 days (n = 8)</td>
<td>26.8</td>
<td>42.2</td>
<td>33.7</td>
</tr>
<tr>
<td>140 days (n = 12)</td>
<td>62.2</td>
<td>91.0</td>
<td>76.3</td>
</tr>
<tr>
<td>161 days (n = 12)</td>
<td>58.2</td>
<td>125.2</td>
<td>97.0</td>
</tr>
<tr>
<td>182 days (n = 9)</td>
<td>87.8</td>
<td>127.0</td>
<td>116.9</td>
</tr>
</tbody>
</table>
After frying the meat was cut into strips of 11/2 cm × 4 cm and served for the assessors on preheated plates with a three digit random number. The meat samples were presented under Northern daylight, and the following attributes were assessed on an unstructured 15 cm line ranging from no (0) to very high intensity (15 cm): Juiciness after 5 chews (juiciness 1), juiciness after 10 chews (juiciness 2), juiciness after 20 chews (juiciness 3), hardness at first bite, and tenderness.

2.4. Statistics

Statistics were performed using the SAS system 8.2 (SAS Institute, Gary, NC, USA). The statistical models included the fixed effect of slaughter age. Moreover, for sensory data the effects of assessor and the interaction between assessor and slaughter age were included as random effects.

On distributed NMR $T_2$ relaxation data principal component analysis (PCA) was applied to the centered data to explore any clustering behaviour of the samples using the Unscrambler software (CAMO, Norway) (version 9.2). Partial least square regressions were carried out to explore the relationship between distributed NMR $T_2$ relaxation data and sensory data. During all regressions, Martens uncertainty test (Martens & Dardenne, 1998) was used to eliminate noisy variables, and all models were validated using full cross-validation (Martens & Martens, 2000).

3. Results

3.1. pH, WHC and cooking loss

Table 2 shows pH$_{24h}$, drip loss and cooking loss for the four different slaughter ages. No significant effect of slaughter age on pH$_{24h}$ was observed. Although not significantly, a clear tendency for an increase in drip loss with increasing slaughter age from 90 to 161 days was observed. In addition, a decrease in cooking loss was observed with increasing slaughter age.

3.2. NMR

Fig. 1a and b displays the score plots from a principal component analysis carried out on the distributed NMR data obtained on fresh and cooked meat, respectively. For both fresh and cooked meat a tendency for clustering according to slaughter age is observed, however, the effect is most evident for samples from 90-day old pigs. The average distributed $T_2$ relaxation times measured in fresh and cooked pork are shown in Fig. 2a and b, respectively. In the fresh meat three $T_2$ populations with relaxation times around 1–5, 30–100 and 100–800 ms are observed, the major population being the one around 30–100 ms (Fig. 2a). A pronounced effect of slaughter age on the slowest population at 100–800 ms is observed. In meat from pigs slaughtered at an age of 140–182 days, the slowest population is located with a maximum around 200–250 ms, while in meat from the pigs slaughtered at an age of 90 days, the maximum of this population is located at a much higher value (~400 ms). In the cooked meat mainly two $T_2$ populations are observed; a minor component at around 1–5 ms together with a major, broad component around 10–200 ms (Fig. 2b). A pronounced effect of

<table>
<thead>
<tr>
<th>pH$_{24h}$ (P-value)</th>
<th>Drip loss (%)</th>
<th>Cooking loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.61 (0.03)</td>
<td>6.0 (1.1)</td>
<td>25.0 (1.2)</td>
</tr>
<tr>
<td>5.58 (0.02)</td>
<td>7.2 (0.9)</td>
<td>23.5 (0.9)</td>
</tr>
<tr>
<td>5.55 (0.02)</td>
<td>8.8 (0.9)</td>
<td>24.3 (0.9)</td>
</tr>
<tr>
<td>5.59 (0.03)</td>
<td>8.1 (1.1)</td>
<td>21.6 (1.0)</td>
</tr>
</tbody>
</table>

LS Mean values are given. Standard errors are given in parentheses.
slaughter age on the characteristics of the major population is observed in the cooked meat, as the population is more symmetrical in meat from 90-day old pigs. In cooked meat from 140–182-day old pigs the major population is asymmetrical and consists of two sub-peaks.

3.3. Sensory analyses

Results from the sensory evaluation are shown in Table 3. Significant effects of slaughter age were found for all juiciness assessments and hardness. For juiciness assessments the highest score was always obtained for meat from pigs slaughtered at an age of 90 days. A decrease in juiciness was observed with increasing slaughter age up to 161 days, however, at an age of 182 days the juiciness increased again. The lowest hardness score was observed in meat from pigs slaughtered at an age of 182 days, while the highest hardness score was observed in meat from pigs slaughtered at an age of 140 days. Tenderness increased with increasing slaughter age.

3.4. Relationship between sensory and NMR data

In order to elucidate the relationship between water distribution determined by NMR and sensory attributes of the meat, PLS2 regressions were carried out with NMR variables as X-variables and sensory attributes as Y-variables, and Fig. 3a and b shows the obtained correlation loading plots for fresh and cooked meat, respectively. Only significant NMR variables, which were identified by jack-

Table 3

Results from sensory analyses of the meat

<table>
<thead>
<tr>
<th></th>
<th>90 days</th>
<th>140 days</th>
<th>161 days</th>
<th>182 days</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juiciness 1</td>
<td>7.15a</td>
<td>6.79b</td>
<td>6.29c</td>
<td>6.75ab</td>
<td>0.01</td>
</tr>
<tr>
<td>Juiciness 2</td>
<td>7.98a</td>
<td>7.51b</td>
<td>7.01ab</td>
<td>7.46a</td>
<td>0.009</td>
</tr>
<tr>
<td>Juiciness 3</td>
<td>8.40a</td>
<td>7.72b</td>
<td>7.15c</td>
<td>7.83ab</td>
<td>0.003</td>
</tr>
<tr>
<td>Hardness</td>
<td>5.19ab</td>
<td>5.66b</td>
<td>5.33a</td>
<td>4.62b</td>
<td>0.04</td>
</tr>
<tr>
<td>Tenderness</td>
<td>8.95</td>
<td>9.12</td>
<td>9.00</td>
<td>9.78</td>
<td>0.12</td>
</tr>
</tbody>
</table>

LS Mean values are given. Standard errors are given in parentheses. Letters indicate significant differences within rows.

Fig. 3. Correlation loading plot (1st and 2nd PLS component) of PLSR2 with NMR variables as X and sensory attributes as Y. Significant NMR variables identified by jack-knifing are shown. (a) Fresh meat, the validated explained variances are 77%/5% for X and 12%/6% for Y. (b) Cooked meat, the validated explained variances are 80%/6% for X and 11%/7% for Y.
knifing, are shown. In fresh meat positive correlations between relaxation times of 4–6 ms, 48–100 ms and 1465–1680 ms and juiciness as well as tenderness are observed, while hardness is correlated with relaxation times of 21–32 ms (Fig. 3a). In cooked meat a positive correlation is observed between relaxation times of 25–50 ms and the sensory attributes juiciness and tenderness (Fig. 3b). Relaxation times of 11–16 ms are negatively correlated with juiciness/tenderness and positively correlated with hardness.

4. Discussion

One of the most important quality attributes of pork is juiciness. The perceived juiciness of the meat is believed to be linked to the water in the meat, and studies have shown a correlation between cooking loss and juiciness (Bejerholm & Aaslyng, 2003; Bouton, Ford, Harris, & Ratcliff, 1975; Serra et al., 2004; Wood, Nute, Fursey, & Cuthbertson, 1995), which could indicate a simple relationship between water content and juiciness. However, it has also been shown that cooking loss alone cannot explain the entire variation observed in juiciness (Toscas, Shaw, & Beilken, 1999), and it has been hypothesised that the biochemical–biophysical state of the water in the meat, i.e. water mobility and distribution, plays a major role for the juiciness of the meat (Trout, 1988). Proton NMR relaxation studies, which enables us to study the intrinsic properties of the water in meat, have demonstrated an association between water mobility and distribution and the sensation of pork juiciness (Bertram et al., 2005; Bertram & Aaslyng, in press; Fjelkner-Modig & Tornberg, 1986). In the present study we investigated how differences in juiciness as a function of slaughter age could be ascribed to differences in water mobility and distribution. NMR T2 data revealed pronounced effects of slaughter age on water mobility and distribution in the muscles, which is in agreement with a previous study (Bertram et al., 2002). A sensory evaluation of pork from pigs slaughtered at an age of either 90, 140, 161 or 182 days revealed a significant effect of slaughter age on juiciness, as juiciness increased with decreasing age from 161 to 90 days, while this was not displayed in the distributed T2 relaxation times. The increase in juiciness with the increase in age should possibly be ascribed to an increase in intramuscular fat. Intramuscular fat has a T2 relaxation time around 60 ms (Laurent, Bonny, & Renou, 2000). However, considering the low amount of intramuscular fat present in M. longissimus dorsi, the contribution from this component to the distributed T2 relaxation time can be expected to be negligible, which explains that the increase in juiciness from 161 to 182 days is not evident in the distributed proton NMR T2 relaxation times.

5. Conclusion

In conclusion, the present study demonstrated a relationship between water mobility and distribution in pork and the sensation of meat juiciness. A higher juiciness score in meat from pigs slaughtered at an age of 90 days could be ascribed to a longer relaxation time of the extramyofibrillar water, corresponding to more mobile water, in the fresh meat of 90-day old pigs compared with pigs slaughtered at an age between 140 and 180 days. In the cooked meat the higher juiciness of meat from 90-day old animals could be ascribed to a more homogenous distribution of the myofibrillar water compared with meat from older pigs.

Acknowledgement

The authors thank The Danish Ministry of Food, Agriculture and Fisheries for funding the project entitled “Characterisation of technological and sensory quality in foods”.
References


