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Development in myofibrillar water distribution of two pork qualities during 10-month freezer storage

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Abstract

The effects of fresh meat quality (PSE versus DFD), freezing temperature (−20 °C versus −80 C°) and duration of freezer storage on changes in water mobility and distribution were followed at intervals of 1–2 months during 10-month freezer storage of pork using low-field NMR T_2 relaxometry. Fresh meat quality was found to have a strong significant effect ($P < 0.0001$) on the amount of loosely bound water (relaxation time >100 ms) also after freezing, which was reflected in a significantly lower cooking yield in PSE meat compared with DFD meat ($P < 0.0001$). While no significant changes in the cooking yield were observed with increasing length of freezer storage, NMR T_2 relaxation measurements revealed a significant increase in the amount of loosely bound water in PSE meat with increasing length of freezer storage. This finding indicates that NMR T_2 relaxation measurements are quite sensitive to freezing-induced changes in the meat structure, causing a shift in the distribution of water and possibly capable of detecting these before they are reflected in a reduced cooking yield. In addition, an interaction between fresh meat quality and effect of length of freezer storage on the amount of very mobile water easily lost as drip was observed, implying that PSE meat is more susceptible to freezer storage-induced deteriorative changes in the meat structure, causing a shift in the distribution of water, than DFD meat.

Keywords: NMR; T_2 relaxation; Water distribution; Freezing rate; Functional properties; PSE; DFD

1. Introduction

Freezer storage is often applied in the meat industry to prolong the storage life of meat. Accordingly, a thorough understanding of the physical and chemical changes induced by freezer storage and their relation to fresh meat is of utmost importance for the meat industry. Several studies have investigated the effect of duration of freezer storage on meat functionality, and decreases in protein solubility (Awad, Powrie, & Fennema, 1968; Farouk, Wieliczko, & Merts, 2003; Yano, Tanaka, Suzuki, & Kanzaki, 2002) and in myofibrillar ATPase activity (Wagner & Añon, 1986) of beef have been reported with increasing freezer storage. In addition, a marked reduction in the water-binding capacity of manufactured pork with increasing length of freezer storage has been reported (Puolanne & Turkki, 1985). However, using differential scanning calorimetry (DSC) to study protein denaturation in pork as a function of duration of freezer storage, contradictory results have been obtained (Mietsch, Halász, & Farkas, 1994; Ngapo, Barbare, Reynolds, & Mawson, 1999). While Mietsch et al. (1994) found a decrease in the myosin peak of pork during a 6-month freezer-storage period, Ngapo et al. (1999) found no differences in the DSC profile of fresh pork and pork freezer-stored for 4 weeks. Accordingly, presently the mechanisms responsible for the observed changes in functionality as a result of freezer storage are limited understood.

A high pH of beef has been found to improve the technological properties and functionality of beef upon freezing and thawing compared with normal pH (Swan & Boles,

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2002; Zhang, Farouk, Young, Wieliczko, & Podmore, 2005), and in pork interactions between fresh meat quality and freezing method on the sensory quality of frozen–thawed meat have been reported (Kondratowicz, Bak, & Denaburski, 2000). Moreover, the microstructure and water characteristics in long-term freezer-stored pork were recently found to depend on fresh meat quality, as structural damage and homogeneity in the distribution of myofibrillar water was less affected by freezer-storage in pork with high pH compared with pork with normal pH (Mortensen, Andersen, Engelsen, & Bertram, 2006). However, in general the understanding of the interaction between fresh meat quality and changes in water properties during frozen storage is poor.

Proton NMR relaxometry facilitates a characterisation of water mobility and distribution of importance for characterisation of WHC in both fresh (Bertram, Andersen, & Karlsson, 2001a; Bertram et al., 2001b; Bertram, Dønstrup, Karlsson, & Andersen, 2002; Brøndum et al., 2000; Brown et al., 2000; Renou, Monin, & Sellier, 1985; Tornberg, Andersson, Göransson, & von Seth, 1993) and cured pork (Andersen, Andersen, & Bertram, 2006). In addition, proton NMR relaxometry has proven successful in characterising water properties in frozen–thawed meat even though only a few studies are reported (Mortensen et al., 2006; Yano et al., 2002). Consequently, in the present study proton NMR relaxometry was included to contribute to a more basic understanding of the interaction between fresh meat quality characteristics (pale, soft and exudative (PSE); dark, firm and dry (DFD)), freezing temperature (−80 °C and −20 °C) and length of freezer-storage period (between 1 and 10 months storage at −20 °C) on water mobility and distribution.

2. Materials and methods

2.1. Fresh meat qualities

To obtain well-defined meat samples of two extreme meat qualities two pigs (littermates) were treated as described below and used in the present study. Before slaughter one pig was subjected to treadmill-exercise (3.8 km/h) for 20 min immediately prior to electrical stunning in order to induce pre-slaughter stress and accelerate postmortem glycolysis as described by Henckel, Karlsson, Oksbjerg, and Petersen (2000), and the other pig was administered adrenaline (subcutaneous injection, 0.1 mg/kg live weight) 16 h before slaughter to increase the final pH of the meat as described previously (Henckel et al., 2000), and exposed to CO_2-stunning (80% CO_2 for 3 min) prior to slaughter. After stunning, the animals were exsanguinated and scalded at 62 °C for 3 min. Cleaning and evisceration of the carcasses were completed within 30 min *postmortem*. The carcasses were split and kept at 12 °C. Within 2–6 h *postmortem* the carcasses were transferred to a chill room, where they were stored at 4 °C. In 24 h *postmortem*, the left *M. longissimus* was excised from each carcass. These pre-slaughter treatments resulted in two extreme pork qualities, as presented in Table 1, and were designated pale soft and exudative (PSE), and dark firm and dry (DFD), respectively.

Table 1
Ultimate pH and drip loss for the two meat qualities

	PSE	DFD
pH anterior end	5.5	6.6
pH posterior end	5.5	6.6
Drip loss (%)	12.1	1.0

2.2. Determination of pH and water-holding capacity (WHC)

pH was measured in the anterior and posterior end of *M. longissimus* with a pH-meter (Metrohm AG CH 9101 Herisau, Switzerland). pH calibration temperature was 4 °C. A two-point calibration was carried out, and the pH of the calibration buffers used was 7.000 and 4.005 pH at 25 °C (Radiometer, Copenhagen, Denmark).

Measurement of water-holding capacity (WHC) was performed using the Honikel bag method (Honikel, 1998). In the anterior and posterior end of *M. longissimus* a slice was excised, trimmed and weighed (∼100 g) in 24 h postmortem. Thereafter, the sample was placed in a net and hung inside an inflated plastic bag for 48 h at 4 °C, after which the sample was weighed again. Drip loss was determined as the percentage difference between weight before and after hanging, and WHC was expressed as % drip loss.

2.3. Sampling and freezing

From the posterior end of *M. longissimus* 10 chops of 5 cm were cut out. From each chop 10 sub-samples with a size of approximately $1 \times 1 \times 4$ cm were cut parallel to muscle fibres and weighed (weight1), resulting in a total of 100 samples from each animal. The samples from the first chop were numbered 1–10; samples from the second chop were numbered 11–20 and so on (see Table 2). Odd numbered samples were frozen at −20 °C and even numbered samples were frozen at −80 °C for 24 h before they were moved to the freezer at temperature of −20 °C. After 1, 2, 4, 5, 6, 7, 8, 9 and 10 months of freezer storage a total of 20 samples, 10 from each meat quality, were thawed and analysed by low-field NMR according to the time schedule (Table 2). Five samples at the time were thawed in a water bath (5 °C) for 1 h. After thawing the samples were tempered in a water bath (25 °C) for 20 min, NMR T_2 relaxation was measured on the samples.

After NMR measurements the samples were heated in a water bath (70 °C) for 15 min, then tempered in a water bath (25 °C) for 20 min before they were dabbed dry and weighed (weight2).