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The potential for predicting purge in packaged meat using low field NMR

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ABSTRACT

The ability of NMR to predict purge from vacuum-packed pork that was stored for 9 days was investigated. T_2 relaxation was measured at 24 h post mortem (*p.m.*) and again after 9 days of chilled storage. NMR measurements from day 1 *p.m.* were limited in predicting day-9 purge ($|r| = 0.37–0.52$). The root mean square error of linear regression (RMSD) for measuring day-9 purge using the relaxation time of intra-myofibrillar water (T_{21}) measured on day 1 *p.m.* ($r = -0.46$) was 1.31% (range: 1.15–7.69% purge), corresponding to ±2.62% (2 × RMSD) prediction error of purge with 95% probability. This indicated that for purge production rate, the distribution and mobility of water in meat on day 1 *p.m.* may be of little relevance. Further tests were conducted to explain this poor predictability, by taking NMR measurements of water mobility and distribution made on the same meat sample (taken at 96 h *p.m.*) every day, during a 9-day storage period. By analyzing the T_{21} and T_{22} domains every day, it was revealed that during the first 5-day of storage, water (86%) moved from intra-myofibrillar space to extra-myofibrillar space. However, this movement did not result in detectable drip. A major liquid loss followed between days 6 and 7 and ceased day 8. This complexity of the water movement between domains during storage may explain the poor predictability of day-9 purge using NMR measurements from day 1.

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1. Introduction

The drip loss of meat during chilled storage depends on the amount of water that is available and the ease with which the water can exit the muscle structural network (Warner, 2014). The drip loss of meat is influenced by four major structural factors: 1) the degree of myofibrils shrinkage during rigor and myofibrillar inter-filamentous spacing; 2) the permeability of the cell membrane to water; 3) the degree of cytoskeletal protein degradation and 4) the development of drip channels and extracellular space (Hughes et al., 2014). Water holding capacity (WHC) is very often measured as drip loss; i.e. the weight loss percentage of a meat sample after a defined period of chilled storage (24 or 48 h) in specifically designed holder (Christensen, 2003) or in a plastic bag (Honikel, 1998), where the meat has no physical contact with drip. Purge, in this paper, refers to the weight loss from meat during storage, where the meat is in contact with the fluid. Purge is the accumulation of a red aqueous solution of proteins in packaged, refrigerated meat and relates to what would be visible to a consumer. Drip loss and purge are important variables relating to profitability and quality of meat products and are highly relevant to both meat industry and consumers. However, these two variables have been reported to be controlled by different processes. Drip loss shows the WHC of meat at certain time post mortem; whereas purge is likely to be the accumulative effect of changes in WHC during storage. Several experiments have recorded a change in drip loss from 24 h *p.m.* up to 14 days p. m (Joo et al., 1999; Kristensen and Purslow, 2001; Moeseke and Smet, 1999; Straadt et al., 2007). using different methods (48 h Honikel bag method or 24 h centrifugation). In general, the measured drip loss (%) peaked at around 48 h post mortem and subsequently decreased. The daily drip loss post mortem seems to be animal/sample dependent. For instance, in the work of Kristensen and Purslow (2001), the average

Abbreviations: CPMG, Carr-Purcel-Meiboom-Gill; LD, *longissimus dorsi*; *p.m.*, post mortem; PSE, Pale Soft Exudative; WHC, water holding capacity.

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centrifugation loss of 6 muscles reached its maximum on day 7 *p.m.*, whereas the average centrifugation loss of 4 other muscles in the same work reached its maximum on day 3 *p.m.*

There exist two explanations regarding the decrease in rate of drip loss (increase in WHC) in meat that is stored in contact with its own drip:

1) The reduction in drip loss with sampling time post mortem is a result of "leaking out", i.e. the meat with poor WHC (i.e. pale soft exudative meat, PSE) will lose relatively more water early postmortem (Joo et al., 1999; Moeseke and Smet, 1999). This leaves limited water available for dripping in later stages. Meat with a normal WHC has relatively more water to lose in later stages and this water serves as a "drip reservoir" that will eventually produce similar amount of drip as meat with poorer WHC (Joo et al., 1999).
2) Degradation of cytoskeleton proteins can result in an increase of WHC later post mortem (Huff-Lonergan and Lonergan, 2005; Kristensen and Purslow, 2001; Melody et al., 2004; Straadt et al., 2007). Cytoskeleton proteins (represented by vinculin, desmin and talin) gradually degrade during 10-day *p.m.* storage period (Kristensen and Purslow, 2001). The inter-myofibrillar linkages and costameric connections are removed, and myofibril shrinkage becomes energetically less favorable. The flow of water into the extracellular space ceases, and previously expelled water can to some degree reverse, and support swelling of the myofibrils. The intramyofibrillar structure has been shown to be more homogeneous after 14 days of storage using a confocal laser scanning microscopy, which supported this hypothesis (Straadt et al., 2007).

There have been very few articles investigating the prediction of purge using data obtained early post mortem (Bidner et al., 2004; Calkins et al., 2005; Huff-Lonergan and Lonergan, 2005). As summarized by Huff-Lonergan and Lonergan (2005), one study have studied using the desmin degradation on day 1 *p.m.* to predict purge loss over 7 days using stepwise regression models. It was found that desmin degradation accounted for only 24.1% variation of purge. Similarly, another study also showed poor prediction of purge using several measurements (21% variation explained), which aimed at predicting 21-day purge in vacuum packaged whole pork loins using models based on variables measured early *p.m.* (including season, fat depth, muscle depth, hot carcass weight, color, pH and electrical impedance) (Calkins et al., 2005). It seems, therefore, that purge is challenging to predict due to the complexity of purge production process. Zarate and Zaritzky (1985) studied the effect of storage conditions on purge production in the package along storage time (until 22-day storage) in packaged refrigerated beef (cut at 48 h *p.m.*). Two temperatures (0 and 4 °C) and two films (low density polyethylene and EVA/SARAN/EVA coextruded film) were studied and compared. During the first 24-h storage (induction period), the purge (%) increased nonlinearly, and then the increase followed a reduced but constant rate. Similar results have been reported by Moeseke and Smet (1999) that the dripping rate decreased after 48 h post mortem. In addition, purge percentage was found to be linearly correlated to the equivalent area/unit volume ratio of the sample (Zarate and Zaritzky, 1985). Their work also suggested that the water that turned into purge during storage was located extracellularly and extramyofibrillarly, and the purge was mainly produced by gravitational force since the purge (%) rate is constant after induction time (Zarate and Zaritzky, 1985). They also refuted that diffusion is to explain the purge production, since a decreasing rate should be expected (Zarate and Zaritzky, 1985).

Since WHC increases with storage time, the WHC difference between meat with high or low initial WHC might decrease significantly towards later storage period, as shown in the study using meat with four different quality groups (Joo et al., 1999). However, the results showed that the meat with initial lower WHC (i.e. PSE) still had lower WHC on day 6 *p.m.* than meat that had a higher initial WHC. It is then reasonable to suggest that the accumulated purge of meat having an initial low WHC might be relatively high. This change in drip loss rate with time might make purge prediction difficult and demand methods with high and relevant analytical precision.

NMR is a powerful tool to study water mobility and distribution, and has been used extensively in studying meat structure and WHC. However, to the best of our knowledge, no studies have addressed the possibility of using NMR to measure purge. In this paper, we explored the ability of low field NMR and other measurements/variables obtained at or before 24 h *p.m.* to predict purge from pork muscle after vacuum-packed storage for 9 days. The 9-day storage period was chosen because it is the average storage time used for fresh meat cuts before displayed in retail stores according to Norwegian meat industry. The correlation between purge and variables obtained on samples after 9-day storage was also studied in order to: 1) determine the predictability of purge on day 9 from NMR measurements on day 1; 2) understand the purge production mechanism during the same number of days.

To support 1) and 2) the measurement error of the NMR instrumentation also needed to be verified to determine if NMR can measure a difference in water content between 80% and 75% water.

2. Materials and methods

2.1. Animals and sampling

In order to obtain meat samples with reasonable WHC variation, 18 pigs were selected from 2 different slaughterhouses (Tønsberg and Oslo, Norway) based on their meat percentage/back fat thickness during three weeks. The chilling rate affects drip loss and this can vary due to the meat percentage/back fat thickness. The animals were, therefore, selected to give variation in fat thickness and two different chilling methods were carried out in the two slaughterhouses. The pigs used had carcass weights between 56.1 and 100.1 kg. Breeds used were LYDD (25% Landrace, 25% Yorkshire and 50% Duroc) and LYLL (25% Yorkshire and 75% Landrace). The pigs were stunned in an atmosphere with 90% carbon dioxide and slaughtered. At Tønsberg slaughterhouse, the carcasses were cooled for 30 min in the shock-cooler/freezer and then chilled down to 7 °C for 18 h. At Oslo slaughterhouse, the carcasses were cooled for 18–20 h to below 7 °C, in a cooling room at 0–1 °C. The left porcine *longissimus dorsi* (LD) muscles were removed. Connective tissue and fat were carefully trimmed around the muscle.

The LD muscle from each animal was divided into two sections based on location (denoted L1 and L2, Fig. 1a) with some space discarded between L1 and L2 (shown in grey, Fig. 1a). The samples were treated as separate samples since a difference of WHC (as drip) has been reported between cranial and caudal ends (Taylor and Dant, 1971). For each location (L1 or L2), the muscle was divided as shown in Fig. 1b on day 1 *p.m.*

In the study of the effect of storage time (Section 3.3), six boars from Landrace and Duroc breed were randomly selected. The LD loins were cut at 96 h *p.m.* One sample was taken from each animal, resulting in a total number of six meat samples.

2.2. Purge measurement

On day 1 p. m., a chop of 12 cm in thickness (for L1 and L2 each) towards cranial end was divided, weighed (M_0, of 348.21–860.55 g)

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