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Analysis of salt penetration enhancement in meat tissue by mechanical treatment using a tumbling simulator

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ABSTRACT

Brining–tumbling is a key step in cured and/or cooked meat product manufacture. The massaging of meat enhances NaCl homogenization which, in combination with mechanical action, enhances protein solubilization. To clarify the underlying mechanisms and quantify their effects, meat tissue from *Semimembranosus* pork muscles was tested under various brining conditions: static brining (a), static brining after massaging (b), and brining–massaging (c). Using trials performed on a lab-scale tumbling simulator, massaging was controlled and characterized by three mechanical indexes. Apparent NaCl diffusivities (D_{salt}) were estimated from measured NaCl profiles using Fick's diffusion theory. It was demonstrated that tissue damage is not the main factor explaining salt migration enhancement: a-*vs*-b comparison showed a 20% increase in D_{salt}, which was explained by observed microstructural changes. a-*vs*-c comparison showed a 200% increase in D_{salt}, possibly due to water movement promoted by meat deformation. Calculations were used to compare spatial distributions of NaCl within small meat cubes during static brining *versus* brining–tumbling.

1. Introduction

Sodium chloride (NaCl) is the main ingredient used in meat curing technologies. It acts as a preservative, improves technological yields, and impacts meat tissue properties such as water-holding capacity and protein solubilization that, in turn, determine processed meat texture. In the manufacture of cooked meat products, curing is widely complemented with tumbling in rotating drums, which is known to improve the meat-product properties (Martin, 2012). Tumbling is generally done under vacuum to prevent protein and lipid oxidation. For larger meat pieces, a high-concentration brine is injected into the meat at a rate of about 10% w/w using needles spaced at around 2–3 cm apart. For smaller meat pieces, the brine is simply placed in the tumbler drum at the beginning of fabrication. In all cases, salt content homogenization is a key phenomenon, since local NaCl content is a determinant factor for protein solubilization and water holding capacity (Offer and Knight, 1988).

On top of the above differences in brine–meat contact, many technological process parameters also influence the final product features, such as animal species, complementary additives to NaCl like nitrite, tumbler diameter, rotational speed, tumbling time and whether or not an intermittent regime is used. Studies carried out with pilot tumblers and reviewed by Siro et al. (2009), Bombrun et al. (2014, 2015) and Daudin et al. (2015) show that tumbling (i) improves water-holding capacity and texture compared to static brining and (ii) is necessary to produce a protein-containing exudate that determines piece-to-piece adhesion after cooking and thus end-product sliceability. However, the spatial distribution of NaCl content varies along tumbling but is rarely effectively known. The upshot is that the respective effects of mechanical action and local NaCl content cannot be separated in pilot tumbler studies.

NaCl diffusion in meat has been extensively studied in immersion-brining with or without other additives. Recent papers provide data on apparent NaCl diffusivity (D_{salt}) according to meat tissue characteristics, offering a frame of comparison against older studies (Pinotti et al., 2002; Vestergaard et al., 2004, 2005; Graiver et al., 2006; Hansen et al., 2008; Villacis et al., 2008; Lebert and Daudin, 2014). However, data on tumbling remains scarce. Solomon et al. (1980) compared NaCl penetration by continuous or intermittent tumbling in 3 major ham muscles using an industrial tumbler. The results showed that salt homogenization is far from achieved after 24 h, but D_{salt} was not calculated from the spatial distributions of measured NaCl content. To our knowledge, Siro et al. (2009) is the only paper that has assessed D_{salt} when immersion-brining is assisted by a mechanical (tumbling or ultrasonic) treatment. The authors showed that the

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constant diffusion coefficient model is able to describe the time–course increase in mean NaCl content in samples of pork loin, and that D_{salt} increases exponentially as a function of ultrasonic intensity. They also claim tumbling is the most efficient way to speed up salt homogenization, but the mechanical action could not be characterized since they used a pilot tumbler.

Our aim here was to quantify the impact of the mechanical action on NaCl homogenization speed in meat tissue. Massaging was kept controlled using a new lab-scale tumbling simulator (described in detail in Daudin et al., 2015).

Many terms are used in meat technology to define the type of brining process. In this paper, 'static brining' means brining meat tissue by putting the sample surface in contact with brine without mechanical action and 'brining–massaging' means that a controlled mechanical action is applied to the sample in addition to 'static brining'.

The concept of apparent diffusivity was used as a comparison index since it can be calculated from NaCl profiles in meat tissue using a well-accepted theory, even if the underlying mechanisms that promotes NaCl transport is not strictly diffusion.

2. Materials and methods

2.1. Samples and physicochemical analysis

All tests used *Semimembranosus* (SM) pork muscle, which is widely employed in cooked ham manufacture. The muscles were stored for 4 days at 4 °C after slaughter and chilling in order to reach their ultimate pH, i.e. 5.6 ± 0.15. The muscles were then trimmed of their connective tissue envelope, vacuum-packed in plastic bags, frozen and stored at −18 °C until use. The muscles necessary for a given trial were previously thawed overnight at 4 °C.

2.2. Brining or/and massaging trials

The four conditions used to brine the samples are presented in Fig. 1. The brine was a straightforward mixture of water and NaCl only, and salt content (Csalt) is expressed as a percentage (g NaCl/100 g brine). In all experiments, contrary to standard practice, we used an excessive amount of brine in relation to sample weight to ensure only negligible changes in brine composition over time. All trials were performed at 4 °C.

Vestergaard et al. (2007) assessed NaCl apparent diffusivity during immersion-brining in *Longissimus dorsi* pork muscles and concluded that animal effect is significant. Consequently, in order to evaluate the impact of mechanical action, each type of comparison (cases 1–2 or cases 3–4) was done on two halves of one muscle that had been cut orthogonally to its main length.

2.2.1. Cases 1 and 2

According to the method proposed by Lebert and Daudin (2014), unidirectional NaCl transfer was promoted along the main axis of a meat cylinder (about 20 g; 300 mL of brine; Csalt 5%) placed in a plastic sample-holder and held in surface contact with brine at one base for 5 days. Meat tissue fibres were approximately orthogonal to direction of mass transfer.

Six cylinders were excised from the non-massaged first muscle half and used as reference. Six cylinders were excised from the second muscle half after massaging (see below) but with no brine in the simulator tank.

2.2.2. Cases 3 and 4

In these trials, one muscle half was brined in the lab-scale tumbling simulator. Brine-to-meat mass ratio was 10 times higher than in practice (1 instead of 1/10), and the brine NaCl content was much lower, i.e. Csalt was 13% compared to over 25% in practice. These conditions had two advantages: (1) potential structural modifications due to high NaCl content (Pinotti et al., 2002; Graiver et al., 2009) in the outer layer of our samples were limited, and (2) the mass transfer surface-boundary condition was almost constant with time, making it possible to fit the measured NaCl profiles with an analytical solution of Fick's second law (Crank, 1975).

At the end of the trial, a 1 cm-thick cross-section was cut in the middle of the sample and a 1 cm-width strip was removed from this section to profile NaCl content. In case-3 trials, no massaging was performed but the sample was rotated for 5 h in the brining tank in the same ways as in case 4. Massaging conditions for case 4 were the same as in case 2, as explained further. Each trial case was repeated three times.

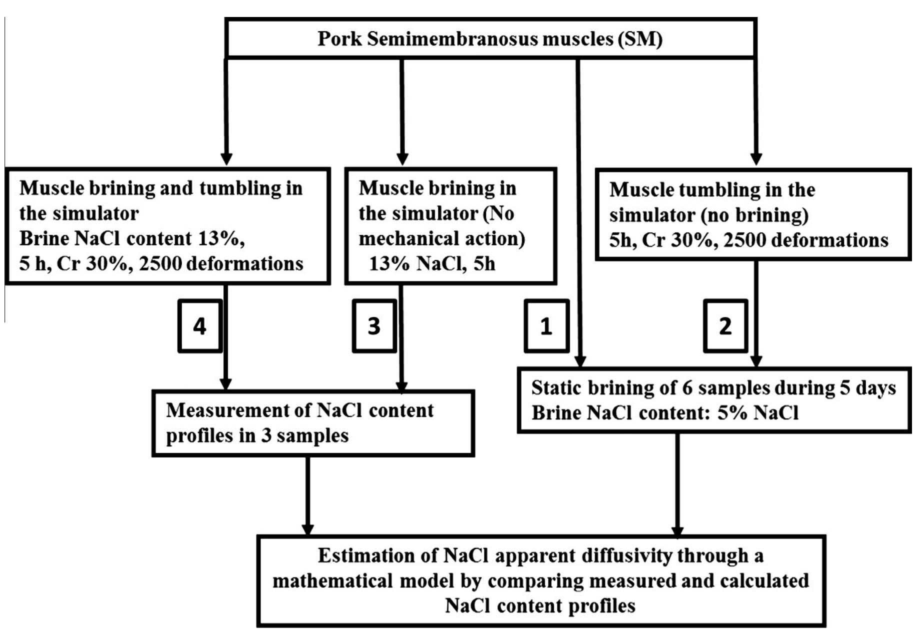

Fig. 1. The 4 treatments tested to investigate potential mechanisms to explain NaCl diffusion enhancement in tumbling.