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Low-field NMR determination of water distribution in meat batters with NaCl and polyphosphate addition

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ABSTRACT

The objective was to elucidate the influence of NaCl and polyphosphates in the stage of protein swelling on the water-holding capacity (WHC) of meat batter. The meat batters were formulated with salt in different ways by adding established amounts of only NaCl, only polyphosphates, jointly adding NaCl and polyphosphates, and a control without any salt. An increase ($p < 0.05$) in water retention was found when a combination of NaCl and polyphosphates was used. A high textural parameter was observed in the two treatments with NaCl, but not in the group with only polyphosphate. For the polyphosphate group, T_{22} was lower ($p < 0.05$) than in the other three before heating; however, after heating, T_{21} and T_{22} were both significantly decreased, and a new component emerged, T_{23}, which was significantly lower than the others. For the NaCl treatment, heated or not, T_{22} was always the highest. It was revealed that NaCl had affected the WHC by increasing the mobility and distribution of water, particularly with polyphosphate, but polyphosphate could not be an equal substitute for NaCl given its resulting lowest textural properties and poor microstructure. By presenting different hydration states in the protein swelling stage, the meat batter qualities were differentiated.

1. Introduction

Finely emulsified meat products have a complex structure and consist of numerous components that are held together by a variety of attractive forces (Gordon, Barbut, & Schmidt, 1992). Chopping, during the manufacture of meat emulsion, for the most popular comminuted meats, such as frankfurters and bologna, plays quite important role. It makes the preparation of meat batter go through critical stages including the salt-soluble proteins extraction, swelling of proteins, and formation of a matrix with homogeneous meat batters containing emulsified fat particles (Barbut, 1995; Shao et al., 2016). While in the initial stage of chopping, salt is often added to lean meat and comminuted mainly to extract the salt-soluble protein components which may subsequently influence the swelling stage states of proteins by presenting specific protein hydration states (Nostro & Ninham, 2012). The distribution and mobility of water in meat have a profound influence on essential meat quality attributes like juiciness, tenderness, firmness and appearance (Dhall, Halder, & Datta, 2012; Shao et al., 2016).

NaCl contributes to the flavour, texture, facilitates the processing, and thus plays an essential role in meat processing (Corral, Salvador, & Flores, 2013; Grossi, Søltoft-Jensen, Knudsen, Christensen, & Orlien, 2012; Tobin, O'Sullivan, Hamill, & Kerry, 2013). It appears to play a key role in the solubilisation of myofibrillar proteins for subsequent denaturation/aggregation to give good water/fat-holding capacity and acceptable rigidity/elasticity of the meat gels (Gordon et al., 1992). NaCl reduction in meat products thus has adverse effects on water/fat-holding capacity, impairing overall texture and increasing cooking loss, and also on sensory quality, especially taste (Ruusunen & Puolanne, 2005). Therefore more basic knowledge about the protein hydration states during chopping adding no emulsified fat concerning NaCl addition on the functional (emulsification, tenderness and juiciness) and technological properties should be emphasised.

Phosphates are believed to act on meat proteins by increasing the pH and ionic strength and, specifically by complexing protein-bound Mg and Ca, thus leading to increased solubilisation of myofibrillar proteins (Fernández-Martín, Cofrades, Carballo, & Jiménez-Colmenero, 2002). The most commonly used polyphosphates in the meat and poultry industries are mainly sodium tripolyphosphate (STP), sodium pyrophosphate (SPP), and sodium hexametaphosphate (SHMP). Rulliere, Perenes, Senocq, Dodi, and

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Marchesseau (2012) reported that these three polyphosphates all have tenderising effects on the muscle when used alone, thus improving the texture and stability by sequestering metal ions. Xiong (2005) found phosphate types specifically influenced the dynamics of brine penetration into muscle fibrils; the presence of pyrophosphate and tripolyphosphate greatly facilitated brine penetration, throughout marination. In contrast, hexametaphosphate promoted water uptake only for the first few minutes. In this study, the three components were chosen as a whole to analyse their synergetic effects. The simultaneous addition of sodium chloride and phosphate to meat therefore yields considerable modification of the physicochemical features of the myofibrillar proteins (Gordon et al., 1992). A thorough understanding of the differences that cause the changes in water-holding capacity (WHC) and texture properties that accompany treatment with NaCl and polyphosphates is necessary.

Low-field NMR use has been successfully expanded to the effects of cooking and different freezing and storage conditions on the quality of various meats, the assessment of pork quality, particularly as a tool for fast non-destructive analysis of WHC in industry, and mainly provides specific information about water–protein interactions within meat (Li, Rui, et al., 2014; Sánchez-Alonso, Moreno, & Careche, 2014). By multi-exponential fitting analysis, different water components may be identified as those tightly associated with macromolecules, within highly organised protein structures, or located outside the myofibrillar network (Li et al., 2012; McDonnell et al., 2013). The relaxation time acts as an indicator for water mobility, while the area under the curve can indicate the amount of water within each component. It has been proved useful to improve the understanding of the interaction between different salt conditions and major quality characteristics (Andersen, Andersen, & Bertram, 2007). Studies have demonstrated that low-field ^{1}H NMR is a technique capable of measuring water distributions and can be applied to provide an improved understanding of the effect of additives such as sodium polyphosphate on the quality of frozen shrimp (Carneiro et al., 2013). However, investigations just choosing NaCl and polyphosphates as the main components without any other additives are thereby limited; how the protein hydration states at the beginning stage of chopping influence the processing properties of the protein and then the product quality is not that clear. Therefore, further studies of the effects of NaCl and polyphosphates on water distribution induced only by salt addition are needed, for the purpose of establishing a relationship between the protein hydration changes and the water-related macro-quality properties. Based on our previous studies, the fat protons and water protons were taken together as the factors that could influence the water- and oil-binding properties to be analysed (Shao et al., 2016).

The goal of this work was to use low-field NMR relaxometry to differentiate water distributions in the four groups to obtain more information about the protein hydration states, combining the results of colour determination and textural properties to judge the chopping conditions, or whether the salt addition amount and the type is due in the protein swelling stage, thus building a relationship between the protein hydration changes and the water-related macro-quality properties. This research could be used to provide a theoretical basis for developing new meat products with low salt or with salt substitutes.

2. Materials and methods

2.1. Materials

Fresh pork meat (*longissimus dorsi*) was purchased from the local market. Other chemical compounds sodium chloride (NaCl), glutaraldehyde, osmium tetraoxide, ethanol, disodium hydrogen phosphate, monosodium phosphate, and polyphosphates (including sodium tripolyphosphate (STP), sodium pyrophosphate (SPP), sodium hexametaphosphate (SHMP) in proportions of 1:1:1) were all analytical grade reagents.

2.2. Preparation of meat batters

All visible connective tissue and fat was trimmed from the meat. The meat was then passed through a grinder (MM-12, Guangdong, China) using a 6-mm plate. Samples of 1000 g were placed into polyethylene bags and stored at 4 °C before being chopped (samples were stored for not more than 5 h before use).

Four different types of meat batter were formulated: control meat batter (Control), prepared with only 250 g iced water (ice: water, 1:1); meat batter with sodium chloride (NaCl), containing 50 g NaCl and 250 g water; the third meat batter with polyphosphates (polyphosphate), manufactured with 6.25 g prepared polyphosphates and 250 g water; and finally a sample with the same amount of sodium chloride, polyphosphates, and water (polyphosphate + NaCl).

The manufacturing process was as described below. Meat was put into the prepared chilled bowl chopper (UMC-5C; Stephan Machinery, Hameln, Germany), then NaCl and polyphosphates were directly added into the meat according to formulation, and the mixture chopped at the high-speed setting (3000 rpm) for 1 min under vacuum conditions. Finally, the vacuum was released and the iced water added; the whole meat batter was again chopped for 4 min under these conditions. The final temperature of the meat batter did not exceed 18 °C in all cases. Parts of each batter sample were vacuum-packed to remove trapped air. Approximately 35 g samples were stuffed into 50-mL polypropylene tubes, then hermetically sealed. The plastic containers were centrifuged (Model Allegra 64R; Beckman-Coulter, Fullerton, CA) at 2300 rpm (4 °C), then allowed to settle for 5 min to remove any remaining air bubbles. Then the centrifuged samples were stored in a chiller at 4 °C until analysed.

2.3. Cooking loss analysis

The cooking loss was determined according to Álvarez and Barbut (2013) with minor adjustment. The centrifuged samples were heated in a constant temperature water-bath at 75 °C for 30 min; then the containers were opened and stood upside-down for 1 h to release the separated fluid onto a plate. So the cooking loss was calculated as percentage of weight loss to initial sample weight before and after cooking. Six determinations were performed on each sample.

2.4. Texture profile analysis

Texture profile analysis (TPA) was performed using a TA.XT*plus* texture analyser, with Texture Exponent software (Stable Micro Systems, Crawley, UK). The heated samples were naturally cooled to room temperature and then six cooked cores (diameter 16 mm and height 10 mm) per treatment were selected. The chosen speed parameters were pre-test, 2 mm/s, test, 1 mm/s, post-test, 1 mm/s, and the trigger force was 5.0 kg; all prepared cores were compressed twice to 50% of their original height by a P/50 probe. TPA curves were obtained and the main attributes were calculated as follow: hardness (Hd), peak force (g) required for the first compression; springiness (Sp), the height ratio of the second compression to that of the first (dimensionless); cohesiveness (Ch), ratio of active work done under the second compression curve to that done under the first compression curve (dimensionless); chewiness