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The effect of pressure-assisted heating on the water holding capacity of chicken batters

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ABSTRACT

The ability of gel-type meat products to hold water is an important quality attribute, which is affected by processing. The aim of this research was to investigate the effects of pressure-assisted heating, which can disrupt myofibrils and hinder heat-induced protein denaturation, on the water holding capacity of chicken meat batters. High pressure-assisted heating (100–400 MPa, 65 °C, and 30 min) and heating-only (0.1 MPa, 65 °C, and 30 min) was applied to chicken meat batters, the centrifugal loss, water distribution and mobility, microstructure, and residual denaturation enthalpy were determined. A threshold pressure of between 300 and 400 MPa was found, below which the WHC was improved, but impaired at greater pressures. Distributed exponential analysis of the T_2 relaxation revealed three states of water binding (T_{2b}, T_{21} and T_{22}), each of which was significantly correlated with WHC. Pressure-treated batters had a higher amount of bound water than the heat-only batters, and showed a decrease in immobilized water and an increase in free water with increasing pressure. Myofibril structures were degraded by high pressure. High pressure resulted in a porous microstructure which held more water. However, pressures greater than the threshold caused loose gel-networks and decreased water holding capacities. The heat-denaturation of meat proteins was affected by high pressure. Actin was denatured by high pressure instead of heating, while collagen and some myosin derivatives were preserved from being denatured by heating. The changes in protein denaturation and batter microstructure were correlated with water distribution properties. The results contributed to a better understanding of the effects of high-pressure with heat on the water holding capacity of chicken batters.

Industrial relevance: A beneficial threshold pressure of between 300 and 400 MPa was found, below which the water holding capacity was improved, and above which water holding capacity was reduced. As the effect of high pressure on physical properties and sterilization were not always consistent, this finding reminds the meat industry need to adopt a suitable pressure to achieve a balance between physical properties and sterilization. The low filed nuclear magnetic resonance could be adopted in a routine examination of product quality.

1. Introduction

The water holding capacity of meat products is an important quality attribute, not just for the sensory aspects, but also for economic benefits. Meat has a water content of approximately 75% which is distributed in intra- and extra-myofibrillar spaces (Pace & Rathbun, 1945). Further, additional water is usually added to gel-type meat products during processing, making it difficult for the meat products to retain water. When the meat product is cooked, the heat-induced shrinkage of myofibrils results in the migration of water from intra-myofibrillar to the extra-myofibrillar spaces, potentially resulting in water loss (Tornberg, 2005; Van der Sman, 2007). Understanding the water distribution and its migration is essential for developing meat product formulations and processing technology.

The application of high pressure processing (HPP) has increased rapidly during the last 30 years. HPP has being used in the food industry for various purposes including its effectiveness for reducing numbers of viable microorganisms, meat tenderization, protein gelation, starch gelatinization and food frozen/unfrozen (Balasubramaniam & Farkas, 2008; Suzuki, 2002). HPP has long been recognized as a “cold processing” technology, mostly because of its “cold pasteurization” effect (Heinz & Buckow, 2010). However, a combination of high pressure

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and high temperature, namely heating under pressure (HUP), that is, applying two physical effects simultaneously to a foodstuff, can improve the food product. This has not been thoroughly explored. In meat products, one of the beneficial effects is reducing water loss. This has been reported by several studies on chicken, pork and beef (Fernandez Martin, Fernandez, Carballo, & Colmenero, 1997; Jiménez-Colmenero, Fernández, & Carballo, 1998; Sikes & Tume, 2014; Zheng et al., 2015; Zheng et al., 2017).

Several changes related to the WHC of HUP-treated meat products have been suggested, such as the breakdown of myosin molecules, a denaturation-preserving effect, and disruption of myofibrils (Jimenez-Colmenero, Cofrades, Carballo, Fernandez, & Fernandez-Martin, 1998; Zheng et al., 2015; Zheng et al., 2017). However, these findings were based on indirect determinations or subjective observations and were unable to explain the actual pattern of water distribution and movement within the cellular environment. Several studies have shown that low-field nuclear magnetic resonance (LF-NMR) proton relaxometry can provide information about water mobility and distribution based on the measurement of transverse water proton relaxation (Berendsen, 1992; Bertram, Aaslyng, & Andersen, 2005). Also, it is a rapid, non-invasive, and nondestructive tool for the characterization of water properties (Han, Wang, Xu, & Zhou, 2014).

The aim of this study was to investigate the effect of high pressure assisted heating on the water holding capacity of chicken meat batters using low-field NMR proton T_2 relaxometry, scanning electron microscopy (SEM), and differential scanning calorimetry (DSC) in combination with traditional meat quality measurements. This work can contribute to the application of high pressure processing in the meat industry.

2. Material and methods

2.1. Materials and chemicals

Chicken breast meat (*M. pectoralis major*) was transported from a meat company (Jiangsu Tyson Foods Co, LTD., China) at low temperature (0–4 °C) within 24 h after slaughtering. All chemicals used were of analytical grade, except sodium chloride and sodium polyphosphates, which were food grade.

2.2. Preparation of batters

A total of 10 kg chicken meat was trimmed to remove visible fat and connective tissue, cut into strips, and then minced through a meat-grinding machine (MOD TC/12E, Sirman, Italy) fitted with a plate made up of 5-mm-holes. Then, the minced meat was mixed and divided into 5 equal parts before being chopped separately. The minced chicken (80 g/100 g) was chopped with ice (17.7 g/100 g), sodium chloride (2 g/100 g), and sodium tripolyphosphate (0.3 g/100 g) for 5 min in a chopper (K15E, Talsabell S. A., Spain) at 1800 rpm. The temperature of chicken batters during the cutting was maintained below 13 °C. The meat batter was subjected to vacuum to remove the air bubbles before stuffing into plastic casings with a diameter of 26 mm and linked every 20 cm. The sausages (120 g each) were vacuum packaged in vacuum bags separately and then stored at 0–4 °C prior to further treatment on the following day.

2.3. Pressure/thermal treatments

Vacuum packaged chicken meat batters were subjected to 0.1, 100, 200, 300, or 400 MPa and heat at 65 °C for 30 min. Heat-only (0.1 MPa) treatment was performed in a water bath (TW20, JULABO Technology Co. Ltd., Germany). The pressure assisted heating (100–400 MPa) was performed in a 0.3 L high-pressure unit (S-FL-850-9-W/FPG5620YHL, Stansted Fluid Power Ltd., UK) by using a mixture of water and propylene glycol (7:3, w/v) as the compression fluid. The high-pressure chamber was heated to 65 °C and kept constant by a water bath (ILB-WCS, STIK Shanghai Co., Ltd.). The temperature in the sample chamber was monitored during processing by a thermocouple located inside the top of the chamber. A heating time of 30 min as suggested by Fernandez Martin et al. (1997), was used for all samples. Compression led to a temperature increase of 3 °C/100 MPa and decompression led to a temperature decrease of 4 °C/100 MPa. The initial temperature of the compression fluid was reduced before each run to counteract the temperature increase caused by adiabatic heating. The pressurization and depressurization rates were 5 MPa/s and 20 MPa/s, respectively.

All samples were then cooled in a running tap water immediately for 1 h after being heated, and then stored in a 0–4 °C room.

2.4. Determination of water distribution and mobility

Water distribution and mobility were determined according to the method of Han et al. (2014) by using low-field nuclear magnetic resonance (LF-NMR), with minor modifications. A sub-sample (approximately 2 g) was cut from the sausage and placed in a cylindrical glass tube (15 mm in diameter). The relaxation measurements were performed on a bench top pulsed NMR analyser (PQ001, Niumag Electric Corporation, China) with a corresponding resonance frequency for protons of 22.6 MHz. Transverse relaxation, T_2, was measured using the Carr-Purcell-Meiboom-Gill (CPMG) sequence (Carr & Purcell, 1954; Meiboom & Gill, 1958). The T_2 measurements were performed with a τ value (time between 90° pulse and 180° pulse) of 200 μs. The repetition time between two succeeding scans was 5 s. Data were acquired from 3000 echoes as an average of 8 repetitions. Each measurement was performed in quintuplicate. The transverse low-field NMR relaxation data were fitted to a multi-exponential curve with the MultiExp Inv Analysis software (Niumag Electric Corporation, China). This analysis yielded a plot of relaxation amplitude for individual relaxation processes versus relaxation time. The relaxation peak time (T_2) and peak area (P_2) were calculated from the curve.

2.5. Determination of water holding capacity

Centrifugal loss was determined by the centrifugation method as described by Zheng et al. (2017). Samples were cut into 1 cm long cylinders, weighed (W_{start}) and wrapped with a filter paper. Then, the sample was centrifuged at 10,000 × *g* for 10 min at 10 °C. After removing the filter paper, the sample was reweighed (W_{end}). The centrifugal loss was expressed as the percentage of water loss to total weight.

$$\text{Centrifugal loss (\%)} = \frac{W_{start} - W_{end}}{W_{start}} \times 100$$

2.6. Structural observation

Subsamples were taken from the central part of sausages and cut into 0.1 mm × 1 mm × 2 mm blocks and fixed with 2.5% glutaraldehyde in 0.1 mol/L phosphate buffer solution (pH 7.0). The ethanol dehydration, freeze-drying and sputter-coating were performed according to the procedure of Cao, Xia, Zhou, and Xu (2012). Samples were observed and photographed by using a scanning electron microscope (S-3000N, Hitachi, Japan) at a voltage of 10 kV.

2.7. Determination of thermal properties

Samples (15–20 mg) were encapsulated in aluminum pans and hermetically sealed. The samples were equilibrated at 25 °C for 2 min before scanning from 25 to 90 °C at 5 °C/min in a differential scanning calorimeter (DSC1, Mettler-Toledo International Inc., Switzerland) with an empty aluminum pan as a reference. Dry matter content was determined for thermal data normalization to dry matter content by