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Effect of pre-emulsification of plant lipid treated by pulsed ultrasound on the functional properties of chicken breast myofibrillar protein composite gel

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ABSTRACT

To explore novel methods for reducing the saturated fatty acid content in meat products, pre-emulsified plant lipids prepared using pulsed ultrasound were used to replace animal fat. Chicken breast myofibrillar protein (MP)–soybean oil emulsion composite gels (SMG) were prepared from 3% chicken breast MP with 27.5% soybean oil incorporated as pre-emulsification with 0.5% sodium caseinate (0.6 M NaCl and 50 mM phosphate solution, pH 6.25). One-factor-at-a-time experiments were carried out to investigate the effect of different ultrasound treatment times on the texture [rheology and texture profile analysis (TPA)], water- and fat-binding (WFB) capacities, and microstructural properties of SMG. Rheological tests showed that ultrasound-treated samples formed a more viscoelastic gel than the control. WFB and textural properties were also significantly improved by pulsed ultrasound ($P < 0.05$). The ultrasound-treated gels exhibited homogeneous fine network microstructures when the ultrasound time was 6 min. $G'_{72\ °C}$ and $G''_{72\ °C}$ were highly correlated ($P < 0.01$) with WFB and TPA (hardness, springiness, chewiness, cohesiveness, and resilience). These findings show that ultrasound treatment has potential in improving the fatty acid composition of emulsion-type meat products with good functional properties and high yields.

1. Introduction

Consumers have recently become concerned about possible harmful effects that may result from the excess intake of saturated fats in their diet, and are showing interest in healthier options with regard to fat content and fatty acid composition of meat products (Herrero, Carmona, & Pintado, 2012). Certain vegetable oils pre-emulsified with non-meat proteins have been recommended on a nutritional basis to replace part of the animal fat in processed meats (Cáceres, García, & Selgas, 2008; Delgado-Pando, Cofrades, Ruiz-Capillas, Teresa Solas, & Jiménez-Colmenero, 2010). However, the oil in water emulsions used as animal fat replacers can affect the quality of meat products in different ways (Osburn & Keeton, 1994; Triki, Herrero, Jiménez-Colmenero, & Ruiz-Capillas, 2013).

Myofibrillar proteins (MPs) are key proteins primarily responsible for the textural and functional properties of emulsion composite gel-type meat products (Hong & Xiong, 2012; Liu, Stevenson, & Lanier, 2013). The salt-soluble MPs are amphiphilic, with polar and non-polar amino acid residues. These proteins enable emulsion formation by bringing together water and fat through changes in surface tension. Sodium caseinate (SC) is a widely used natural multi-functional food additive that has excellent emulsion stabilizing properties. SC molecules are flexible because they lack the secondary structure of the α-helix and β-sheet layers, which allow them to form layers of resilient hydrophilic protein films (Dickinson, 1999; Farshchi, Ettelaie, & Holmes, 2013).

Application of ultrasonic technology in the food processing industry has recently received considerable attention (Chandrapala, Oliver, Kentish, & Ashokkumar, 2012; Jambrak, Lelas, Mason, Krisic, & Badaniak, 2009). One of the major issues in using high-intensity ultrasound is the need to control the resulting changes in the properties of food protein gels. Acoustic cavitation generates violent physical forces that include shear forces, shock waves, and turbulence, thereby potentially changing the functional properties of proteins by physical or chemical methods (Gulseren, Guzey, Bruce, & Weiss, 2007). Ultrasonic emulsification is one of the best established applications of ultrasound in food processing (Chandrapala et al., 2012). The energy required to produce an emulsion by ultrasound is less than that required using conventional methods, and emulsions generated by ultrasound are more stable (Chemat & Khan, 2011). However, few studies have focused on their use for pre-formed emulsions on the functional properties and yields of low-saturated fat meat products.

This study aimed to determine the influence of pre-formed soybean oil emulsions using pulsed ultrasound on chicken breast MP gels. Changes in the rheological behavior, water- and fat-binding (WFB) capacities, and resulting textural characteristics were specifically investigated.

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2. Materials and methods

2.1. Materials

Spray dried SC (88.21% protein) was provided by Mengniu Dairy Company Ltd. (Nanjing, Jiangsu Province, China). Commercially available Jinlongyu soybean oil (pure) produced by Yihai Kerry Food Company (Shanghai, China) was purchased from a local supermarket. The soybean oil contained 16% saturated fatty acid, 25% monounsaturated fatty acid, and 59% polyunsaturated fat.

On each of three occasions, four six-week-old three-yellow chickens were obtained from a local market (Nanjing, China) and used on the same day to prepare MP extracts. For each extraction, four birds were euthanized and the muscles were pooled. Breast muscle (*Musculus pectoralis major*) was trimmed of any excess fat and connective tissue, and immediately stored at 0 °C to 4 °C for 24 h prior to extraction. The meat was cut into 1 cm to 2 cm cubes, and ground for 7 s at 2000 r/min (repeated three times) using a Waring Blender (GM 200, Retsch, Germany). MPs were isolated from chicken breast meat according to the method of Han, Zhang, Fei, Xu, and Zhou (2009) and Xu, Han, Fei, and Zhou (2011) with minor modifications. The ground chicken breast muscle (150 g to 180 g) was mixed with four volumes (1:4, w/v) of ice-cold isolation buffer (10 mM Na_2HPO_4/NaH_2PO_4, 0.1 mM NaCl, 2 mM $MgCl_2$, 1 mM EGTA, pH 7.0, 4 °C) and homogenized three times for 30 s at 10,000 r/min. The homogenates were filtered through a 20-mesh sieve (aperture 0.9 mm) and centrifuged (Beckman Avanti® J-E, Beckman Coulter, USA) at 2000 ×*g* for 15 min. The supernatant was decanted, and the pellet was collected as a crude MP. The aforementioned steps were repeated two times to obtain high-quantity MP. The MP pellet was blended in four volumes of salt solution (0.1 M NaCl), centrifuged, and washed three times. The final pellet was collected as 'pure MP' and used in the succeeding tests. All isolation steps were conducted at 0 °C to 4 °C. The biuret method was used to determine the protein concentration of pure MP using bovine serum albumin as the standard.

2.2. Emulsion preparation using high-intensity ultrasound

The pre-formed emulsions were prepared in phosphate buffer A (0.6 M NaCl, 50 mM Na_2HPO_4/NaH_2PO_4, pH 6.25) to yield an SC: phosphate buffer A: soybean oil ratio (by weight) of 0.09:4:5 (Jiang & Xiong, 2013; Serrano, Cofrades, & Jiménez-Colmenero, 2006). The mixture was homogenized and emulsified three times for 20 s at 6000 r/min using a high-speed homogenizer (Ultra Turrax T-25 Basic, IKA Company, Germany) to obtain crude pre-formed emulsions. These emulsions (150 mL each) were sonicated by a Vibra-Cell™ Ultrasound Processor (VC 750, SONICS, USA) in a glass double-walled beaker equipped with a cooling jacket for 0, 3, 6, 9, and 12 min (on- and off-time pulse durations of 4 and 2 s, respectively) using a 20 kHz ultrasonic probe (13 mm diameter). During sonication, the instrument delivered a set power of 450 W, and ice water was continuously circulated through the cooling jacket to maintain the sample temperature at 4 °C to 8 °C. These pre-emulsions were stored at 0 °C to 4 °C overnight.

2.3. Preparation of MP–soybean oil composite sols

The pre-formed emulsions were added to the MP sols in phosphate buffer A. These emulsions were then homogenized and emulsified two times for 20 s at 6000 r/min using a high-speed homogenizer (Ultra Turrax T-25 BASIC, IKA Company, Germany) to prepare MP–soybean oil composite sols. The final composites (0.5% SC, 3% MP, and 27.5% lipid) were immediately used for dynamic rheological measurements. The remaining composites were formed into gels for WFB properties, texture profile analysis (TPA), and scanning electron microscopy (SEM). Each composite was placed into 50 mL cylindrical plastic tubes, and centrifuged (Beckman Avanti® J-E; Beckman Coulter, USA) at 2000 ×*g* for 5 min to remove air bubbles. To form gels, all emulsions were placed in a water bath (ZKSY-600, Keer Co. Ltd., Nanjing, Jiangsu Province, China) at 20 °C and heated to 80 °C at a rate of 1 °C/min. The gels were briefly chilled in a freezer and stored overnight at 0 °C to 4 °C. All preparation steps were conducted at 0 °C to 4 °C.

2.4. Dynamic rheological measurements

Dynamic rheological measurements (both viscoelastic properties and viscosity) of MP-emulsified soybean oil composite sols were performed using a rheometer (Physica MCR301, Anton Paar Corporation, Austria).

Viscoelastic properties were measured to examine the dynamic formation of a gel network, as described by Jiang and Xiong (2013). Samples were loaded between two 50 mm diameter parallel plates with a 1 mm gap. To induce gel formation, samples were stored at 20 °C for 3 min and heated from 20 °C to 80 °C at a heating rate of 1 °C/min. Prior to heating, the exposed composites were sealed with silicone oil. To ensure that working conditions remained within the linear viscoelastic region, measurements were performed at a constant strain and angular frequency of 0.012 and 1 Hz, respectively. Changes in the storage modulus (G′), loss modulus (G″), and phase shift angle (δ) were constantly recorded.

The viscosities of MP-emulsified soybean oil composites receiving different ultrasound treatments were measured in triplicate samples using 50 mm-diameter parallel plates. Using the method of Picotti et al. (2013) with slight modifications, the samples were equilibrated in parallel plates for 30 s prior to measurements to obtain a desirable temperature of 25 °C. Viscosity was then recorded as the shear rate that linearly increased from 0.1 s^{-1} to 1000 s^{-1} (total shearing time of 330 s).

2.5. Determination of TPA

TPA was performed using a TA-XT plus texture analyzer (Stable Micro Systems Co. Ltd., Surrey, England) fitted with a cylindrical probe (P/50, 50 mm diameter), which was compressed two times to 40% of its original thickness. Prior to TPA testing, the gels, which were stored at 4 °C, were equilibrated at room temperature for 30 min and cut into 2 cm long (2.4 cm diameter) sections. Analysis was performed using the following conditions: pre-speed, 3.00 mm/s; trigger force, 5 g; test speed, 2.00 mm/s; and post-speed, 5.00 mm/s. No delay occurred between the two compression cycles (Savadkoohi, Shamsi, Hoogenkamp, Javadi, & Farahnaky, 2013). The data acquisition rate was 200 pps. The textural properties of gels were expressed as hardness, springiness, chewiness, cohesiveness, and resilience (Cáceres, García, & Selgas, 2006).

2.6. Determination of WFB properties

The WFB capacities were determined by measuring water and fat loss according to the methods of Shao, Zou, Xu, Wu, and Zhou (2011) and Álvarez and Barbut (2013) with slight adjustments. The composite gels were centrifuged (Beckman Avanti® J-E, Beckman Coulter, USA) at 10000 ×*g* for 15 min. The containers were opened and left to stand upside down (for 1 h) to release the separated fat and water onto a plate. The tubes were inverted to drain and collect the supernatant fluid. WFB (%) was defined as the ratio of the pellet weight to the original gel weight multiplied by 100. Determinations were carried out three times separately.

2.7. SEM

Observation and photomicrography of composite gel samples were performed using SEM (Hitachi S-3000N, Hitachi High Technologies Corp., Tokyo, Japan) according to the procedure described by Maltais,