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Textural and rheological properties of Pacific whiting surimi as affected by nano-scaled fish bone and heating rates

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ABSTRACT

Textural and rheological properties of Pacific whiting (PW) surimi were investigated at various heating rates with the use of nano-scaled fish bone (NFB) and calcium chloride. Addition of NFB and slow heating improved gel strength significantly. Activity of endogenous transglutaminase (ETGase) from PW surimi was markedly induced by both NFB calcium and calcium chloride, showing an optimal temperature at 30 °C. Initial storage modulus increased as NFB calcium concentration increased and the same trend was maintained throughout the temperature sweep. Rheograms with temperature sweep at slow heating rate (1 °C/min) exhibited two peaks at ~35 °C and ~70 °C. However, no peak was observed during temperature sweep from 20 to 90 °C at fast heating rate (20 °C/min). Protein patterns of surimi gels were affected by both heating rate and NFB calcium concentration. Under slow heating, myosin heavy chain intensity decreased with NFB calcium concentration, indicating formation of ε-(γ-glutamyl) lysine cross-links by ETGase and NFB calcium ion.

1. Introduction

The United States Pacific whiting (PW) fisheries averaged harvests of 199,000 metric tons (MT) annually from 2007 to 2011 (NMFS, 2013). The majority of the harvest has been used for surimi production due to its bland taste, white color, low cost, and abundance. An intrinsic protease problem in Pacific whiting, which contributes to gel textural softening, has been resolved by addition of food grade protease inhibitors (such as egg white, whey protein concentrate and potato extract) or adopting fast cooking (for example, ohmic cooking) (Yongsawatdigul, Hemung, & Choi, 2014). A lower concentration of calcium ions in the flesh was thought to be a primary factor for relatively lower gel values of PW surimi after setting compared to those of Alaska pollock (AP) surimi (Park, 2005). Gordon and Roberts (1977) reported the calcium content of Pacific whiting, at 8.7 mg/100 g meat, while pollock contained 63 mg calcium/100 g meat (Sidwell, 1981). Consequently, the effectiveness of calcium compound addition was more pronounced with PW surimi than with AP surimi (Lee & Park, 1998).

It is generally accepted that calcium ion improves gel texture, mainly by inducing endogenous transglutaminse (ETGase), which is capable of catalyzing acyl transfer reactions by introducing non-disulfide covalent cross-links among myosin molecules (Lanier, Carvajal, & Yongsawatdigul, 2005). Yongsawatdigul and Sinsuwan (2007) reported that cross-links of myosin heavy chain were not disrupted by SDS-urea-2-mercaptoethanol solution and increased with calcium ion concentration. In addition to activating TGase, calcium ion has also been found to have a direct effect on conformational changes of myosin by inducing myosin unfolding. As a result, more exposure of the reactive residues favoured TGase-mediated reactions and led to enhancement of hydrophobic interactions (Yongsawatdigul & Sinsuwan, 2007). Furthermore, calcium ions have a divalent positive charge (Ca^{2+}), which may form ionic linkages between negatively charged sites in two adjacent myofibrillar proteins, resulting in gel texture improvement (Lanier et al., 2005).

Fish bone is the main solid leftover of the surimi processing industry, accounting for 10–15% of total fish biomass. Fish bone is rich in calcium compounds, which have been reported to possess high bioavailability (Malde et al., 2010). Despite increasing efforts to obtain new products from fish bone, the majority is still used for fishmeal, which is of low economic value. To make fisheries more sustainable and profitable, efforts should be focussed on utilizing this calcium-rich material as a high value-added product.

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Calcium compounds from fish bone have been reported to activate ETGase from different fish species (Hemung, 2013; Yin & Park, 2014). In addition, fish bone particles, downsized to a nanoscale, are capable of being imbedded in the surimi gel matrices without disrupting the myofibrillar gel network (Yin, Reed, & Park, 2014). Accordingly, nano-scaled fish bone (NFB) may be useful for calcium enrichment and gel texture enhancement of Pacific whiting surimi seafood. However, the effects of NFB addition on the properties of Pacific whiting surimi gel have not been investigated.

Our objectives were to evaluate the role of NFB on textural and rheological properties of Pacific whiting surimi heated at various heating rates.

2. Material and methods

2.1. Materials

Pacific whiting (*Merluccius productus*) surimi, made with 4% sucrose, 4% sorbitol and 0.3% sodium tripolyphosphate without food-grade protease inhibitor, was obtained from Trident Seafoods (Seattle, WA, U.S.A.). Frozen surimi was cut into about 800 g blocks, vacuum-packaged, and stored in a freezer (−18 °C) throughout the experiments. Dried Pacific whiting fish bone was obtained from Trident Seafoods (Newport, OR, U.S.A.).

Dried egg white (EW) was obtained from Henningsen Foods (K-200, Omaha, NE, U.S.A.). Calcium chloride, N, N′-dimethylated casein (DMC), and monodansylcadaverine (MDC), were purchased from Sigma Chemical Company (St. Louis, MO, U.S.A.). Dithiothreitol (DTT) was purchased from Fluka (Buchs, Switzerland). Reagents used for gel electrophoresis were obtained from Bio-Rad (Hercules, CA, U.S.A.). All other chemicals were of analytical grade.

2.2. NFB preparation

Preparation of NFB was carried out according to the method described by Yin and Park (2014). Briefly, fish bone was soaked in sodium hydroxide solution (pH 12) for 2 h and rinsed with tap water three times to remove myofibrillar proteins and dried in an oven (105 °C) overnight. Dried fish bone was mixed with deionized water and further processed to nano-scaled fish bone emulsion (NFB) by Custom Processing Services (Reading, PA, U.S.A.), using a wet mill (Labstar, Netzsch Premier Technologies, Co., Exton, PA, U.S.A.). D_{50} of the fish bone particle in the emulsion was 280 nm, which was analyzed by Custom Processing Services (Reading, PA, U.S.A.), using a Laser particle size analyzer (LA-950 V2, Horiba Co., Kyoto, Japan). Total calcium concentration was 32.4 mg/g emulsion, as analyzed by Universal Testing Company (Quincy, IL, U.S.A.), using inductively coupled plasma (ICP) spectrometry.

2.3. Gel preparation

Frozen surimi was tempered at room temperature for 1 h before being cut into about 3 cm cubes. Surimi cubes, with approximately −5 °C core temperature, were chopped at 1, 800 rpm for 1 min, using a silent cutter (UM 5 universal, Stephan Machinery Co., Columbus, OH, U.S.A.) equipped with an ethylene glycol chilling system. Chopping was continued at 1, 800 rpm for 1 min with 2% salt. NFB emulsion (at 0, 1, 3, 5, 10 mg calcium/g surimi paste) or calcium chloride (at 1 mg calcium/g surimi paste) was added to the salted surimi paste. 1% DEW was then added as protease inhibitor with the assumption of protease inhibition by 80–90% (Hunt, Park, & Handa, 2009). Moisture content was adjusted to 77%, using ice water (0 °C) and sucrose before chopping at 1800 rpm for a further 1 min. Sucrose was added to the treatments without NFB or with reduced NFB as an inert ingredient to substitute for NFB while maintaining equal moisture content. For the final 3 min, chopping continued at 3, 600 rpm while a vacuum was maintained at 0.5–0.6 bar. The final temperature was approximately 15 °C, which is the optimum final chopping temperature for PW surimi (Poowakanjana & Park, 2014). The paste prepared above was packed into a polyethylene bag and subjected to a vacuum packaging machine (Reiser VM-4142, Roescher Werke, Osnabrueck, Germany) to remove air pockets. The paste was stuffed into a nylon tube (Nylatron MC 907, Quadrant Engineering Plastic Products, Reading, PA, U.S.A.) with a 3 cm inner diameter and approximately 15 cm long. The paste was heated, using an ohmic heating apparatus, as described by Yongsawatdigul, Park, Kolbe, Dagga, and Morrissey (1995). Samples were heated from ~15 to 90 °C with five different heating rates: 0.5, 1, 5, 20, or 80 °C/min. The approximate applied voltages for each heating rate were 25 V (0.5 °C/min), 35 V (1 °C/min), 50 V (5 °C/min), 80 V (20 °C/min), and 140 V (80 °C/min), giving voltage gradients (V/cm) of 1.67, 2.33, 3.33, 5.33, and 9.33, respectively. Gels were placed in plastic bags, submerged in cold iced water for 15 min before storing overnight in a refrigerator (4 °C).

2.4. Fracture gel evaluation

Fracture gel evaluation of the gels was performed using a TA-XT texture analyzer (Stable Micro Systems, Surrey, U.K.). Cold gels (4 °C) were placed at room temperature for 2 h prior to gel testing. Cylinder-shaped samples with lengths of 2.5 cm were prepared and subjected to fracture analysis. Breaking force and penetration distance were measured, using the texture analyzer equipped with a spherical plunger (diameter 5 mm) at a crosshead speed of 60 mm/min. For each treatment, mean values were obtained from at least four measurements.

2.5. Oscillatory dynamic measurement

The surimi paste was subjected to a temperature sweep to monitor heat-induced gelation, using a CVO rheometer (Malvern Instruments Ltd., Worcestershire, U.K.). Sample paste was applied between a cone (4° and 40 mm diameter) and plate with a gap of 150 μm. Sample was covered by a trapper with moistened sponge to avoid the sample drying out during heating. Samples were subjected to temperature sweep (from 20 to 90 °C) at two different heating rates of 20 °C/min and 1 °C/min, respectively, shear stress of 100 Pa, which was in the linear viscoelastic region through shear stress sweep, and a fixed frequency of 0.1 Hz.

2.6. TGase activity

TGase activity was assayed by the method of Yongsawatdigul, Worratao, and Park (2002) with slight modifications; 5 g of surimi were homogenized in 4 volumes of extraction buffer (10 mM NaCl and 10 mM Tris-HCl, pH 7.5). The homogenate was centrifuged at 16, 000×*g* (Sorvall, DuPont Co., Newton, CT, U.S.A.) at 4 °C for 30 min. The supernatant was used as crude extract. The assay mixtures contained 1.0 mg/ml DMC, 15 μM MDC, 3 mM DTT, and 50 mM Tris-HCl (pH 7.5). NFB or $CaCl_2$ solution was added to the mixtures and vortexed immediately. The mixtures were incubated at 20 °C, 30 °C, 40 °C, 50 °C, 60 °C and 70 °C for 5 min. 100 μl of crude enzyme were added and further incubated for 10 min. After incubation, EDTA solution was added to a final concentration of 20 mM to stop the reaction of TGase immediately (Yongsawatdigul et al., 2002). The fluorescence intensity was measured with excitation and emission wavelengths of 350 and 480 nm, respectively, using a Shimadzu spectrofluorometer (RF-1501; Shimadzu Co., Kyoto, Japan). One unit of TGase activity