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Effects of microwave combined with conduction heating on surimi quality and morphology

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ABSTRACT

Past studies have reported that microwave heating (MW) usually leads to higher cooking loss and texture deterioration in surimi processing. The objective of this study was to evaluate the effects of different microwave heating methods on surimi gel properties. Compared to traditional two steps water bath heating method (WB), using microwave heating to replace the first step of water bath heating would lead to the deterioration of surimi quality. By contrast, using microwave heating to replace the second step of water bath heating could significantly improve gel strength and water holding capacity. Microwave heating contributed to gelation and promoted the cross-linking of proteins via disulfide and non-disulfide covalent bonds. From scanning electron microscopy (SEM) and confocal laser scanning microscopy (CLSM), microwave heating coupled to the traditional water heating method resulted in more compact network structures. Although the favorable gel strength was obtained by both the time-dependent mode and temperature preservation mode, CLSM three-dimensional micrographs revealed that the time-dependent mode contributed to shrinkage and rough surfaces. Therefore, the rapid heating rate of microwave results in the aggregation of proteins with superior texture, and the temperature-preservation mode results in desirable morphology and improved texture.

1. Introduction

Sea bream (*Pagrosomus major*), one of the most important fish species in Chinese mariculture, is widely distributed in the Pacific Ocean and the Indian Ocean (Cai, 2014). Sea bream, which is very popular among consumers because of its fine taste and texture (Ducept et al., 2012; Iglesiasotero et al., 2010; Tong et al., 1998), is commonly sold in the form of surimi. Surimi mainly consists of salt-soluble minced fish protein, which can simulate the unique texture properties of seafood products (Kong et al., 2016). The texture properties of surimi are dependent on gel strength (Wang et al., 2017), water holding capacity, and whiteness. Among all the texture properties, gel strength is an important quality indicator of surimi products (Lin et al., 2015).

Surimi products undergo thermal treatment; both temperature and heating rates determine the quality of surimi products (Konno et al., 2003; Zhang et al., 2016). In general, surimi is chopped in the presence of salt, which dissolves myofibrillar proteins resulting in the formation of collosol. Collosol forms a translucent gel at below 50 °C. However, 50 °C–70 °C is considered to be the gel-cracking zone, i.e., where the gel structure gradually breaks due to active proteolytic enzymes (Fort et al., 2007). At the gel-cracking zone, myofibrillar proteins are degraded and gel strength decreases. After thermal treatment above 70 °C, a highly elastic opaque gel is formed (Tadpitchayangkoon et al., 2012b). Therefore, the thermal treatment of traditional surimi products is a two-step process by water bath (Mao et al., 2006). The traditional conduction heating method using water as heat transfer medium, which requires a fine temperature control and consumes energy, involves long treatment times at 50 °C–70 °C, which contributes to nutrient losses (Zhang et al., 2015). Microwave irradiation can penetrate into the core of

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foods and simultaneously heat the inside and outside of foods (Sánchez-Pardo et al., 2008). Microwave heating has several advantages including short heating times, high heating rates and thermal efficiency, energy saving properties, and ease of control; therefore, it is a potential thermal treatment for surimi products. Heating rate has a crucial effect on muscle protein (Tadpitchayangkoon et al., 2012a). Microwave heating can expand soybean protein molecules and effectively enhance the interaction between molecules. Even with short microwave heating time, gel strength can be significantly enhanced (Bhattacharya and Jena, 2007). Microwave heating can rapidly pass through the gel-cracking zone (Skara et al., 2014); therefore, gel network formation is an added advantage of microwave heating, which will form better gel than water bath heating. However, microwave heating rates can result in insufficient gelation below 50 °C, myofibrillar protein molecules may not be fully extended and the stability of mutual crosslinking network structure may be poor, thereby affecting the surimi gel properties (Fu et al., 2012).

Microwave fast-heating has been used to study gel strength of surimi products. However, fast heating contributes to moisture loss (Jiang et al., 2013; Yarmand and Homayouni, 2009), especially when the internal temperature reaches the boiling point (Uzzan et al., 2006). Surimi products obtained only by microwave fast-heating are harder as opposed to more elastic, furthermore, the rapid heating of microwave will make the surface of the surimi gel dry, rough and wrinkled. Compared with only microwave heating, traditional conduction heating could achieve fine morphology, but the energy consumption is large and the gel strength is lower. Therefore, the use of water bath heating for gelation followed by microwave heating may improve gel strength and elasticity of surimi products, save time, and improve production efficiency (Chang et al., 2011). First, myofibrillar protein molecules could be fully extended to form the crosslinking network structure in the surimi gel. Second, microwave heating rapidly passes through the gel-cracking zone to achieve higher gel quality. At last, the surimi gel should obtain both higher gel strength and fine morphology. Currently, few studies have evaluated the combined use of water bath heating and microwave heating. The objective of this study was to investigate the effects of different microwave heating methods on the gel strength of surimi compared to traditional conduction heating method and provide a more reliable microwave combine heating mode in the surimi processing.

2. Materials and methods

2.1. Materials

Sea bream AAA-grade surimi (sucrose + sorbitol + glucose 3%–5%, sodium tripolyphosphate 0.1%–0.5%, sea bream minced fish 92–95%) was kept at −20 °C prior to use (Fujian AnjoyQ Food Co., Ltd. Xiamen, Fujian province, China). Polyethylene-based casing with a folding diameter of 5 cm was purchased from Shuanghui Food Co., Ltd. (The Great Northern Wilderness, Harbin, China). All chemicals were of analytical grade and supplied by Sigma (St. Louis, Mo, USA) or Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China).

2.2. Preparation of surimi gel

The frozen surimi samples were allowed to thaw at 4 °C for 8–12 h and cut into 2 × 2 × 2 cm cubes. These cubes were chopped in a commercial chopper for 2 min with a rotating speed of 1500 × g. Subsequently, 3% salt (w/w) was added, and moisture content was adjusted to 78%. Surimi was chopped for 3 min to form a surimi paste. During this entire process, the cylinder of the chopper was surrounded by ice and water. The chopper was stopped every 40 s, and the surimi on the inner wall of the cylinder was scrapped off to prevent excessive heat. The surimi paste was poured into the polyethylene-based casing and sealed.

2.3. Application of different heating processes

The prepared surimi sausages were heated by microwave oven (Model NN-7251WBGTG, Panasonic, Japan) with a rotated turntable (rate is 5 r/min). The power range of the microwave oven is 100–900 W, microwave heating system is controlled by microwave station (Model OSR-8, Fiso, Canada). The microwave power was set at 7 W/g, 5 W/g, and 3 W/g corresponding to high, medium, and low power levels, respectively. The actual output power was determined according to international standard law IEC 60364-7-705:1984. 1 L deionized water was heated at a certain microwave power for a certain period of time t (the Water temperature difference should be more than 20 °C), then stir rapidly and determine temperature difference (ΔT). The actual output power (P) of microwave is calculated as following (Equation (1)):

$$P = \frac{mc_p \Delta T}{t} = \frac{4718 \Delta T}{t} \tag{1}$$

Where m is the weight of 1 L water, and c_p (4718 J/(Kg·°C)) is specific heat capacity of water.

Then the power level (p) of certain weight of surimi (m) was calculated as Equation (2):

$$\text{Power level} = \frac{p}{m} \tag{2}$$

The prepared surimi sausages were heated by microwave with an intermittent heating mode. The relation between temperature and dielectric of water solution is obvious in wet food. For wet food containing salt, the dielectric loss factor usually increases with increasing temperature under low frequency microwave power, which can lead to the so-called “thermal runaway” phenomenon (Schubert et al., 2005). In order to avoid boiling and sudden heating, the microwave workstation was operated on 24 s on followed by 24 s off. We performed different experiments as shown in Table 1:

In the microwave heating experiments, the temperature was allowed to fluctuate at the setting temperature ±2 °C. After heating, all surimi sausages were immediately placed in ice water.

2.4. Determination of gel strength

Gel strength is an important quality indicator of surimi products. Following microwave heating, surimi sausages were immediately placed in ice water, stored at room temperature (25 °C), and cut into pieces of 2.5 cm in length (Balange and Benjakul, 2009). Gel strength was measured using a TA-XT2 texture analyzer (Stable Micro Systems, Surrey, UK) equipped with a P/5s spherical probe. The pre-test speed was 2 mm/s, the test speed was 1 mm/s, the return speed was 10 mm/s, and the maximum displacement was 15 mm with a trigger force of 5 g. Parallel tests were performed five times. The breaking force was measured and read on the force vs. deformation curve by the value of the first force peak (g). The deformation was read on the same curve by dividing the sample height between the start point and the first peak force point (cm) (Zhang et al., 2013). Gel strength was the gel forming ability of the surimi after heat solidification or coagulation, also known as elasticity, which was calculated according to Equation (3):

$$\text{Gel strength (g} \times \text{cm)} = \text{Breaking force (g)} \times \text{Deformation (cm)} \tag{3}$$