LWT - Food Science and Technology 75 (2017) 497–504

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Acoustic intensity in ultrasound field and ultrasound-assisted gelling of surimi

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ARTICLE INFO

Article history:
Received 4 March 2016
Received in revised form
4 August 2016
Accepted 4 August 2016
Available online 10 August 2016

Keywords:
Acoustic intensity
Gel strength
Media
Ultrasound
Surimi

ABSTRACT

The effects of ultrasound parameters, and of the container materials used for surimi, on acoustic intensity were investigated. The frequency of ultrasound significantly affected the acoustic intensity. However, the relationship between the acoustic intensity and the frequency of the ultrasound device was not linear. The acoustic intensity increased as the height of the media increased. In addition, the acoustic intensity increased initially, but then decreased, as the volume of the media increased. Two container materials were tested: polyvinyl chloride (PVC) film and an aluminum box. The acoustic intensity was decreased significantly by the use of either material. The barrier effect of the aluminum box was weaker than that of the PVC film at lower frequencies, whereas the barrier effect of the PVC film was weaker than that of the aluminum box at higher frequencies. The gel strength of surimi increased with as the acoustic intensity increased when the latter was above a certain level. Changes in the secondary structure of myofibrillar protein were found to cause the increase in the gel strength.

1. Introduction

Ultrasound has attracted great interest in recent years, and its application in the food industry has shown promising advantages because it can generate powerful physical forces, such as microjets, shear force, shock waves, and turbulence, through acoustic cavitation, which can improve the quality of foods. Ultrasound is mainly used in food detection and food processing, which require different levels of acoustic intensity.

Food detection using ultrasound is increasingly common in the food industry because it provides a rapid, accurate, inexpensive, simple and nondestructive method for assessing and monitoring the properties of foods online during process operations, such as the sugar content of melon (Mizrach, Galil, Rosenhouse, & Teite, 1991), the solid content of semicrystalline fats (Coupland, 2004), and the fat droplet-size distribution in homogenized milk (Miles, Shore, & Langley, 1990).

Food processing using ultrasound includes the ultrasonic emulsification of food-grade nanoemulsion formulations (Ghosh, Mukherjee, & Chandrasekaran, 2013), the tenderization of meat (Carcel, Benedito, Bon, & Muletet, 2007; Pohlman, Dikeman, & Kropf, 1997), ultrasonic salting (McDonnell, Allen, Morin, & Lyng, 2014), ultrasonic cutting (Arnold, Leiteritz, Zahn, & Rohm, 2009; Zahn, Schneider, Zucker, & Rohm, 2005), ultrasound-assisted extraction (Cabredo-Pinillos, Cedron-Fernandez, Gonzalez-Brion-gos, Puente-Pascua, & Saenz-Barrio, 2006; Porto, Decorti, & Kikic, 2009; Xia, Shi, & Wan, 2006), ultrasound-assisted filtration (Liu, Vorobiev, Savoire, & Lanoisellé, 2013), ultrasound-assisted osmotic dehydration (Nowacka, Wiktor, Sledz, Jurek, & Witrowa-Rajchert, 2012), and ultrasound-assisted antimicrobial effects (Sango, Abela, McElhatton, & Valdramidis, 2014). In addition, ultrasound promotes the nucleation of ice and the growth of crystals during freezing. Specifically, the nucleation of ice induced by ultrasound has been found to commence after irradiation; ultrasound-triggered nucleation at different temperatures results in different sizes of ice crystals in model food samples, such that lower nucleation temperatures induce smaller ice crystals (Kiani, Zhang, & Sun, 2013; Xin, Zhang, & Adhikari, 2014). However, when ultrasound is used for food processing, the ultrasound

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http://dx.doi.org/10.1016/j.lwt.2016.08.002
0023-6438/

parameters are crucial, because bioactivators in foods may be damaged if the intensity is too high. Conversely, if the intensity is too low, ultrasound may have no effect on the materials. Research into the effects of ultrasound on meat brining has shown that ultrasound can accelerate brine distribution throughout the muscle (Carcel et al., 2007; McDonnell et al., 2014). However, when the intensity was too high (19 W/cm^2), the myosin in the muscle was denatured, although the denaturation did not penetrate further than 2 mm into porcine muscle (McDonnell et al., 2014). Therefore, it is crucial to establish appropriate parameters for the application of ultrasound.

The actual acoustic intensity differs from the theoretical value of the ultrasonic equipment, so it is necessary to measure the actual acoustic intensity applied to the materials. Pohlman et al. (1997) found that ultrasound had a considerable effect on the color of beef muscle. However, Jayasooriya, Torley, D'Arcy, and Bhandari (2007) found that ultrasound treatment did not affect any of the chrominance indices (L*, a* and b*). The discrepancy between the results of these studies may have resulted from differences in the actual acoustic intensities transmitted to the beef. Hence, it is necessary to measure the actual ultrasonic power delivered to the materials to accurately determine the optimal ultrasound parameters.

Calorimetry and hydrophone measurements are currently the most common methods for determination of acoustic intensity (Carcel et al., 2007; McDonnell et al., 2014). Calorimetry involves determining the temperature increase in the first 90 s of ultrasound application. The acoustic intensity is then calculated from the temperature using the equation $P = \mathrm{d}T/\mathrm{d}t\, C_\mathrm{p} M$ (Raso, Pagan, & Sala, 1999). Although this method has its advantages, it is based on the assumption that all of the ultrasonic energy transferred to the liquid is eventually converted into heat. However, calorimetric measurements deviate from the actual acoustic intensity because some ultrasonic energy inevitably escapes into the external environment. Alternatively, hydrophones, such as the piezoelectric ceramic hydrophone, magnetostrictive hydrophone, and needle hydrophone, convert the pressure signal into an electrical signal. More accurate results should in principle be obtained by hydrophone measurement. In this research, an acoustic intensity meter (AIM) was used to determine the acoustic intensity. Although an AIM is theoretically similar to a hydrophone, it has several advantages, such as greater portability and precision.

The strength of surimi gels is closely related to the properties of surimi. Therefore, many studies have been done on the gel strength of surimi gels. Chemical and biological ingredients or additives have been used to improve the gel strength, including starch (Cipsy, Gustavo, & Novas, 2004; Yong & Park, 1998), hydrocolloids (Barrera, Ramirez, & Gonzalez-Cabriales, & Vazquez, 2002), transglutaminase (Dondero, Figueroa, & Morales, 2006), and γ-polyglutamic acid (Ji et al., 2012). However, the application of these compounds in industry has been limited for various reasons, including safety.

The objectives of this study were to investigate the effects of the frequency of the ultrasound device, the volume of the media, the height of the media, and the barrier effects of the materials on either the acoustic field or the acoustic intensity and to investigate the effects of ultrasound on the gel strength of surimi gels.

2. Material and methods

2.1. Ultrasonic equipment

The devices used for ultrasonic output were of the model XO-5200DTS (SINOTECH, Nanjing, China) with an output power of 300 W. Two devices with four frequency settings (25, 45, 80, and 130 kHz) were used. An AIM (YP0511F, HSUE, Hangzhou, China) with a piezoelectric ceramic probe was used to measure the acoustic intensity. The AIM converts the pressure signal into an electrical signal, which is presented in the form of a voltage. The acoustic intensity is then calculated using the equation:

$$\mathrm{I} = 0.47\mathrm{V}^2 \quad (1)$$

where V is the value of the voltage, and I is the acoustic intensity.

2.2. Sample preparation

Frozen silver carp surimi was obtained from Honghu Hongye Aquatic Foods Co. Ltd. (Honghu, Hubei, China). Surimi pastes were prepared using the procedure described by Jaczynski and Park (2003, 2004). Briefly, frozen surimi was thawed in a refrigerator (4 °C) for 1 night. The surimi was cut into small pieces and then blended for 2 min in a food processor. Salt (3 g/100 g) was then added to the surimi and mixed for 5 min. During homogenization [Please clarify: does this refer to blending in the food processor, or mixing with salt?], ice water was added to adjust the final moisture content of the paste to 78 g/100 g and maintain the temperature in the range of 4 °C–12 °C. The paste was then pressed into metal boxes (aluminum), and the boxes were lidded. Next, the samples were placed into the ultrasonic devices (80 kHz) at six positions with different acoustic intensities [Please clarify: did the different acoustic intensities arise from the different positions, or were they user-controlled settings?] and treated at 40 °C for 20 min. In addition, samples treated in a water bath (40 °C for 20 min) without ultrasonication served as the control group. Then, the samples were heated in a water bath at 90 °C for 30 min. The gels were then cooled in ice water for 20 min and stored at 4 °C overnight for gel strength analysis.

Myofibrillar protein was extracted according to Hemung, Li-Chan, and Yongsawatdigul (2008) with slight modifications. Five samples treated with ultrasound at 0, 0.35, 0.53, 0.69, and 0.82 W/cm^2, respectively, were rinsed with 10 times the volume of low-phosphate buffer (20 mmol/L Tris-HCl, 50 mmol/L NaCl, 10 mmol/L sodium dihydrogen phosphate, 30 mmol/L disodium hydrogen phosphate, pH 7.5) and then centrifuged at 5000 rpm at 4 °C for 10 min after homogenization. The obtained precipitates were rinsed and centrifuged twice using the above method. After that, the precipitates were rinsed with 10 times the volume of high-phosphate buffer (20 mmol/L Tris-HCl, 0.5 mol/L NaCl, 10 mmol/L sodium dihydrogen phosphate, 30 mmol/L disodium hydrogen phosphate, pH 7.5) and then centrifuged at 8000 rpm at 4 °C for 10 min. The supernatant liquid was precipitated again with 3 times the volume of cold water for 30 min and then centrifuged at 8000 rpm at 4 °C for 20 min. Finally, the precipitated myofibrillar protein was collected and dissolved in 0.6 mol/L sodium chloride and stored in a refrigerator at 4 °C.

Bovine serum albumin (BSA), Tris, phenylmethanesulfonyl fluoride (PMSF) and Xylene Brilliant Cyanine G were purchased from Sigma Chemical Co. (Wuxi, China). [This information would be more appropriate at the beginning of the section.]

2.3. Acoustic intensity

After adding 4.0 L deionized water into the ultrasonic output devices, the coordinate system of the devices was established by choosing one corner of the device as the origin to determine the direction of length for the x axis and the direction of width for the y axis on a plane ($h = 0.8$ cm, that is, 0.8 cm from the bottom of the device; Fig. 1). To determine the acoustic intensity, the probe of the AIM was situated at the chosen coordinate position while the