Physical properties of surimi sausages subjected to high hydrostatic pressure treatment

Nam Seok Oh¹ · Min Young Kim¹ · Gwi Yeong Jang² · Yoon Jeong Lee¹ ·
So Yune Baek¹ · Jounsoo Lee¹ · Heon Sang Jeong¹

Received: 16 August 2018 / Revised: 17 January 2019 / Accepted: 5 March 2019 / Published online: 26 March 2019
© The Korean Society of Food Science and Technology 2019

Abstract We aimed to investigate the effect of high pressure treatment (HPT) on the physical properties of surimi sausages. For protein gelation, high hydrostatic pressure of 400, 500, and 600 MPa was applied for 5, 15, and 30 min, respectively. Elasticity of samples containing 50% surimi was 36.68%, but that of samples containing 70% surimi was 36.87–42.88%. Shear and puncture forces for 50% surimi samples subjected to heat treatment were 1543.25 N and 3337.92 N/mm, respectively, while the shear and puncture forces for 70% surimi samples under all treatment conditions were 226.41–429.61 N and 911.72–1486.98 N/mm, respectively. After HPT, the number of pores increased from 27 to 73 with increasing

pressure and time while the pores were elliptically shaped for samples subjected to heat treatment after HHPT. These results suggest that HPT improves the physical properties of surimi sausages with lower starch content.

Keywords Surimi · Surimi sausage · High hydrostatic pressure · Texture · Gelation

Introduction

During the last few decades, food produced from fish meat has been widely used. One of the most typical fish products is surimi, an intermediate product composed of boneless minced water-washed lean white fish meat (Lee, 1984). To make surimi, fish is skinned, boned, rinsed repeatedly to remove the characteristic fish smell and pigments, and ground into a paste (Tabilo-Munizaga and Barbosa-Canovas, 2004b). Surimi is an intermediate product used in a variety of products, ranging from the traditional kamaboko products of Japan to various surimi seafood products; surimi is also a known shellfish substitutes (Park, 2013). The quality of surimi products is determined by its coloring, flavor, and elasticity. Among these, elasticity is a key factor in determining quality. The factors that influence elasticity include the raw material and the species of fish used, type and quantity of additives added, the heating method used, and the water content of the samples (Shin et al., 2009). Ordinarily surimi production involves heat treatment, which decreases the food quality. However, since treatment with high hydrostatic pressure (HHP) can induce protein gelation (400–600 MPa), improving textural characteristics, flavor, luster, density, and elasticity, the properties of surimi samples subjected to HHP are quite

✉ Heon Sang Jeong
hsjeong@chungbuk.ac.kr

Nam Seok Oh
nada6411@naver.com

Min Young Kim
kmyqwer@naver.com

Gwi Yeong Jang
janggy@korea.kr

Yoon Jeong Lee
yjyj2@hanmail.net

So Yune Baek
6004_@naver.com

Jounsoo Lee
junsoo@chungbuk.ac.kr

¹ Department of Food Science and Biotechnology, Chungbuk National University, 1 Chungdaero, Seowon-gu, Cheongju 361-763, Republic of Korea

² Department of Herbal Crop Research, National Institute of Horticultural and Herbal Science, Rural Development Administration, Eumseong 27709, South Korea

different from those of samples treated with heat alone (Yoshioka and Yamada, 2002).

High hydrostatic pressure treatment (HHPT) is currently considered an attractive non-thermal treatment for preserving the attributes of food (Yang et al., 2019). High hydrostatic pressure technology for food processing has been developed extensively and potentially meets the requirements of modern consumers, who prefer minimally processed foods (Gould, 2001). An advantage of HHP technology is that it does not use heat; therefore, sensory and nutritional attributes of food products remain virtually unaffected, yielding foods with improved quality compared to those processed by traditional thermal methods (De Cordt et al., 1997; San Martin et al., 2002). High pressure disrupts the secondary and tertiary structures of micro-molecules, such as proteins and polysaccharides and alters their structural and functional integrity in a pressure-dependent manner (Marcos et al., 2005). The effectiveness of the treatment depends primarily on the pressure applied and on the holding time. HHP treatment usually has a more destructive effect in organisms with a high degree of organization and structural complexity, like the eukaryotes (Yuste et al., 2001).

Although consumers prefer high quality surimi sausages with reduced additive and increased surimi content, sausages with high surimi content produced by heat treatment do not possess the preferred physical properties. Moreover, studies have attributed the beneficial effects of protein gelation to HPT. In our best knowledge, this is the first study on the use of HPT in the manufacture of surimi sausage. The aim of this study was to investigate the physical properties of surimi sausages subjected to HPT and identify the effects of HPT.

Materials and methods

Materials

A raw surimi was purchased from GNK C., Ltd (Busan, Korea). Other additives, such as potato starch (Choheung Co., Ltd, Iahnsan, Korea), sugar (Samyangcorp Co., Ltd, Ulsan, Korea), table salt (Hanjucorp, Ulsan, Korea), condiment (Dasida gold, Cjcheiljedang Co., Ltd, Busan, Korea), and oil (soybean oil, Ottogi co., Ltd, Anyang, Korea) were purchased from the market.

Surimi sausage paste

The surimi (GNK C., Ltd) sample was melted at room temperature for 3 h. Using a wooden mortar and pestle, surimi (GNK C., Ltd) was ground for 10 min. Additives like potato starch (Choheung Co., Ltd), sugar

(Samyangcorp Co., Ltd), table salt (Hanjucorp), monosodium glutamate (MSG; Dasida gold, Cjcheiljedang Co., Ltd), oil (soybean oil, Ottogi co., Ltd), and water were added and the ingredients were ground for 10 min again after addition of the additives (Yun et al., 2017). After grinding, the samples were packaged in polyethylene (PE) film (Newpack, Seoul, Korea). The proportion of additives in the samples was as follows: 1% sugar (Samyangcorp Co., Ltd), 1% table salt (Hanjucorp), 1% oil (soybean oil, Ottogi co., Ltd), 0.5% MSG (Dasida gold, Cjcheiljedang Co., Ltd), and 21.5% water. Samples containing 50% of surimi (GNK C., Ltd) and 25% starch powder (Choheung Co., Ltd) were compared with those containing 70% surimi (GNK C., Ltd) and 5% starch powder (Choheung Co., Ltd).

High pressure treatment (HPT)

HPT was performed using a pressure treatment system with 0.5 L volume, max pressure as 600 MPa, air driven Pump, temperature is RT, and internal diameter is 50–100 ϕ (CIP-M300-50-150, Ilsin autoclave Inc, Daejeon, Korea). The surimi paste samples packed in PE films (Newpack) were subjected to pressures of 400, 500, and 600 MPa at 25 °C for 5, 15, and 30 min, respectively.

Heat treatment

The surimi paste samples were subjected to heat treatment by incubation in boiling water (100 °C) for 15 min. Samples were boiled following HHPT and analyzed in comparison with those subjected to heat treatment alone.

Stress-relaxation test

The stress relaxation test was performed using a texture (TA-XT2 express, Stable Micro System Ltd., Haslemere, Surrey, England) with a cylindrical aluminum probe (45 mm in diameter). The surimi samples were of 10-mm thickness. The surimi samples were compressed by a trigger force 10 g and the compressive strain applied was 60% of the strain (determined in a previous experiment). The test parameters were set as follow: pre-test speed, 3 mm/s; test speed, 3 mm/s; return speed, 3 mm/s; test distance, 6 mm; and hold time, 5 s (Shellhammer et al., 1997).

Puncture test

The puncture test was performed using a texture analyzer (TA-XT2 express, Stable Micro System Ltd.) with a cylindrical aluminum probe (3 mm in diameter). The surimi samples analyzed were of 10-mm thickness. Using a trigger force of 10 g the samples were penetrated up to 90% of the sample length (determined in a previous

experiment), and the magnitude of the penetration force was determined from the first peak of the curve (Lee and Chung, 1989). The test parameters were as follows: pre-test speed, 3 mm/s; test speed, 3 mm/s; return speed, 3 mm/s; test distance, 9 mm; and number of test cycles, 1. The force/diameter (N/mm) was calculated according to the following equation (Kim, 1981);

$$F/D = Kc \times D + Ks$$

F: yield-point force, D: diameter, Kc: compression coefficient, Ks: shear coefficient.

Shear test

The shear test was performed using a texture analyzer (TA-XT2 express, Stable Micro System Ltd.) with a light knife blade probe (1 mm blade). The surimi samples analyzed were of 10-mm thickness. Samples were subjected to a trigger force of 10 N and shear strain was applied 90% of sample length (determined in a previous experiment). The test parameters were as follows: pre-test speed, 3 mm/s; test speed, 3 mm/s; return speed, 3 mm/s; test distance, 9 mm; and number of test cycles, 1 (Walrath and Adams, 1983).

Scanning electron microscope (SEM)

Surimi samples were dried in a freeze dryer (FD5508, Ilshin Biobase, Kyunggi-do, Korea) and cut into sections of 1–2 mm thickness for microscopic examination. After coating with silver, the samples were viewed under a scanning electron microscope (S-2500C, Hitachi, Ltd., Tokyo, Japan). The size and number of pores on the cut surface was determined and the average value was used in analysis; the shape of the pores on the cut surface was also determined.

Statistical analysis

The surimi samples were measured in triplicates, and the results were expressed as mean $\pm$ standard deviation values. The correlation coefficients for different treatment conditions (heat treatment, HPT, and heat treatment after HPT) were analyzed by the Student's *t* test. The significance of differences in the mean values of treatment duration were determined by one-way analysis of variance (ANOVA) using the SPSS statistics software version 23.0 (SPSS Inc., Chicago, IL, USA).

Results and discussion

Evaluation of stress-relaxation parameters

The stress relaxation parameters of surimi products are summarized in Table 1. The hardness of samples containing 50% surimi subjected to heat treatment was 1328.33 N. The hardness of samples containing 70% surimi subjected to heat treatment after HPT ranged from 1001.40–1330.83 N, which was similar to the hardness of samples containing 50% surimi subjected to heat treatment.

Table 1 Stress–relaxation parameters of surimi sausage by heat treatment, HPT, and heat treatment after HPT, containing 70% of surimi

Treatment	Initial force (N)	Ration of relaxation (%)
Heat treatment		
50% surimi	1328.33 $\pm$ 84.26	36.68 $\pm$ 0.61
70% surimi	809.87 $\pm$ 63.59	39.28 $\pm$ 0.96
HPT		
400 MPa		
5 min	585.83 $\pm$ 58.49 ^{a**}	37.92 $\pm$ 0.45 ^b
15 min	586.80 $\pm$ 22.00 ^{ab**}	42.13 $\pm$ 0.56 ^{a**}
30 min	508.10 $\pm$ 77.94 ^{b**}	42.88 $\pm$ 0.69 ^{a***}
500 MPa		
5 min	409.87 $\pm$ 69.25 ^{b***}	37.28 $\pm$ 0.44 ^{b*}
15 min	583.70 $\pm$ 34.08 ^{a**}	38.81 $\pm$ 0.21 ^b
30 min	524.80 $\pm$ 78.54 ^{a**}	41.24 $\pm$ 0.34 ^{a*}
600 MPa		
5 min	566.75 $\pm$ 52.11 ^{a**}	37.08 $\pm$ 0.64 ^b
15 min	584.08 $\pm$ 96.46 ^{a*}	39.14 $\pm$ 0.19 ^{ab}
30 min	551.03 $\pm$ 14.98 ^{a**}	40.61 $\pm$ 0.53 ^a
Heat treatment after HPT		
400 MPa		
5 min	1003.20 $\pm$ 49.63 ^{b*}	36.87 $\pm$ 1.79 ^{b*}
15 min	1001.40 $\pm$ 88.70 ^{ab**}	38.28 $\pm$ 0.74 ^{a*}
30 min	1152.35 $\pm$ 21.90 ^{a***}	38.95 $\pm$ 0.53 ^a
500 MPa		
5 min	1060.28 $\pm$ 95.55 ^{b*}	37.50 $\pm$ 0.80 ^{b*}
15 min	1116.95 $\pm$ 79.63 ^{b**}	39.34 $\pm$ 1.57 ^a
30 min	1367.98 $\pm$ 14.06 ^{a***}	38.98 $\pm$ 0.04 ^a
600 MPa		
5 min	1151.75 $\pm$ 11.90 ^{b**}	38.79 $\pm$ 1.05 ^b
15 min	1289.43 $\pm$ 80.65 ^{a***}	37.19 $\pm$ 0.49 ^{c*}
30 min	1330.83 $\pm$ 35.10 ^{a***}	40.27 $\pm$ 0.39 ^a

* < 0.05, ** < 0.01, and *** < 0.001 indicate a significant between control (70%, heat treatment) and HPT conditions by *t* test

Different small letters in same pressure indicate a significant difference (*p* < 0.05) among different treatment time by Duncan's multiple range test

However, the hardness of samples containing 70% surimi subjected to HPT and heat treatment was 409.87, 586.80 and 809.87 N, respectively. The relaxation ratio indicates the springiness of the sample. A relaxation ratio of 100% indicates that the samples were completely springy, while elasticity was the main sensory attribute of the surimi sausages. The relaxation ratio of samples containing 50% surimi subjected to heat treatment was 36.68%. However, the elasticity, 36.87–42.88%, of samples containing 70% surimi was higher than that for samples containing 50% surimi under all treatment conditions. The elasticity increased with increasing treatment duration. Montero et al. (2001) and Zasyplin et al. (1996) reported that the relaxation ratio was higher for samples subjected to the combination treatment of high hydrostatic pressure and heat. These results postulated that a firmer protein structure was induced by the combined effect of heat and HPT (Apichartsrangkoon and Ledward, 2002).

Evaluation of the shear and puncture forces

Shear and puncture test results of surimi samples are summarized in Tables 2 and 3, respectively. The shear force and puncture force are correlated with elasticity. The greater the elasticity of the sample, the greater is its ability to maintain the initial shapes. Both forces were calculated by multiplying the penetration force with the distance of penetration (Tabilo-Munizaga and Barbosa-Canovas, 2004a). According to the results of the stress-relaxation test, samples containing 50% surimi was altered faster than samples containing 70% surimi. The first breaking position of samples containing 70% surimi was further along the sample, away from the starting point; consequently, the distance of penetration decreased. On multiplying these values, the shear and puncture forces for samples containing 70% surimi were lower than those for samples containing 50% surimi. For samples subjected to heat treatment, the shear force for samples containing 50% and 70% surimi were 1543.25 and 468.47 N, respectively. For samples containing 70% surimi subjected to HPT, the shear force was 226.41–381.29 N. For samples containing 70% surimi subjected to heat treatment after HPT, the shear force was 211.30–429.61 N, and decreased with increasing treatment duration. The same pattern was observed for the puncture force. For samples subjected to heat treatment, the puncture force for samples containing 50% and 70% surimi was 3337.92 and 1241.26 N/mm, respectively. For samples containing 70% surimi subjected to HPT, the puncture force was 911.72–1168.44 N/mm while for samples containing 70% surimi subjected to heat treatment after HPT, the force was 1140.45–1486.98 N/mm, and showed a decrease with increasing treatment duration. The shear force is affected by tip length and dither-to-receiver

Table 2 Shear test parameters of surimi sausage by heat treatment, HPT, and heat treatment after HPT, containing 70% of surimi

Treatments	Shear force (N)
Heat treatment	
50%	1543.25 ± 41.65
70%	468.47 ± 57.28
HPT	
400 MPa	
5 min	381.20 ± 39.67 ^{a*}
15 min	338.76 ± 40.42 ^{b**}
30 min	226.41 ± 32.96 ^{c***}
500 MPa	
5 min	383.53 ± 31.25 ^{a**}
15 min	349.93 ± 31.29 ^{a**}
30 min	289.64 ± 38.51 ^{b**}
600 MPa	
5 min	365.78 ± 50.04 ^{a*}
15 min	360.62 ± 39.05 ^{a**}
30 min	269.81 ± 49.20 ^{b***}
Heat treatment after HPT	
400 MPa	
5 min	424.21 ± 75.73 ^a
15 min	416.00 ± 63.71 ^a
30 min	324.21 ± 20.12 ^{b***}
500 MPa	
5 min	429.61 ± 68.85 ^a
15 min	410.06 ± 76.45 ^a
30 min	353.91 ± 73.87 ^{b*}
600 MPa	
5 min	419.30 ± 44.98 ^a
15 min	403.21 ± 58.57 ^a
30 min	311.30 ± 51.45 ^{b**}

* < 0.05, ** < 0.01, and *** < 0.001 indicate a significant between control (70%, heat treatment) and HPT conditions by *t* test

Different small letters in same pressure indicate a significant difference (*p* < 0.05) among different treatment time by Duncan's multiple range test

distance (Venkatesh et al., 2018). By the elasticity values of the surimi samples were increased with increasing pressure and duration, the probe for shear force was affected and the values was decreased with increasing treatment duration.

Number of pores and ratio of pore size

The number of pores and the pore size ratio are shown in Figs. 1 and 2, respectively. The number of pores decreased with increasing pressure and treatment duration for all treatment conditions. For samples subjected to heat

Table 3 Puncture test parameters of surimi sausage by heat treatment, HPT, and heat treatment after HPT, containing 70% of surimi

Treatments	Penetration force (N)	Force/Diameter (N/mm)
Heat treatment		
50% surimi	509.08 ± 71.85	3337.92 ± 202.31
70% surimi	197.75 ± 35.58	1241.26 ± 94.12
HPT		
400 MPa		
5 min	257.43 ± 31.07 ^{a**}	1168.44 ± 69.63 ^{a*}
15 min	223.44 ± 4.68 ^{b**}	1052.23 ± 51.67 ^{b***}
30 min	242.67 ± 23.94 ^{a**}	986.02 ± 25.86 ^{b***}
500 MPa		
5 min	245.38 ± 22.15 ^{a**}	1131.93 ± 63.53 ^{a***}
15 min	230.02 ± 23.51 ^{a*}	1021.88 ± 43.30 ^{b***}
30 min	183.13 ± 19.93 ^{b*}	911.72 ± 41.16 ^{c***}
600 MPa		
5 min	228.60 ± 7.92 ^{b**}	1116.29 ± 25.10 ^{a***}
15 min	253.53 ± 12.95 ^{a***}	1112.66 ± 56.29 ^{a***}
30 min	172.80 ± 7.40 ^{c**}	1025.50 ± 77.50 ^{b***}
Heat treatment after HPT		
400 MPa		
5 min	315.07 ± 47.93 ^{a*}	1444.00 ± 87.80 ^{a**}
15 min	259.77 ± 47.89 ^{b*}	1382.08 ± 98.74 ^a
30 min	219.67 ± 1.04 ^{b**}	1374.33 ± 70.13 ^{a*}
500 MPa		
5 min	272.31 ± 44.02 ^{a**}	1486.98 ± 70.10 ^{a***}
15 min	233.06 ± 21.39 ^{a***}	1361.49 ± 82.00 ^{b**}
30 min	200.94 ± 25.95 ^b	1218.57 ± 87.36 ^c
600 MPa		
5 min	274.92 ± 6.44 ^{a***}	1344.64 ± 12.64 ^{a**}
15 min	^b 224.86 ± 29.37 ^{b**}	1334.15 ± 60.17 ^a
30 min	215.57 ± 15.41 ^{c**}	1140.45 ± 47.87 ^{b***}

* < 0.05, ** < 0.01, and *** < 0.001 indicate a significant between control (70%, heat treatment) and HPT conditions by *t* test

Different small letters in same pressure indicate a significant difference (*p* < 0.05) among different treatment time by Duncan's multiple range test

treatment, 77 and 80 pores were observed in samples containing 50% and 70% surimi, respectively. For samples containing 70% surimi subjected to HPT at 400 MPa, the number of pores was 43–73; for samples subjected to HPT at 500 MPa the number of pores was similar, 47–68 and for samples subjected to HPT at 600 MPa, the number of pores was 24–28. A similar pattern was observed for samples subjected to heat treatment after HPT. For such samples, at 400 MPa, the number of pores was 53–64; at 500 MPa, the number of pores was similar, 49–56; and at 600 MPa, the number of pores was 16–36. The pores were classified into one of three categories (less than 30 µm, 30–60 µm, and

more than 60 µm). For samples subjected to HPT and for samples subjected to heat treatment after HPT, the number of pores with a pore size of more than 60 µm increased with increasing pressure and duration. For samples subjected to HPT at 400 MPa, the number of pores with a pore size less than 30 µm was 26–39%, with a pore size of 30–60 µm was 22–35%, and with a pore size more than 60 µm was 26–52%. At 500 MPa, the ratio of pores with a pore size less than 30 µm was 15–23%, with a pore size of 30–60 µm was 25–41%, and with a pore size more than 60 µm was 41–60%. At 600 MPa, the ratio of pores with a pore size less than 30 µm was 10–24%, with a pore size of 30–60 µm was 11–14%, and with a pore size more than 60 µm was 62–75%. For samples subjected to heat treatment after HPT, the pattern observed was similar to that observed for samples subjected to HPT. At 400 MPa, the ratio of pores with a pore size less than 30 µm was 21–39%, with a pore size of 30–60 µm was 25–32%, and with a pore size of more than 60 µm was 35–52%. At 500 MPa, the ratio of pores with a pore size less than 30 µm was 23–29%, with a pore size of 30–60 µm was 15–21%, and with a pore size than 60 µm was 43–59%. At 600 MPa, the ratio of pores with a pore size less than 30 µm was 3–19%, with a pore size of 30–60 µm was 11–25%, and with a pore size more than 60 µm was 66–81%. These results follow the same pattern as that reported by Tabilo-Munizaga and Barbosa-Canovas (2005) that surimi samples subjected to a pressure of 650 MPa showed a more compact structure than surimi gels subjected to 400 MPa pressure.

Shape of pores

The microstructure of the cutting surface of surimi samples is shown in Fig. 3. The samples subjected to only heat treatment or HPT showed circular pores or pores of free shape. However, samples subjected to heat treatment after HPT showed elliptical shaped pores compared to samples subjected to heat treatment or HPT. The pore size increased with increasing pressure. Lesch et al. (2002) reported that the free volume, resulting from imperfect molecular packing, determines the sensitivity of proteins against pressure, which decreases the volume. In contrast, heat treatment has the opposite effect and causes stronger molecular fluctuations, and, thus, increases the free volume. Consequently, exposure to combined heat and HPT may result in elliptical diagrams that indicate protein stability.

In this study, High pressure treatment (HPT) is an efficient method that is significantly used for the extraction of functional compounds and in sterilization. HPT is advantageous in that it allows gelation of proteins without exposure to heat; however, it was not used in the

Fig. 1 The pore number of surimi sausage by heat treatment, HPT, and heat treatment after HPT, containing 70% of surimi. * < 0.05, ** < 0.01, and *** < 0.001 indicate a significant between control (70%, heat treatment) and HPT conditions by *t* test

Fig. 2 The ratio of pore size of surimi sausage by HPT, containing 70% of surimi

Fig. 3 Microstructure of cutting surface on samples containing of 50% (A), 70% (B) surimi by heat treatment and 400 MPa (C), 500 MPa (D), and 600 MPa (E) by HPT and 400 MPa (F), 500 MPa (G), and 600 MPa (H) by heat treatment after HPT

manufacture of food products. Surimi sausage is a part of diverse dietary patterns, in particular, and it is made with various additives, such as starch and gel enhancers, that maintain its shape and sensory attributes. Recently, the consumer preference is for high-quality surimi products that contain reduced quantities of additives, such as starch and gel enhancers, and increased surimi content. In this study, the surimi sausages were manufactured with HPT and heat treatment. The physical properties, which depend on the treatment conditions and the quantities of the additives, were investigated. The elasticity of surimi samples improved on HPT and on heat treatment after HPT compared to that of samples subjected to heat treatment alone. The shear and puncture forces decreased in samples containing 70% surimi compared to samples containing 50% surimi due to increased elasticity of 70% surimi samples. Both forces were calculated by multiplying the penetration force with the distance of penetration. According to the stress-relaxation ratio, samples containing 50% surimi are easily altered than 70% surimi samples. In contrast, samples containing 70% surimi had higher elasticity than samples containing 50% surimi, and this increased elasticity induces less variation and the magnitude of shear and puncture forces, thus, decreased. The number of pores decreased with increasing pressure and treatment duration for all treatment conditions. These results indicated that the structure of protein becomes more compact on pressure treatment compared to heat treatment. The pores were elliptical shaped for samples subjected to a combination of HPT and heat treatment; this elliptical shape is indicative of protein stability. These results indicated that manufacturing processes that involve heat treatment after HPT can manufacture a surimi product containing decreased quantities of additives, such as starch and gel enhancers.

Acknowledgement This research was supported by the High Value added Food Technology Development Program (316052-03), Ministry of Agriculture, Food and Rural Affairs.

References

- Apichartsrangkoon A, Ledward DA. Dynamic viscoelastic behaviour of high pressure treated gluten–soy mixtures. *Food Chem.* 77: 317–323 (2002)
- De Cordt S, Denys S, Ludikhuyze L, Van den Broeck I, Van Loey A, Weemaes C, Tobback P. *High pressure application in food preservation and processing* (High Pressure Research in the Biosciences and Biotechnology), Leuven University Press, Leuven, Belgium. pp. 311–314 (1997)
- Gould GW. *The evolution of high pressure processing of foods* (Ultra high pressure treatments of foods), Springer, LD, UK. pp. 3–21 (2001)
- Kim YA. Texture properties of acron starch gels. *J. Food Sci. Nutri.* 20: 173–178 (1981)
- Lee CH. Surimi process technology. *Food Technol.* 38: 69 (1984)
- Lee CM, Chung KH. Analysis of surimi gel properties by compression and penetration tests. *J. Texture Stud.* 20: 363–377 (1989)
- Lesch H, Stadlbauer H, Friedrich J, Vanderkooi JM. Stability diagram and unfolding of a modified cytochrome c: what happens in the transformation regime? *Biophys. J.* 82: 1644–1653 (2002)
- Marcos B, Aymerich T, Garriga M. Evaluation of High Pressure Processing as an Additional Hurdle to Control *Listeria monocytogenes* and *Salmonella enterica* in Low-Acid Fermented Sausages. *J. Food Sci.* 70: 339–344 (2005)
- Montero P, Solas T, Pérez-Mateos M. Pressure-induced gel properties of fish mince with ionic and non-ionic gums added. *Food Hydrocoll.* 15: 185–194 (2001)
- Park JW. *Surimi and surimi seafood*. 3rd ed, CRC press, Boca Raton, US. (2013)
- San Martin MF, Barbosa-Cánovas GV, Swanson BG. Food processing by high hydrostatic pressure. *Crit. Rev. Food Sci. Nutr.* 42: 627–645 (2002)
- Shellhammer TH, Rumsey TR, Krochta JM. Viscoelastic properties of edible lipids. *J. Food Eng.* 33: 305–320 (1997)
- Shin YJ, Kim KS, Park GS. Texture and sensory characteristics of fish paste containing white Poria cocos wolf powder. *Korean J. Food Cook Sci.* 25: 119–125 (2009)
- Tabilo-Munizaga G, Barbosa-Canovas G.V. Color and textural parameters of pressurized and heat-treated surimi gels as affected by potato starch and egg white. *Food Res. Int.* 37: 767–775 (2004a)
- Tabilo-Munizaga G, Barbosa-Canovas G.V. Ultra high pressure technology and its use in surimi manufacture: an overview. *Food Sci. Technol.* 10: 207–222 (2004b)
- Tabilo-Munizaga G, Barbosa-Canovas G.V. Pressurized and heat-treated surimi gels as affected by potato starch and egg white: microstructure and water-holding capacity. *LWT. Food Sci. Technol.* 38: 47–57 (2005)
- Walrath DE, Adams DF. The Iosipescu shear test as applied to composite materials. *Exp. Mech.* 23: 105–110 (1983)
- Yang Y, Xia Y, Wang G, Tao L, Yu J, Ai L. Effects of boiling, ultra-high temperature and high hydrostatic pressure on free amino acids, flavor characteristics and sensory profiles in Chinese rice wine. *Food Chem.* 275: 407–416 (2019)
- Yoshioka K, Yamada A. Textural properties and sensory evaluation of soft surimi gel treated by high pressurization. *Biotechnol. Prog.* 19: 475–480 (2002)
- Yun JU, Jung KE, Kim DH, Nam KH, Sim KB, Jang MS. Quality characteristics of fried fish paste with squeezed Aronia melanocarpa juice. *Korean J. Food Preserv.* 24: 13–20 (2017)
- Yuste J, Capellas M, Pla R, Fung DY, Mor-mur MONTSERRAT. High pressure processing for food safety and preservation: a review. *J. Rapid Methods. Autom. Microbiol.* 209: 1–10 (2001)
- Venkatesh V, Northcutt R, Heinemann C, Sundaresan V. B. A. structural model of ultra-microelectrodes for shear-force based scanning electrochemical microscopy. *J. Intell. Mater. Syst. Struct.* 29: 3562–3571 (2018)
- Zasyplin DV, Dumay E, Cheftel JC. Pressure-and heat-induced gelation of mixed β -lactoglobulin/xanthan solutions. *Food Hydrocoll.* 10: 203–211 (1996)

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.