Managing the lionfish: influence of high intensity ultrasound and binders on textural and sensory properties of lionfish (*Pterois volitans*) surimi patties

L. Jiménez-Muñoz^{1,2,3} · M. Quintanilla³ · A. Filomena^{2,3}

Revised: 20 January 2019 / Accepted: 6 March 2019 / Published online: 21 March 2019
© Association of Food Scientists & Technologists (India) 2019

Abstract Lionfish (*Pterois volitans*) is an invasive and predatory species whose proliferation over the Caribbean Sea threatens to cause great damage to coral reefs by negatively affecting the balance of the ecosystem. Control strategies have been the most effective way to reduce the negative impact of the lionfish. The development of diversified food products based on lionfish could support these strategies. The objective of the present study was to investigate the influence of ultrasound and the addition of binders in different concentrations: Egg white liquid (EWL) and corn starch (ST) on texture, microstructure and sensory evaluation properties of patties made of lionfish surimi. Each set of binders was added up to 3% varying proportions. The texture profile, water holding capacity, sensory qualities and fractal dimension of scanning electron microscopy images were analyzed to evaluate the quality of the product based on surimi gel. Results showed that the application of ultrasound and the use of binders enhanced the properties of patties made of lionfish surimi. The addition of EWL (3%) improved the water holding capacity and hardness of the final product. However, the

fractal dimension of the images was higher in samples processed using ultrasound and without binder addition.

Keywords Fractal dimension · Lionfish · Patties · Surimi · Ultrasound

Introduction

Invasion of predatory lionfish species (*Pterois volitans*) poses a threat to the coral ecosystems of the western Atlantic Ocean. Lionfish have the capacity to spread rapidly to new marine environments, drastically reducing the population of species present in the reefs (Morris et al. 2011). This species has established in an area that encompasses the eastern coast of the United States, Bermuda, Gulf of Mexico and the Caribbean region. To mitigate the negative impact that this species represents, control strategies such as removal and consumption at a local scale have been performed (Morris et al. 2011). The diversification of lionfish consumption could lead to increasing the effectiveness of these strategies.

Surimi gel has earned great acceptance in the global market due to its characteristics: high myofibrillar proteins concentration which have an excellent gel-forming ability, low-fat content, ready-to-eat product and a unique texture (Fan et al. 2017a, b). To obtain surimi, a process of washing cycles must be carried out, which removes sarcoplasmic proteins, nitrogen compounds, fat, blood, aromatic compounds and other impurities. This improves the quality of the myofibrils (Athallah and Park 2016) resulting in a product with better texture, color and smell (Park et al. 2013). However, each washing cycle requires large amounts of water (Martín-Sánchez et al. 2009), some alternatives evaluated for surimi production showed a

Electronic supplementary material The online version of this article (<https://doi.org/10.1007/s13197-019-03698-6>) contains supplementary material, which is available to authorized users.

✉ A. Filomena
anna.filomena@unisabana.edu.co

¹ Maestría en Diseño y Gestión de Procesos, Universidad de La Sabana, Chía, Colombia

² Grupo de investigación Alimentación, Gestión de Procesos y Servicios, Universidad de La Sabana, Chía, Colombia

³ Grupo de investigación Procesos Agroindustriales, Universidad de La Sabana, Chía, Colombia

decrease in water usage. Power ultrasound (20 kHz; 10–1000 W) is an emerging technology able to replace a washing cycle in surimi processing (Filomena et al. 2012) which is usually used to achieve physical or chemical modifications of food properties (Kentish and Ashokkumar 2011). Generally, ultrasound increases the efficiency of the diffusion of components, and cavitation generates high shear forces and microbubbles that enhance surface erosion, fragmentation and mass transfer. Ultrasound has been shown to improve the hardness and WHC of the gel (Zhang et al. 2011). When high-quality surimi is the main component of a product, the predominant texture tends to be gummy (Tabilo-Munizaga and Barbosa-Cánovas 2005). To adapt the product to the textural preferences of consumers, it is necessary to add ingredients to the surimi to improve the textural properties and water holding capacity (WHC) (Park et al. 2013). Sodium Citrate was used as a cryoprotectant, a food additive used to prevent denaturation in surimi during frozen storage (Pavathy and Sajan 2014).

Starch is an additive used as a thickener or gelling agent that adds stability and replaces expensive ingredients. According to Park et al. (2013) starch is used to maintain the hardness of the gel and those with high amylopectin content form cohesive and adhesive gels. The egg white is also a common additive in the production of surimi. These binders are the ingredients used to improve the functional, textural and sensory properties of surimi-type products (Park et al. 2013).

Considering lionfish is a new species introduced in the human diet, there are few reports on the sensory acceptance of its derived products. Sensory attributes, texture properties, and consumer acceptance should be studied (Morris et al. 2011). The objective of this research was to evaluate the influence of ultrasound and different percentages of binders on the textural properties and sensory acceptability of lionfish surimi patties.

Materials and methods

Lionfish acquired in local markets of Cartagena (10° 23'58 "N; 75° 30'51"W) (Colombia), was transported and stored at a temperature of -20°C for a term of less than a week before processing surimi patties.

Surimi preparation process

Sixteen samples of surimi patties were studied (Table 1). The samples were prepared using two methods: conventional (CN) and ultrasound (US). These variables are reported to affect the texture of surimi (Hunt et al. 2010; Zhang et al. 2011; Filomena-Ambrosio et al. 2015).

Conventional method: Sliced lionfish fillets ($2 \times 2 \times 2$ cm), were leached with water at 4°C in a ratio p/p 1:3 (fillet: water), for three washing cycles (15 min), pressed and homogenized with salt (0.1–0.2%), sugar (0.2–0.3%) and sodium citrate (0.3–0.4%).

Ultrasound method: Sliced lionfish fillets ($2 \times 2 \times 2$ cm), were leached with water at 4°C in a ratio p/p 1:3 (fillet: water), for two washing cycles (15 min), then placed in an ultrasound bath (ELMA, Singen, Germany), at 37 kHz; 150 W, 15–20 (min), pressed and homogenized with salt (0.1–0.2%), sugar (0.2–0.3%) and sodium citrate (0.3–0.4%).

To obtain a set of surimi patties with ranges of different textural characteristics 16 different sample formulations were selected. Each patty weighed 80 ± 2.0 g. The patties were prepared by adding 3% (2.4 g) salt, 2% (1.6 g) sugar and 0.3% (0.24 g) sodium citrate. The rest of the formulation consisted of a different concentration of binders (cornstarch maizena® (ST) and liquid egg white (EW) up to 3% as shown in Table 1.

Surimi patties preparation process

The patties prepared from surimi using two treatments, CN and US, were mixed in a ratio of 3:1 w/w, seasoned with spices in a semi-fat medium, called guiso. The preparation of the stew used tomato (62%), onion (33%) and garlic (5%) cut in small pieces, previously homogenized and fried over low heat, without the addition of salt.

Lionfish patty is presented in Fig. 1. The patties were prepared following the method suggested by Dreeling (Ramadhan et al. 2012). Each patty was cooked on both sides on a flat surface grill until the minimum internal temperature of 80°C was reached. Subsequently, it was coated with wheat flour, egg yolk, and breadcrumb, then cooked a second time during six min.

Water holding capacity

This parameter was measured using the modified method of Jauregui et al. (1981). Samples of 1.500 ± 0.100 g were placed on pre-weighed filter paper (a piece of #3 Whatman filter paper n.50°). The samples were centrifuged at 4°C for 20 min (Universal 32R Hettich Zentrifugen), and the filter paper was weighed again to determine the WHC by the weight difference (Filomena-Ambrosio et al. 2015). The measurements were made in triplicate.

Moisture

Samples of $5.0 \text{ g} \pm 0.1 \text{ g}$ were dried during 4 h at $102^{\circ}\text{C} \pm 0.1^{\circ}\text{C}$ using the stove drying method (985.14 AOAC).

Table 1 Coding for different treatments studied

Treatment	Method	Concentration of corn starch % (w/w)	Concentration of egg white % (w/w)
CN_CTRL	Conventional	0	0
CN_3EW	Conventional	0	3
CN_3ST	Conventional	3	0
CN_1.5EW	Conventional	1.5	1.5
CN_2.01EW	Conventional	0.99	2.01
CN_0.99EW	Conventional	2.01	0.99
CN_2.25EW	Conventional	0.75	2.25
CN_0.75EW	Conventional	2.25	0.75
US_CTRL	Ultrasound	0	0
US_3EW	Ultrasound	0	3
US_3ST	Ultrasound	3	0
US_1.5EW	Ultrasound	1.5	1.5
US_2.01EW	Ultrasound	0.99	2.01
US_0.99EW	Ultrasound	2.01	0.99
US_2.25EW	Ultrasound	0.75	2.25
US_0.75EW	Ultrasound	2.25	0.75

CN conventional, *US* ultrasound, *EW* egg white, *ST* corn starch

Fig. 1 Patty elaborated from lionfish surimi

Texture profile analysis

A texture profile analysis (TPA) was performed on a TA.XT Plus Texture Analyzer (Stable Micro Systems, UK) with a 25 mm aluminum test tube and a strain distance of 10 mm. The software used for the analysis was Texture Exponent. The attributes evaluated were hardness, cohesiveness and gumminess (Texture technologies 2003).

Sensory analysis

Four of the sixteen samples were selected to perform the sensory analysis. The selection was made according to the desirability level of the product based on their WHC (the samples reporting the highest and lowest). The treatments with lowest values were CN_CTRL, CN_1.5EW and with highest values were US_CTRL and US_3ST. The

descriptive analysis of texture, taste, flavor, saltiness, and sweetness was evaluated by the panelists using a nine-point scale, in which 9 represented the highest score for the attribute and 1 represented the lowest (Stone et al. 2012). The samples were presented to each participant in a sequential monadic manner. The sample presentation was randomized. Thirty-two gastronomy students from Universidad de La Sabana who were currently studying sensory analysis participated in the test as panelists.

Scanning electron microscopy

To perform scanning electron microscopy, the samples were lyophilized using the equipment Labconco, model FreeZone 12L, USA. The process consisted of three steps: Freezing (− 40 °C for 3 h), sublimation (0 and − 10 °C for a period of 24 h) and finally desorption (20 °C and vacuum pressure of 4 mbar).

Fractal dimension analysis obtained from SEM images

The dried samples were placed on carbon tape (Ted 57, Pella, Inc., Mountain Lakes Blvd, Redding, US) and observed by scanning electron microscope (SEM, Phenom G2 Pro®, Belgium). To appreciate the difference in the microstructure of the patties, photos were taken at a magnification of 5000× and 5 kV. The samples were cut into 5 mm portions. The microscope images were analyzed with ImageJ and SDBC Image J plugin. The fractal

dimension values (Df) indicate the degree of gel surface irregularity since protein aggregate formation can be characterized as a kind of fractal. Df was calculated using the box count method (Zhu et al. 2016).

Statistical analysis

A categorical multifactorial experimental design with two factors (method and binder) was employed. A two-way analysis of variance was carried out. The effects of the method and mixture of binders (egg white and starch) were evaluated. In all the models, normal distribution of residuals and homogeneous variances were detected. The Tukey HSD test was performed to identify the difference in means between treatments. All experimental runs were performed in triplicate. Four treatments were selected according to the desirability of the product based on their WHC (the two highest and the two lowest). For the sensory test, an ANOVA was carried out. The frequencies were used to calculate the Chi square value. The statistical software used were Design expert v10 and Statgraphics XVII.

Results and discussion

Surimi patties analysis

The values for WHC, texture parameters and fractal dimension (Df) are presented in Table 2.

Water holding capacity (WHC)

The statistical analysis of the results indicated that the two factors (method and binder) had an effect on WHC and that there was also an interaction between factors ($p < 0.05$). The treatments that had higher values for WHC were US_3ST and US_3EW. Starch is used primarily for its high water-holding capacity and its ability to replace a portion of fish protein while maintaining ideal gel properties (Park et al. 2013). The strengthening effect of cornstarch on the surimi gel induced by cooking heat is probably due to the starch granules embedded in the matrix and exerting pressure on it, resulting in a more compact and hard gel (Kim and Lee 1987). Authors such as Alvarez et al. (1997) reported that waxy maize starch had a boosting effect on WHC in cooked surimi gels and the mixed network of surimi-starch retained the added water during the gel preparation. The starch granules absorb and retain water during the formation of the gel (Paker and Matak 2017), when applying high temperatures they interact with the protein and gelatinize, increasing the hardness of the gel (Hunt et al. 2010). Hema et al. (2016) mentioned that to increase the WHC of products made from surimi gel with addition of cornstarch, it is necessary to process them at high temperatures (> 80 °C). Since the gelatinization temperature is influenced by the presence of myofibrillar proteins and the available hydrodynamic water for gelation. However, in their experiments, the WHC of the surimi prepared

Table 2 Water holding capacity, texture profile analysis and fractal dimension of surimi patties processed by conventional and ultrasound method with different binder concentrations

Treatment	Water holding capacity (g of held water/g of sample)	Hardness (N)	Cohesiveness	Gumminess (N)	Fractal dimension
CN_CTRL	29.45 ± 1.62 ^a	16.76 ± 3.09 ^a	0.60 ± 0.07 ^d	10.05 ± 2.07 ^{abcd}	2.44 ± 0.01 ^a
CN_3EW	36.59 ± 2.79 ^{bc}	29.26 ± 1.59 ^{cde}	0.35 ± 0.07 ^{abc}	10.29 ± 2.67 ^{abcd}	2.50 ± 0.01 ^c
CN_3ST	38.55 ± 1.44 ^{bc}	24.36 ± 1.52 ^{bc}	0.41 ± 0.09 ^{bc}	10.13 ± 2.82 ^{abcd}	2.51 ± 0.01 ^{cd}
CN_1.5EW	37.53 ± 2.47 ^b	28.11 ± 4.18 ^{bcd}	0.36 ± 0.07 ^{abc}	10.43 ± 3.40 ^{abcd}	2.50 ± 0.01 ^c
CN_2.01EW	38.44 ± 3.12 ^{bc}	27.32 ± 3.86 ^{bcd}	0.35 ± 0.04 ^{abc}	9.48 ± 1.31 ^{abc}	2.46 ± 0.01 ^b
CN_0.99EW	37.97 ± 0.50 ^{bc}	33.64 ± 0.85 ^{de}	0.44 ± 0.05 ^c	15.02 ± 1.90 ^{def}	2.54 ± 0.01 ^e
CN_2.25EW	38.87 ± 2.58 ^{bc}	22.54 ± 4.01 ^c	0.30 ± 0.03 ^{ab}	6.84 ± 2.10 ^{ab}	2.52 ± 0.01 ^{cd}
CN_0.75EW	39.21 ± 2.60 ^{bcd}	22.02 ± 0.50 ^{ab}	0.29 ± 0.06 ^a	6.37 ± 1.27 ^a	2.51 ± 0.01 ^{cd}
US_CTRL	36.21 ± 1.60 ^{bc}	22.63 ± 2.75 ^{bc}	0.36 ± 0.06 ^{abc}	7.13 ± 1.32 ^{abc}	2.60 ± 0.01 ^f
US_3EW	43.10 ± 1.25 ^{de}	31.30 ± 3.39 ^{de}	0.39 ± 0.07 ^{abc}	12.12 ± 1.07 ^{cde}	2.52 ± 0.01 ^d
US_3ST	45.93 ± 1.29 ^e	27.23 ± 1.65 ^{bcd}	0.39 ± 0.01 ^{abc}	10.62 ± 0.54 ^{abcd}	2.50 ± 0.01 ^c
US_1.5EW	39.63 ± 2.82 ^{cd}	32.27 ± 4.73 ^{de}	0.34 ± 0.07 ^{abc}	11.44 ± 3.85 ^{bcd}	2.51 ± 0.01 ^{cd}
US_2.01EW	39.82 ± 2.35 ^{cd}	35.36 ± 6.47 ^e	0.45 ± 0.12 ^c	16.73 ± 7.18 ^{ef}	2.46 ± 0.01 ^b
US_0.99EW	39.47 ± 3.63 ^{bcd}	42.20 ± 6.86 ^f	0.46 ± 0.03 ^c	19.29 ± 3.08 ^f	2.59 ± 0.02 ^f
US_2.25EW	38.96 ± 2.80 ^{bc}	29.04 ± 2.61 ^{cde}	0.42 ± 0.08 ^c	12.32 ± 2.86 ^{cde}	2.52 ± 0.01 ^d
US_0.75EW	40.00 ± 1.31 ^{cd}	25.43 ± 5.48 ^{bc}	0.39 ± 0.01 ^{abc}	9.89 ± 1.90 ^{abc}	2.45 ± 0.01 ^{ab}

Data are given as mean ± standard deviation. Different letters indicate statistically significant differences ($p < 0.05$)

with cornstarch was lower than that of the control. This was probably due to the fact that the starch granules are more thermostable and start to gel after the protein groups (Kong et al. 1999). Both the protein and the starch compete for the water available in the gel. As the proteins form crosslinks more quickly, the gelation of the starch is partially prevented by the lack of water or because the granules are trapped in the protein network (Hunt et al. 2010). According to Paker and Matak (2017), it is also possible that the high water absorption and retention capacity of the starch granules increase the thermal stability of the protein fraction without competing with protein groups for the absorption of water. Protein gelation can physically and chemically bind water in the gel matrix, which limits the availability of water for starch gelation (Chung and Lee 1991). When there is enough water in the system to hydrate and gelatinize the starch there is no competition between starch and protein that affects the gelling of its components, thus starch would have the ability to gel properly (Alvarez et al. 1997). It is possible that in US_3ST surimi patties, the added stew “guiso” provided enough water for both starch and protein to properly gel, which increased WHC values.

In the research conducted by Hema et al. (2016), it was reported that surimi gels prepared with EW had higher moisture content than other treatments. Egg white forms stabilizing foam with proteins at neutral pH, which are more stable due to the lack of repulsive interactions. This promotes interactions between fish proteins-egg white proteins and the formation of the viscofilm at the interface, which adsorbs more protein. Subsequently, the heating coagulates the egg white protein, leaving cracks and crevices that have non-polar groups increasing the WHC in the gel matrix. In mixed gels, egg white, starch, and fish proteins compete for available water, which prevents the starch from obtaining the water necessary for its swelling and gelatinization (Tabilo-Munizaga and Barbosa-Cánovas 2005). This phenomenon explains why the WHC of mixed gel treatments did not present the highest value.

Treatments processed with US obtained higher values for WHC than gels processed by CN. These data coincide with those reported by McClements (1995) and Turantas et al. (2015). Ultrasound works by generating wave frequencies that act on the matrix as pulsations that affect the spaces formed between the myofibrils (Zhang et al. 2011). The wave frequencies modify the structure of the sarcolemma containing the sarcoplasmic proteins, which are removed during the washing stages due to their low molecular weight, thus creating a structure that retains a greater amount of water (Filomena-Ambrosio et al. 2015).

Texture profile analysis (TPA)

Hardness

The values obtained for the hardness of patties are presented in Table 2. Method and binder had an effect on hardness ($p < 0.05$). However, there is no interaction between the factors. The patties processed with US showed higher values for hardness than the ones processed with CN ($p < 0.05$). According to Fan et al. (2017), high acoustic intensities generated by ultrasound can develop greater hardness in the surimi gel. This is due to the mechanical effect of the ultrasound, which improves the packing compactness of the molecules of protein, as well as the degree of interaction between them. The ultrasound treatment US_0.99EW had higher hardness values than that of the control. According to Suklim et al. (2003) and Hunt et al. (2009), starch increases the hardness of surimi more effectively at low concentrations (3%) than higher concentrations (6–9%). However, US_3EW treatment had a greater hardness than US_3ST, probably due to the coagulant capacity of ovalbumin present in egg white (Hema et al. 2016). Iso et al. (1985) suggested that egg white absorbs water within the structural network without increasing the number of protein cross-links in the gel.

Cohesiveness

The addition of binders did not improve the cohesiveness of treatments processed with CN ($p < 0.05$). The addition of binders in surimi patties processed with CN showed a decrease in cohesiveness compared to the control. Ultrasound has been shown to increase water holding capacity and cohesiveness in meat and meat products (McClements 1995; Turantas, et al. 2015). The cohesiveness of treatments US_2.01EW, US_2.25EW and US_0.75EW were greater than those processed with the same addition of binders but obtained by CN. According to Suklim et al. (2003) the addition of albumin up to 2% can improve the cohesiveness of meat products such as squid patties. The addition of starch in a gel matrix (e.g., surimi) also increases the hardness of the gel and the cohesiveness due to its ability to increase its size, absorb and bind the surrounding water in the gel once gelatinized (Suklim et al. 2003). Consequently, the gel becomes more compact and firm.

Gumminess

Both factors had an effect on the gumminess of surimi patties ($p < 0.05$). There was no interaction between them. The addition of binders increased the gumminess values for US treatments compared to the controls. The surimi patties

made with US showed higher values than those made with CN because the gumminess was calculated by multiplying hardness and cohesiveness (Tabilo-Munizaga and Barbosa-Cánovas 2005).

Scanning electron microscopy (SEM)

The SEM images of the treatments are presented in Fig. 2. The D_f values indicate uniformly distributed porosity level around the centroid of the total image (Zhu et al. 2016). According to the values obtained for the different treatments, the D_f can vary according to the processing method and the concentration of the binder present in the structure, these vary from 2.44 to 2.60. In addition, interaction

between the two factors was found ($p < 0.05$). The value of D_f for surimi patties made with ultrasound and no addition of binder (US_CTRL) obtained the highest value (2.60) while the value obtained by CN_CTRL had the lowest value (2.44). The treatments processed with CN showed higher values than its control when the binders were added. The addition of binders favors a high degree of complexity and the formation of a more ordered microstructure (Marangoni, et al. 2000). However, this behavior is not observed on the patties processed with US, probably due to a reorganization of the three-dimensional protein structure when adding the binders. Surimi patties obtained by the US method exhibit a higher interconnected protein network than those obtained by CN.

In the SEM image of US_1.5EW, corn starch granules (15 μm) can be observed (Izidoro et al. 2007; Park et al. 2013; Alcázar-Alay and Meireles 2015). On the contrary, in none of the samples obtained by the US method these granules are appreciated. This could be related to the molecular structure of the starch that allows it to pass through different stages, from the absorption of water up to the disintegration of the granule. The absorption of water and consequent swelling of the starch granule contributes to the separation of amylose-amylopectin phase and loss of crystallinity, which in turn promotes leaching of amylose in the inter-granular space (Alcázar-Alay and Meireles 2015). It is possible that in the surimi patties elaborated by CN the starch granule did not reach the disintegration phase.

Sensory analysis

The sensory attributes hardness and gumminess showed significant differences between treatments ($p < 0.05$). The sample US3_EW was perceived by panelists as the patty with hardest texture. Montero & Gómez-Guill (1996) found that the egg had a positive effect on the hardness of sardine surimi (*Sardina pilchardus*). Egg white absorbs water within the network structure without increasing the number of protein crosslinks in the gel (Suklim et al. 2003). According to Hema et al. (2016) the egg white provides strength to the gel due to the coagulation capacity of ovalbumin and it is suited for surimi based products. The sample US_3ST was perceived as the gummiest patty, starch can improve gel strength which might increase gumminess (hardness*cohesiveness) values (Sarıçoban et al. 2009). There were no significant differences for the attributes saltiness, sweetness and overall flavor ($p > 0.05$). The mean of the sensory attributes are shown in Table 3.

In the sensory test only the texture parameter showed significant differences ($p < 0.05$) with an $X^2 = 12.25$. In which the patty US3_EW was marked more frequently as the product with better texture. According to Chang-Lee

Fig. 2 Scanning electron microscopy of surimi patties at 5000×

Table 3 Mean of scores and standard deviations

Attributes	Samples			
	CN_CTRL	CN_1.5EW	US_3ST	US_3EW
Hardness	5.4 ± 2.2 ^a	5.6 ± 1.8 ^a	5.8 ± 2.5 ^a	6.8 ± 1.8 ^b
Gumminess	5.6 ± 2.5 ^a	4.8 ± 2.2 ^a	6.7 ± 1.8 ^b	5.8 ± 2.3 ^a
Overall flavor	6.6 ± 2.1 ^a	6.5 ± 1.8 ^a	6.2 ± 2.1 ^a	6.8 ± 2.5 ^a
Saltiness	5.0 ± 2.3 ^a	4.8 ± 1.5 ^a	4.8 ± 1.9 ^a	4.8 ± 2.0 ^a
Sweetness	3.9 ± 2.4 ^a	3.5 ± 2.6 ^a	3.2 ± 2.4 ^a	3.2 ± 2.2 ^a

Data are given as mean ± standard deviation. Different letters indicate statistically significant differences ($p < 0.05$)

CN conventional, US ultrasound, EW egg white, ST corn starch

et al. (1990) and Sun and Holley (2011) protein additives such as egg white can improve the characteristics of the gel by providing greater gel hardness.

Conclusion

The use of new raw materials as lionfish and emerging technologies as ultrasound proved to be a successful approach to understand the effect on textural, microstructure and sensory parameters of novel products. The ultrasound treatment could be an ideal method because of its technological and sensory advantages, in line with consumer preference of the final products. Binders provide an improvement in texture for hardness and gumminess which evidence that ultrasound and binders could be used together to develop lionfish surimi derived products of good quality. The sample processed with US and addition of 2.01% starch and 0.99% egg white (w/w) showed the best performance for hardness, gumminess and fractal dimension.

Acknowledgements Authors would like to thank the University of La Sabana and COLCIENCIAS for funding the development of research within the framework of Project EICEA-98-2015., Project 761-2016 of COLCIENCIAS.

References

- Alcázar-Alay SC, Meireles MA (2015) Physicochemical properties, modifications and applications of starches from different botanical sources. *Food Sci Technol* 35(2):215–236. <https://doi.org/10.1590/1678-457X.6749>
- Alvarez C, Couso I, Solas M, Tejada M (1997) Waxy corn starch affecting texture and ultrastructure of sardine surimi gels. *Eur Food Res Technol* 204:121–128. <https://doi.org/10.1007/s002170050048>
- Athaillah ZA, Park JW (2016) Characterization of surimi slurries and their films derived from myofibrillar proteins with different extraction methods. *Food Biosci* 15:118–125. <https://doi.org/10.1016/j.fbio.2016.07.002>
- Chang-Lee MV, Lampila LE, Crawford DL (1990) Yield and composition of surimi from Pacific whiting (*Merluccius productus*) and the effect of various protein additives on gel strength. *J Food Sci* 55(1):83–86. <https://doi.org/10.1111/j.1365-2621.1990.tb06022.x>
- Chung KH, Lee CM (1991) Water binding and ingredient dispersion pater effects on surimi gel texture. *Food Sci* 56(5):1263–1266. <https://doi.org/10.1111/j.1365-2621.1991.tb04748.x>
- Fan D, Huang L, Li B, Huang J, Zhao J, Yan B, Zhang H (2017a) Acoustic intensity in ultrasound field and ultrasound-assisted gelling of surimi. *LWT Food Sci Technol* 75:497–504. <https://doi.org/10.1016/j.lwt.2016.08.002>
- Fan M, Hu T, Zhao S, Xiong S, Xie J, Huang Q (2017b) Gel characteristics and microstructure of fish myofibrillar protein/casava starch composites. *Food Chem* 218:221–230. <https://doi.org/10.1016/j.foodchem.2016.09.068>
- Filomena A, Diaz L, Puig Ana, Sotelo I (2012) Efecto de ultrasonido sobre la actividad ATP-asa y propiedades funcionales en surimi de tilapia (*Oreochromis niloticus*). *Vitae* 19(1):S379–S381
- Filomena-Ambrosio A, Quintanilla-Carvajal MX, Puig A, Hernando I, Hernandez-Carrion M, Sotelo-Diaz I (2015) Changes of the water-holding capacity and microstructure of panga and tilapia surimi gels using different stabilizers and processing methods. *Food Sci Technol Int* 22(1):68–78. <https://doi.org/10.1177/1082013214568876>
- Hema K, Shakila RJ, Shanmugam SA, Jawahar P (2016) Functional properties of restructured surimi gel product prepared from low valued short nose white tripod fish (*Triacanthus brevirostris*). *J Food Process Technol* 7(6):6–11. <https://doi.org/10.4172/2157-7110.1000597>
- Hunt A, Getty KJK, Park JW (2009) Roles of Starch in surimi seafood: a review. *Food Review International* 25(4):299–312. <https://doi.org/10.1080/87559120903155834>
- Hunt A, Getty KJ, Park JW (2010) Development of temperature tolerant surimi gels using starch-protein interactions. *J Food Qual* 33(S1):119–136. <https://doi.org/10.1111/j.1745-4557.2010.00303.x>
- Iso N, Mizuno H, Saito T, Lin CY, Fujita T, Nagashisa E (1985) The effect of additives (egg white and soy protein) on the rheological properties of kamaboko. *Bull Jpn Soc Sci Fish* 51:485–488. <https://doi.org/10.2331/suisan.51.485>
- Izidoro DR, Junior BD, Windson C, Haminiuk I, Sierakowski MR, João R, Scheer ADP (2007) Granules morphology and rheological banana (*Musa cavendishii*) and corn (*Zea mays*) starch gels. *Ciência e Agrotecnol* 35(5):1443–1448
- Jauregui C, Regenstien A, Baker R (1981) A simple centrifugal method for measuring expressible moisture, a water binding property of muscle foods. *J Food Sci* 46(4):1271–1273. <https://doi.org/10.1111/j.1365-2621.1981.tb03038.x>
- Kentish S, Ashokkumar M (2011) The physical and chemical effects of ultrasound. In: Feng H, Barbosa-Cánovas GV, Weiss J (eds) *Ultrasound technologies for food and bioprocessing*. Springer, New York, pp 1–10
- Kim JM, Lee CM (1987) Effect of starch of textural properties of surimi gel. *J Food Sci* 52(3):722–725. <https://doi.org/10.1111/j.1365-2621.1987.tb06711.x>
- Kong CS, Ogawa H, Iso N (1999) Compression properties of fish-meat gel as affected by gelatinization of added starch. *J Food Sci* 64:283–286. <https://doi.org/10.1111/j.1365-2621.1999.tb15883.x>
- Marangoni AG, Barbut S, Mcgauley SE, Marcone M, Narine SS (2000) On the structure of particulate gels—the case of salt-induced cold gelation of heat-denatured whey protein isolate.

- Food Hydrocoll 14:61–74. [https://doi.org/10.1016/S0268-005X\(99\)00046-6](https://doi.org/10.1016/S0268-005X(99)00046-6)
- Martín-Sánchez AM, Navarro C, Pérez-Álvarez JA, Kuri V (2009) Alternatives for efficient and sustainable production of surimi: a review. *Compr Rev Food Sci Food Saf* 8(4):359–374. <https://doi.org/10.1111/j.1541-4337.2009.00087.x>
- McClements DJ (1995) Advances in the application of ultrasound in food analysis and processing. *Trends Food Sci Technol* 6(9):293–299. [https://doi.org/10.1016/S0924-2244\(00\)89139-6](https://doi.org/10.1016/S0924-2244(00)89139-6)
- Montero P, Gómez-Guill C (1996) Behaviour of egg white and starch in gelation of sardine muscle (*Sardina pilchardus*). *Eur Food Res Technol* 202(4):294–295. <https://doi.org/10.1007/BF01206099>
- Morris JA, Thomas A, Rhyné AL, Breen N, Akins L, Nash B (2011) Nutritional properties of the invasive lionfish: a delicious and nutritious approach for controlling the invasion. *Aquac Aquar Conserv Legis* 5:99–102
- Paker I, Matak KE (2017) Effects of starch concentration on calcium-enhanced black bullhead catfish protein gels. *Food Sci Nutr* 5(3):763–769. <https://doi.org/10.1002/fsn3.456>
- Park JW, Ooizumi T, Hunt AL (2013) Ingredient technology for surimi and surimi seafood, 3rd edn. CRC Press, Boca Raton
- Pavathy U, Sajjan G (2014) Influence of cryoprotectants levels on storage stability of surimi from *Nemipterus japonicus* and quality of surimi-based products. *J Food Sci Technol* 51:982. <https://doi.org/10.1007/s13197-011-0590-y>
- Ramadhan K, Huda N, Ahmad R (2012) Physicochemical and sensory characteristics of burger made from duck surimi-like material. *J Poult Sci* 91(9):2316–2323. <https://doi.org/10.3382/ps.2011-01747>
- Sarıoğan C, Yılmaz MT, Karakaya M (2009) Response surface methodology study on the optimisation of effects of fat, wheat bran and salt on chemical, textural and sensory properties of patties. *Meat Sci* 83(4):610–619. <https://doi.org/10.1016/j.meatsci.2009.07.010>
- Stone H, Bleibaum R, Thomas HA (2012) Sensory evaluation practices. In: Academic Press (ed) Descriptive analysis, 4th edition. Food Science and Technology, London, pp 233–289. <https://doi.org/10.1016/b978-0-12-382086-0.00006-6>
- Suklim K, Flick GJ Jr, Marcy JE, Eigel WN (2003) Effect of starch and egg white albumin on the textural and cooking properties of restructured squid patties (*Illex illecebrosus*). *J Aquat Food Prod Technol* 12(2):47–60. https://doi.org/10.1300/J030v12n02_05
- Sun XD, Holley RA (2011) Factors Influencing Gel Formation by Myofibrillar Proteins in Muscle Foods. *Compr Rev Food Sci Food Saf* 10(1):33–51. <https://doi.org/10.1111/j.1541-4337.2010.00137.x>
- Tabilo-Munizaga G, Barbosa-Cánovas GV (2005) Pressurized and heat-treated surimi gels as affected by potato starch and egg white : microstructure and water-holding capacity. *LWT Food Sci Technol* 38(1):47–57. <https://doi.org/10.1016/j.lwt.2004.04.013>
- Texture Technologies (2003) Textural profile analysis explained and annotated. www.texturetechnologies.com/texture_profile_analysis.html. Accessed 22 Nov 2017
- Turantas F, Kiliç GB, Kiliç B (2015) Ultrasound in the meat industry: general applications and decontamination efficiency. *Int J Food Microbiol* 198:59–69. <https://doi.org/10.1016/j.ijfoodmicro.2014.12.026>
- Zhang Y, Zeng QX, Zhu ZW, Zhou R (2011) Effect of ultrasonic treatment on the gel strength of tilapia (*Sarotherodon nilotica*) surimi. *J Food Process Eng* 34(2):533–548. <https://doi.org/10.1111/j.1745-4530.2009.00374.x>
- Zhu J, Fan D, Zhao J, Zhang H, Huan J, Zhou W, Chen W (2016) Enhancement of the gelation properties of surimi from yellowtail Seabream (*Parargyrops edita*, Sparidae) with Chinese Oak Silkworm Pupa, *Antheraea pernyi*. *J Food Sci* 81(2):E396–E403. <https://doi.org/10.1111/1750-3841.13184>

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