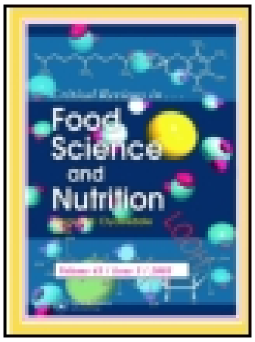


Critical Reviews in Food Science and Nutrition

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

Recent developments in maintaining gel properties of surimi products under reduced salt conditions and use of additives

Abdul Razak Monto, Mengzhe Li, Xin Wang, Ganesha Yanuar Arief Wijaya, Tong Shi, Zhiyu Xiong, Li Yuan, Wengang Jin, Jianrong Li & Ruichang Gao

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2021.1931024

Taylor & Francis
Taylor & Francis Group

REVIEW

Recent developments in maintaining gel properties of surimi products under reduced salt conditions and use of additives

Abdul Razak Monto[a*], Mengzhe Li[a*], Xin Wang[a*], Ganesha Yanuar Arief Wijaya[a], Tong Shi[a], Zhiyu Xiong[a], Li Yuan[a], Wengang Jin[b], Jianrong Li[c], and Ruichang Gao[a,b]

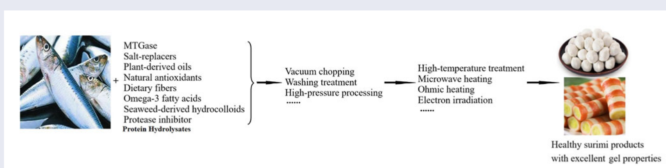
[a]School of Food and Biological Engineering, Jiangsu University, Zhenjiang, China; [b]Bio-resources Key Laboratory of Shaanxi Province, School of Biological Science and Engineering, Shaanxi University of Technology, Hanzhong, China; [c]College of Food Science and Technology, Bohai University, Jinzhou, China

ABSTRACT

Salt is a necessary condition to produce a surimi product that is based on the gelation of salt-soluble myofibrillar proteins. Recently, there has been a growing concern among consumers to consume healthy foods due to the threat of several chronic diseases caused by an unhealthy diet. Methods of reducing salt content out of concern for health issues caused by excessive sodium intake may affect the gel properties of surimi, as can many health-oriented food additives. Several studies have investigated different strategies to improve the health characteristics of surimi products without decreasing gel properties. This review reports recent developments in this area and how the gel properties were successfully maintained under reduced-salt conditions and the use of additives. This review of recent studies presents a great deal of progress made in the health benefits of surimi and can be used as a reference for further development in the surimi product processing industry.

KEYWORDS
food additives; gel properties; healthy surimi product; salt reduction; surimi

GRAPHICAL ABSTRACT



Highlights

1. Low-salt surimi can be manufactured by using salt replacers.
2. Several additives are beneficial to the nutrition and properties of surimi.
3. Surimi industry must adjust to a shift in consumer behavior toward healthy foods.
4. Strategies to improve healthy characteristics of surimi products are needed.

Introduction

Surimi is a term for concentrated myofibrillar proteins obtained by successive washing and mixing with cryoprotectant before storage (Kong et al. 2016; Muriel-Galet et al. 2015). By removing sarcoplasmic proteins and undesirable substances such as fat, blood, pigment, and odorous substances, successive washing yields mostly white muscles as the primary ingredient for further surimi processing. The whole processing is generally continued by comminuting/chopping the washed muscle with salt (1-3%), adding other ingredients or functional additives, shaping, and heating (Lanier, Yongsawatdigul, and Carvajal-Rondanelli 2014; Ma et al. 2018; Park 2005).

Surimi products such as fish balls, kamaboko, chikuwa, and crabstick have been recognized for their unique gelling properties and high nutritional value (Kong et al. 2016). Moreover, surimi is also categorized as a ready-to-eat food since no treatment is needed before consumption (Grete et al. 2010; Zhang et al. 2013). Thus, due to its characteristic health and convenience, interest in surimi products has increased in recent years. Since the 1980s in North America surimi consumption has risen rapidly and spread globally in both developed and developing countries (Endoo and Yongsawatdigul 2014; Pietrowski, Tahergorabi, and Jaczynski 2012). Today it has become one of the most common foods in our daily diet.

CONTACT Jianrong Li lijr6491@163.com College of Food Science and Technology, Bohai University, Jinzhou 121013, China; Ruichang Gao xiyuan2008@ujs.edu.cn School of Food and Biological Engineering, Jiangsu University, 301 Xuefu Road, Zhenjiang, Jiangsu province, 212013, China.
*These authors have equal contribution.

In recent years, there has been a growing concern among consumers about eating healthy foods. People are becoming well aware of the long-term detrimental effects of unhealthy foods that increase the risk of many diseases, such as cardiovascular disease (CVD), cancer, and other lethal diseases (World Health Organization (WHO), 2017). As a result, today there is a growing shift in consumer behavior toward eating healthy foods globally. Consequently, the surimi production industry must adjust to this shift. Although Surimi based seafood products are considered as healthy foods and the sodium content is lower than other myofibrillar based processed foods, scientists and researchers must be inspired to improve the health factors of surimi products by finding alternative ways of reducing the salt content during gelation and using many different strategies to make the surimi and surimi products much healthier than before.

Enhancements to the health benefits of surimi should not be at the cost of quality. To achieve the desired texture, surimi must undergo a gelation process, a crucial step that is directly related to myofibrillar protein functionality (Cando et al. 2016b; Duangmal and Taluengphol 2009). Gelation results in a more compact gel structure from protein denaturation and aggregation (Ferry 1948; Guo et al. 2017; Kinsella and Melachouris 1976; Yuan et al. 2017; 2018). As a product formed by a gelation process, the gel properties of surimi – such as gel strength, water holding capacity (WHC), whiteness, texture, rheological behavior, thermal transition, microstructure, etc. are critical factors determining the final quality of surimi products and affect its desirability to consumers. Therefore, to produce healthy surimi products with good quality, any method used to improve the health benefits of surimi must optimize the gel properties of the final restructured products as well.

The various methods used to improve the gel properties of surimi in many studies have mostly incorporated several gel enhancers or have modified the processing steps. It has been known that processing methods and functional additives are factors influencing the gelling properties of surimi (Guo et al. 2019; Lanier, Yongsawatdigul, and Carvajal-Rondanelli 2014). In addition to the contribution of intrinsic factors of the fish, such as the level of proteases, fat content, endogenous transglutaminase (eTGase), etc. (Kaewudom, Benjakul, and Kijroongrojana 2013) to determining surimi texture. Moreover, as discussed previously, surimi processing is a multi-step process from washing until final heating. Modification of certain steps and utilization of new technologies such as either by reducing the salt content directly during the processing or by using salt replacers at the surimi processing level by manufacturers has great potential in curbing CVD. Additionally, plant oils like soybean, corn, rap, and peanut oils, are perfect alternatives to animal oils because they are free of cholesterol and have higher unsaturated fatty acids. Konjac glucomannan (KGM) which contains indigestible dietary fiber and has a non-caloric nature can be used due to its active role in weightcontrol, modification of the intestinal microbial metabolism, lowering of plasma cholesterol, scavenging of free radicals, and inhibiting tumor genesis. Also, additives such as seaweed hydrocolloids aids in the absorption of heavy metal ions, reduction of blood pressure, blood sugar, and blood fat, among many more health benefits. Amalgamating protein hydrolysates with alternative production processes to surimi production will not only enhance its physicochemical property but make the surimi product healthier for the consumption of humans from aside yielding surimi products with better gel properties compared to using conventional procedures. Surimi products made out of these mechanisms can be considered as a functional food (FF) as many scientists defined functional foods as industrially processed or natural foods that when regularly consumed within a diverse diet at efficacious levels have potentially positive effects on health beyond basic nutrition (Granato, Nunes, and Barba 2017, Granato et al. 2020), foods manufactured using potentially functional substances recovered from industrial by-products (Dalle and Szendrő 2011, Tahergorabi, Matak, and Jaczynski 2015) or by adopting certain technological processes (Gutiérrez 2018), whiles others definition is based on enrichment with essential minerals (Adadi et al. 2019). FFs global market is projected to grow globally aside from being a lucrative food production venture with an average annual growth rate of 8.5% (Bogue, Collins, and Troy 2017).

Again, low-sodium seafood products have enormous health benefits and good acceptability as many kinds of researches have shown, based on research conducted by Quadros et al. (2015), it is possible to reduce the salt level by 50% (0.75 g/100 g salt) in Serra Spanish Mackerel (*Scomberomorus brasiliensis*) fish burger formulations to obtain a product that is well accepted by consumers with characteristics similar or better than a product containing 1.5 g/100 g salt.

This current review describes the recent developments in maintaining gel properties of surimi products under reduced salt conditions and the use of additives. This paper summarizes the strategies used to improve or maintain the physical properties of low-salt surimi, such as utilization additives, addition salt replacers and protease inhibitors, and alternative technologies. Moreover, health beneficial and natural additives on surimi were referred, which not only enhanced health but also improved gel properties which in effect makes the surimi wholesome for consumption. This review paper can be used as reference material for manufacturers to develop surimi products beneficial to health.

Development of low-salt surimi

Background

Low-salt surimi is a restructured surimi product developed by scientists as a result of growing concern among consumers over excess sodium consumption. It has been known that excessive sodium intake (>2 grams/day, equivalent to 5 g salt/day) is linked to hypertension and high blood pressure, which may increase the risk of stroke and premature death from CVD (Barat et al. 2013; World Health Organization 2016). CVD may refer to strokes, ischemic heart disease (the most common CVD), coronary heart disease (CHD), or heart failure (Action on Salt 2019). CVD has

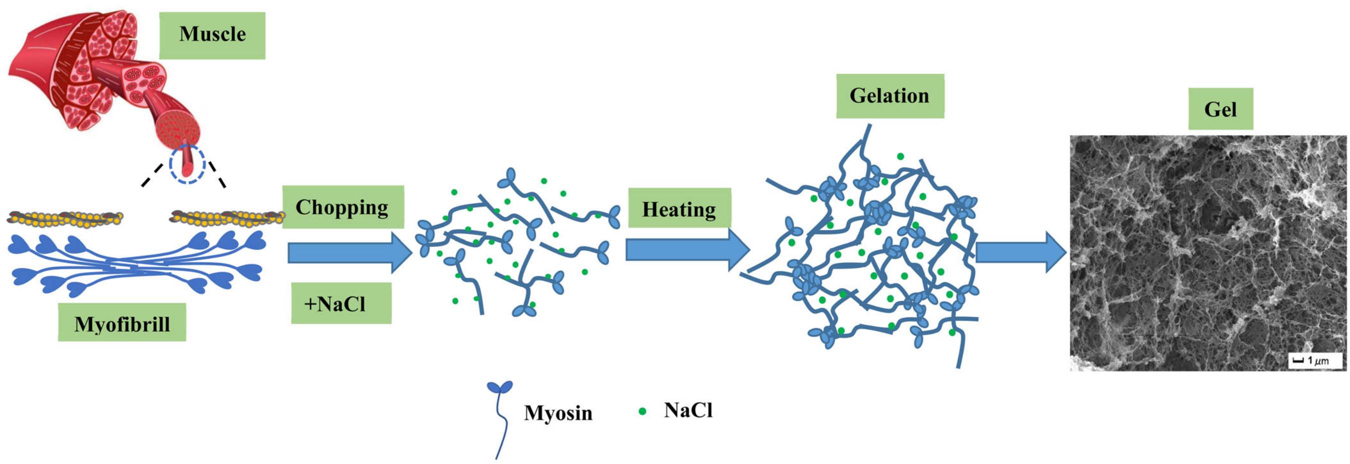


Figure 1. The role of salt (NaCl) in the processing of surimi products.

become the world's biggest killer, accounting for a combined 18.6 million deaths in 2019 (Roth et al., 2020). This type of disease has remained the leading cause of death globally in the last 15 years (World Health Organization 2017). Moreover, high sodium consumption also can lead to other diseases, such as osteoporosis, stomach cancer, kidney disease, and kidney stones (American Heart Association 2014).

Salt or sodium chloride has long been used as a condiment all over the world. It constitutes the main source of sodium in the Western diet, which by one report contains 39% of sodium ions (European Food Safety Authority (EFSA)), 2005). The recommended maximum level of salt intake is 5 g per day, but most people consume too much salt, on average 9-12 g per day (World Health Organization 2016). Less salt intake (<5 g per day), just under a teaspoon, may be difficult to achieve because 70% of the sodium people eat every day comes from processed foods, mostly bakery products and meat products including surimi-based products (Action on Salt 2019). In other words, controlling salt or sodium intake for consumers is demanding because sodium is added to food during processing, which is fully under the control of manufacturers. Therefore, the reduction of sodium at the food processing level by manufacturers has great potential to help reduce CVD. In the scope of surimi-based products, several studies have been conducted in recent years to surimi products with acceptable gel properties under reduced-salt conditions. However, it might not be easy since salt plays a critical role in surimi gelation.

Functional role of salt on surimi processing

The addition of salt is necessary for surimi processing and production (Figure 1). With perceived saltiness mainly due to the impact of Na^+ and Cl^- present, salt has a flavor-enhancing effect on surimi products (Desmond 2006; Miller and Barthoshuk 1991; Ruusunen and Puolanne 2005). Moreover, during the manufacturing of surimi products, salt is required to extract myofibrillar proteins and consequently develop a desired texture upon cooking. A reduction in the amount of solubilized and extracted protein is induced by a decrease in salt content and additionally affecting the protein binding capacity (Ramírez et al. 2011) which is detrimental for surimi gelation. Salt also suppresses the growth of food-borne pathogens by lowering water activity. Surimi products generally contain 1-3% salt (Tahergorabi et al. 2012). Recently, the importance of salt during surimi gelation was studied by Núñez-Flores et al. (2018). On gel samples made without salt, there was no polymerization of myosin heavy chains (MHC), resulting in poor gel properties. Thus, yielding low-salt surimi (generally 0.3% salt) with the same gel properties as regular-salt surimi (1-3% salt), several methods have been assayed by scientists over the years as shown in Table 1.

Strategies used on reduced-salt surimi

In general, there are two ways to make low-salt surimi products, either by reducing the salt content directly during the processing or by using salt replacers (Figure 2) (Barat et al. 2013). As discussed previously, reducing salt content may result in weaker gel properties. Hence, several strategies are required to improve or maintain gel properties of reduced-salt surimi (Gao et al. 2018). All strategies used in the reduced-salt condition and their positive results in recent studies (most from the past 5 years) are presented in Table 1.

Utilization of additives

Recently, it has been reported that the incorporation of several additives such as microbial transglutaminase (MTGase) (Cando, Borderías, and Moreno 2016a; Feng et al. 2018), tetra-sodium pyrophosphate (Cando et al. 2016b), and amino acids (Cando, Borderías, and Moreno 2017; Cando et al. 2016b) could improve the gel properties of low-salt surimi.

MTGase has become one of the most commonly used additives in surimi products. MTGase affected surimi differently depending on the fish species used as material, but overall, it has been successfully used as a gel enhancer in many studies, either as a single additive (Chanarat and Benjakul 2013; Guo et al. 2019) or in combination with other additives, such as gelatin (Kaewudom, Benjakul, and Kijroongrojana 2013), dietary fibers (Cardoso, Ribeiro, and Mendes 2012), and curdlan (Hu et al. 2015). Recent studies showed that the addition of MTGase could enhance the gel properties of low-salt surimi (Cando, Borderías, and Moreno 2016a; Feng et al. 2018). Moreover, most of these recent studies indicated that the addition of MTGase in the proportion 0.4-0.6 unit/g sample was optimum to produce the most favorable gel properties (Cando, Borderías, and Moreno 2016a; Chanarat and Benjakul 2013; Hu et al. 2015). MTGase induces the acyl-transfer reaction between lysine and glutamines residues (Kaewudom, Benjakul, and Kijroongrojana 2013). The role of MTGase is generally similar to eTGase. However, compared to eTGase, MTGase shows lower deamidation affinity and does not depend on calcium addition to activate it (Guo et al. 2019; Ramírez et al. 2011).

Presented in Table 1, the effectivity of other additives as gel enhancers in low-salt surimi had been examined in several studies. The addition of tetra-sodium pyrophosphate (0.05%), lysine (0.1%), and cysteine (0.1%) significantly improved gel properties of reduced-salt surimi (0.3% salt) (Cando, Borderías, and Moreno 2017; Cando et al. 2016b). Xiong et al. (2021) indicated that the improvement of gel strength and WHC of low-salt (0.5%) surimi gels could be obtained by adding arginine at various levels (0.1-0.4%) rather than oxidized caffeic acid (0.1-0.9%, based on protein content). Yuan et al. (2021) suggested that the influence of myosin aggregation-induced using L-glutamic (L-Glu) increased ion-dipole interactions, hydrogen bonds and electrostatic repulsions, which changed the microstructure of surimi, as a consequence, the WHC of surimi gels with L-Glu increased significantly.Regardless of these positive results, the effects of other additives on reduced-salt surimi are still unknown. Therefore, the use of other additives needs to be evaluated by scientists in further studies.

Salt replacers

Recently, efforts to reduce sodium content in surimi products have been purposed to reduce or replace Na^+ with other cations such as K^+, Mg^{2+}, Ca^{2+}, and Zn^{2+} (Table 1). In contrast to sodium, these cations have been known to have beneficial roles in the human body. Moreover, several studies have shown that these cations possessed the same functionality as Na^+ during the surimi gelation process. Thus, these cations have the potential to replace the use of sodium in surimi. Among all these cations, $Ca^{2+}$is the most commonly used in surimi processing. Ca^{2+} is important as it activates the eTGase in the fish protein during gelation, which promotes protein unfolding (Núñez-Flores et al. 2018). According to Jia et al. (2015), $CaCl_2$ enhanced the gelling properties of silver carp myosin by directly inducing conformational changes in myosin and promoting hydrophobic interactions, disulfide bonds, and Ca bridges of "set" gel. Recently, it was also found that these cations have another role as part of alternative washing solutions for surimi. According to Zhang et al. (2018), washing with $MgCl_2$ and $CaCl_2$ promoted a more intense gel-forming process, resulting in superior gel properties, especially washing with 0.2% $CaCl_2$.

At similar ionic strength, using KCl as NaCl replacer resulted in a very good gelling strength with a better gel structure than $MgCl_2$ and $CaCl_2$ respectively (Feng et al. 2018; Ge et al. 2020; Tahergorabi et al. 2012). As sodium has been related to hypertension, potassium has been shown, conversely, to have antihypertensive properties (Tahergorabi et al. 2012), and insufficient potassium intake (less than 3.5 grams/day) may increase the risk of CVD (World Health Organization 2016). Magnesium plays an important role in many biochemical processes in the human body. Deficiency of Mg^{2+} (less than 136 mg/day), is more common among older people and decreases the efficiency of gastrointestinal and renal mechanisms (Barat et al. 2013). Zinc has also been known to have an important role in neurogenesis, neurotransmission, and numerous physiological processes, such as growth, development, the immune system, and endocrinal functions (Arfat and Benjakul 2013; Prasad 1979; Sandstead et al. 1998). However, the bitter tastes of these chloride salts might reduce the taste scores of the resulting gels. Taking some measures to reduce the bitterness of these chlorides in surimi products may provide opportunities for future research. For example, L-lysine derivative can be used to mask the metallic-bitter aftertaste of KCl (Tahergorabi and Jaczynski 2012) and bitter flavor remover such as γ-polyglutamic acid (Hu et al. 2018) can be used to improve the taste of surimi products. In addition, the desirable taste provided by glycation (Liu et al. 2021) may reduce the undesirable sensory effects of chloride salts.

Overall, the use of salt replacers is very encouraging. Besides the functionality of these cations as salt replacers, their addition to low-salt surimi products may improve health factors and furthermore reduce the risk of CVD and other salt-related health diseases notwithstanding the fact that several studies have highlighted some sensorial issues with these cations after consumption.

Alternative protease inhibitors

Marine fish used as surimi materials usually contain endogenous protease due to their infection with myxosporidian parasites living in the ocean. This protease may damage the myofibrillar protein of surimi during the gelation process at a temperature range of 50-60 °C, leading to gel softening. This occurrence is usually called as "**modori phenomenon**".

Initially, beef plasma protein (bovine and porcine plasma proteins), pig plasma protein, egg white protein, or chicken plasma protein are usually used to retard the activity of endogenous protease (Fowler and Park 2015b; Ramírez et al. 2011). However, alternative protease inhibitors have been used recently to replace the blood plasma proteins from cattle that have been prohibited due to the occurrence of mad cow disease, religious constraint, and the outbreak of avian influenza (Kudre, Benjakul, and Kishimura 2013; Singh and Benjakul 2017). Based on recent studies, alternative protease

Table 1. Several strategies used with reduced-salt surimi summarized from recent studies (2012–2020).

Strategies used in reduced- salt condition		Recent Developments
Utilization of additives	MTGase	- MTGase has successfully enhanced the physicochemical and rheological properties of low-salt (0.3 %) Alaska Pollock surimi gels (Cando, Borderías, and Moreno 2016a) and partially-reduced salt (0.4 mol/L) Grass carp MP (Feng et al. 2018).
	Tetra-sodium pyrophosphate	- Alaska Pollock surimi with 0.05 % tetra-sodium pyrophosphate exhibited a more compact and well-structured network, compared to low-salt surimi gel without tetra-sodium pyrophosphate (Cando et al. 2016b).
	Amino acids	- With the addition of Lysine (0.1 %) & Cystine (0.1 %), physicochemical properties achieved in the reduced-NaCl surimi gels were similar to those of the gels with regular NaCl content (3 g/100 g) (Cando et al. 2016b). - Gel properties of low-salt Alaska Pollock surimi with the addition of Lysine (0.1 g/100 g) & Cystine (0.1 g/100 g) remained stable up to at least 14 days of chilled storage, indicating a successful gelation process and a well stabilized protein network (Cando, Borderías, and Moreno 2017). Surimi processing by-products hydrolysates (trypsin and alcalase) effectively retarded sulfhydryl oxidation, carbonylation, myosin denaturation, and exposure of hydrophobic amino acids during frozen storage of silver carp (*Hypophthalmichthys molitrix*) (Zhang et al. 2020). - The improvement of gel strength and water-holding capacity (WHC) of low-salt (0.5%) surimi gels could be obtained by adding Arg at various levels (0.1-0.4%) rather than OCF (0.1-0.9%)(Xiong et al. 2021).
Salt Replacers	KCl, $MgCl_2$ and $CaCl_2$	- The replacement of NaCl with KCl, $MgCl_2$ and $CaCl_2$ showed no deterioration effects. The physicochemical properties of Grass carp MP with the addition of KCl was similar with those products added with normal NaCl content (Feng et al. 2018). - Alaska Pollock surimi added with KCL-based salt substitute (contained 68 g/100 of KCl, L-lysine mono-hydrochloride and calcium stearate) resulted in similar physicochemical properties with surimi gels added with normal salt, but had lower sodium content (Tahergorabi et al. 2012). - KCL-based salt substitute (28 g/1000 g) improved rheological & textural characteristics of Alaska Pollock surimi gel (Debusca et al. 2013) - Protein oxidation and Substitution of 25% NaCl by KCl enhanced water Holding Capacity and gel quality in Myofibrillar Proteins. (Ge et al. 2020)
	Zinc Salts	- Whiteness of both kamaboko and modori yellow stripes surimi gels increased with increasing levels of zinc salts. Kamaboko gel had a highly interconnected, denser, and finer network, with smaller voids with zinc salts, especially $ZnSO_4$at 60 μmol/kg. The higher breaking force and deformation were generally found in kamaboko gels added with $ZnSO_4$, compared with $ZnCl_2$ (Arfat and Benjakul, 2013).
Alternative protease inhibitors		- Beef plasma protein (bovine and porcine plasma proteins), pig plasma protein, egg white protein, or chicken plasma protein are usually used to retard the activity of endogenous protease (Fowler and Park 2015b; Ramírez et al. 2011). - Alternative protease inhibitors have been used recently to replace the blood plasma proteins from cattle that have been prohibited due to the occurrence of mad cow disease, religious constraint, and the outbreak of avian influenza (Kudre, Benjakul, and Kishimura 2013; Singh and Benjakul 2017). - Addition of protein isolates from black bean and mung bean was found to retard the proteolysis activity in sardine surimi gelation, resulting in increased gel strength (Kudre, Benjakul, and Kishimura 2013). - Trypsin inhibitors from adzuki beans showed inhibitory activities against sarcoplasmic proteinase and autolysis on threadfin bream, which also improved gel properties (Klomklao and Benjakul 2015). - Salmon plasma protein was able to inhibit both cysteine and serine proteases on pacific whiting and salmon mince (Fowler and Park 2015a; 2015b). - Serine protease inhibitor from squid ovary was able to retard the autolysis of Indian mackerel surimi, improved gel properties, and also had no negative effect on sensory attributes (Singh and Benjakul 2017).
Alternative Processing	High-Pressure Processing (HPP)	- HPP (300 MPa) improved the physicochemical properties of low-salt Alaska Pollock surimi gel (Cando, Borderías, and Moreno 2016a; 2017; Cando et al. 2015), golden threadfin bream surimi (Wang et al. 2019) and Reduced Salt Surimi (RSS) containing 0.8% (w/w) κ-carrageenan (RSS-K) gels (Ye et al. 2019) - The best gel properties were observed with HHP of 350 MPa for 8 min for hairtail (Trichiurus haumela) surimi. (Chen et al., 2020) - However, greater pressure treatment ($\geq$ 450 MPa) weakens the gel properties of low-salt golden threadfin bream surimi (Wang et al. 2019).
	Microwave Heating (MW)	- The mechanical and functional properties of non-salted and low-salt silver carp surimi were improved by MW (15 W/g power intensity) heating for 60 s and 80 s, significantly ($P < 0.05$), except for the cook loss (Fu et al. 2012). - Microwave treatment significantly enhanced the gelling properties of fish oil-fortified silver carp surimi gel. (Jiao et al., 2019).

inhibitors were relatively safe and did not have any detrimental effects on surimi gel properties. Moreover, alternatives inhibitors were obtained from natural ingredients and also had a reasonable price under commercial production (Table 1).

One of the most promising sources of a natural protease inhibitor is legume seed. Legumes have been known to be a rich source of protease inhibitors and are abundant in nature (Klomklao and Benjakul 2015; Kudre, Benjakul, and Kishimura 2013). The addition of protein isolates from black

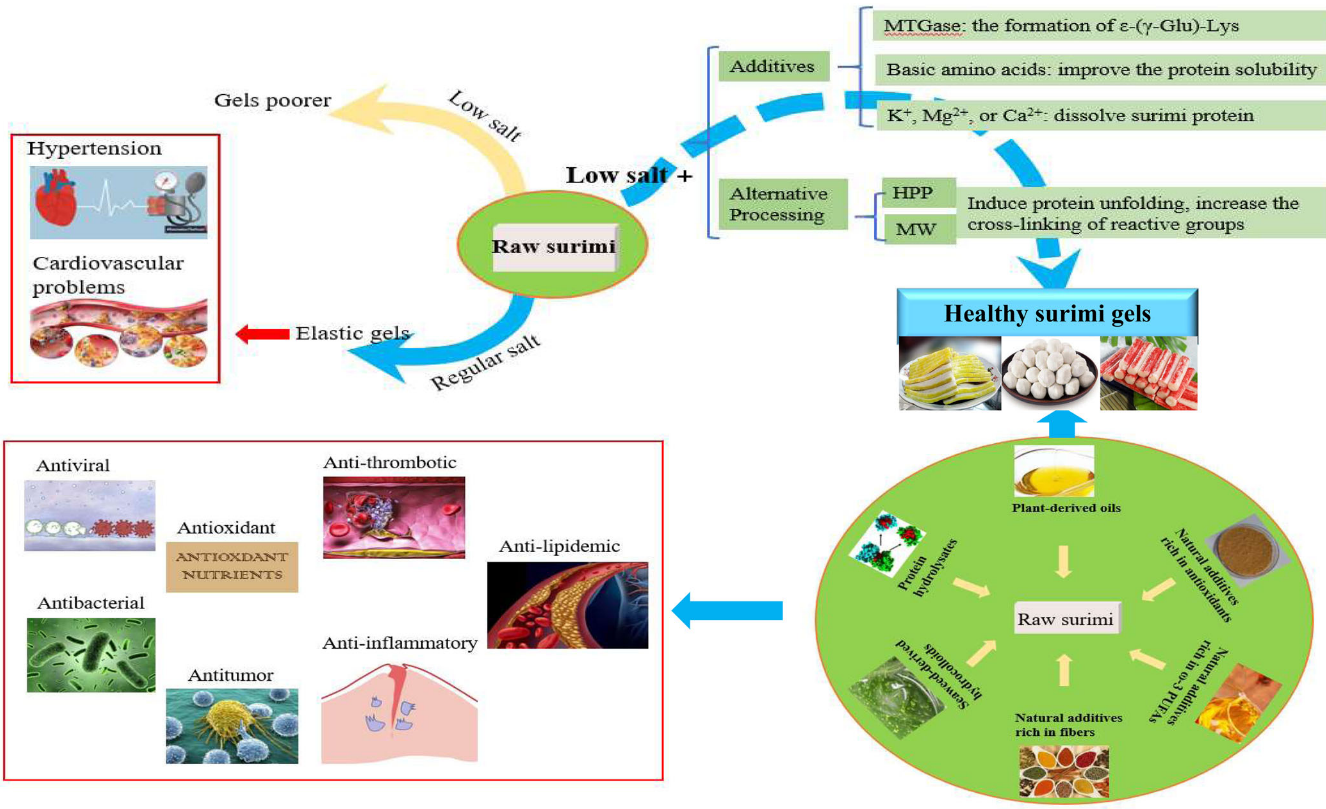


Figure 2. The strategies to improve the health characteristics of surimi products.

bean and mung bean has been found to retard the proteolysis activity in sardine surimi gelation. Trypsin inhibitors (TI) from adzuki beans showed inhibitory activities against sarcoplasmic proteinase and autolysis on threadfin bream, which also improved gel properties (Klomklao and Benjakul 2015). Moreover, protein isolate from Bambara groundnut, a legume indigenous to southern Thailand, could inhibit autolysis and improve the gel properties of threadfin bream (Oujifard et al. 2012).

Besides legumes, protease inhibitors can be derived from marine captures. Serine protease inhibitor from squid ovary was able to retard the autolysis of Indian mackerel surimi, improved gel properties, and also had no negative effect on sensory attributes (Singh and Benjakul 2017). Salmon plasma protein was able to inhibit both cysteine and serine proteases on pacific whiting and salmon mince (Fowler and Park 2015a; 2015b). Protein isolate from catla (*Catla catla*) roe could improve the textural properties of red-bellied pacu surimi by inhibiting endogenous proteinase, resulting in higher likeness scores (Bharane, Bethi, and Kudre 2020). The use of alternative protease inhibitors has shown to be promising in this domain but further studies by using new types of protease inhibitors are expected in the future by scientists.

Alternative processing

Recently, the use of alternative technologies in surimi processing, such as High-Pressure Processing (HPP) and Microwave heating (MW) have successfully improved the gel properties of surimi under a low-salt condition (Table 1).

High-pressure, a non-thermal physical processing technology, showed a pronounced effect in destabilizing non-covalent protein-protein interactions at the tertiary and quaternary protein structure levels, which promoted the dissociation of oligomeric proteins, the formation of more complex systems, and the unfolding and breakdown of others (Cando et al. 2015). HPP has been used in previous studies to enhance the gel properties of surimi. HPP is a non-thermal procedure that can induce non-thermal denaturation of protein by increasing the TGase activity for polymerization (Zhu et al. 2014). During HPP, protein unfolding, the formation of hydrogen bonds and hydrophobic interactions are increased to reach optimum gelation and improved gel properties (Buamard and Benjakul 2018).

HPP pretreatment of surimi gels with low salt (NaCl 1.5%) from silver carp containing κ-carrageenan showed a significant WHC and good gel strength (Ye et al. 2019). A combination of the HPP mechanism with the addition of κ-carrageenan, which is a dietary fiber, will increase the healthiness of the surimi product since it yielded quality gel strength with reduced salt content and added dietary fiber to the silver carp surimi gel. This will help reduce the risk of CHD and other dangerous health conditions associated with a high intake of salts. HPP exposed more reactive groups in protein, and the addition of additives may increase the cross-linking of these reactive groups (Buamard and Benjakul 2018). Moreover, the optimum pressure requires to induce optimum gelation was mostly found at

300 MPa (Buamard and Benjakul 2018; Cando, Borderías, and Moreno 2017; Cando et al. 2015; Wang et al. 2019). However, other studies found that optimum gel properties can also be obtained at 200 MPa (Moreno et al. 2015) and 400 MPa (Ma et al. 2015).

Besides HPP, MW also successfully improved the gel properties of low-salt surimi, however, it can lead to a high cooking loss (Fu et al. 2012). According to Cao et al. (2018), a combination of MW with conventional water bath heating may reduce the cooking loss of surimi as compared to MW alone, which comes as good news in helping to reduce the health implications of using salts to produce quality surimi gels. But, the use of this combination with reduced-salt surimi needs to be evaluated for further studies.

Development of health beneficial and natural additives on surimi

Plant-derived oils

Animal oils have traditionally been widely used to enhance the quality of many meat products, including surimi products. However, due to the increased risk of high cholesterol and other dangerous diseases (obesity, hypertension and CVD) resulting from the regular consumption of animal oil, the surimi seafood industry has learnt to use plant-based oils, such as soybean, peanut, and corn oils, which are safer and healthier than animal oils (Chang et al. 2015; Shi et al. 2014).

Some plant oils, namely soybean, corn, rap, and peanut oils, are perfect alternatives to animal oils because they are free of cholesterol and have higher unsaturated fatty acids (Chang et al. 2015; Shi et al. 2014). Additionally, they also play a critical role as gel enhancers. In recent years, different types of plant-derived oils have been successfully used as gel enhancers in surimi products in addition to adding health benefits (Table 2). The addition of camellia tea oil (8 g/100 g) improved the physicochemical properties of white croaker surimi. It has been known that camellia tea oil is rich in oleic acids and natural antioxidants, which act as anticancer agents (Zhou et al. 2017). Virgin coconut oil (VCO) improved the textural properties, whiteness and sensory properties of croaker surimi. Lauric acid, which is abundant in VCO, has antiviral and antibacterial functions. VCO is also rich in other beneficial substances such as trilaurin, tripalmitin, and short fatty acids, which have anticancer functions (Gani, Benjakul, and Nuthong 2018; Gani and Benjakul 2018).

According to Chang et al. (2015), the addition of soybean oil has successfully improved the textural and color properties of silver carp surimi. Meanwhile, corn, rap, and peanut oils improved the textural, color, microstructure, sensory, and rheological properties of silver carp surimi (Shi et al. 2014). These positive results have strengthened the idea of replacing animal oils with plant-derived oils in commercial surimi products. Also, the natural availability and variety of plant-based oils increase their possibilities for large-scale production.

Natural additives rich in antioxidants

Antioxidants are useful in meat products to prevent quality deterioration during processing and storage by retarding the oxidation process corresponding to several detrimental effects, such as color deterioration and rancidity (Echegaray et al. 2018). Natural additives from plants and vegetables are promising antioxidant sources without undesirable effects (Echegaray et al. 2018; Ribeiro et al. 2019).

Recently, several natural antioxidants rich in phenolic groups have been successfully used to maintain gel stability and extend the shelf life of surimi products (Table 2). Tea polyphenols effectively maintained the storage stability and degradation of myofibril in fish fillet during cold storage of Commercial tilapia (*oreochromis niloticus*) (Feng et al. 2017). It also enhanced the physicochemical properties and microstructure of gurnard surimi (Zhou et al. 2019). Perilla frutescens leaf extract riches in phenolic slowed down lipid and protein oxidation during storage of surimi fish balls, resulting in the overall acceptability higher than control samples during the storage process by sensory analysis (Zhao et al. 2019). Thinned young apple, which is abundant in China, could maintain the quality and shelf-life of freshwater surimi during storage (Sun et al. 2017). Caffeic acid, catechin, ferulic acid, and tannic acid have been successfully used to enhance the gel properties of bigeye snapper (Prodpran, Benjakul, and Phatcharat 2012). Coconut husk extract enhanced the physicochemical and rheological properties of sardine surimi (Buamard, Benjakul, and Konno 2017; Buamard and Benjakul 2015; 2018). Kiam wood and cashew bark extracts could enhance the gel properties of cuttlefish (Temdee and Benjakul 2014). Most of these natural antioxidants are rich in polyphenols which possess antioxidant and anticancer activities (Buamard and Benjakul 2018; Feng et al. 2017; Prodpran, Benjakul, and Phatcharat 2012; Sun et al. 2017; Temdee and Benjakul 2014). In addition, squid ink can be used as a gel enhancer in surimi by the same mechanism as natural antioxidants. Tyrosinase contained in squid ink has been known to possess antioxidant and antibacterial activities successfully used to maintain gel stability and improve physicochemical properties of sardine surimi (Vate, Benjakul, and Agustini 2015; Vate and Benjakul 2016).

Natural additives rich in ω-3 PUFAs

Omega-3 fatty acids possess anti-inflammatory, anti-thrombotic, and anti-lipidemic effects which can prevent dangerous diseases (Itsiopoulos et al. 2018). Regular consumption of ω-3 polyunsaturated fatty acids (PUFAs) has been linked to the reduction of dangerous diseases such as CHD, rheumatoid arthritis, and asthma (Pietrowski, Tahergorabi, and Jaczynski 2012; Riediger et al. 2009). According to Riediger et al. (2009), Omega-3 fatty acids, especially eicosapentaenoic acid (EPA) and docosahexaenoic (DHA), play a role in blood regulation and have anti-arrhythmic properties that may prevent cardiac events generally referred to as CVD by a mechanism specific to the membrane directly. Recently, several studies proved that ω-3 PUFAs have pronounced effects in preventing diabetes mellitus, obesity, and

Table 2. Health beneficial and natural additives on surimi summarized from recent studies (2012–2020).

Health Beneficial & Natural Additives		Health Benefits	Recent Developments
Plant-derived Oils	Camellia tea oil	- It is rich in oleic acids and contains many natural antioxidants with various biological activities (Zhou et al. 2017)	- White croaker surimi with the addition of 8 g/100 g camellia tea oil showed the most favorable physicochemical properties (Zhou et al. 2017)
	Virgin Coconut Oil (VCO)	- It is a rich source of lauric acid which has antiviral, antibacterial functions and other beneficial substances such as trilaurin, tripalmitin, and short fatty acids to prevent cancer (Gani, Benjakul, and Nuthong 2018)	- VCO affected textural properties, whiteness & sensory properties of croaker surimi (Gani, Benjakul, and Nuthong 2018; Gani and Benjakul 2018)
	Soybean oil	- It is free cholesterol & has higher unsaturated fatty acids than animal fats. Therefore, it is used to substitute animal oil because animal oil may increase the risk of cardiovascular disease, hypertension & other diseases (Chang et al. 2015)	- It improved the textural & color properties of silver carp surimi (Chang et al. 2015)
	Corn, rap, peanut oils	- They are free cholesterol & used to replace animal oils (Shi et al. 2014)	- It improved the textural, color, microstructural, sensory, and rheological properties of silver carp surimi (Shi et al. 2014)
Additives rich in antioxidants	Tea polyphenol	- Rich in cathecins, gallocathecin, epigallocatechin digallates, and epicatechindigallate which effective against cancer & cardiovascular disease (Feng et al., 2012).	- It effectively maintained the storage stability of black sea bream surimi (Feng et al., 2012). It also enhanced the physicochemical properties & microstructure of gurnard surimi (Zhou et al. 2019)
	Thinned young apple polyphenol	- It is rich in polyphenols. Polyphenol content about ten times than ripe apple (Sun et al. 2017)	- It could maintain the quality & shelf-life of freshwater surimi during storage (Sun et al. 2017)
	Kiam wood and Cashew bark extracts	- Rich in phenolic contents which possess antioxidant & anticancer activities (Temdee and Benjakul 2014)	- They could enhance gel properties of cuttlefish (Temdee and Benjakul 2014)
	Caffeic acid, catechin, ferullic acid and tannic acid	- Rich in phenolic contents which possess antioxidant & anticancer activities(Prodpran, Benjakul, and Phatcharat 2012)	- They could enhace gel properties of bigeye snapper (Temdee and Benjakul 2014)
	Coconut Husk Extract	- Rich in phenolic contents which possess antioxidant & anticancer activities(Buamard, Benjakul, and Konno 2017; Buamard and Benjakul 2015; 2018)	- It enhanced the physicochemical & rheological properties of sardine surimi (Buamard, Benjakul, and Konno 2017; Buamard and Benjakul 2015; 2018)
	Squid Ink	- Tyrosinase contained in squid ink possess antioxidant and antibacterial activities (Vate, Benjakul, and Agustini 2015; Vate and Benjakul 2016).	- It could improve the physicochemical properties and antioxidative stability of sardine surimi (Vate, Benjakul, and Agustini 2015; Vate and Benjakul 2016).
Additives rich in ω-3 PUFAs	Flaxseed, algae, menhaden, krill, corn and blend oils (Plant-derived oils)	- Sources of EPA & DHA, enriching the health factor of surimi products. Higher concentration of ALA than salmon oil (Debusca et al. 2014; Pietrowski et al. 2011; Sell et al. 2015)	- Enhancing the textural properties, likeness of surimi frank (Sell et al. 2015), and chemical, textural & rheological properties of Alaska Pollock surimi (Pietrowski et al. 2011; Debusca et al. 2014)
	Salmon oil (Fish-derived oil)	- Sources of EPA & DHA, enriching the health factor of surimi products. Greater digestibility than plant-derived oils (Sell et al. 2015)	- It enhanced the textural properties and likeness of surimi frank (Sell et al. 2015)
Additives rich in fiber	Dietary fiber (Long-chain powdered cellulose)	- It is protective against cardiovascular disease (CVD), diabetes, obesity, intestinal disorder (Anderson et al. 2009; Debusca et al. 2013., Debusca et al. 2014)	- It improved the physicochemical & rheological properties of Alaska Pollock surimi (Debusca et al. 2013., Debusca et al. 2014)
	Oat bran	- Soluble fiber from oat bran is very effective in lowering blood cholesterol, normalizing blood sugar level & lowering the risk of	- The addition of oat bran (6 g/100 g) enhanced the textural properties of Alaska Pollock surimi

(*continued*)

Table 2. Continued.

Health Beneficial & Natural Additives		Health Benefits	Recent Developments
		CVD, obesity & type 2 diabetes (Alakhrash, Anyanwu, and Tahergorabi 2016; Brand-Miller et al. 2012)	gels (Alakhrash, Anyanwu, and Tahergorabi 2016)
	Highly resistant rice starch	- Highly resistant rice starch (RSII) has lower caloric content than conventional starch (Yang et al. 2014)	- It improved the physicochemical properties of grass carp surimi gels (Yang et al. 2014)
	Modified starches	- Modified starches have the same health benefits as native starch but they are more effective in enhancing the gel properties (Kong et al. 2016)	- It enhanced the physicochemical & rheological properties of Alaska Pollock surimi (Kong et al. 2016)
	Konamizuki Sweet potato starch	- A new cultivar which has the same health benefits as native starch but it is more resistant and results in unique & better gel properties (Jia et al. 2018)	- It showed protective effects on gel structure & reduce starch granule after freezing & thawing of surimi (Jia et al. 2018)
	Hydrolyzed Wheat Gluten (HWG)	- It has the same health benefits as other fibers (Zhang et al., 2015a)	- It significantly improved the textural properties of Alaska Pollock surimi & the thermal stability under high temperature (Zhang et al., 2015a)
	Konjacglucomannan (KGM)	- KGM contains indigestible fiber and has non caloric nature. It is being increasingly used for its active role in weight-control, modification of the intestinal microbial metabolism, lowering the plasma cholesterol, scavenging free radicals, and inhibiting tumor genesis and metastasis, also classified as GRAS (generally recognized as safe) by the FDA (Iglesias-Otero, Borderías, and Tovar 2010; Zhang et al., 2015b)	- Both Native and Deacetylated KGMs could improve the gel properties of Alaska Pollock surimi subjected to high temperature (Zhang et al., 2015b; Zhang et al. 2016). It could also improve the gel properties of low-quality surimi (Iglesias-Otero, Borderías, and Tovar 2010; Liu, Wang, and Ding 2013). It could also play a good role as a less sugar cryoprotectant on surimi (Xiong et al. 2009).
Additives obtained from seaweeds	Sulfated Polysaccharides from green alga	- It has several biological activities such as antitumor, immunomodulating, & antioxidant (Alipour et al. 2018).	- The addition up to 0.25 g/ 100 g improved the physicochemical properties & microstructure of silver carp surimi gels (Alipour et al. 2018).
	Brown seaweed (*Sargassumtenerrimum*) extract	- A rich source of bioactive compounds mainly phlorotannins that exhibit antimicrobial potential against the pathogenic microbes (Shitole, Balange, and Gangan 2014)	- It improved the textural properties and had no negative effect on color and odor likeness of lesser sardine surimi (Shitole, Balange, and Gangan 2014)
	Iota &cappa carrageenan	- Carrageenan has the same health benefits as other seaweed-derived additives and it has been widely used to improve the quality of seafood products (Hunt and Park 2013)	- It enhanced the physical properties of Alaska Pollock surimi by increasing the gel strength & water retention ability (Hunt and Park 2013)
Alternative Protease Inhibitors	Protein isolates from black bean & mungbean	- Natural protease inhibitors are used to replace beef plasma proteins (bovine & porcine plasma proteins) which have been prohibited due to the occurrence of mad cow disease & religious constraint (Singh &Benjakul, 2017).	- The addition of protein isolates form black bean & mung bean could retard the proteolysis activity on sardine surimi gelation, leading to the increase of gel strength (Kudre, Benjakul, and Kishimura 2013)
	Trypsin Inhibitor (TI) from Adzuki Bean	Conversely, several alternatives inhibitors are used because their additions to seafood products do not give any detrimental effect to human body.	- TI from adzuki bean showed inhibitory activities against sarcoplasmic proteinase and autolysis on threadfin bream and it also improved the gel properties (Klomklao and Benjakul 2015).
	Bambara Groundnut Protein Isolate		- It inhibited the autolysis and improved gel properties of threadfin bream (Oujifard et al. 2012)
	Serine protease inhibitor from squid ovary (SOSPI)		- The SOSPI could inhibit the autolysis of indian mackerel,

(*continued*)

Table 2. Continued.

Health Beneficial & Natural Additives		Health Benefits	Recent Developments
			improved the gel properties and had no negative effect on sensory attributes (Singh and Benjakul 2017)
	Salmon plasma (SP) protein		- SP inhibited both cysteine & serine proteases on pacific whiting & salmon mince (Fowler & Park, 2015b)
Other natural additives	Micro Fish Bone (MFB) & Nano Fish Bone (NFB)	- Fish bone is rich in calcium (234 g/kg dry bone)	- MFB & NFB significantly improved gel properties of silver carp surimi (Yin, Park, and Xiong, 2017) and Alaska Pollock surimi (Yin, Reed, and Park, 2014, Yin and Park, 2014)
	Gellan	- Both gellan & pullulan are polysaccharides obtained from microbes. They can be used as gel enhancers & had no negative effect to human body (Wu. S, 2016; Petcharat and Benjakul, 2018)	- Gellan at appropriate level could improve gel strength of bigeye snapper surimi with an increased acceptability (Petcharat and Benjakul, 2018).
	Pullulan		- Pullulan improved the physical properties of *S. niphonius* surimi (Wu. S, 2016)
	Protein Hydrolysates	- Antioxidant activity of protein hydrolysates mainly relies on peptides present in the hydrolysate (Gao et al. 2021).	- Pepsin derived from the frame, bone and skin showed a great antioxidant activity based on chemical and biological assays. (Wiriyaphan, Chitsomboon, and Yongsawadigul 2012). Trypsin & Alcalase) made from surimi processing by-products when added to silver carp (*Hypophthalmichthys molitrix*) surimi, decreased myosin denaturation, sulfhydryl oxidation, carbonylation, great improvement in gelation properties good water-holding capacity of the surimi (Zhang et al. 2020)

metabolic syndrome (Albracht-Schulte et al. 2018; Itsiopoulos et al. 2018). Moreover, they are also required for the growth and development of embryos and infants. The improvement of visual acuity and hand-eye coordination in infants during pregnancy has also been reported (Riediger et al. 2009). Thus, due to these multiple benefits, the incorporation of ω-3 PUFAs in food products significantly improves nutrition and health.

Regardless of the health benefits, the effectiveness of ω-3 PUFAs as gel enhancers in surimi products has also been recently studied (Table 2). The addition of plant-derived oils containing ω-3 PUFAs, namely, flaxseed, algae, menhaden, krill, corn, and blend oils enhanced the textural properties and appeal of surimi franks (Sell et al. 2015), and also improved chemical, textural and rheological properties of Alaska Pollock surimi (Debusca et al. 2014; Pietrowski et al. 2011). These oils have been known to be rich sources of EPA and DHA and have a higher concentration of α-linolenic acid than salmon oil (Debusca et al. 2014; Pietrowski et al. 2011; Sell et al. 2015). Moreover, the addition of fish oil is also a potential gel enhancer in surimi products. According to Sell et al. (2015), besides plant-based oils, salmon oil also enhanced the textural properties and appeal of surimi franks. Salmon oil is also a rich source of EPA and DHA and has greater digestibility than plant-derived oils (Sell et al. 2015). Also, none of these studies reported any negative effects on gel properties due to the incorporation of ω-3 PUFAs, strengthening the idea of commercial production of surimi containing ω-3 PUFAs.

Natural additives rich in fibers

Erstwhile studies defined dietary fiber as a part of plants that is resistant to digestive enzymes in the human digestive tract (Anderson et al. 2009; Debusca et al. 2013). Dietary fiber has been known to have several beneficial effects on health, such as lowering blood pressure, maintaining blood glucose, improving immune function, and reducing the risk of dangerous diseases such as diabetes, hypertension, CHD, obesity, and stroke (Anderson et al. 2009). Moreover, dietary fiber has hydro colloidal properties that can enhance food characteristics (Debusca et al. 2014).

Previous studies of dietary fiber on surimi products examined many different types of fiber (Table 2). Dietary fiber in the form of long-chain powdered cellulose has successfully been used to improve the physicochemical and rheological properties of Alaska Pollock surimi (Debusca et al. 2013, Debusca et al. 2014). The addition of oat bran (6 g/100 g) enhanced the textural properties of Alaska Pollock surimi gels. Soluble fiber from oat bran is very effective in lowering blood cholesterol, normalizing blood sugar levels, and lowering the risk of CVD, obesity, and type 2 diabetes (Alakhrash, Anyanwu, and Tahergorabi 2016; Brand-Miller et al. 2012).

Moreover, several modified and new types of fiber have been used in various studies (Table 2). Highly resistant rice starch, which has a lower caloric content than conventional starch has been shown to effectively enhanced the physicochemical properties of grass carp surimi gels (Yang et al. 2014). Modified starches effectively improved the physicochemical and rheological properties of Alaska Pollock surimi (Kong et al. 2016). Konamizuki sweet potato starch is a new cultivar that has the same health benefits as native starch, but has higher resistance, and results in unique and better gel-forming properties (Jia et al. 2018), Konamizuki sweet potato starch showed protective effects on gel structure and reduced starch granules after freezing and thawing surimi. Hydrolyzed wheat gluten significantly improved the textural properties of Alaska Pollock surimi and thermal stability under high temperatures (Zhang, Zhang, and Wang 2015a).

Among many types of dietary fibers, KGM was the most commonly used on surimi. KGM contains indigestible fiber and has a non-caloric nature. It is being increasingly used due to its active role in weight-control, modification of the intestinal microbial metabolism, lowering of plasma cholesterol, scavenging of free radicals, and inhibiting tumor genesis and metastasis, and its safety (Iglesias-Otero, Borderías, and Tovar 2010; Zhang et al. 2015b). Both native and deacetylated KGM was effective gel enhancers in Alaska Pollock surimi subjected to high temperature (Zhang et al. 2015b; 2016). It could also improve the gel properties of low-quality surimi (Iglesias-Otero, Borderías, and Tovar 2010; Liu, Wang, and Ding 2013) and play a beneficial role as a sugarless cryoprotectant in surimi (Xiong et al. 2009).

Seaweed-derived hydrocolloids

Hydrocolloids from seaweed have been known to have several health benefits such as antitumor, antibacterial, anti-HIV, antiaging, and anti-inflammatory effects (Panlasigui et al. 2003; Wang et al. 2011). It also aids in the absorption of heavy metal ions, reduction of blood pressure, blood sugar, and blood fat, among many more health benefits. Additionally, hydrocolloids from seaweed are also excellent gelling agents, with their own characteristics, hydrocolloids contained in seaweed – mainly alginate, carrageenan, and agar – could improve the gel properties of various food products from bakery, brewing, to meat products (Qin 2018a).

Recently, seaweed-derived hydrocolloids were used in several studies to improve surimi gel properties (Table 2). The sulfated polysaccharides from green seaweed up to 0.25 g/100 g improved the physicochemical properties and microstructure of silver carp surimi gels (Alipour et al. 2018).

The addition of brown seaweed extracts improved the textural properties of lesser sardine surimi and also, κ-carrageenan in silver carp surimi production resulted in a good gelling property and WHC (Ye et al. 2019). It has been known that brown seaweed is a rich source of bioactive compounds, mainly phlorotannins that exhibit antimicrobial potential against pathogenic microbes (Shitole, Balange, and Gangan 2014). Moreover, in the study by Hunt and Park (2013), refined iota and κ-carrageenan enhanced the physical properties of Alaska Pollock surimi by increasing gel strength and water retention ability (Hunt and Park 2013). Carrageenan has been widely used as an additive in food products in the form of refined carrageenan or semi-refined carrageenan (Qin 2018b). However, the use of other types of hydrocolloids, namely, alginate and agar in surimi gel products, need to be evaluated since these hydrocolloids have been successfully used in other food products.

Protein hydrolysates

Protein hydrolysates comprise an alternative to intact protein and elemental formulas in the development of special formulations designed to provide nutritional and health support to people and patients with different nutritional needs (Clemente 2000).

Protein hydrolysates have been reported to inhibit lipid oxidation in food and cellular systems (Park et al. 2010). The antioxidant activity of protein hydrolysates mainly relies on peptides present in the hydrolysate (Gao et al. 2021) as in Table 2. Protein hydrolysates (trypsin and alcalase) made from surimi processing by-products when added to silver carp (*Hypophthalmichthys molitrix*) surimi, successfully decreased myosin denaturation, sulfhydryl oxidation, carbonylation, great improvement in gelation properties accompanied by a very good water-holding capacity of the surimi in addition to exposing various hydrophobic amino acids during frozen storage (Zhang et al. 2020). Furthermore, protein hydrolysate pepsin derived from the frame, bone and skin showed a great antioxidant activity based on chemical and biological assays (Wiriyaphan, Chitsomboon, and Yongsawadigul 2012).

These protein hydrolysates can be used as natural antioxidant-cryoprotectant and gel textures in freshwater fish surimi production. Hydrolysates rich in peptides containing hydrophobic amino acids, such as Pro, Leu, Ala, Trp, and Phe, are believed to possess high antioxidant activity (Kim and Mendis 2006).

Antioxidants as many pieces of research have shown are substances that help to prevent damage to cells caused by unstable molecules (free radicals) that the body produces as a reaction to environmental and other pressures such as oxidative stress, which has been linked to heart diseases, cancer, arthritis, stroke, respiratory diseases, immune deficiency, emphysema, Parkinson's disease, and other inflammatory or ischemic conditions. Incorporating these protein hydrolysates with tremendous value into surimi will not only enhance its physicochemical property but will make the surimi product much healthier for the consumption of humans irrespective of age and nutritional needs.

Future perspectives of the health surimi

Although many additives have been studied, there are still many nutritional additives with multiple functions in the natural world that can be studied to improve the health of surimi and promote the development of the surimi industry. Finally, it is the fervent hope of the authors to suggest further research into the incorporation of Glycyrrhizic acid which is a triterpene glycoside found in the roots of licorice plants (*Glycyrrhiza glabra*) and considered as a natural flavor into low-salt surimi products made of salt replacers (K^+, Mg^{2+}, Ca^{2+}, Zn^{2+}) to prevent the sensorial issues that may arise. Research shows that Glycyrrhizic acid in its pure form can be used to eliminate undesirable tastes, prolong sweetness and enhance flavors. Additionally, its nutraceutical properties, maintaining blood pressure and volume and regulating glucose/glycogen balance, antiviral, antiulcer, anti-inflammatory and antispasmodic properties which when able to incorporate into surimi will help improve health. The more choices in health beneficial and natural additives, the higher the chances to produce high-quality surimi in the future, and increase the effectiveness of surimi processing.

Conclusions

In general, the development of healthier surimi products has shown much progress in the past 5 years. Today, it is possible to produce low-salt surimi with the same quality as regular-salt surimi by using several strategies used in recent studies. Moreover, several additives beneficial to health added to surimi not only enhanced health but also improved gel properties which in effect makes the surimi wholesome for consumption. These additives were also obtained from natural abundant natural ingredients, easily found, have a reasonable price, and have the potential for large production. Furthermore, recent studies describe much progress made in surimi processing.

Though the seafood industry, in general is considered one of the healthiest, it can further be improved by incorporating the aforementioned strategies in this paper. Furthermore, these strategies also can be used in other seafoods (lobsters, crabs, shrimps, snails, and crayfish etc.) to make it the healthiest and wholesome food industry.

Ethical approval

This article does not contain any studies with human participants performed by the author and any of the coauthors.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the National Natural Science Foundation of China [No. U20A2067, 32072248] and the China Agriculture Research System [CARS-46].

ORCID

Wengang Jin http://orcid.org/0000-0002-9838-3905
Ruichang Gao http://orcid.org/0000-0001-5742-5446

References

Action on Salt. 2019. Accessed January 28, 2019. http://www.actiononsalt.org.uk/salthealth/salt-and-cardiovascular-disease/.

Adadi, P., N. V. Barakova, K. Y. Muravyov, and E. F. Krivoshapkina. 2019. Designing selenium functional foods and beverages: A review. *Food Research International (Ottawa, ON)* 120:708–25. doi: 10.1016/j.foodres.2018.11.029.

Alakhrash, F., U. Anyanwu, and R. Tahergorabi. 2016. Physicochemical properties of Alaska pollock (*Theragra chalcograma*) surimi gels with oat bran. *LWT - Food Science and Technology* 66:41–7. doi: 0.1016/j.lwt.2015.10.015. doi: 10.1016/j.lwt.2015.10.015.

Albracht-Schulte, K., N. S. Kalupahana, L. Ramalingam, S. Wang, S. M. Rahman, J. Robert-McComb, and N. Moustaid-Moussa. 2018. Omega-3 fatty acids in obesity and metabolic syndrome: A mechanistic update. *The Journal of Nutritional Biochemistry* 58:1–16. doi: 10.1016/j.jnutbio.2018.02.012.

Alipour, H. J., M. Rezaei, B. Shabanpour, and M. Tabarsa. 2018. Effects of sulfated polysaccharides from green alga Ulva intestinalis on physicochemical properties and microstructure of silver carp surimi. *Food Hydrocolloids* 74:87–96. doi: 10.1016/j.foodhyd.2017.07.038.

American Heart Association. 2014. Accessed January 28, 2019. https://www.heart.org/en/healthy-living/healthy-eating/eat-smart/sodium/effects-of-excess-sodium-infographic/.

Anderson, J. W., P. Baird, R. H. Davis Jr., S. Ferreri, M. Knudtson, A. Koraym, V. Waters, and C. L. Williams. 2009. Health benefits of dietary fiber. *Nutrition Reviews* 67 (4):188–205. doi: 10.1111/j.1753-4887.2009.00189.x.

Arfat, Y. A., and S. Benjakul. 2013. Gel strengthening effect of zinc salts in surimi from yellow stripe trevally. *Food Bioscience* 3:1–9. doi: 10.1016/j.fbio.2013.04.009.

Barat, J. M., E. Pérez-Esteve, M.-C. Aristoy, and F. Toldrá. 2013. Partial replacement of sodium in meat and fish products by using magnesium salts. A review. *Plant and Soil* 368 (1-2):179–88. doi: 10.1007/s11104-012-1461-7.

Bharane, P. R., C. M. S. Bethi, and T. G. Kudre. 2020. Effect of Catla catla roe protein isolate on textural and sensorial properties of surimi gel from *Piaractus brachypomus*. *Journal of Food Measurement and Characterization* 14 (3):1391–401. doi: 10.1007/s11694-020-00389-1.

Bogue, J., O. Collins, and A. J. Troy. 2017. Market analysis and concept development of functional foods. *Developing New Functional Food and Nutraceutical Products* 2017:29–45. doi: 10.1016/b978-0-12-802780-6.00002-x.

Brand-Miller, J. C., F. S. Atkinson, R. J. Gahler, V. Kacinik, M. R. Lyon, and S. Wood. 2012. Effects of added PGX®, a novel functional fibre, on the glycaemic index of starchy foods. *British Journal of Nutrition* 108 (2):245–8. doi: 10.1017/S0007114511005447.

Buamard, N., and S. Benjakul. 2015. Improvement of gel properties of sardine (*Sardinella albella*) surimi using coconut husk extracts. *Food Hydrocolloids* 51:146–55. doi: 10.1016/j.foodhyd.2015.05.011.

Buamard, N., and S. Benjakul. 2018. Combination effect of high pressure treatment and ethanolic extract from coconut husk on gel properties of sardine surimi. *LWT - Food Science and Technology* 91:361–7. doi: 10.1016/j.lwt.2018.01.074.

Buamard, N., S. Benjakul, and K. Konno. 2017. Improvement of gel quality of sardine surimi with low setting phenomenon by ethanolic coconut husk extract. *Journal of Texture Studies* 48 (1):47–56. doi: 10.1111/jtxs.12207.

Cando, D., A. J. Borderías, and H. M. Moreno. 2016a. Combined effect of aminoacids and microbial transglutaminase on gelation of low salt surimi content under high pressure processing. *Innovative Food Science & Emerging Technologies* 36:10–7. doi: 10.1016/j.ifset.2016.05.010.

Cando, D., A. J. Borderías, and H. M. Moreno. 2017. Influence of amino acid addition during the storage life of high pressure processed low salt surimi gels. *LWT- Food Science and Technology* 75: 599–607. doi: 10.1016/j.lwt.2016.10.012.

Cando, D., B. Herranz, A. J. Borderías, and H. M. Moreno. 2015. Effect of high pressure on reduced sodium chloride surimi gels. *Food Hydrocolloids* 51:176–87. doi: 10.1016/j.foodhyd.2015.05.016.

Cando, D., B. Herranz, A. J. Borderías, and H. M. Moreno. 2016b. Different additives to enhance the gelation of surimi gel with reduced sodium content. *Food Chemistry* 196:791–9. doi: 10.1016/j.foodchem.2015.10.022.

Cao, H., D. Fan, X. Jiao, J. Huang, J. Zhao, B. Yan, W. Zhou, W. Zhang, and H. Zhang. 2018. Effects of microwave combined with conduction heating on surimi quality and morphology. *Journal of Food Engineering* 228:1–11. 10.1016/j.jfoodeng.2018.01.021. doi: 10.1016/j.jfoodeng.2018.01.021.

Cardoso, C., B. Ribeiro, and R. Mendes. 2012. Effects of dietary fibre and microbial transglutaminase addition on the rheological and textural properties of protein gels from different fish species. *Journal of Food Engineering* 113 (4):520–6. doi: 10.1016/j.jfoodeng.2012.06.023.

Chanarat, S., and S. Benjakul. 2013. Impact of microbial transglutaminase on gelling properties of Indian mackerel fish protein isolates. *Food Chemistry* 136 (2):929–37. doi: 10.1016/j.foodchem.2012.09.021.

Chang, T., C. Wang, X. Wang, L. Shi, H. Yang, and M. Cui. 2015. Effects of soybean oil, moisture and setting on the textural and color properties of surimi gels. *Journal of Food Quality* 38 (1):53–9. doi: 10.1111/jfq.12121.

Chen, Y., A. Xu, R. Yang, R. Jia, J. Zhang, D. Xu, and W. Yang. 2020. Chemical interactions and rheological properties of hairtail (Trichiurus haumela) surimi: Effects of chopping and pressure. *Food Bioscience* 38:100781 doi:10.1016/j.fbio.2020.100781.

Clemente, A. 2000. Enzymatic protein hydrolysates in human nutrition. *Trends in Food Science & Technology* 11 (7):254–62. doi: 10.1016/S0924-2244(01)00007-3.

Dalle, Z. A., and Z. Szendrő. 2011. The role of rabbit meat as functional food. *Meat Science* 88 (3):319–31. doi: 10.1016/j.meatsci.2011.02.017.

Debusca, A., R. Tahergorabi, S. K. Beamer, K. E. Matak, and J. Jaczynski. 2014. Physicochemical properties of surimi gels fortified with dietary fiber. *Food Chemistry* 148:70–6. doi: 10.1016/j.foodchem.2013.10.010.

Debusca, A., R. Tahergorabi, S. K. Beamer, S. Partington, and J. Jaczynski. 2013. Interactions of dietary fibre and omega-3-rich oil with protein in surimi gels developed with salt substitute. *Food Chemistry* 141 (1):201–8. doi: 10.1016/j.foodchem.2013.02.111.

Desmond, E. 2006. Reducing salt: A challenge for the meat industry. *Meat Science* 74 (1):188–96. doi: 10.1016/j.meatsci.2006.04.014.

Duangmal, K., and A. Taluengphol. 2009. Effect of protein additives, sodium ascorbate, and microbial transglutaminase on the texture and colour of red tilapia surimi gel. *International Journal of Food Science & Technology* 45 (1):48–55. doi: 10.1111/j.1365-2621.2009.02102.x.

Echegaray, N., B. Gómez, F. J. Barba, D. Franco, M. Estévez, J. Carballo, K. Marszałek, and J. M. Lorenzo. 2018. Chestnuts and by-products as source of natural antioxidants in meat and meat products: A review. *Trends in Food Science & Technology* 82:110–21. doi: 10.1016/j.tifs.2018.10.005.

Endoo, N., and J. Yongsawatdigul. 2014. Comparative study on chemical and gel forming properties of surimi from freshwater and marine fish during frozen storage. *Food and Applied Bioscience Journal* 2:192–202. doi: 10.14456/fabj.2014.17.

European Food Safety Authority (EFSA). 2005. Opinion of the scientific panel on dietetic products, nutrition and allergies on a request from the commission related to the tolerable upper intake level of chloride. *EFSA Supporting Publications* 3 (6):1–9. doi: 10.2903/j.efsa.2005.210.

Feng, L., T. Jiang, Y. Wang, and J. Li. 2012. Effects of tea polyphenol coating combined with ozone water washing on the storage quality of black sea bream (Sparus macrocephalus). *Food Chemistry* 135 (4): 2915–21. doi:10.1016/j.foodchem.2012.07.078. 22980890

Feng, J., A. Cao, L. Cai, L. Gong, J. Wang, Y. Liu, Y. Zhang, and J. Li. 2018. Effects of partial substitution of NaCl on gel properties of fish myofibrillar protein during heating treatment mediated by microbial transglutaminase. *LWT- Food Science and Technology* 93:1–8. doi: 10.1016/j.lwt.2018.03.018.

Feng, X., V. K. Ng, M. Mikš-Krajnik, and H. Yang. 2017. Effects of fish gelatin and tea polyphenol coating on the spoilage and degradation of myofibril in fish fillet during cold storage. *Food and Bioprocess Technology* 10 (1):89–102. doi: 10.1007/s11947-016-1798-7.

Ferry, J. D. 1948. Protein gels. *Advances in Protein Chemistry* 4:1–78. doi: 10.1016/S0065-3233(08)60004-2.

Fowler, M. R., and J. W. Park. 2015a. Effect of salmon plasma protein on Pacific whiting surimi gelation under various ohmic heating conditions. *LWT - Food Science and Technology* 61 (2):309–15. doi: 10.1016/j.lwt.2014.12.049.

Fowler, M. R., and J. W. Park. 2015b. Salmon blood plasma: Effective inhibitor of protease-laden Pacific whiting surimi and salmon mince. *Food Chemistry* 176:448–54. doi: 10.1016/j.foodchem.2014.12.093.

Fu, X., K. Hayat, Z. Li, Q. Lin, S. Xu, and S. Wang. 2012. Effect of microwave heating on the low-salt gel from silver carp (*Hypophthalmichthys molitrix*) surimi. *Food Hydrocolloids* 27 (2): 301–8. doi: 10.1016/j.foodhyd.2011.09.009.

Gani, A., and S. Benjakul. 2018. Impact of virgin coconut oil nanoemulsion on properties of croaker surimi gel. *Food Hydrocolloids* 82: 34–44. 2018.03.037. doi: 10.1016/j.foodhyd.

Gani, A., S. Benjakul, and P. Nuthong. 2018. Effect of virgin coconut oil on properties of surimi gel. *Journal of Food Science and Technology* 55 (2):496–505. doi: 10.1007/s13197-017-2958-0.

Gao, R., Y. Wang, J. Mu, T. Shi, and L. Yuan. 2018. Effect of l-histidine on the heat-induced aggregation of bighead carp (*Aristichthys nobilis*) myosin in low/high ionic strength solution. *Food Hydrocolloids* 75:174–81. doi: 10.1016/j.foodhyd.2017.08.029.

Gao, R., Q. Yu, Y. Shen, Q. Chu, G. Chen, S. Fen, M. Yang, L. Yuan, D. J. McClements, and Q. Sun. 2021. Production, bioactive properties, and potential applications of fish protein hydrolysates: Developments and challenges. *Trends in Food Science & Technology* 110:687–99. doi: 10.1016/j.tifs.2021.02.031.

Ge, G., Y. Han, J. Zheng, M. Zhao, and W. Sun. 2020. Physicochemical characteristics and gel-forming properties of myofibrillar protein in an oxidative system affected by partial substitution of NaCl with KCl, $MgCl_2$ or $CaCl_2$. *Food Chemistry* 309:125614. doi: 10.1016/j.foodchem.2019.125614.

Granato, D., F. J. Barba, D. B. Kovačević, J. M. Lorenzo, A. G. Cruz, and P. Putnik. 2020. Functional foods: Product development, technological trends, efficacy testing, and safety. *Annual Review of Food Science and Technology* 11 (1):93–118. doi: 10.1146/annurev-food-032519-051708.

Granato, D., D. S. Nunes, and F. J. Barba. 2017. An integrated strategy between food chemistry, biology, nutrition, pharmacology, and statistics in the development of functional foods: A proposal. *Trends in Food Science & Technology* 62:13–22. doi: 10.1016/j.tifs.2016.12.010.

Grete, L., Y. Elinor, L. O. Ragnar, and S. Taran. 2010. Thermal inactivation and growth potential of *Listeriainnocua* in rehydrated salt-cured cod prepared for ready-to-eat products. *Food Control* 21 (8): 1121–6. doi: 10.1016/j.foodcont.2010.01.006.

Guo, M., S. Liu, M. Ismail, M. M. Farid, H. Ji, W. Mao, J. Gao, and C. Li. 2017. Changes in the myosin secondary structure and shrimp surimi gel strength induced by dense phase carbon dioxide. *Food Chemistry* 227:219–26. doi: 10.1016/j.foodchem.2017.01.050.

Guo, X., L. Shi, S. Xiong, Y. Hu, J. You, Q. Huang, and T. Yin. 2019. Gelling properties of vacuum-freeze dried surimi powder as influenced by heating method and microbial transglutaminase. *LWT- Food Science and Technology* 99:105–11. doi: 10.1016/j.lwt.2018.09.050.

Gutiérrez, T. J. 2018. Plantain flours as potential raw materials for the development of gluten-free functional foods. *Carbohydrate Polymers* 202:265–79. doi: 10.1016/j.carbpol.2018.08.121.

Hu, Y., W. Liu, C. Yuan, K. Morioka, S. Chen, D. Liu, and X. Ye. 2015. Enhancement of the gelation properties of hairtail (*Trichiurus* *haumela*) muscle protein with curdlan and transglutaminase. *Food Chemistry* 176:115–22. doi: 10.1016/j.foodchem.2014.12. 006.

Hunt, A., and J. W. Park. 2013. Alaska pollock fish protein gels as affected by refined carrageenan and various salts. *Journal of Food Quality* 36 (1):51–8. doi: 10.1111/jfq.12010.

Hu, Y., Y. Shao, C. Wu, C. Yuan, G. Ishimura, W. Liu, and S. Chen. 2018. γ-PGA and MTGase improve the formation of ε-(γ-glutamyl) lysine cross-links within hairtail (*Trichiurus haumela*) surimi protein. *Food Chemistry* 242:330–7. doi.org/10.1016/j.foodchem.2017.08.087. doi: 10.1016/j.foodchem.2017.08.087.

Iglesias-Otero, M. A., J. Borderías, and C. A. Tovar. 2010. Use of konjac glucomannan as additive to reinforce the gels from low-quality squid surimi. *Journal of Food Engineering* 101 (3):281–8. doi: 10.1016/j.jfoodeng.2010.07.009.

Itsiopoulos, C., W. Marx, H. L. Mayr, O. A. Tatucu-Babet, S. R. Dash, E. S. George, G. L. Trakman, J. T. Kelly, C. J. Thomas, and L. Brazionis. 2018. The role of omega-3 polyunsaturated fatty acid supplementation in the management of type 2 diabetes mellitus: A narrative review. *Journal of Nutrition & Intermediary Metabolism* 14: 42–51. doi: 10.1016/j.jnim.2018.02.002.

Jia, G., S. Nirasawa, X. Ji, Y. Luo, and H. Liu. 2018. Physicochemical changes in myofibrillar proteins extracted from pork tenderloin thawed by a high-voltage electrostatic field. *Food Chemistry* 240: 910–6. doi: 10.1016/j.foodchem.2017.07.138.

Jia, D., J. You, Y. Hu, R. Liu, and S. Xiong. 2015. Effect of $CaCl_2$ on denaturation and aggregation of silver carp myosin during setting. *Food Chemistry* 185:212–8. doi: 10.1016/j.foodchem.2015.03.130.

Jiao, X., H. Cao, D. Fan, J. Huang, J. Zhao, B. Yan, W. Zhou, W. Zhang, W. Ye, and H. Zhang. 2019. Effects of fish oil incorporation on the gelling properties of silver carp surimi gel subjected to microwave heating combined with conduction heating treatment. *Food Hydrocolloids*. 94:164–73. doi:10.1016/j.foodhyd.2019.03.017.

Kaewudom, P., S. Benjakul, and K. Kijroongrojana. 2013. Properties of surimi gel as influenced by fish gelatin and microbial transglutaminase. *Food Bioscience* 1:39–47. doi: 10.1016/j.fbio.2013.03.001.

Kim, S.-K., and E. Mendis. 2006. Bioactive compounds from marine processing byproducts-A review. *Food Research International* 39 (4): 383–93. doi: 10.1016/j.foodres.2005.10.010.

Kinsella, J. E., and N. Melachouris. 1976. Functional properties of proteins in foods: A survey. *Critical Reviews in Food Science and Nutrition* 7 (3):219–80. doi: 10.1080/10408397609527208.

Klomklao, S., and S. Benjakul. 2015. Effect of trypsin inhibitor in adzuki bean (*Vigna angularis*) on proteolysis and gel properties of threadfin bream (*Nemipterus bleekeri*). *LWT - Food Science and Technology* 63 (2):906–11. doi: 10.1016/j.lwt.2015.04.034.

Kong, W., T. Zhang, D. Feng, Y. Xue, Y. Wang, Z. Li, W. Yang, and C. Xue. 2016. Effects of modified starches on the gel properties of Alaska Pollock surimi subjected to different temperature treatments. *Food Hydrocolloids* 56:20–8. doi: 10.1016/j.foodhyd.2015.11.023.

Kudre, T., S. Benjakul, and H. Kishimura. 2013. Effects of protein isolates from black bean and mungbean on proteolysis and gel properties of surimi from sardine (*Sardinella albella*). *LWT - Food Science and Technology* 50 (2):511–8. doi: 10.1016/j.lwt.2012.08.018.

Lanier, T., J. Yongsawatdigul, and P. Carvajal-Rondanelli. 2014. Surimi gelation chemistry. In *Surimi and Surimi seafood*, ed. J. W. Park, 3rd ed, 101–40. Boca Raton, FL: Taylor and Francis Group.

Liu, J., X. Wang, and Y. Ding. 2013. Optimization of adding konjac glucomannan to improve gel properties of low-quality surimi. *Carbohydrate Polymers* 92 (1):484–9. doi: 10.1016/j.carbpol.2012.08.096.

Liu, H., H. Zhang, Q. Liu, Q. Chen, and B. Kong. 2021. Filamentous myosin in low-ionic strength meat protein processing media: Assembly mechanism, impact on protein functionality, and inhibition strategies. *Trends in Food Science & Technology* 112:25–35. doi.org/ doi: 10.1016/j.tifs.2021.03.039.

Ma, Y., S. Xiong, J. You, Y. Hu, Y. Q. Huang, and T. Yin. 2018. Effects of vacuum chopping on physicochemical and gelation properties of myofibrillar proteins from silver carp (*Hypophthalmichthys molitrix*). *Food Chemistry* 245:557–63. doi: 10.1016/j.foodchem.2017.10.139.

Ma, X., S. Yi, Y. Yu, J. Li, and J. Chen. 2015. Changes in gel properties and water properties of *Nemipterus virgatus* surimi gel induced by high-pressure processing. *LWT - Food Science and Technology* 61 (2):377–84. doi: 10.1016/j.lwt.2014.12.041.

Miller, I. J., and L. M. Barthoshuk. 1991. Taste perception, taste bud distribution and spatial relationship. In *Smell and taste in health disease*, eds. T. V. Geychell, L. M. Barthoshuk, R. L. Doty, and J. B. Snow, 205–33. New York: Raven Press.

Moreno, H. M., V. Bargiela, C. A. Tovar, D. Cando, A. J. Borderias, and B. Herranz. 2015. High pressure applied to frozen flying fish (*Parexocoetus brachyterus*) surimi: Effect on physicochemical and rheological properties of gels. *Food Hydrocolloids* 48:127–34. doi: 10.1016/j.foodhyd.2015.01.029.

Muriel-Galet, V., G. López-Carballo, R. Gavara, and P. Hernández-Muñoz. 2015. Antimicrobial effectiveness of lauroyl arginate incorporated into ethylene vinyl alcohol copolymers to extend the shelf-life of chicken stock and surimi sticks. *Food and Bioprocess Technology* 8 (1):208–17. doi: 10.1007/s11947-014-1391-x.

Núñez-Flores, R., D. Cando, A. J. Borderías, and H. M. Moreno. 2018. Importance of salt and temperature in myosin polymerization during surimi gelation. *Food Chemistry* 239:1226–34. doi: 10.1016/j.foodchem.2017.07.028.

Oujifard, A., S. Benjakul, M. Ahmad, and J. Seyfabadi. 2012. Effect of bambara groundnut protein isolate on autolysis and gel properties of surimi from threadfin bream (*Nemipterus bleekeri*). *LWT - Food Science and Technology* 47 (2):261–6. doi: 10.1016/j.lwt.2012.01.016.

Panlasigui, L. N., O. Q. Baello, J. M. Dimatangal, and B. D. Dumelod. 2003. Blood cholesterol and lipid-lowering effects of carrageenan on human volunteers. *Asia Pacific Journal of Clinical Nutrition* 12 (2): 209–14. doi: 10.1146/annurev.nutr.23.011702.073312.

Park, J. W. 2005. Ingredient technology for surimi and surimi seafood. In *Surimi and surimi seafood*, eds. J. W. Park, 2nd ed., 649–707. Boca Raton, FL: Taylor and Francis Group.

Park, S. Y., J. S. Lee, H. H. Baek, and H. G. Lee. 2010. Purification and characterization of antioxidant peptides from soy protein hydrolysate. *Journal of Food Biochemistry* 34:120–32. doi: 10.1111/j.1745-4514.2009.00313.x.

Petcharat, T, and S. Benjakul. 2018. Effect of gellan incorporation on gel properties of bigeye snapper surimi. *Food Hydrocolloids*. 77: 746–53. doi:10.1016/j.foodhyd.2017.11.016.

Pietrowski, B. N., R. Tahergorabi, and J. Jaczynski. 2012. Dynamic rheology and thermal transitions of surimi seafood enhanced with ω-3-rich oils. *Food Hydrocolloids* 27 (2):384–9. doi: 10.1016/j.foodhyd.2011.10.016.

Pietrowski, B. N., R. Tahergorabi, K. E. Matak, J. C. Tou, and J. Jaczynski. 2011. Chemical properties of surimi seafood nutrified with ω-3 rich oils. *Food Chemistry* 129 (3):912–9. doi: 10.1016/j.foodchem.2011.05.044.

Prasad, A. S. 1979. Clinical, biochemical, and pharmacological role of zinc. *Annual Review of Pharmacology and Toxicology* 19:393–426. doi: 10.1146/annurev.pa.19.040179.002141.

Prodpran, T., S. Benjakul, and S. Phatcharat. 2012. Effect of phenolic compounds on protein cross-linking and properties of film from fish myofibrillar protein. *International Journal of Biological Macromolecules* 51 (5):774–82. doi: 10.1016/j.ijbiomac.2012.07.010.

Qin, Y. 2018a. Health benefits of bioactive seaweed substances. In *Bioactive seaweeds for food applications*, ed. Y. Qin, 179–200. Amsterdam: Academic Press, Elsevier Inc. doi: 10.1016/b978-0-12-813312-5.00009-1.

Qin, Y. 2018b. Production of seaweed-derived food hydrocolloids. In *Bioactive seaweeds for food applications*, ed. Y. Qin, 53–69. Amsterdam: Academic Press,Elsevier Inc. doi: 10.1016/b978-0-12-813312-5.00003-0.

Quadros, D. A. de, I. F. de Oliveira Rocha, S. M. R. Ferreira, and H. M. A. Bolini. 2015. Low-sodium fish burgers: Sensory profile and drivers of liking. *LWT - Food Science and Technology* 63 (1):236–42. doi: 10.1016/j.lwt.2015.03.083.

Ramírez, J. A., R. M. Uresti, G. Velazquez, and M. Vázque. 2011. Food hydrocolloids as additives to improve the mechanical and functional properties of fish products: A review. *Food Hydrocolloids* 25 (8): 1842–52. doi: 10.1016/j.foodhyd.2011.05.009.

Ribeiro, J. S., M. J. M. C. Santos, L. K. R. Silva, L. C. L. Pereira, I. A. Santos, S. C. da Silva Lannes, and M. V. da Silva. 2019. Natural antioxidants used in meat products: A brief review. *Meat Science* 148: 181–8. doi: 10.1016/j.meatsci.2018.10.016.

Riediger, N. D., R. A. Othman, M. Suh, and M. H. Moghadasian. 2009. A systemic review of the roles of n-3 fatty acids in health and disease. *Journal of the American Dietetic Association* 109 (4):668–79. doi: 10.1016/j.jada.2008.12.022.

Roth, G. A., G. A. Mensah, C. O. Johnson, G. Addolorato, E. Ammirati, L. M. Baddour, N. C. Barengo, A. Z. Beaton, E. J. Benjamin, C. P. Benziger, and GBD-NHLBI-JACC Global Burden of Cardiovascular Diseases Writing Group, et al. 2020. Global burden of cardiovascular diseases and risk factors, 1990-2019: Update from the GBD 2019 study. *Journal of the American College of Cardiology* 76 (25):2982–3021. doi: 10.1016/j.jacc.2020.11.010.

Ruusunen, M., and E. Puolanne. 2005. Reducing sodium intake from meat products. *Meat Science* 70 (3):531–41. doi: 10.1016/j.meatsci.2004.07.016.

Sandstead, H. H., J. G. Penland, N. W. Alcock, H. H. Dayal, X. C. Chen, J. S. Li, F. Zhao, and J. J. Yang. 1998. Effects of repletion with zinc and other micronutrients on neuropsychologic performance and growth of Chinese children. *The American Journal of Clinical Nutrition* 68 (2 Suppl):470S–5S. doi: 10.1093/ajcn/68.2.470s.

Sell, C., S. Beamer, J. Jaczynski, and K. E. Matak. 2015. Sensory characteristics and storage quality indicators of surimi franks nutritionally enhanced with omega-3 rich flaxseed oil and salmon oil. *International Journal of Food Science & Technology* 50 (1):210–7. doi: 10.1111/ijfs.12621.

Shi, L., X. Wang, T. Chang, C. Wang, H. Yang, and M. Cui. 2014. Effects of vegetable oils on gel properties of surimi gels. *LWT - Food Science and Technology* 57 (2):586–93. doi: 10.1016/j.lwt.2014.02.003.

Shitole, S. S., A. K. Balange, and S. S. Gangan. 2014. Use of seaweed (*Sargassum tenerrimum*) extract as gel enhancer for lesser sardine (*Sardinella brachiosoma*) surimi. *International Aquatic Research* 6 (1):55. doi: 10.1007/s40071-014-0055-9.

Singh, A., and S. Benjakul. 2017. Effect of serine protease inhibitor from squid ovary on gel properties of surimi from Indian mackerel. *Journal of Texture Studies* 48 (6):541–9. doi: 10.1111/jtxs.12262.

Sun, L., J. Sun, P. Thavaraj, X. Yang, and Y. Guo. 2017. Effects of thinned young apple polyphenols on the quality of grass carp (*Ctenopharyngodon idellus*) surimi during cold storage. *Food Chemistry* 224:372–81. doi: 10.1016/j.foodchem.2016.12.097.

Tahergorabi, R., S. K. Beamer, K. E. Matak, and J. Jaczynski. 2012. Salt substitution in surimi seafood and its effects on instrumental quality attributes. *LWT - Food Science and Technology* 48 (2):175–81. doi: 10.1016/j.lwt.2012.03.004.

Tahergorabi, R., and J. Jaczynski. 2012. Physicochemical changes in surimi with salt substitute. *Food Chemistry* 132 (3):1281–6. doi.org/10.1016/j.foodchem.2011.11.104. doi: 10.1016/j.foodchem.2011.11.104.

Tahergorabi, R., K. E. Matak, and J. Jaczynski. 2015. Fish protein isolate: Development of functional foods with nutraceutical ingredients. *Journal of Functional Foods* 18:746–56. doi: 10.1016/j.jff.2014.05.006.

Temdee, W., and S. Benjakul. 2014. Effect of oxidized kiam wood and cashew bark extracts on gel properties of gelatin from cuttlefish skins. *Food Bioscience* 7:95–104. doi: 10.1016/j.fbio.2014.07.001.

Vate, N. K., and S. Benjakul. 2016. Effect of the mixtures of squid ink tyrosinase and tannic acid on properties of sardine surimi gel. *Journal of Food Science and Technology* 53 (1):411–20. doi: 10.1007/s13197-015-1974-1.

Vate, N. K., S. Benjakul, and T. W. Agustini. 2015. Application of melanin-free ink as a new antioxidative gel enhancer in sardine surimi gel. *Journal of the Science of Food and Agriculture* 95 (11):2201–7. doi: 10.1002/jsfa.6934.

Wang, J., Z. Li, B. Zheng, Y. Zhang, and Z. Guo. 2019. Effect of ultra-high pressure on the structure and gelling properties of low salt golden threadfin bream (*Nemipterus virgatus*) myosin. *LWT-Food Science & Technology* 100:381–90. doi: 10.1016/j.lwt.2018.10.053.

Wang, W., P. Zhang, C. Hao, X. Zhang, Z. Cui, and H. Guan. 2011. In vitro inhibitory effect of carrageenan oligosaccharide on influenza A H1N1 virus. *Antiviral Research* 92 (2):237–46. doi: 10.1016/j.antiviral.2011.08.010.

Wiriyaphan, C., B. Chitsomboon, and J. Yongsawadigul. 2012. Antioxidant activity of protein hydrolysates derived from threadfin bream surimi byproducts. *Food Chemistry* 132 (1):104–11. doi: 10.1016/j.foodchem.2011.10.040.

World Health Organization. 2016. Accessed January 28, 2019. https://www.who.int/en/news-room/fact-sheets/detail/salt-reduction/.

World Health Organization. 2017. Accessed January 28, 2019. https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds)/.

Xiong, G., W. Cheng, L. Ye, X. Du, M. Zhou, R. Lin, S. Geng, M. Chen, H. Corke, and Y. Cai. 2009. Effects of konjac glucomannan on physicochemical properties of myofibrillar protein and surimi gels from grass carp (*Ctenopharyngodon idella*). *Food Chemistry* 116 (2):413–8. doi: 10.1016/j.foodchem.2009.02.056.

Xiong, Z., T. Shi, W. Zhang, Y. Kong, L. Yuan, and R. Gao. 2021. Improvement of gel properties of low salt surimi using low-dose L-arginine combined with oxidized caffeic acid. *LWT -Food Science and Technology* 145:111303. doi: 10.1016/j.lwt.2021.111303.

Yang, Z., W. Wang, H. Wang, and Q. Ye. 2014. Effects of a highly resistant rice starch and pre-incubation temperatures on the physicochemical properties of surimi gel from grass carp (*Ctenopharynodon idellus*). *Food Chemistry* 145:212–9. doi: 10.1016/j.foodchem.2013.08.040.

Ye, T., H. Dai, L. Lin, and J. Lu. 2019. Employment of κ-carrageenan and high pressure processing for quality improvement of reduced NaCl surimi gels. *Journal of Food Processing and Preservation* 43 (9): e14074. doi: 10.1111/jfpp.14074.

Yin, T., Z. H. Reed, and J. W. Park. 2014. Gelling properties of surimi as affected by the particle size of fish bone. *LWT- Food Science and Technology* 58 (2):412–6. doi:10.1016/j.lwt.2014.03.037.

Yin, T, and J. W. Park. 2014. Effects of nano-scaled fish bone on the gelation properties of Alaska pollock surimi. *Food Chemistry* 150: 463–8. doi:10.1016/j.foodchem.2013.11.041. 24360476

Yin, T., J. W. Park, and S. Xiong. 2017. Effects of micron fish bone with different particle ize on the properties of silver carp (Hypophthalmichthys molitrix) surimi gels. *Journal of Food Quality* 2017:1–8. doi:10.1155/2017/8078062.

Yuan, L., Q. Dang, J. Mu, X. Feng, and R. Gao. 2018. Mobility and redistribution of waters within bighead carp (Aristichthys nobilis) heat-induced myosin gels. *International Journal of Food Properties* 21 (1):835–48. doi: 10.1080/10942912.2018.1476872.

Yuan, L., Y. Kong, W. Leng, Y. Wang, W. Jin, and R. Gao. 2021. L-glutamic acid affects myosin aggregation and the physical properties of bighead carp (*Aristichthys nobilis*) surimi gels. *Food Bioscience* 40 (1):100886. doi: 10.1016/j.fbio.2021.100886.

Yuan, L., Y. Liu, J. Ge, X. Feng, and R. Gao. 2017. Effects of heat treatment at two temperatures on the myosin cluster of bighead carp for gelformation. *CyTA - Journal of Food* 15 (4):574–81. doi: 10.1080/19476337.2017.1321045.

Zhang, L., Q. Li, H. Hong, and Y. Luo. 2020. Prevention of protein oxidation and enhancement of gel properties of silver carp (*Hypophthalmichthys molitrix*) surimi by addition of protein hydrolysates derived from surimi processing by-products. *Food Chemistry* 316:126343. doi: 10.1016/j.foodchem.2020.126343.

Zhang, L., Q. Li, J. Shi, B. Zhu, and Y. Luo. 2018. Changes in chemical interactions and gel properties of heat-induced surimi gels from silver carp (*Hypophthalmichthys molitrix*) fillets during setting and heating: Effects of different washing solutions. *Food Hydrocolloids* 75:116–24. doi: 10.1016/j.foodhyd.2017.09.007.

Zhang, T., Z. Li, Y. Wang, Y. Xue, and C. Xue. 2016. Effects of konjac-glucomannan on heat-induced changes of physicochemical and structural properties of surimi gels. *Food Research International* 83: 152–61. doi: 10.1016/j.foodres.2016.03.007.

Zhang, T., Y. Xue, Z. Li, Y. Wang, and C. Xue. 2015b. Effects of deacetylation of konjacglucomannan on Alaska Pollock surimi gels subjected to high-temperature (120 °C) treatment. *Food Hydrocolloids* 43:125–31. doi: 10.1016/j.foodhyd.2014.05.008.

Zhang, L., Y. Xue, J. Xu, Z. Li, and C. Xue. 2013. Effects of high-temperature treatment (⩾100 °C) on Alaska Pollock (*Theragra chalcogramma*) surimi gels. *Journal of Food Engineering* 115 (1):115–20. doi: 10.1016/j.jfoodeng.2012.10.006.

Zhang, L., F. Zhang, and X. Wang. 2015a. Effects of hydrolyzed wheat gluten on the properties of high-temperature (≥100 °C) treated surimi gels. *Food Hydrocolloids* 45:196–202. doi: 10.1016/j.foodhyd.2014.11.016.

Zhao, Y., H. Kong, X. Zhang, X. Hu, and M. Wang. 2019. The effect of perilla (*Perilla frutescens*) leaf extracts on the quality of surimi fish balls. *Food Science & Nutrition* 7 (6):2083–90. doi: 10.1002/fsn3.1049.

Zhou, X., T. Chen, H. Lin, H. Chen, J. Liu, F. Lyu, and Y. Ding. 2019. Physicochemical properties and microstructure of surimi treated with egg white modified by tea polyphenols. *Food Hydrocolloids* 90:82–9. doi: 10.1016/j.foodhyd.2018.07.031.

Zhou, X., S. Jiang, D. Zhao, J. Zhang, S. Gu, Z. Pan, and Y. Ding. 2017. Changes in physicochemical properties and protein structure of surimi enhanced with camellia tea oil. *LWT- Food Science and Technology* 84:562–71. doi: 10.1016/j.lwt.2017.03.026.

Zhu, Z., T. C. Lanier, B. E. Farkas, and B. Li. 2014. Transglutaminase and high pressure effects on heat-induced gelation of Alaska pollock (*Theragra chalcogramma*) surimi. *Journal of Food Engineering* 131:154–60. doi: 10.1016/j.jfoodeng.2014.01.022.