Frontiers in Food, Drug and Natural Sciences (2025), Vol 3: 22-30
An international peer-reviewed online journal
Available online: fd-science.com

Review Article

Enhancement of gel strength and quality in surimi-based products: The influence of natural additives and processing techniques

Shadab Hushmandi
Department of Fisheries, Faculty of Natural Resources, University of Tehran, Karaj, Iran

ARTICLE INFO
Received: 28 April 2025
Received in revised: 19 May 2025
Accepted: 30 May 2025
Published online: 2 June 2025

* *Direct inquiries to the author: hushmandi.sh@gmail.com*

ABSTRACT
Surimi, a highly refined fish protein concentrate, occupies a pivotal position within the seafood industry, serving as a versatile foundation for various products. The origins of surimi production can be traced back over nine centuries; however, it underwent significant modernization in the 1960s, evolving into a global enterprise, particularly prominent in Japan, China, and South Korea. The production of surimi involves a comprehensive series of processes, including deboning, washing, refining, and stabilization through the application of cryoprotectants, followed by freezing and packaging. The gelation mechanisms pertinent to surimi, encompassing thermal, cold-set, high-pressure, transglutaminase-mediated, and pH-dependent gelation, are crucial for achieving the desired texture and stability. The integration of these processes with various additives serves to enhance the gel strength, elasticity, and water retention of surimi products. The additives utilized may be of animal origin, such as plasma proteins, egg whites, and fish gelatin, or plant-based, including legume proteins, starches, and rice flour. Furthermore, cryoprotectants, such as polyols and gums, along with functional additives like ascorbic acid and unsaturated fatty acids, contribute to the preservation, stability, and nutritional profile of surimi. These techniques and additives collectively facilitate the production of high-quality surimi-based products characterized by improved texture, flavor, and shelf life, thereby increasing their popularity in the global marketplace for a diverse range of seafood offerings.

Keywords: Additives; Elasticity; Fish; Gel strength; Surimi.

1. Introduction

Fish flesh is known for its distinctive qualities, including a high protein content, a well-balanced amino acid profile, and a rich supply of polyunsaturated and essential fatty acids, particularly omega-3 fatty acids. Additionally, it is low in harmful cholesterol and saturated fats (Wohlfarth & Schroeder, 1979). As consumer awareness of health issues continues to increase, the demand for fish and fishery products is experiencing steady growth. Nonetheless, large-scale processing industries, including canning and filleting, remain underdeveloped within our nation.

To optimize capacity utilization and create a diverse array of value-added products, the processing of underutilized fish species into surimi-based products presents immediate advantages to the current fish processing sector. Consequently, it is imperative to develop innovative processing methods for these underutilized protein resources to render them both functional and appealing for human consumption (Osman & Zidan, 2014). Enhancing the gel strength and overall quality of surimi-based products can be effectively achieved through the incorporation of natural additives and the optimization of processing methods. Specifically, plant-based natural ingredients contribute not only to the texture and flavor but also to the nutritional value of surimi products, thereby increasing their appeal to consumers (Abdullah *et al.*, 2019). Furthermore, a comprehensive understanding of the gelation process, which entails the formation of a protein network, is critical for reinforcing the gel and enhancing product quality. Protein-protein interactions, especially those occurring between actin and myosin, play a critical role in influencing gel quality, with stronger interactions correlating with improved product characteristics (Adhawati *et al.*, 2017).

The utilization of transglutaminase promotes protein cross-linking, which in turn enhances both gel strength and stability (Adhawati *et al.*, 2017).

Additionally, the optimization of essential processing steps, including grinding, mixing, and heating, is vital for improving the texture and overall quality of surimi-based products (Agustini *et al.*, 2009). The integration of these strategies substantially enhances the commercial attractiveness and market viability of surimi products.

The surimi and surimi seafood industry, which originated in Japan during the 1960s, has evolved into a global market by the late 20th century. Japan, China, and South Korea dominate the global surimi industry, collectively accounting for over 70% of the world's surimi production (906,000 tonnes) and nearly 2.5 million tonnes of surimi-based seafood (Leadbitter *et al.*, 2020). The term "surimi," which translates to "ground fish meat" in Japanese, is extensively utilized as a source of frozen fish proteins for a variety of seafood products. In 2015, Japan commemorated the 900th anniversary of kamaboko and initiated the Kamaboko Road 1000 project (Guenneugues & Ianelli, 2013). Historically, surimi has been employed in the production of fish balls in Fujian Province, China, and is also incorporated into traditional dishes across numerous Asian countries, including Thailand, Vietnam, Korea, Indonesia, and Myanmar (Leadbitter *et al.*, 2020). The production of surimi involves the isolation of fish myofibrillar proteins through a series of processing steps, which include harvesting, sorting, heading, gutting, deboning, washing, and refining. The proteins are subsequently stabilized with cryoprotectants prior to being shaped into blocks, frozen, and packaged. Each stage of the process significantly influences the final quality and yield of surimi. Effective management of temperature and time throughout processing and storage is essential for preserving surimi quality over extended periods. Furthermore, the thorough elimination of undesirable substances such as fats, sarcoplasmic proteins, and lipids is critical for achieving high-quality surimi. Typically, fish protein derived from surimi constitutes 20 to 30% of the final product composition (Leadbitter *et al.*, 2020).

Fish-paste products, commonly known as fish cakes, are made from frozen surimi and are widely consumed in Korea and Japan (Hwang *et al.*, 2013). In the Korean Food Standards Codex, fish cakes are classified as processed marine products containing salt-soluble proteins derived from fish meat. In 2010, South Korea produced 141,544 tons of fish cakes, valued at around 340 billion won

Table 1.
Lists of additives used in fish and fishery products.

Additive function	Categories	Examples	Application	Reference
To maintain palatability and wholesomeness (preservatives)	Antimicrobial agents	Benzoates, sorbates, NaCl NO_3, NO_2, organic acids, essential oils	Surimi/minced fish products dried, salted or cured fish, fish fillets	(Syamdidi, 2012)
To aid in the processing	Anticaking agents	$Ca_3(PO_4)_2$, Na_2SiO_3, Ca_2SiO_4, $MgCO_3$, Na_4P2O_7	Paste/minced products	(Taylor & Nordlee, 1993)
To aid in the processing	Cryoprotectants	PP	Paste products, fillets, frozen crustaceans	(Vijayan *et al.*, 2021)
Green pepper	Inhibited the growth of wild type strain of *Pseudomonas aeruginosa* and attenuated its virulence properties	Essential oils	Fish-based products	(Myszka *et al.*, 2019)
Punica granatum peels and *Hibiscus sabdariffa* calyxes	Colorant, preservative, and antimicrobial action	Essential oils	Burger and surimi	(Tayel *et al.*, 2018)

(Ha *et al.*, 2013). Fish cakes can be prepared by frying, boiling, with over 95% of them are fried in South Korea (Sotolu, 2011). Fried fish cakes (FFC) are known to include functional ingredients like fiber (Yook *et al.*, 2000), mushrooms, and anchovies (Bae & Lee, 2007).

2. Role of chemical additives and natural alternative solutions by definition

Additives are substances used to enhance or preserve the safety, freshness, flavor, texture, or appearance of food. These additives are commonly introduced at various stages of production, processing, storage, packaging, and transportation of fish and fishery products. Additives can be classified into two categories: synthetic (chemical) and natural (Vijayan *et al.*, 2021). Among chemical additives, sodium chloride (NaCl) is the most widely used. Similarly, sugar, which is readily available, is commonly added to seafood products. Sugar can significantly lower the pH and reduce volatile bases such as total volatile base nitrogen (TVB-N) (Fan *et al.*, 2014). It also acts as a cryoprotectant in frozen surimi and other products (Sultanbawa & Li-Chan, 1998; Sych *et al.*, 1991), helps preserve myofibrillar protein (Ohshima *et al.*, 1993), reduces biogenic amine accumulation in sausages and dry-cured grass carp (Bover-Cid *et al.*, 2001), and prevents protein denaturation in minced fish meat. The combination of sugar and salt can also slow spoilage and enhance various sensory properties (Fan *et al.*, 2014). For example, the traditional Nordic product "gravad" is made using this combination of sugar and salt (Lyhs *et al.*, 2001). Additionally, sodium citrate can improve cooking yield and texture by preventing excessive pH drops (Agrafioti & Katsanidis, 2012). Sodium or potassium lactate is another effective additive for seafood products. It has been shown to extend shelf life in minced fish products (Birkeland & Rotabakk, 2014), exhibit antibacterial effects in sliced and cold-smoked salmon (Sallam, 2007), and improve preservation in catfish fillets (Williams, 1995).

3. Cryoprotectants

Although surimi possesses a historical lineage exceeding 900 years, contemporary surimi production commenced in the 1960s, when Japanese researchers Kyosuke Nishiya and Fumio Takeda at the Hokkaido Fishery Research Center identified the advantageous function of sugar as a cryoprotectant. This pivotal discovery demonstrated that sugar could mitigate protein denaturation during the processes of freezing and frozen storage, thereby establishing the foundational principles for the global surimi industry by facilitating the transition from fresh to frozen surimi. Initially, an 8% concentration of sugar was employed in surimi production derived from pollock; however, this concentration was subsequently reduced to 4% and substituted with sorbitol, as the initial 8% was deemed excessively sweet. Additionally, a combination of sodium tripolyphosphate (STPP) and tetrasodium pyrophosphate (TSPP) in an equal ratio of 50/50, at a concentration of 0.3%, was also incorporated into the production process (Leadbitter *et al.*, 2020).

4. Natural additives

4.1. Plant-derived products

The utilization of plant-based natural compounds, including essential oils, plant extracts, hydrocolloids, and phenolic compounds, has garnered considerable attention in the preservation of seafood. These compounds exhibit significant antimicrobial and antioxidant properties, rendering them invaluable within the food industry. Derived from various plant parts—such as petals, leaves, fruits, stems, and roots—plant extracts and essential oils confer antioxidant effects attributed to volatile organic compounds, terpenoids, and phenolic components. Notably, essential oils demonstrate greater efficacy against gram-positive bacteria compared to gram-negative bacteria, as the lipopolysaccharide cell wall of the latter obstructs the penetration of these oils into the membrane (Bajpai *et al.*, 2008). Although essential oils and plant extracts are commonly employed to prolong the shelf life and uphold the quality of fish and seafood, their pronounced odors, high volatility, intricate chemical compositions, and limited bioavailability pose significant challenges. Additionally, variability in plant genetics and extraction methodologies further influences their practical applications (Stevanović *et al.*, 2018). The incorporation of seaweed and algal extracts is on the rise as natural sources of antioxidants and nutritional benefits. Among the hydrocolloids frequently utilized, agar-agar primarily serves as a thickening agent in fish paste products, while carrageenan enhances the gelling properties of fish mince (Borderías *et al.*, 1996), and improves the organoleptic qualities of mussels and squids (Guldas & Hecer, 2013). Sodium alginate is routinely employed as a stabilizer and thickener in coatings. Hydrocolloids such as konjac further augment the gelling capabilities of surimi-derived products (Park, 1996) Other substances, including starch (Gómez-Guillén *et al.*, 1997) Various gums like guar, xanthan, and guar contribute to the elasticity and gelling properties of fish-based products. Furthermore, iota carrageenan and xanthan (Montero *et al.*, 2000). They are noted for their cryoprotective effects (Da Ponte *et al.*, 1987). Plant-derived products, including soybean protein, wheat gluten, and starch, are also utilized as additives in fish paste formulations (Bashir *et al.*, 2017).

4.2. Animal-derived products

Animal-derived products such as chitosan, gelatin, and whey proteins are commonly used as food additives. Chitosan is a natural polymer extracted from chitin, which is found in the exoskeletons of shellfish and fungal cell walls. Gelatin is a protein sourced from the collagen of animal tissues, while whey protein is one of the two primary proteins in milk, alongside casein. These compounds are often used to coat food products, providing antioxidant and antimicrobial properties that help extend their shelf life. Adding these compounds directly to packaging materials further enhances their preservative effects (Ahmed *et al.*, 2017). In fish paste products, additives like plasma hydrolysate, plasma proteins, ovomucoid, egg albumin, and egg white are used to improve product strength (Bashir *et al.*, 2017) Studies have also shown that egg whites and hydrolyzed beef plasma proteins contribute to the binding in surimi gels (Park, 1994), while bovine plasma powder and egg white powder enhance the gel properties in arrow-tooth surimi (Wasson *et al.*, 1993).

4.3. Microbial-derived products

Bacteriocin, an efficacious biopreservative predominantly extracted from Lactobacillus, demonstrates substantial antimicrobial properties. Its mechanism of action involves

Table 2.
Natural food additives used to improve the gel properties of fish-paste products.

Common name	Categories	Species	Cooking method	Used as	Metrics	Optimum amount or treatment condition	Reference
Fish gelatin	Seafood additives	Commercial fish gelatin (gelatin rousselot)	Heated in a water bath	Powder	Color, mechanical, functional, sensory attributes	10 g. kg^{-1}	(Hernández-Briones *et al.*, 2009)
Squid ink tyrosinase (SIT) + tannic acid (TA)	Seafood additives	*Todarodes pacificus*	Heated in a water bath	Mixture	Tyrosinase activity, in vitro oxidation assay, color, textural and sensory attributes	SIT: 500U. g^{-1} protein + TA: 1%	(Vate & Benjakul, 2016)
Soy protein isolate	Plant source additives	*Glycine max*	Heated in a water bath	Commercial soy protein isolate	Total nitrogen and moisture content, gel strength, color	10%	(Luo *et al.*, 2004)
Potato starch	Plant source additives	*Solanumtu berosum*	Heated in the Krehalone casing film	Powder	Proximate analysis, protein composition, color, folding text, textural and sensory attributes	8%	(Yoo, 2011)
Amorphophallus konjac flour (AKF) NaCl + high	Cryoprotectants and humectants	*Amorphophallus konjac*	Heated in a water bath	Flour	Water retention ability, color, textural and sensory attributes	10%	(Choi & Kim, 2012)
Eicosapentaenoic acid, docosahexaenoic acid	Cryoprotectants and humectants	-	Heated in a water bath	Oil	Proximate analysis, color, water-holding capacity, physical attributes	5%–30%	(Fukushima *et al.*, 2007)
Whey protein concentrate	Other Functional Additives	*Bos taurus*	Heated in a water bath	Whey protein concentrate	Water-holding capacity, color, autolytic activity	3%	(Rawdkuen & Benjakul, 2008)

the disruption of bacterial cell wall synthesis via pore formation, which results in the leakage of intracellular contents and subsequently inhibits bacterial proliferation (Sharma *et al.*, 2018). In addition to its antimicrobial properties, bacteriocins are characterized by their non-toxic nature and effectiveness across a diverse spectrum of pH levels and temperatures, thus categorizing them as generally recognized as safe (GRAS) additives (Woraprayote *et al.*, 2016). Representative bacteriocins produced by *Lactobacillus* include nisin, lacticin, and pediocin, many of which have proven particularly efficacious against endospore-forming bacteria. When utilized in conjunction with other preservation techniques, bacteriocins frequently exhibit enhanced effectiveness. For instance, the combination of microencapsulated Ziziphora clinopodioides essential oil and nisin has been demonstrated to significantly preserve the sensory quality of fish burgers (Shahinfar *et al.*, 2017). Nonetheless, the high production costs associated with bacteriocins hinder their widespread application. Research indicates that a synergistic combination of plant, animal, and microbial-derived products can yield superior preservative effects compared to their singular application (Wu *et al.*, 2019).

5. Improvement of the gel Properties of fish-paste products

The mechanisms underlying surimi gelation are fundamental for attaining the desired texture and stability in a range of seafood products. Prominent methods encompass thermal gelation, wherein heat induces protein denaturation and the formation of a gel-like structure, thereby enhancing the product's texture and stability. Cold-set gelation entails the application of low temperatures alongside cross-linking agents such as calcium ions to yield diverse textures and flavors, particularly in products like kamaboko and crab sticks.

High-pressure gelation employs significant pressure to achieve analogous outcomes, frequently in conjunction with other techniques to amplify the effect. Furthermore, transglutaminase-mediated gelation utilizes the enzyme transglutaminase to facilitate the cross-linking of proteins, permitting a variety of textures and flavors in both surimi seafood and meat analogues.

Lastly, pH-dependent gelation alters the pH of the surimi mixture to induce gel formation, thereby further enhancing the quality of the final product. These mechanisms collectively operate to generate surimi products characterized by desirable attributes.

5.1. Animal-based additives

Plasma proteins, sourced from beef, pork, and chicken, augment gel strength and elasticity; however, elevated concentrations may result in off-flavors or adverse effects.Egg whites and whey proteins also contribute to improved gel formation, with egg whites specifically enhancing breaking strength and gel deformation. Fish gelatin exerts a minimal influence on texture, whereas fish bones can significantly enhance water retention and gel strength.

5.2. Seafood-based additives

Shrimp head protein hydrolysate aids in preserving gel structure by mitigating freeze-induced protein denaturation. Fish plasma proteins, such as those derived from salmon, inhibit autolysis, while squid ink-based additives may enhance gel firmness.

5.3. Plant-based additives

Legume proteins, inclusive of soy, black cowpea, and Bambara groundnut proteins, act as protease inhibitors and reinforce gels, although they may marginally diminish whiteness. Starches, particularly those extracted from potatoes and sweet potatoes, are frequently employed to bolster elasticity and water retention in surimi, with their amylose content influencing gel strength. Rice flour serves as an alternative to wheat flour, improving both gel texture and the sensory properties of surimi products.

5.4. Cryoprotectants and humectants

Polyols, sugars, and polyunsaturated fatty acids are utilized to maintain the quality of surimi during cold storage and freezing, ensuring stability and structural integrity. Additional compounds such as polyuronides, saccharides, and salts also confer benefits. Konjac and xanthan gums enhance the viscoelastic properties of gels, contributing to increased firmness and stability. Potassium, serving as a substitute for sodium, aids in reducing sodium levels in fish products; however, it may influence consumer preference due to variations in taste.

5.5. Other Functional Additives

Ascorbic acid fortifies gels through the oxidation of protein sulfhydryl groups. Unsaturated fatty acids, including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), enhance gel stability and enrich the nutritional profile of surimi products. Plant extracts, such as tannins and coconut husk, are advantageous for sustaining surimi quality, preserving gel strength, and improving sensory properties over time. Each of these additives influences gel characteristics, encompassing breaking force, deformation, water retention, and occasionally color and flavor, rendering them appropriate for various applications contingent upon the intended attributes of the final product (Bashir *et al.*, 2017).

6. Conclusions and perspectives

Surimi is derived from myofibrils, which are structural proteins constituting approximately 65-80% of the muscle mass in fish. When combined with NaCl, fish protein paste exhibits both viscous and elasticproperties. During thermal processing, this protein paste undergoes a transformation into a gel, with only a minor proportion retaining its viscous characteristics. The influence of temperature on gelation is contingent upon various factors, including the species of fish, processing methodologies, and the historical context of the surimi. According to the Food and Agriculture Organization (FAO), surimi production reached one million tons in 2010, with the United States identified as the largest producer, contributing 300,000 tons. In contrast, Japan emerged as the leading global consumer, utilizing 500,000 tons of surimi. As the demographic of quality-conscious consumers expands, the demand for natural additives in surimi products is anticipated to rise, juxtaposed with the diminishing use of synthetic ingredients.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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