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Review Article

Natural Food Additives and Preservatives for Fish-Paste Products: A Review of the Past, Present, and Future States of Research

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Fish-paste products, also known as fish cakes or surimi-based products, are worldwide favorites. Surimi, a wet protein concentrate of fish muscle, is used as an intermediate raw material to produce surimi seafood. The flavor, texture, taste, shelf-life, and market value of surimi-based products depend on the source of the fish meat, type of applied heat treatment, and additives used to prepare the surimi. While preparing surimi with chemical additives, several problems have been observed, such as a lack of unique characteristics, inferior acceptability, and poor functionality. Various types of fish-paste products have been developed by using different ingredients (e.g., vegetables, seafood, herbs and oriental medicines, grains and roots including carrots, and functional food materials). However, a systematic review of fish-paste products prepared using natural food additives has not yet been performed. Therefore, the quality characteristics of fish-paste products and their functionalities were elucidated in this study. With the increasing demand for surimi seafood products, the functional properties, physiochemical properties, and shelf-life of surimi-based products need to be improved. This review will aid the preparation of new value-added products in the surimi industry.

1. Introduction

Fish-paste products, popularly known as fish cakes, are produced from frozen surimi (i.e., they are a kind of surimi-based product) and are popular in Korea and Japan [1]. In the Korean Food Standards Codex, fish cakes are known as a processed marine product comprising salt-soluble proteins isolated from fish meat [2]. Fish muscle is mechanically deboned, washed with water, and blended with cryoprotectants to prepare a wet concentrate of proteins called surimi. Surimi is a Japanese term that is also known as washed fish mince. It is a refined fish myofibrillar protein manufactured through numerous step-by-step processes including heading, gutting, filleting, deboning (mincing), washing, dewatering, refining, mixing with cryoprotectants, freezing, and metal detection for HACCP [3]. The myofibrillar proteins make it an excellent ingredient for developing food products. It has excellent gelling properties and forms strong and elastic gels upon heating [4].

The setting and deformation are important to prepare surimi and surimi-based products. Setting, also known as "suwari" in Japanese, is a very important process, which has a significant influence on the physiological and rheological properties of surimi-based products. Setting is a vital process in the quality estimation of surimi because it helps to improve the water-holding capacity as well as the gel texture of surimi-based products. When fish mince paste (sol) is heated at a low temperature (up to 50°C), a loose network (suwari) is formed from myosin and actomyosin molecules; this process is referred to as setting. Setting is species dependent and occurs over a range of temperatures (up to 50°C) and to a varying extent. As the temperature is increased to around 70°C, suwari is partially disrupted to form a broken net structure (modori), a phenomenon attributed to the dissociation of myosin from actin and the possible fragmentation of the actin filament [5–7].

Most of the surimi-based products are different types of fish-paste products, while less than 10% include fish burgers, fish ham, and fish sausages [3]. Surimi-based products are prepared by mixing the raw or frozen surimi with salts and other ingredients, molded and heated to form the final product in the specified shape and texture, and pasteurized before packaging. The kind of heat treatment depends on the flavor, texture, and appearance of the desired final product and may include broiling, steaming, deep-fat frying, and boiling [8], while fish-paste products in South Korea are mostly prepared by frying [9]. Textural characteristics such as gel strength are the major determinant of surimi price and quality [10]. Several studies have attempted to enhance the textural quality of surimi or surimi-based products using various protein additives [11–14].

Surimi quality and gelling property are mainly affected by both intrinsic factors (effect of fish species, seasonality, sexual maturity, and freshness or rigor) and extrinsic factors (harvesting, handling, water characteristics, processing time and temperature, solubilization of myofibrillar proteins during processing, the activity of the endogenous or added protein oxidants, and proteolytic enzymes, washing cycles, salinity, and pH) [3, 134]. Surimi forms thermoirreversible gels upon heating, which do not deform with further change in the temperature. This phenomenon of surimi and surimi-based products is similar to that observed in other proteins, such as egg white, milk-lactoglobulin, and wheat gluten. Additionally, surimi produces gels of very high deformability and strength. This heat-induced gelation property of surimi makes it a very valuable food ingredient [134].

The gel-forming ability and capacity of surimi are adversely affected by the proteolytic degradation of myofibrillar proteins. The presence of indigenous proteinases caused gel softening in surimi made from fish species, for example, threadfin bream [135], arrow tooth flounder [136], Pacific whiting [137], and lizard fish and bigeye snapper [20, 59]. Various active proteinases in fish muscle are responsible for softening of the surimi gels. Nakamura and Ogawa and An et al. testified that cathepsins L and B were the most active cysteine proteinases in Pacific whiting surimi and fish fillets, respectively [7, 138]. The myofibril-associated proteinases observed in lizardfish surimi were serine proteinases and cysteine, while a serine proteinase was reported in the bigeye snapper surimi [20, 59].

Seasonal analysis of the compositional properties of Alaska pollock and Pacific whiting showed higher protein contents in winter, while the moisture contents were higher in summer [139, 140]. Surimi prepared from cold-water fish species with low thermostability of myofibrillar proteins makes setting easier. Normally, a myofibrillar protein with low thermostability is optimum to do setting because its reactivity is increased due to the loose internal structure by sodium chloride addition and heat denaturation. In contrast, the myofibrillar protein of tropical fish species with high heat stability is difficult to denature and form the myofibrillar protein network structure in surimi [3].

Several research groups have studied ways to enhance the quality of surimi-based products by investigating the changes in microbial content, enzyme activity, nutrient content and acceptability characteristics, the use of raw materials, the standardization of the manufacturing process, storage, and marketing. Natural and chemical food-grade additives such as konjac flour, proteinase inhibitors, egg white, and hydrocolloids have been used to enhance the gelling properties of surimi [12, 17, 20, 23, 34, 141–143]. The trypsin inhibitor in egg white plays a major role in improving the gel strength of surimi. The addition of egg white inhibits the proteolytic activity of the modori-inducing enzyme in fish meat and suppresses the decrease of elasticity in surimi. Serum proteins have strong inhibiting abilities against the action of various proteases with different active centers such as SH groups and serine groups. In addition, they also contain transglutaminases that accelerate the setting. Egg white and serum proteins also play an important role in inhibiting the enzymatic activity of the parasites. Apart from the use of additives, gel strengthening can be achieved by treating the gels at low temperatures (0–40°C) before cooking [144, 145]. Furthermore, the gel quality of surimi and surimi-based products can also be enhanced by using alternate fish species, or by acid and alkali washing to increase the myofibrillar protein concentrations [7, 146, 147].

Surimi production worldwide reached around 800,000 MT by 2011-2012 [3], while South Korea alone contributed approx. 156,000 MT in 2013. Over the years, the size of the market for Korean fish-paste products has gradually increased, reaching ~350 million US dollars in 2013 (based on the amount produced) [148]. However, manufacturers have had several problems in producing surimi-based products, such as a lack of unique characteristics and inferior acceptability and functionality. Therefore, there have been several attempts to develop new fish-paste products with excellent acceptability and functionality. To this end, numerous types of fish-paste products have been developed using various natural ingredients such as vegetables, seafood, animals, plants, herbs and oriental medicines, seaweed, and functional food materials. It is of worldwide interest to use these natural food preservatives instead of chemical or synthetic ones. However, to date, no systematic review of fish-paste products supplemented with various food raw materials has been performed. Therefore, the quality characteristics of fish-paste products and their functionalities were elucidated in this study.

2. Improvement of the Gel Properties of Fish-Paste Products

Various food additives derived from animals (e.g., beef, swine, and chicken), seafood (e.g., fish, invertebrates), plants (e.g., legumes, cereals), sugars, polyols, and functional materials used in fish-paste products to improve their gelling capabilities and strength are listed in Table 1 and described below.

2.1. Animal Source Additives. Various food-grade protease inhibitors from animal sources are used to enhance the physical properties of surimi-based products as well to prevent the protein degradation. The ability of beef plasma and other food-grade additives in surimi and fish mince prepared from Pacific whiting *(Merluccius productus)* was studied by Morrissey et al. [12]. The strongest proteolytic inhibition was observed with beef plasma protein at a concentration as low as 1%. Reppond and Babbitt reported the increase in gel strength of gels prepared by arrow tooth flounder at a concentration of 2%, with a yellow hue color [16]. Weerasinghe et al. characterized the inhibitory activity of these food-grade inhibitors and reported that the inhibitory activity was mainly because of specific serine proteinase inhibitors [17]. The addition of 2% dried bovine plasma to steamed fish-paste slightly increased the chewiness and hardness, but it showed a negative effect on the gel strength [18]. Duangmal and Taluengphol reported that the higher levels of beef plasma protein unfavorably affected gel characteristics of red tilapia surimi gels [19].

The effect of porcine plasma protein on the bigeye snapper *(Priacanthus tayenus)* surimi gel characteristics was investigated by Benjakul et al. [14]. The gels supplemented with 0.5% porcine plasma protein had the highest level of deformation and breaking force. Benjakul and colleagues later reported the effect of porcine plasma protein on the gel characteristics of surimi from bigeye croaker *(Pennahia macrophthalmus)*, bigeye snapper *(P. tayenus)*, barracuda *(Sphyraena jello)*, and threadfin bream *(Nemipterus bleekeri)* [20]. The porcine plasma protein was effective in increasing the deformation and breaking force of kamaboko gels. Higher breaking forces and levels of deformation occurred when chicken plasma protein was supplemented to sardine kamaboko gels at levels up to 2% [21]. The inhibitory activities of cysteine proteinase inhibitor fraction from chicken plasma on Pacific whiting and arrow tooth flounder mince were reported by Rawdkuen et al. [22]. Furthermore, similar results were observed in their extended study on Pacific whiting surimi, where chicken plasma at a level of 2% inhibited the degradation of myosin heavy chain proteins [23].

Ovomucoid is a mucoprotein obtained from egg white that has been tested for its potential as a gel-degradation inhibitor [24, 25]. The addition of 2% ovomucoid could increase the breaking strength and gel deformation [28]. The autolytic activities of lizardfish *(Saurida tumbil)* surimi and mince under the application of protease inhibitors were investigated by Yongsawatdigul and Piyadhammaviboon [26]. At all preincubation conditions, egg white enhanced the gel-forming capability of *S. tumbil* surimi to a greater extent than did whey protein concentrate. The addition of 1% egg white and preincubation at 25°C increased the breaking force by twofold. Campo-Deaño and Tovar [27] reported that the addition of egg albumen at 1.5% and 2% for Alaska pollock and Pacific whiting surimi, respectively, enhanced the gel strength of crab sticks. According to Hunt et al., the incorporation of 2%-3% special dried egg white improved the gel textural characteristics of Alaska pollock and Pacific whiting surimi [28].

Whey is the complete set of proteins isolated from the watery portion of milk. Whey protein is comprised of 20% milk protein and 80% casein [149]. Whey protein concentrates have generally been used as an emulsifier, filler, water binder, protein supplement, foam stabilizer, and thickener as well as gelling agent [150]. Rawdkuen and Benjakul investigated the effect of whey protein concentrate on the gelling characteristics of surimi prepared from goatfish *(Mulloidichthys vanicolensis)*, bigeye snapper *(P. tayenus)*, lizardfish *(S. tumbil)*, and threadfin bream *(N. bleekeri)* [29]. All the tested surimi supplemented with 3% whey protein concentrate displayed inhibitory activity against autolysis and significantly reduced gel whiteness. However, better water-holding capacity was obtained by increasing concentrations of whey protein concentrate.

Plasma proteins produced from pig, cow, and chicken byproducts are relatively affordable and easily collectible sources [143, 151, 152]. However, outbreaks of foot-and-mouth disease, avian influenza, and mad cow disease, as well as a ban on proteins from pig bone and skin in some states for religious causes, have made it essential to search alternative sources [153, 154]. Various fish plasma proteins have been tested, including those from rainbow trout and salmon [31, 35, 36].

2.2. Seafood Additives. The effects of shrimp head protein hydrolysate from different shrimp, namely, black tiger shrimp *(Penaeus monodon)*, northern pink shrimp *(Pandalus eous)*, and endeavour shrimp *(Metapenaeus endeavouri)* on the gelling properties of lizardfish (*Saurida* spp.) surimi were investigated by Ruttanapornvareesakul et al. [30]. It was reported that the freeze-induced denaturation of lizardfish muscle protein could be reduced by the supplementation of shrimp head protein hydrolysate at a concentration of 5%, resulting in higher Ca-ATPase activity and gel strength. The effects of rainbow trout plasma proteins on the gelling properties of surimi prepared by Alaska pollock were investigated by Li et al. [31]. Gel degradation, deformation, the breaking force, water-holding capacity, and whiteness enhanced with increasing amounts of rainbow trout plasma protein and decreased at higher concentrations. The rainbow trout plasma protein at a concentration of 0.75 mg/g could be used as a potential protease inhibitor to inhibit gel weakening in Alaska pollock surimi. Li et al. reported the higher inhibitory activities of the recombinant chum salmon cystatin against autolysis of Alaska pollock surimi [155].

Fish gelatin is extracted from the collagen of fish skin and it is used as a food additive. Hernández-Briones et al. studied the functional and mechanical properties of Alaska pollock surimi gels while using fish gelatin as an additive [32]. The increasing concentration of gelatin affected the whiteness but the sensory panelists were unable to detect it. These results showed that fish gelatin was not effective as a functional additive in Alaska pollock surimi. Nevertheless, it could be added at up to 10 g/kg without negatively affecting the mechanical properties of surimi. Yin et al. reported a significant improvement in the endogenous transglutaminase activity of Alaska pollock surimi prepared with nanoscaled

Table 1: Natural food additives used to improve the gel properties of fish-paste products.

Common name	Species	Cooking method	Used as	Fish source for surimi	Metrics	Optimum amount or treatment condition	References
Animal source additives							
Beef plasma hydrolysate	*Bos taurus*	Heated in a water bath	Dried powder	Atlantic menhaden *(Brevoortia tyrannus)*, Alaska pollock *(Theragra chalcogramma)*	Moisture content, protein content, cooking loss, water-holding capacity, texture, torsion test	0.5%–1.5%	[15]
Bovine plasma	*Bos taurus*	Heated in a water bath	Powder	Arrowtooth flounder *(Atheresthes stomias)*, Walleye pollock	Moisture content, punch, torsion, color test	2%	[16]
Beef plasma protein	*Bos taurus*	—	Powder	Pacific whiting *(Merluccius productus)*	Protein content, inhibitory assay	4%	[17]
Dried bovine plasma	*Bos taurus*	Steaming	Powder	Alaska pollock *(T. chalcogramma)*	Nutrient content, pH, water-holding capacity, texture and sensory evaluation	2%	[18]
Beef plasma protein	*Bos taurus*	Heated in a water bath	Dried powder	Red tilapia (*O. niloticus* x *O. placidus*)	Color, texture, expressible water, protein, total sulfhydryl content	2 g/kg	[19]
Porcine plasma protein	*Sus scrofa domesticus*	Heated in a water bath	Dried powder	Bigeye snapper *(Priacanthus tayenus)*	Expressible drip amount, color, texture, setting conditions	0.5%	[14]
Porcine plasma protein	*Sus scrofa domesticus*	Heated in a water bath	Dried powder	Threadfin bream *(Nemipterus bleekeri)*,Bigeye snapper *(P. tayenus)*, Baracuda *(Sphyraena jello)* and Bigeye croaker *(Pennahia macrophthalmus)*	Trichloroacetic acid-soluble peptides, color, texture, protein content	0.5%	[20]
Chicken plasma protein	*Gallus gallus domesticus*	Heated in a water bath	Dried powder	Sardine *(Sardinella gibbosa)*	Color, texture, expressible moisture, protein content, autolysis activity	2%	[21]
Cysteine proteinase inhibitor from Chicken plasma	*Gallus gallus domesticus*	Heated in a water bath	Dried powder	Arrowtooth flounder *(A. stomias)*,Pacific whiting *(M. productus)*	Autolysis and inhibitory activity, pH, protein content	3%	[22]
Chicken plasma	*Gallus gallus domesticus*	Heated in a water bath	Dried powder	Pacific whiting *(M. productus)*	Torsion and fracture test, dynamic rheological attribute	2%	[23]
Ovomucoid	*Gallus gallus domesticus*	Heated in a water bath	Ovomucoid solution	Alaska pollock	Puncture test, textural and sensory attributes	2%	[24]
Ovomucoid	*Gallus gallus domesticus*	Heated in a water bath	Ovomucoid solution	Alaska pollock	Puncture test, textural and sensory attributes	2%	[25]
Egg white (EW)	*Gallus gallus domesticus*	Heated in a water bath	Powder	Lizardfish *(Saurida tumbil)* mince and surimi	Autolytic activity, textural attributes	EW: 1%	[26]
Egg albumin	*Gallus gallus domesticus*	Heated in the cooking roller	Egg white itself	Surimi-based crab sticks from Alaska pollock (AP), Pacific whiting (PW); *(M. productus)*	Transient test, strength test, texture, dynamic rheological and physical attributes	AP: 1.5%, PW: 2%	[27]

Table 1: Continued.

Common name	Species	Cooking method	Used as	Fish source for surimi	Metrics	Optimum amount or treatment condition	References
Regular dried egg white (REW), special dried egg white (SEW), liquid egg white (LEW)	*Gallus gallus domesticus*	Heated in a water bath	Spray-dried powder	Pacific whiting *(M. productus)*	Total sulfhydryl groups, fracture test, dynamic rheological attribute	SEW: 2%-3%	[28]
Whey protein concentrate	*Bos taurus*	Heated in a water bath	Whey protein concentrate	Bigeye snapper *(P. tayenus)*, Goatfish *(Mulloidichthys vanicolensis)*, Threadfin bream *(N. bleekeri)* and Lizardfish *(S. tumbil)*	Water-holding capacity, color, autolytic activity	3%	[29]
Seafood additives							
Shrimp head protein hydrolysate from, northern pink shrimp, endeavour shrimp, and black tiger shrimp	*Pandalus eous, Metapenaeus endeavouri, Penaeus monodon*	Heated in a water bath	Dried matter	Lizardfish (*Saurida* spp.)	Gel strength, color, gel-forming ability, Ca-ATPase activity	5%	[30]
Rainbow trout plasma protein	*Oncorhynchus mykiss*	Heated in a water bath	Freeze-dried plasma	Alaska pollock	Proximate analysis, water-holding capacity, color, texture, protein content	0.75 mg/g	[31]
Fish gelatin	Commercial fish gelatin (Gelatin Rousselot)	Heated in a water bath	Powder	Alaska pollock	Color, mechanical, functional, sensory attributes	10 g/kg	[32]
Nanoscaled fish-bone of Pacific whiting	*M. productus*	Heated in a water bath	Powder	Alaska pollock	Texture, scanning electron microscopy	1 g/100 g	[33]
Nanoscaled fish-bone (NFB) + dried egg white (DEW)	*M. productus, Gallus gallus domesticus*	Heated in a water bath	Powder	Pacific whiting: *(M. productus)*	Rheological and textural attributes	DEW: 1% + 10 mg NFB Ca/g surimi paste	[34]
Salmon blood plasma	*Oncorhynchus tshawytscha*	Ohmic heating	Freeze-dried plasma	Pacific whiting *(M. productus)*	Scanning electron microscopy, protein content, dynamic rheological attributes	1 g/100 g	[35]

Table 1: Continued.

Common name	Species	Cooking method	Used as	Fish source for surimi	Metrics	Optimum amount or treatment condition	References
Freeze-dried chinook salmon plasma (FSP) and concentrate salmon plasma (CSP)	*Oncorhynchus tshawytscha*	Ohmic heating	Freeze-dried plasma	Pacific whiting *(M. productus)* surimi and Salmon mince	Proteolytic inhibition, autolysis, protein content	Salmon mince: CSP > FSP Pacific whiting surimi: FSP	[36]
Partially purified trypsin inhibitor from the roe of yellowfin tuna fish	*Thunnus albacares*	Heated in a water bath	Freeze-dried	Bigeye snapper *(Priacanthus macracanthus)*	Proteolysis, color, water-holding capacity, gelling properties	3 g/100 g	[37]
Squid ink tyrosinase (SIT) + tannic acid (TA)	*Todarodes pacificus*	Heated in a water bath	Mixture	Sardine *(Sardinella albella)*	Tyrosinase activity, *in vitro* oxidation assay, color, textural and sensory attributes	SIT: 500 U/g protein + TA: 1%	[38]
Plant source additives							
Soybean protein, wheat gluten	*Glycine max*, *Triticum aestivum*	Heated in a water bath	Soybean protein, Wheat gluten	Alaska pollock *(T. chalcogramma)*	Expressible water, moisture content, gel strength, physical attributes	5%	[39]
Soy protein, egg white (EW), whey protein concentrate (WPC), *Lactalbumin* (LA), milk protein isolate (MPI)	*Glycine max*, *Gallus gallus domesticus*, *Bos taurus*	Cooked in a steam cooker	Powder	Alaska Pollock *(T. chalcogramma)*	Texture, expressible moisture content, water retention properties	EW and MPI	[40, 41]
Legume seed extract from, black cowpea, white cowpea, soybean seeds, Mungbean, peanut	*Vigna unguiculata*, *Glycine max* *Vigna radiata* *Arachis hypogaea*	—	Freeze-dried proteinase inhibitor extracts	Threadfin bream (Nemipteridae)	Thermal stability, pH, protein content, proteinase inhibitory assay	Black cowpea, soybean seeds: 30 mg/g	[42]
Legume seed extract from Cowpea, pigeon pea, bambara groundnuts	*Vigna unguiculata*, *Cajanus cajan*, *Voandzeia subterranea*	—	Partially purified Trypsin	Threadfin bream (Nemipteridae)	Sarcoplasmic modori-inducing proteinase activity, color	30 k units/g	[43]
bambara groundnut protein isolate	*Vigna subterranea*	Heated in a water bath	Powder	Threadfin bream *(N. bleekeri)*	Color, autolysis	0.25 g/100 g	[44]
Soy protein isolate	*Glycine max*	Heated in a water bath	Commercial soy protein isolate (JinQui 1200)	Alaska pollock *(T. chalcogramma)*, Common carp *(Cyprinus carpio)*	Total nitrogen and moisture content, gel strength, color	10%	[45]

TABLE 1: Continued.

Common name	Species	Cooking method	Used as	Fish source for surimi	Metrics	Optimum amount or treatment condition	References
Soybean protein, wheat gluten	*Glycine max*, *Triticum aestivum*	Heated in a water bath	Soy protein, wheat gluten	Alaska pollock *(T. chalcogramma)*	Expressible water, moisture content, gel strength, physical attributes	5%	[46]
Dietary fiber (DF) from pea and chicory + microbial transglutaminase (MTGase)	*Cichorium intybus* *Pisum sativum*	Heated in a water bath	Powder	Hake *(M. capensis)*, Gilthead seabream *(Sparus aurata)*, Sea bass *(Dicentrarchus labrax)* Meagre *(Argyrosomus regius)*	Dynamic rheological attributes	MTGase: 100 U/g	[47]
Protein isolates from Mungbean (MBPI), black bean (BBPI), bambara groundnut (BGPI)	*Phaseolus aureus*, *Phaseolus vulgaris*, *Vigna subterranea*	—	Freeze-dried powder	—	Scanning electron microscopy, proteolytic, autolytic and trypsin inhibitory activity assay, color, texture, trichloroacetic acid-soluble peptide content	1 g/100 g	[48]
Partially purified trypsin inhibitor from adzuki bean	*Vigna angularis*	Heated in a water bath	Freeze-dried powder	Threadfin bream (*N. bleekeri*)	Protein content, texture, color, trypsin inhibitory activity, autolytic activity assay	3 g/100 g	[49]
Amylose (A) and amylopectin (AP)	—	Heated in a water bath	Powder	Walleye pollock *(T. chalcogramma)*	Gelation and breaking strength	Amylose: 70% + Amylopectin: 4%	[50]
Wheat starch	*Triticum aestivum*	Heated in a water bath	Powder	Alaska pollock *(T. chalcogramma)*	Compression test, dynamic viscoelasticity, scanning electron microscopy	Starch: 10 g + Surimi: 10 g	[51]
Native sweet potato starch (NSPS) and Modified sweet potato starch (MSPS)	*Ipomoea batatas*	Heated on a controlled stress rheometer	Powder	Alaska pollock *(T. chalcogramma)*	Dynamic rheological attributes	5%	[52]
Potato starch	*Solanum tuberosum*	Heated in the Krehalone casing film	Powder	Pacific sand lance (*Ammodytes personatus* Girard)	Proximate analysis, protein composition, color, folding text, textural and sensory attributes	8%	[53]
Rice flour	*Oryza sativa*	Fried	Powder	Alaska pollock *(T. chalcogramma)*	Gel strength, color, rheological and sensory attributes	10–15%	[54]
Rice flour	*Oryza sativa*	Fried	Powder	Threadfin bream (Nemipteridae)	Moisture content, pH, color, textural and sensory attributes	50%	[55]
Rice flour	*Oryza sativa*	Fried	Powder	Golden threadfin bream *(Nemipterus virgatus)*	Gel strength, sensory attributes	14%	[56]
Cryoprotectants and humectants							
Xanthan (X), locust bean (LB) gums alone, X/LB ratio	*Ceratonia siliqua*	Heated in a water bath	Powder	Silver carp *(Hypophthalmichthys molitrix)*	Torsion test, gel-forming ability, mechanical attributes	X/LB: 0.25/0.75	[57]
Pectin gum (HM, LM) + $CaCl_2$	—	Heated in a water bath	Gum and powder	Silver carp *(H. molitrix)*	Water-holding capacity, mechanical and textural attributes	Pectin gum: 1% + $CaCl_2$: 0.2%	[58]

Table 1: Continued.

Common name	Species	Cooking method	Used as	Fish source for surimi	Metrics	Optimum amount or treatment condition	References
Chitosan 7B from prawn shell	Not mentioned	Heated in a water bath	Not mentioned	Barred garfish (*Hemiramphus far*)	Protein content, SEM, textural attributes	1%	[59]
Konjac glucomannan aqueous dispersion	*Amorphophallus konjac*	Heated in a water bath	Aqueous dispersion	Giant squid (*Dosidicus gigas*), Alaska pollock (*T. chalcogramma*)	Protein solubility, pH, textural and viscoelastic rheological attributes	1%	[60]
Carrageenan + NaCl or KCl	—	Heated in a water bath	Hydrocolloid	Alaska pollock (*T. chalcogramma*)	Gel strength, color, compression test	Carrageenan: 1% + KCl: 1.5%	[61]
Amorphophallus konjac flour (AKF)	*Amorphophallus konjac*	Heated in a water bath	Flour	Giant squid (*D. gigas*)	Water retention ability, color, textural and sensory attributes	10%	[62]
NaCl + high hydrostatic pressure (HHP)	—	Heated in a water bath	Powder	Alaska pollock (*T. chalcogramma*)	Proximate analysis, FTIR, SEM, color, mechanical, rheological and sensory attributes	HHP: 300 MPa + NaCl: 0.3%	[63]
Sodium chloride, sugars, polyols	—	Heated in a water bath	Powder and liquid	Yellow corvina (*Larimichthys polyactis*)	Water activity, VBN, color moisture content	Sodium chloride: 4%, Glucose: 10%, Glycerin: 10%	[64]
Starch, glycine, sodium lactate	—	Heated in a water bath	Powder and liquid	Yellow corvina (*L. polyactis*)	Water activity, VBN, color, moisture content	Sodium lactate: 7.5%	[65]
Glycerol	—	Steamed	Liquid	Mackerel (*Scomber japonicus*), and Brazilian sandperch (*Pseudopercis semifasciata*)	Water activity, textural and sensory attributes	20%	[66]
Na and Ca salts of polyuronides and carboxymethyl cellulose	—	Heated in a water bath	Powder	Alaska pollock (*T. chalcogramma*)	Gel-strengthening effects	2%–6%	[67]
L-ascorbic acid (AsA) and dehydro-L-ascorbic acid (DAsA)	—	Heated in a water bath	Powder	Alaska pollock (*T. chalcogramma*)	Gel strength analysis	DAsA: 10 μg/g	[68]
Sodium-L-ascorbate (SA)	—	Steamed in Nojax cellulose casing	Powder	Alaska pollock (*T. chalcogramma*)	pH, textural and sensory attributes	0.2%	[69]
ω-3 fatty acids from algae	Not mentioned	Heated in a water bath	Oil	Cod (*Gadus morhua*)	TBARS, fatty acid content, color	500 mg/85 g	[70]
Eicosapentaenoic acid, docosahexaenoic acid	—	Heated in a water bath	Oil	Walleye pollock (*T. chalcogramma*)	Microscopic observation, viscosity, gel-forming ability	10%	[71]

Table 1: Continued.

Common name	Species	Cooking method	Used as	Fish source for surimi	Metrics	Optimum amount or treatment condition	References
Eicosapentaenoic acid, docosahexaenoic acid	—	Heated in a water bath	Oil	Walleye pollock *(T. chalcogramma)*, Threadfin bream (Nemipteridae), White croaker *(Genyonemus lineatus)*, and Japanese jack mackerel *(Trachurus japonicus)*	Proximate analysis, color, water-holding capacity, physical attributes	5%–30%	[72]
ω-3 PUFAs-rich oils	Flaxseed, algae, menhaden, krill, blend (flaxseed : algae : krill, 8 : 1 : 1).	Heated in a water bath	Oil	Alaska pollock *(T. chalcogramma)*	Torsion test, and rheological attributes	9 g/100 g	[73]
Ethanolic Kiam wood extract (EKWE) + commercial tannin (CT)	*Hopea* sp.	Heated in a water bath	Overdried powder	Striped catfish *(Pangasius hypophthalmus)*	pH, VBN, TBARS, color, TCA-soluble peptide, moisture, protein contents, textural attributes	EKWE: 0.08% CT: 0.02%–0.04%	[74]
Coconut husk extract with ethanol, 60% (CHE-E60), 80% (CHE-E80)	*Cocos nucifera*	Heated in a water bath	Freeze-dried powder	Sardine *(S. albella)*	Total phenolic, expressible moisture, TCA-soluble peptide, and protein contents, color, textual, rheological, and sensory attributes	CHE-E60: 0.125%	[75]
Oxidized phenolic compounds: ferulic acid (OFA), tannic acid (OTA), catechin (OCT), caffeic acid (OCF)	—	Heated in a water bath in polyvinylidene casing	Solution	Mackerel *(Rastrelliger kanagurta)*	SEM, expressible moisture, protein content, color, textural and sensory attributes	OFA: 0.40%, OTA: 0.50%, OCF: 0.50%, OCT: 0.10%	[76]
Oxidized phenolic compounds: ferulic acid (OFA), tannic acid (OTA), catechin (OCT), caffeic acid (OCF)	—	Heated in a water bath in polyvinylidene casing	Powder	Bigeye snapper *(P. tayenus)*	SEM, expressible moisture, protein, and free amino acid content, color, textural and sensory attributes	OFA: 0.20%, OTA: 0.05%, OCF: 0.15%, OCT: 0.05%	[77]
Egg white powder (EW), whey protein concentrate (WPC)	*Gallus gallus domesticus*, *Triticum aestivum*	Heated in a water bath	Powder and concentrate	Lizardfish *(S. tumbil)* mince and surimi	Autolytic activity, TCA-soluble oligopeptides, protein content, textural attributes	EW: 4% WPC: 4%	[26]
Zinc sulfate ($ZnSO_4$), sodium tripolyphosphate (STPP)	—	Heated in a water bath in polyvinylidene casing	Powder	Yellow stripe trevally *(Selaroides leptolepis)*	Expressible moisture, lipid, phospholipid, and protein content, Ca-ATPase activity, color, textural attributes	$ZnSO_4$: 60 μmol/kg + STPP: 0.5%	[78]

SEM: scanning electron microscopy; FTIR: Fourier-transform infrared spectroscopy; VBN: volatile basic nitrogen; TBARS: thiobarbituric acid reactive substances; TCA: trichloroacetic acid.

fish bones [33]. Furthermore, a study on the rheological and textural attributes of Pacific whiting surimi showed that slow heating and the addition of nanoscaled fish bones significantly enhanced gel strength [34].

Fowler and Park reported an enhanced gelling strength and effectively inhibited proteinase activity in Pacific whiting surimi gels heated ohmically [35]. Fowler and Park later studied the effects of salmon plasma from Chinook salmon on proteolytic inhibition of surimi [36]. Salmon plasma effectively inhibited both serine and cysteine proteases as well as proteases isolated from Pacific whiting. Salmon plasma concentrated by ultrafiltration performed slightly better than freeze-dried salmon plasma at inhibiting autolysis in salmon mince.

Klomklao et al. reported inhibitory activity of a partially purified trypsin inhibitor (TIYTR) from yellowfin tuna *(Thunnus albacores)* on the gelling characteristics of bigeye snapper *(Priacanthus macracanthus)* surimi [37]. The incorporation of TIYTR with a level of 3.0 g/100 g resulted in the enhanced deformation and breaking force of surimi gels, suggesting that the TIYTR could be employed as an affordable and alternative proteinase inhibitor to enhance the gel strength of surimi prepared by bigeye snapper.

Vate and Benjakul investigated the effects of squid ink tyrosinase mixtures of tannic acid and protein on the gelling characteristics of sardine surimi [38]. The highest deformation and breaking force were obtained when surimi gels were allowed to react for 90 min while being supplemented with 1% tannic acid and 500 U/g squid ink tyrosinase protein. However, gels with an added squid ink tyrosinase/tannic acid mixture were whiter than the control. The surimi gels supplemented with squid ink tyrosinase/tannic acid mixture showed the maximum overall acceptance scores, suggesting that it could be used as an additive to increase the surimi gel properties.

2.3. Plant Source Additives. The chicken plasma protein, egg white, and beef plasma protein are considered as the most effective protease inhibitors for surimi [17, 22, 23, 156]. However, the use of chicken plasma and beef plasma protein has been forbidden because of the occurrence of avian influenza and mad cow disease, respectively. In addition, higher concentrations of beef plasma proteins have also been associated with off-flavors, while egg white is expensive and has an unwanted egg-like odor [29, 156]. Additionally, vegetarians would not want to consume surimi-based products prepared with additives from animal or even seafood sources. Therefore, alternate food-grade additives are still desired to enhance the gel strength of surimi, without affecting the customer demand. Various natural additives derived from the plant sources have been briefly described below.

2.3.1. Legumes. The effects of vegetable protein content, moisture, heating, and setting conditions on the physical attributes of kamaboko were examined by Yamashita [39]. A firm gel was obtained at 60°C for kamaboko with soybean protein and at 80°C with wheat gluten. When the kamaboko gels were supplemented with 5% vegetable protein, the changes in jelly strength, softness, and expressible water of the kamaboko with wheat gluten were somewhat greater than those of the kamaboko with soybean protein. According to the results of Chung and Lee, the addition of plant proteins including soy protein isolate, lactoalbumin, and wheat gluten remarkably lessened the strength of non-animal protein-incorporated surimi gels [40]. The textural and sensory attributes of fiberized surimi gel products were categorized as an increase in overall textural desirability and an increase in gel strength. In another study, egg white and milk protein isolate showed higher water retention ability than whey protein concentrate, soy protein isolate, and lactoalbumin [41].

Protein isolates from legume seeds can be used as alternate protein additives for the quality improvement of surimi gels. Legume seed isolates comprise trypsin inhibitors and have been used as the protease inhibitor in the preparation of surimi and surimi-based products [42, 43]. Benjakul et al. reported higher protease inhibitory activities of inhibitor extracts from soybean and black cowpea seeds [42]. A reduced gel-degradation activity (modori) and a high thermal stability were reported. In another study, they reported inhibitory effects of proteinase inhibitor extracts from Bambara groundnuts *(Voandzeia subterranea)*, pigeon pea *(Cajanus cajan)*, and cowpea *(Vigna unguiculata)* on autolysis and gel-degradation activity (modori) of threadfin bream surimi [43]. The whiteness of surimi gels reduced slightly with the addition of proteinase inhibitor. Similar results were obtained by Oujifard and colleagues [44]. The Bambara groundnut protein extracts at a level of 0.25 g/100 g showed improved autolytic inhibition, deformation, and breaking force in surimi prepared by threadfin bream *(N. bleekeri)* [44]. However, a slight reduction in whiteness was observed at increasing levels of Bambara groundnut protein isolates. These studies show that the addition of Bambara groundnut protein extracts at a suitable level could serve as an alternative food inhibitor to enhance the gelling properties of surimi.

Plant protein isolates, mainly soy protein isolates, have been used in the surimi industry because of their safety and rational price [45]. Luo et al. indicated the legumin and vicilin, two main legume seed storage proteins, as binders and cogelling agents in surimi gels [45]. Protease inhibitors isolated from legume seeds not only can help to reduce the gel-degradation process in surimi but can also improve the surimi gel properties by acting as filler or binder. Luo et al. reported higher breaking force and quality characteristics of silver carp surimi when supplemented at a ratio of 10% soy protein isolate [46]. Cardoso et al. studied the effects of dietary fiber and microbial transglutaminase from chicory and pea on the rheological properties of protein paste from gilthead sea bream, hake, meagre, and seabass [47]. It was found that a high degree of protein denaturation boosted gel hardness while a low degree of protein denaturation created gels with high deformability. It shows that the addition of microbial transglutaminase could serve as a possible additive for gels of those species having lesser protein unfolding ability.

Kudre et al. studied the effects of black bean *(Phaseolus vulgaris)* and mung bean (*Phaseolus aureus*) protein isolates on gelling properties and proteolysis of sardines *(Sardinella* *albella)* surimi [48]. An increase in deformation, breaking force, and water-holding capacity, as well as a lower level of degradation, was observed while the whiteness of kamaboko gels reduced slightly. Therefore, mung bean or black bean protein isolates could be effectively used to retard the proteolysis in sardine surimi, leading to improved gel strength. Klomklao and Benjakul studied the effects of the partially purified trypsin inhibitor from adzuki bean on the gelling properties and proteolysis of threadfin bream *(N. bleekeri)* surimi [49]. An increase in autolysis and inhibitory activity against sarcoplasmic proteinases as well as an increase in deformation and breaking force of kamaboko gel was observed at increasing levels of trypsin inhibitor while gel whiteness decreased slightly.

2.3.2. Starch. Starch is widely used to make fish-paste products as it enhances elasticity and increases the weight of the products. In attempts to control thermal stability, stickiness, and/or wetness under different serving and storage conditions, the functional characteristics of surimi seafood products have been widely studied using modified starches. Starch is the second most abundantly used ingredient in the manufacturing of fish-paste products because of its higher water-holding ability and capacity to replace fish proteins partially while preserving the desired gel features at a reduced cost [69, 157–161].

Kim et al. reported a positive correlation between the amount of added starch and the quality of the food products [162]. Konoo et al. studied the effects of adding starch and amylose to amylopectin contents of starch on the gelation properties of frozen walleye pollack surimi [50]. The breaking strength of gel was not affected by the change in amylose : amylopectin ratio. However, it increased as the content of amylose increased in pregelatinized starch [51]. A lower packing effect was observed at 90°C which hypothesized that the gelatinization of starch in fish meat can be prevented at this temperature. A strong correlation between the amylose to amylopectin contents and the textural and rheological properties of starch-containing surimi gels was also reported by Lanier et al. [134].

The addition of normal and modified potato or sweet potato starch resulted in reductions in the characteristic storage modulus of surimi sols during heating [52]. Surimi gels supplemented with potato starch showed the highest firmness and cohesiveness. Yoo reported the best textural properties of the sand lance *(Ammodytes personatus)* fish-paste products at a level of 8% potato starch [53]. These studies show that potato or sweet potato starch can also be used as a potent food additive for the production of surimi.

2.3.3. Rice/Rice Flour. Fish meat and wheat flour are the major ingredients used for the production of surimi-based products. Rice flour, however, can be an important ingredient to enhance the rheological properties of surimi-based products. Several attempts have been made to evaluate the potential of rice flour as an alternate of wheat flour in the preparation of surimi products [41]. The effect of rice flour addition methods and milling types on the sensory and rheological attributes of surimi products were studied by Cho et al. [54]. Roll-mil rice at a concentration of 10%–15% displayed higher gel strength and sensory properties which show that roll-mill rice had strong potential for replacing wheat flour. The surimi products containing rice flour showed similar rheological and sensory characteristics to those of a finest commercial surimi product. Hence, rice flour might be an effective alternative to wheat flour for high-quality surimi products.

To replace wheat flour, Kwon and Lee examined the quality characteristics of fried fish cakes containing rice flour [55]. The total content of corn starch and rice flour was 28.83% of the total content of fish cake dough. There were no noteworthy differences in the pH, moisture level, appearance, color, flavor, taste, and overall acceptance as compared to the control group. The addition of 50% rice flour to surimi-based products could be an effective way to increase the content of rice flour without decreasing texture acceptability. Yoon et al. optimized the content of water and rice flour in surimi-based products [56]. The surimi-based products manufactured under optimal environment were comparable in gel strength to the commercial products. However, higher sensory evaluation scores were observed compared to those of the commercial products. These studies advocate that the rice flour not only can be employed as an alternative to wheat flour but can also be used to enhance the quality of surimi and surimi-based products.

2.3.4. Potato Powder. The food additives extracted from potato and potato protease inhibitors used in the preparation of fish-paste products are discussed in Sections 2.1, 2.3.2, and 2.4.4.

2.4. Cryoprotectants and Humectants. To inhibit denaturation and to lessen the damage of gel quality during cold storage, cryoprotectants are usually added to surimi products. Polyunsaturated fatty acids, protein additives, polyols, sugars, amino acids, salts, and plant extracts are frequently used as cryoprotectants and humectants to avoid fluctuations in myofibrillar proteins promoted by freezing, storage, or thawing [163]. Mechanical properties of surimi gels can be improved by the addition of numerous hydrocolloids such as konjac, carrageenan, locust bean, xanthan gum, and different microbial transglutaminases during the preparation of surimi products [57, 164–166]. In contrast, the addition of alginates has been reported to weaken surimi gels [69].

2.4.1. Saccharides. Xanthan is a nongelling polysaccharide produced by the aerobic fermentation of *Xanthomonas campestris* [167]. The property of xanthan to form highly viscous and stable solution at low levels makes it acceptable in the food industry [168]. Xanthan displays quite remarkable synergistic interactions with other nongelling polysaccharides of the galactomannan family, leading to increases in gel formation and viscosity [168, 169]. The three commercially available galactomannans are tara gum, locust bean gum, and guar gum.

The impact of low methoxyl pectin on the mechanical properties of silver carp surimi gels was studied by Barrera et al. [58]. An increase in hardness, shear stress, and water-holding capacity of the surimi gel was observed while no significant improvement in the mechanical properties was observed as compared to the control. Benjakul et al. reported the effects of prawn-shell chitosan on surimi prepared by barred garfish *(Hemiramphus far)* [59]. Prawn-shell chitosan at a level of 1% of the surimi gel showed an increase in gel-enhancing effect on the heat-induced gelation of myofibrillar proteins. The addition of microbial transglutaminase generally increases the deformation and breaking force of surimi gel. However, this effect was significantly retarded in the presence of prawn-shell chitosan, resulting in lower magnitudes of deformation and breaking force.

The viscoelastic properties and the thermal stability of low-grade squid *(Dosidicus gigas)* surimi were investigated by Iglesias-Otero et al. [60]. The konjac glucomannan aqueous dispersion at a level of 1% expressed the best rheological properties, suggesting that the konjac glucomannan aqueous dispersion may be used to enhance the quality characteristics of low-grade squid surimi gel. Ramírez et al. evaluated the effect of protein-hydrochlorides on the gel-forming ability of myofibrillar proteins [142]. The xanthan/locust bean gum, at a ratio of 0.25/0.75, showed a positive improvement in the mechanical attributes of surimi gels. Eom et al. investigated the impact of carrageenan on the gelation property of salt-based Alaska pollock surimi [61]. The addition of 1.5% KCl rather than 2% NaCl significantly enhanced the gelling property of κ-carrageenan-induced surimi gel and showed increased gel strength, breaking force, and whiteness values.

2.4.2. Salts. Salts help in protein-protein interaction and the addition of salt is critical during the processing of fish-paste products. However, the high levels of sodium in foods, and consequently human consumption of sodium, have become a global issue. The prime harmful effects of excess sodium intake are hypertension and increased blood pressure. Subsequently, these conditions lead to cardiovascular diseases, including instances of stroke, heart attack, and related diseases, as well as gastric cancer and osteoporosis [170–172]. Therefore, to reduce sodium intake levels in fish-paste products, Hwang et al. prepared the sodium-reduced fried fish cakes containing potassium as a substitute for sodium [1]. The quality characteristics of 30% sodium-reduced fried fish cakes were not notably different from those of full-sodium fried fish cakes; however, the addition of potassium changed the color and reduced consumer acceptance. To increase the consumer preference for sodium-reduced fried fish cakes, the use of different food additives might be advantageous.

The weak gel-forming ability and the strong fishy smell of the giant squid *(D. gigas)* make it undesirable for the manufacturing of surimi-based products. To overcome these problems, Choi and Kim used *Amorphophallus konjac* flour to enhance the quality characteristics of giant-squid surimi products [62]. The increasing levels of *A. konjac* flour showed increases in gel texture and water retention ability while a reduction in color and taste was observed as compared to the commercial surimi products. The incorporation of the seasoning ingredients, such as sweeteners, might be helpful in removing the fishy smell of *D. gigas*, ultimately improving the gel properties of giant-squid surimi. Cando et al. reported that the sensory and mechanical properties of surimi gels with reduced-NaCl contents can be improved by the application of 300 Mpa high hydrostatic pressures [63]. The gels made with lower-NaCl contents revealed stronger and stable networks as showed by the ones with higher-NaCl contents.

2.4.3. Water Activity. It has been reported that humectants had the greatest effect on lowering water activity (a_w), with the efficiency of the reduction in a_w value decreasing in the order of NaCl, sodium lactate, glycerin, propylene glycol, and sorbitol when each of them was combined with other humectants [173]. Kim and Park reported the impact of humectants such as sodium chloride, sugars, and polyols to lower the water activity (a_w) of various model kamaboko gels [64]. The effect of sodium chloride on lowering water activity (a_w) was the highest among all of the examined treatments while glucose caused browning reaction on the surface of kamaboko. In another study, they examined the effect of starch, glycine, and sodium lactate in lowering the water activity (a_w) of model kamaboko gels [65]. Sánchez Pascua et al. reported that glycerol (15%–50%) was effective in reducing the water activity (a_w), in Brazilian sand perch *(Pseudopercis semifasciata)* and mackerel *(Scomber japonicus marplatensis)* [66]. Among the tested humectants, the efficiency of the reduction in water activity (a_w) was observed decreasing in the order of sodium lactate, glycine, and starch.

2.4.4. Polyuronides. The effect of sodium and calcium salts of carboxymethyl and polyuronides cellulose on the strengthening of kamaboko gels was investigated by Niwa et al. [67]. It was reported that the calcium salts of pectinic acid, pectic acid, alginic acid, and carboxymethyl cellulose enhanced the breaking force of Alaska pollock surimi, whereas their sodium salts except Na-pectinate failed to increase the breaking force. The increase in the breaking force induced by calcium carboxymethyl cellulose vanished upon increasing the degree of substitution of hydroxyl groups to carboxymethyl groups. Furthermore, fine cellulose particles enhanced the breaking strain and breaking force and reduced the amount of expressible water but were unsuccessful in the case of coarser particles. The addition of potato starch can increase the effectiveness even in the presence of coarse particles of cellulose.

2.4.5. Ascorbic Acid. The addition of dehydro-L-ascorbic acid and L-ascorbic acid to Alaska pollock surimi increased the gel strength [68]. It was suggested that the positive effect of L-ascorbic acid on gel formation might be due to the oxidation of sulfhydryl groups in fish proteins. Lee et al. studied the effects of sodium-L-ascorbate on the gel-forming abilities of surimi prepared by Alaska pollock [69]. Sodium-L-ascorbate remarkably enhanced the gel firmness, cohesiveness, strength, and sensory properties of the fiberized products at a level of 0.2%. It directly influenced the surimi quality regardless of vacuum treatment, indicating that airborne oxygen was not important. Freeze-syneresis, stimulated by ascorbate during frozen storage, was lessened by the application of hydroxypropylated-modified starch.

2.4.6. Unsaturated Fatty Acids. The addition of nutritionally beneficial ω-3 fatty acids during surimi preparation could enhance the gel strength and stability [70]. For the effective use of highly unsaturated fatty acids such as docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) in surimi-based products, Okazaki et al. studied the gel-forming properties of frozen walleye pollock surimi containing DHA and EPA [71]. They reported that, to achieve a good quality product, the vigorous agitation of surimi with fish oil is essential to allow the heat-induced gelation of its emulsified product, through the formation of fine oil droplets.

Fukushima et al. investigated changes in the physical properties of heat-treated surimi gels prepared from threadfin bream, walleye pollock, Japanese jack mackerel, and white croaker [72]. The breaking strain, breaking strength, and water-holding capacity of the heat-treated gels became greater as the amount of fish oil increased. Furthermore, surimi seafood was nutritionally enhanced with ω-3 polyunsaturated fatty acid- (PUFA-) rich oils isolated from natural sources such as algae, flaxseed, menhaden, blend, and krill [73]. The Alaska pollock surimi supplemented with ω-3 PUFA-rich oils showed improved protein fundamental textural properties, heat-induced gelation, and endothermal transitions. These studies show that the interaction of unsaturated fatty acids and surimi proteins could contribute to the improvement in gel properties without altering the textural attributes.

2.4.7. Plant Ethanol Extracts. The effect of commercial tannin and ethanolic Kiam wood extract on the gelling characteristics of ice stored mackerel *(Rastrelliger kanagurta)* surimi was investigated by Balange et al. [74]. During 12 d of iced storage, pH, TBARS, TCA-soluble peptide and trimethylamine (TMA) contents, as well as total volatile base (TVB), of mackerel mince increased while gel-forming ability, myosin heavy chain band intensity, and whiteness decreased consistently. Deterioration, lipid oxidation, and protein degradation proceeded as storage time increased. An increase in deformation and breaking force of surimi gel was observed with the addition of 0.30% commercial tannin or 0.15% ethanolic Kiam wood extract during the first 6 d of storage. Therefore, commercial tannin and ethanolic Kiam wood extract had not shown a gel-enhancing effect on mackerel surimi. Furthermore, Buamard and Benjakul investigated the effects of coconut husk ethanolic isolates on the gel-forming ability of sardine *(S. albella)* surimi [75]. Breaking force increased with the increasing levels of coconut husk ethanolic isolates while a decrease in whiteness and no detrimental effect on the sensory attributes of surimi gel was observed. It was concluded that the addition of coconut husk extracts at a suitable concentration could enhance the gel strength of sardine surimi with increased acceptability.

2.5. Compound Additives. The effect of different oxidized phenolic compounds such as tannic acid, OTA; ferulic acid, OFA; caffeic acid, OCF; and catechin, OCT, on the gelling attributes of mackerel *(R. kanagurta)* surimi was studied by Balange and Benjakul [76]. Gels supplemented with 0.50% OTA, 0.40% OFA, 0.10% OCT, or 0.50% OCF showed increases in deformation and breaking forces while a decrease in the expressible moisture content and myosin heavy chain band intensity was observed. In another study, they investigated the effects of oxidized phenolic compounds on the gel-forming abilities of bigeye snapper *(P. tayenus)* surimi [77]. An increase in breaking force and deformation with a decrease in expressible moisture contents was observed. Gels supplemented with the oxidized phenolic compounds had a finer matrix with smaller strands. The physicochemical characteristics of natural actomyosin advocate that oxidized phenolics could trigger the induction of disulfide bond formation or the conformational changes and cross-linking through amino groups. Therefore, the addition of oxidized phenolic compounds at an optimum concentration could enhance the strength of surimi gel.

Yongsawatdigul and Piyadhammaviboon reported an inhibition in autolysis of surimi and mince prepared by lizardfish *(S. tumbil)* caused by p-tosyl-L-phenylalanyl chloromethyl ketone and phenylmethanesulfonyl fluoride, indicating the involvement of myofibrillar-associated serine proteinase. Tropomyosin and myosin heavy chain proteins were mainly hydrolyzed, resulting in poor textural properties [26]. Arfat and Benjakul investigated the effect of zinc chloride ($ZnCl_2$) and zinc sulfate ($ZnSO_4$) on the gel-forming abilities of surimi produced by yellow stripe trevally *(Selaroides leptolepis)* [78]. The kamaboko gels with $ZnSO_4$ added up to levels of 60 μmol/kg showed increased deformation, whiteness, and breaking force, as well as highly denser and interconnected gels. Therefore, $ZnSO_4$ at a suitable concentration could enhance gel strength and whiteness of dark-fleshed fish surimi.

3. Improvement in Quality and Functionality of Fish-Paste Products

Various food additives from seafood (e.g., fish, invertebrates, and seaweed), plants (e.g., vegetables, fruits, and herbal medicines), mushrooms, animal sources, and functional materials used to improve the quality and functionality of fish-paste products are listed in (Table 2) and described below.

3.1. Seafood Additives. It has been reported that various types of seafood, namely, fish including dried anchovy *(Engraulis japonicus)* powder [79, 80], pufferfish *(Lagocephalus lunaris)* powder [88], and skate *(Raja kenojei)* powder [81, 82], and invertebrates including warty sea squirt *(Styela clava)* ground flesh [83], its freeze-dried tunic powder [84], omandungi *(Styela plicata)* ground flesh [85], shrimp *(Acetes japonicus)* powder [86], and seaweed such as green laver (*Ulva* spp.) [87], have been used to enhance the quality and functionality of fish-paste.

The boiled and dried Japanese anchovy *(E. japonicus)* is a popular fisheries product in Korea and Japan. As the flesh can be eaten together with bone, boiled and dried anchovy products are regarded as good sources of calcium [174]. Bae and Lee evaluated the properties of fried fish-paste with added anchovy *(E. japonicus)* powder containing a high amount of calcium [79]. The fish-paste containing 10% anchovy powder displayed the highest values of adhesiveness, hardness, and strength. In the overall acceptance of sensory

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

Common name	Species	Cooking method	Used as	Fish source for surimi	Metrics	Optimum amount or treatment condition	References
Seafood additives							
Anchovy	*Engraulis japonicus*	Fried	Dried powder	Sea bream	Calcium content, color, textural and sensory attributes	1%-2%	[79]
Anchovy	*Engraulis japonicus*	Fried	Dried powder	Sea bream	Calcium content, color, textural and sensory attributes	5%	[80]
Skate	*Raja kenojei*	Fried	Hot wind-dried skin and cartilage (6 : 4) powder	Sea bream	Moisture content, color, textural and sensory attributes	3%	[81]
Skate	*Raja kenojei*	Steamed	Fermented flesh	*Nemipterus virgatus*	Amino acid, and moisture content, color, textural and sensory attributes	20%	[82]
Warty sea squirt	*Styela clava*	Fried	Ground flesh	Himeji (Frozen yellow tentacle)	Color, textural and sensory attributes	5%	[83]
Warty sea squirt	*Styela clava*	Fried	Freeze-dried tunic powder	Frozen Itoyori	Color, textural and sensory attributes	1%	[84]
Pleated sea squirt	*Styela plicata*	Fried	Grinded flesh	Himeji (Frozen yellow tentacle)	Color, textural and sensory attributes	15%	[85]
Shrimp	*Acetes japonicus*	Fried	Powder	Frozen sea bream surimi	Moisture content, color, textural and sensory attributes	5%	[86]
Green laver	*Ulva* spp.	Fried	Powder	Frozen sea bream surimi	Color, sensory attributes	5%	[87]
Pufferfish	*Lagocephalus lunaris*	Fried	Powder	*Nemipterus* spp.	Moisture, crude protein, lipid, color, textural and sensory attributes	5%	[88]
Maesaengi	*Capsosiphon fulvescens*	Fried	Freeze-dried powder	Frozen sea bream surimi	Color, textural and sensory attributes	5%	[89]
Red snow crab	*Chionoecetes japonicus*	Fried	Leg-meat powder	Frozen Alaska pollock *(T. chalcogramma)*	Physiochemical and sensory attributes	6%	[90]
Plant source additives							
Mulberry leaf	*Morus alba*	Fried	Powder	Sea bream	Color, texture, sensory attributes	0.5%	[91]
Onion	*Allium cepa*	Fried	Ethanol extract	Cutlassfish paste	Moisture content, TBC, VBN, color, sensory attributes	3%	[70]
Lotus leaf	*Nelumbo nucifera*	Fried	Powder	Sea bream	Color, textural and sensory attributes	0.5%	[92]
Beetroot and Spinach	*Beta vulgaris* and *Spinacia oleracea*	Microwave in kamaboko shape mold	Fresh beet root, spinach dish	Not mentioned	Moisture, texture analysis	Beetroot: 10% Spinach: 15%	[93]
Citrus fruits	*Citrus limon, C. junos, C. unshiu, Fortunella japonica* var. margarita	Steamed	Ground flesh pulp without seeds	Min Daegu flesh	Color, textural and sensory attributes	Cumquat	[94]

Table 2: Continued.

Common name	Species	Cooking method	Used as	Fish source for surimi	Metrics	Optimum amount or treatment condition	References
Oat bran + SiO_2	*Avena sativa*	Boiled	Powder	Frozen Alaska pollock surimi	Color, textural and physiochemical attributes	6 g Oat bran/100 g SiO_2	[95]
Yam	*Dioscorea japonica*	Fried	Powder	Pollock, squid, shrimp	Folding test, color, textural and sensory attributes	2%	[96]
Wolfberry/Chinese Goji	*Fructus lycii*	Fried	Powder	Sea bream	Textural and sensory attributes	3%	[97]
Red ginseng	*Panax ginseng* C.A. Meyer	Fried	Powder	Not described	Color, lipid oxidation, sensory attributes	1%	[98]
Korean angelica root	*Angelicae gigantis* Radix	Fried	Powder	Sea bream	Textural and sensory attributes	0.5%	[99]
Turmeric	*Curcuma longa* L.	Fried	Powder	Pollock, squid, shrimp	Color, rheological and sensory attributes	3%	[100]
Wasabi	*Wasabia japonica*	Fried	Freeze-dried powder	Silver pomfret *(Pampus argenteus)*	Color, TBC, viable cell count, textural and sensory attributes	1.8%	[101]
Wolfiporia extensa	*Poria cocos*	Fried	Powder	Sea bream	Color, textural and sensory attributes	3%	[102]
Mushroom additives							
Button mushroom	*Agaricus bisporus*	Fried	Chopped fresh	*Argyrosomus argentatus*	Textural and sensory attributes	10%	[103]
Enoki mushroom	*Flammulina velutipes*	Fried	Chopped fresh	*A. argentatus*	Textural and sensory attributes	5%	[104]
Shiitake mushroom	*Lentinus edodes*	Fried	Chopped fresh	*A. argentatus*	Textural and sensory attributes	10%	[105]
King oyster mushroom	*Pleurotus eryngii*	Fried	Paste	Silver white croaker *(Pennahia argentata)*	Textural and sensory attributes	10%	[106]
King oyster mushroom	*Pleurotus eryngii*	Steamed	Paste	Cuttlefish *(Sepia esculenta)*	Textural, physiochemical, sensory attributes	40%	[107]
Animal source additives							
Poultry chicken	*Gallus gallus domesticus*	Fried	Breast meat batter	Itoyori; Japanese threadfin bream, *(Nemipterus japonicus)*	Chemical composition, color, fatty acid composition, TBARS, sensory attributes	7.46% or 14.93%	[108]
Functional food additives							
Long-chain cellulose	—	Boiled	Powdered cellulose	Alaska pollock surimi	Textural and rheological attributes	6%	[109]
Dietary fiber from ascidian tunic	*Halocynthia roretzi*	Boiled	Refined dietary fiber	Alaska pollock surimi	Color, textural, physiological, and sensory attributes	5%	[110]

Table 2: Continued.

Common name	Species	Cooking method	Used as	Fish source for surimi	Metrics	Optimum amount or treatment condition	References
Fiber and/ω-3 oil	—	Heated in a water bath	Powdered fiber, ω-3 oil	Alaska pollock surimi	Textural and rheological attributes	Fiber: 6–10 g and/ω-3: 100 g	[111]
Flaxseed or salmon oil	Not described	Cooked in a water bath	Oil	Frozen Alaska pollock surimi *(T. chalcogramma)*	TBARS, color, textural and sensory attributes	2 g/100 g franks	[112]
Soybean oil	*Glycine max*	Heated in a water bath	Oil	Frozen silver carp surimi	Color, textural attributes	Soybean oil: >3%	[113]
Calcium powder of cuttlefish bone treated with acetic acid	*Sepia esculenta*	Heating in a water bath	Calcium powder	Alaska pollock surimi	Moisture content, color, textural and sensory attributes	0.09%	[114]
Propolis	—	Fried	Alcohol extract (100%)	Alaska pollock meat paste	Color, textural and sensory attributes	0.17%	[115]
Propolis	—	Fried	Alcohol extract (100%)	Sand lance *(Hypoptychus dybowskii)*	Acid and peroxide value, VBN, sensory attributes	0.2%	[116]
Cheonggukjang	Fermented *Glycine max* by *Bacillus* sp.	Fried	Powder	Sea bream	Color, textural and sensory attributes	2%	[117]

TBC: total bacterial count; VBN: volatile basic nitrogen; TBARS: thiobarbituric acid reactive substances.

evaluation, small and large size fish-paste with 1% and 2%, respectively, of added anchovy powder was preferred. The similar increasing trend of calcium intensity was observed by Bae et al. [80]. However, the fried fish-paste products containing 20% anchovy powder displayed the highest values of adhesiveness, hardness, and strength. Regarding overall acceptance in the sensory evaluation, the fried fish-paste containing 5% anchovy was preferred. The optimal amounts of added anchovy in the results from Bae and Lee and Bae et al. were different, which might have been due to the different drying methods and sizes of the anchovies used in each study [79, 80]. Despite the differences in the two studies, the results suggest that anchovy powder could be applied to fried fish-paste products to achieve high calcium contents.

Skate contains many essential fatty acids including linolenic acid, linoleic acid, arachidonic acid, DHA, and EPA [175]. Skate skin contains high percentages of collagen, protein, and calcium [176], while its cartilage is rich in chondroitin sulfate [177]. To improve quality and nutrient levels, Cho and Kim prepared fried fish-paste with skate *(R. kenojei)* powder (hot wind-dried skin and cartilage powder [6 : 4]) [81]. According to Park et al., preference testing using steamed fish-paste product with different levels of added 14-day-fermented flesh of skate showed significant increases in brownness, smoothness, and skate flavor scores [82]. The amino acid contents of fish cake samples with 20% skate added had the highest overall preference scores. Consequently, the addition of 20% skate powder was optimal for the steamed fish cake to improve its quality characteristics with higher protein contents.

Warty sea squirt *(S. clava)* aquaculture in the Masan area of Korea's south coast contains abundant unsaturated fatty acids and essential amino acids in its flesh [178] and glycosaminoglycan in its tunic [179]. Warty sea squirt has a unique taste and distinct antioxidant and anticancer activities [180]. Fried fish-paste supplemented with 20% warty sea squirt (Korean name: miduduk) displayed improved quality and functionality [83]. Choi et al. reported a fried fish-paste containing freeze-dried byproduct of warty sea squirt (*S. clava* tunic) [84]. The hardness and strength of fish-paste increased with increasing amounts of tunic powder. For overall acceptance in sensory evaluation, a fish-paste supplemented with 1% *S. clava* tunic obtained a relatively higher score. The results suggested that *S. clava* flesh and tunic could be used for fish-paste products to improve their quality and functionality. Park et al. reported improvement in the functional properties of fish-paste, by adding *S. plicata* (Korean name: omandungi) [85]. Fried fish-paste containing 20% *S. plicata* indicated the highest values of adhesiveness, hardness, and strength. For overall acceptance in sensory evaluation, a fish-paste containing 15% *S. plicata* obtained the highest score.

Seo and Cho reported the preparation of fish-paste with added shrimp *(A. japonicus)* powder [86]. The hardness, springiness, and cohesiveness increased with the increasing concentration of shrimp powder. However, the brittleness and gumminess reduced. In the sensory evaluation, the fish-paste prepared with 5% shrimp powder was most preferred. Cho and Kim reported the preparation of fish-paste with added green laver (*Ulva* spp.) powder [87]. The hardness, springiness, and cohesiveness increased with the increasing concentration of green laver powder. However, the brittleness and gumminess decreased upon the addition of green laver powder. In the sensory evaluation, a fish-paste prepared with 5% green laver powder was preferred over other fish-pastes. These results suggest that green laver powder could be applied to fish-paste to improve its quality and functionality.

Pufferfish containing taurine, hydroxyproline, lysine, and glycine impart a characteristic taste to food [181]. To improve the taste of fish-paste products, Park prepared a fish-paste by adding green rough-backed pufferfish *(L. lunaris)* powder [88]. The hardness, strength, gumminess, springiness, and chewiness of the fish-paste increased depending on pufferfish powder content. The preparation of fish-paste with added *Capsosiphon fulvescens* powder was reported by Park [89]. The hardness, springiness, strength, and cohesiveness increased with the increasing concentrations of *C. fulvescens* powder. However, the brittleness and gumminess reduced with the addition of *C. fulvescens* powder. In the sensory evaluation, overall, the fish-pastes prepared with 5% *C. fulvescens* powder were preferred over other fish-pastes. Thus, the results show that *C. fulvescens* powder could be used to create fish-paste products with high quality and functionality.

Kim et al. reported the changes in the sensory and physicochemical properties of a fish-paste containing red snow crab *(Chionoecetes japonicus)* leg-meat powder [90]. Hardness, gumminess, springiness, and cohesiveness increased with increasing levels of red snow crab leg-meat powder. Based on the sensory evaluation, it was concluded that the addition of red snow crab leg-meat powder at a level of 6% could improve the quality characteristics of fish-paste products.

3.2. Plant Source Additives. It has been reported that various plant sources, namely, vegetables (e.g., mulberry, beetroot, and spinach), fruits (e.g., citrus), and herbal medicines (e.g., Chinese matrimony vine, Korean Angelica root), have a significant effect in improving the quality and functionality of fish-paste products.

Mulberry *(Morus alba)* leaf has been used traditionally to treat a disease symptomized by thirst and stroke [182]. Ever since mulberry leaf was included as a food material in the Food Codex in 1988 by the Ministry of Food and Drug Safety (MFDS; Osong, Chungju, South Korea). Mulberry leaf powder has been used in various processed food products and health functional foods. Shin and Park reported the use of mulberry leaf powder in the preparation of fish-paste products [91]. In a texture meter test, the hardness increased, but the cohesiveness, springiness, gumminess, and brittleness decreased with increasing levels of mulberry leaf powder. In sensory evaluation, the fish-paste with 0.5% mulberry leaf powder revealed the highest acceptance scores in terms of flavor, texture, and overall quality.

Garden onion (bulb onion, *Allium cepa*) is a perennial plant belonging to Liliaceae and is widely used as a spice and seasoning vegetable in both the East and the West. Park et al. investigated the quality characteristics of fried fish-paste supplemented with flavonol-rich ethanol extract of onion [183]. In the sensory evaluation, as the amount of ethanol extract of onion increased, so did the favorability in terms of flavor and taste. Notably, 3% ethanol extract of onion had the best score in overall acceptance. The results indicate that ethanol extract of onion can be used to prepare fried fish-paste products with high quality and functionality.

Shin reported the production of fish-paste with added lotus *(Nelumbo nucifera)* leaf powder [92]. The flavor, adhesiveness, and hardness increased with the increasing levels of lotus leaf powder. The fish-paste with 0.5% lotus leaf powder displayed the highest acceptance scores in terms of springiness, pleasant taste, appearance, texture, flavor, and overall quality. Thorat et al. prepared kamaboko containing green chili, coriander, ginger, garlic spice mixture, and ground beetroot or a spinach dish and then subjected the preparation to microwave cooking [93]. Kamaboko prepared with 10% beetroot and a 15% spinach dish was found to be superior to the others.

Yang and Cho developed a steamed fish cake with added 5% ground citrus fruits with skin [94]. The addition of citrus fruits did not disturb the flexibility of surimi. The pH of surimi samples increased in the following order: lemon *(Citrus limon)*, citron *(Citrus junos)*, tangerine *(Citrus unshiu)*, kumquat (*Fortunella japonica* var. *margarita*), and control. The hardness of surimi was highest for lemon, followed by citron, tangerine, kumquat, and control surimi. In the sensory evaluation, surimi containing kumquat demonstrated higher scores in terms of color, taste, and textural properties. These results suggest that surimi could be prepared by adding citrus fruits to improve the quality and functionality.

Oat bran is a gluten-free dietary fiber that may decrease the risk of diabetes and heart diseases. The physicochemical properties of surimi gels supplemented with oat bran were studied by Alakhrash et al. [95]. The oat bran and SiO_2 incorporation (6 g/100 g) greatly improved water-holding capacity and gel texture while a reduction in whiteness was observed. Kim and Byun conducted tests on the sensory and physicochemical characteristics of fish-paste with added yam *(Dioscorea japonica)* powder [96]. The addition of yam powder increased gumminess, strength, springiness, and cohesiveness. In the sensory evaluation, the addition of 2% yam powder had the best scores in terms of taste, color, and overall preference.

Fructus lycii is a fruit produced by *Lycium barbarum* L. that has been used for nourishment, tonicity, and nourishment of the blood; it has antibacterial, anticancer, and antioxidant properties [182–186]. Shin et al. prepared fried fish-paste containing dried *F. lycii* powder [97]. In the textural analysis, cohesiveness increased, while brittleness and gumminess decreased, with increasing levels of *F. lycii* powder. The 3% *F. lycii* powder sample had the highest acceptance scores in terms of appearance, texture, taste, flavor, and overall acceptability.

Red ginseng-based fried fish-pastes containing different sizes and amounts of red ginseng powder were prepared and their biological properties, including lipid oxidation to improve fish-paste quality, were investigated [98]. The fish-paste products containing red ginseng powder showed a significant increase in hardness and chewiness. Furthermore, an inhibitory effect on lipid oxidation and reduced number of total microbes during storage were observed. These results suggest that high-quality fish-pastes could be achieved with the addition of 1% red ginseng powder, which effectively improved both sensory evaluation and physicochemical properties.

Angelicae Gigantis Radix (the dried root of *Angelica gigas* Nikai), more popularly known as Korean Angelica, is one of the widely used herbal medications [187]. It has been used in Korean medicine as an important medication for anemia and blood circulatory disorders. It has also been used for menstrual pains and postmenopausal syndromes. Shin et al. reported the development of fish-paste with *A. gigas* powder [99]. In a texture test, hardness, chewiness, and brittleness increased with increasing concentrations of Angelicae Gigantis powder. However, cohesiveness and springiness decreased. In the sensory evaluation, the fish-paste with 0.5% Angelicae Gigantis powder showed the highest acceptance scores for appearance, flavor, taste, texture, and overall quality.

Turmeric *(Curcuma longa)* has been used in Ayurvedic medicine from ancient times as a treatment for inflammatory conditions. It has been reportedly used for its various biological activities including antibacterial, antiviral, antifungal, antioxidative, and antiatherogenic effects [188]. Turmeric has been grown as a special crop in the central and southern areas around Jindo in South Korea [189]. Choi et al. investigated the sensory and rheological properties of fish-paste prepared with turmeric powder [84]. In terms of textural attributes, the addition of *C. longa* powder decreased springiness and improved strength. In the sensory evaluation, the addition of 3% *C. longa* powder was associated with the best scores for taste and overall preference.

Wasabi *(Wasabia japonica)* has various, beneficial health properties including antioxidative, antimicrobial, and antimutagenic activities [190, 191]. Jang et al. reported a high-quality fried fish-paste product made with silver pomfret *(Pampus argenteus)*, which is one of the savory, soft, and delicious types of fish prepared by adding wasabi powder [101]. Notably, hardness, gumminess, and chewiness increased significantly with the addition of wasabi powder. In the sensory evaluation, 1.8% wasabi powder showed the best score in overall acceptability. These results show that wasabi could be used as a food additive or preservative in fish-paste products.

White *Poria cocos* wolf is the inner white part of *P. cocos*, a parasite found on *Pinus densiflora*. It is used to treat edema, chronic gastritis, gastric atony, nephrosis, acute gastroenteric catarrh, emesis, dizziness, and vomiting [192, 193]. Shin et al. prepared a fried fish cake with added white *P. cocos* powder and studied the textural and sensory characteristics [102]. In texture tests, brittleness was observed to increase, while springiness decreased, with increasing concentrations of *P. cocos* powder. The fish-paste product containing 3% white *Poria cocos* powder showed the highest acceptance scores for flavor, appearance, texture, taste, and overall quality.

Milk-vetch root is one of the most produced herbal medicines in Korea. It is a peeled and dried root of the herbaceous perennial herb known as *Astragalus membranaceus,* which belongs to the Fabaceae family [194]. It has been reported that milk-vetch root exerts diuretic, tonic, antihypertensive, hypoglycemic, immune-enhancing, antitumor, and antiviral effects [195]. Kim investigated the sensory and physicochemical properties of fish-paste prepared with milk-vetch root powder [196]. The strength, cohesiveness, brittleness, and gumminess of the fish-paste increased, while its springiness decreased, with an increasing amount of milk-vetch root powder. In the sensory evaluation, the addition of 1.0% milk-vetch root powder indicated best scores for taste, texture, color, and overall preference.

3.3. Mushroom Additives. Mushroom is a nutritional and functional food, as well as a vital source of physiologically beneficial medicines. Mushrooms have been used as traditional medicines in Korea, Japan, China, and other Asian countries for curing various diseases, including lymphatic disease, gastroenteric disorder, oral ulcer, and various cancers [197]. It has been reported that edible mushrooms in Korea number approximately 350 species [198]. Several edible mushrooms that are highly preferred have been added to fish-paste to enhance their quality and functionality.

Ha et al. prepared a fried fish-paste product with added *Agaricus bisporus*, which is a product described as having a racy flavor and taste [103]. The elasticity, hardness, brittleness, and gumminess of fish-paste with the added mushroom increased; however no significant difference in strength was observed. Regarding overall acceptance in a sensory evaluation, a fish-paste supplemented with 10% *A. bisporus* mushroom showed the highest scores.

Enoki mushroom *(Flammulina velutipes)* is well known for its anticarcinogenic and blood pressure-reducing properties. To utilize its functional properties, enoki mushroom was added to fried fish cake [104]. The sample containing 15% mushroom received the highest values for strength, gumminess, and brittleness. In the sensory evaluation, the fish cakes with 5% mushroom obtained favorable scores for overall acceptance.

Shiitake mushroom *(Lentinus edodes)* is known for its high level of β-glucans. Son et al. investigated the effects of shiitake mushroom on the textural properties of fried fish cake [105]. The fish cake containing shiitake mushroom received the highest values for strength, hardness, gumminess, and brittleness. In the sensory evaluation, the fish cakes with 10% shiitake mushroom sample obtained the best score for overall acceptance.

Kim et al. prepared a fried fish cake using cultured king oyster mushroom *(Pleurotus eryngii)* and silver white croaker *(Pennahia argentata)* surimi to enhance its physiological effects [106]. In assessing its quality properties, fish cake to which 10% mushroom was added received the highest values for strength, hardness, gumminess, and brittleness. The effect of king oyster mushroom on the textural and physicochemical properties of steamed cuttlefish *(Sepia esculenta)* fish cake was investigated by Chung et al. [107]. The fish-paste with added king oyster mushroom paste revealed significant decreases in gumminess, cohesiveness, and hardness while the springiness increased with increasing concentrations of king oyster mushroom paste. On the sensory evaluation basis, the cuttlefish-paste supplemented with 30%–50% king oyster mushroom showed higher overall acceptability. In the studies by Kim et al. and Chung et al., the optimal amounts of king oyster mushroom differed, which might have been due to the different cooking methods and surimi used in each study [106, 107].

3.4. Animal Source Additives. Jin et al. investigated the effect of chicken meat on the quality characteristics of Itoyori (Japanese threadfin bream, *Nemipterus japonicus*) surimi [108]. The physicochemical properties such as fatty acid composition, shear force, and gel characteristics were affected by substitution with spent laying hen meat batter. However, sensory characteristics were less affected by this substitution. A huge amount of waste in the processing of grass carp is discarded. To deal with this waste, Gao et al. studied the processing technology used for fish and mushroom paste with salted fish cubes, mushroom, soybean, and fermented soybeans [199].

3.5. Functional Food Additives. Functional food additives including dietary fiber, ω-3-rich oil, calcium additives, and propolis have been used in the preparation of fish-paste products to increase their quality and functionality. Western populations have an inadequate quantity of health beneficial dietary fiber in their diets. Besides fiber, most Western populations also consume an insufficient amount of ω-3 PUFAs, while their sodium consumption greatly surpasses the recommended maximum. Debusca et al. prepared Alaska pollock surimi fortified with commercial long-chain cellulose as a source of dietary fiber [109]. Fiber fortification, up to a level of 6%, improved both texture and color; a slight decline in these values was observed at levels of 8% fiber. An increase in gel elasticity and thermal gelation of the fish cake was observed.

Yook et al. prepared a fish-paste by adding dietary fiber extracted from ascidian *(Halocynthia roretzi)* tunic to enhance its physiological properties [110]. The hardness, gumminess, adhesiveness, shear force, and chewiness of the fish-paste improved with the incorporation of the ascidian dietary fiber. The fish-paste with 5% ascidian dietary fiber scored the highest and was generally preferred by sensory panels. Tolasa et al. reported that the oxidative stability and the uniform dispersion of ω-3 unsaturated fatty acids can be attained in a highly consistent surimi gel system without the use of antioxidants [200].

Surimi and surimi-based products are famous throughout the world. In fact, US consumption increased in the 1980s, while the rate leveled off thereafter. The nutrification of food products with ω-3 PUFAs increases the health benefits of food, consequently increasing their market demand. Pietrowski et al. prepared surimi seafood products nutritionally enhanced with ω-3 PUFAs [201]. Although the nutrification of ω-3 PUFAs indicated an increase in lipid oxidation, it was within limits acceptable to consumers. The color of surimi seafood nutrified with ω-3 PUFAs generally improved but no effect on textural characteristics was observed.

Debusca et al. reported that the fortification of Alaska pollock surimi with either ω-3 oil or dietary fiber alone, or in combination, improved both the textural and rheological properties [111]. The ω-3 oil and fiber in combination revealed greater gelation of surimi and a slight reduction in color properties, indicating their interaction with myofibrillar proteins. Thus, it was suggested that the ω-3 oils and fiber could be effectively used as a fortifying agent to prepare high-quality surimi products with nutritional benefits. Sell et al. prepared surimi franks fortified with salmon oil or flaxseed [112]. The textural properties showed differences between frank types, with the flaxseed franks being cohesive, less gummy, softer, and chewy while the sensory evaluation showed no significant differences.

Chang et al. determined the effects of soybean oil and moisture contents on the physical properties of surimi gels [113]. The increasing levels of soybean oil and moisture contents resulted in an increase in whiteness and reduction in the chewiness, hardness, and breaking force. Setting in combination with soybean oil improved the textural and color parameters of surimi gels, indicating that soybean oil could be used to improve the color and textural properties of surimi seafood products.

Kim et al. prepared boiled fish cake using acetic acid-treated cuttlefish bone as a calcium additive agent [114]. The results of sensory evaluation of texture and whiteness were similar to those without this supplementation. In the mineral content analysis of heat-induced surimi gel, calcium content increased depending on the increasing concentration of acetic acid-treated cuttlefish bone powder, while phosphorus content did not change. The optimal concentration of acetic acid-treated cuttlefish bone powder for the preparation of high-quality heat-induced surimi gel was 0.09%.

Kim et al. prepared Alaska pollock fried fish-paste supplemented with propolis [115]. The addition of propolis enhanced the antispoiling and antioxidative ability, as well as gel strength, of fried fish-paste. In the sensory evaluation, the addition of 0.17% propolis showed the best score in overall acceptability. In another study, Kim et al. later studied sand-lance *(Hypoptychus dybowskii)* meat paste prepared with propolis [116]. Similar to the previous report, the addition of propolis on the fried fish-paste showed higher antioxidative and antispoiling activities. The fried sand-lance meat paste prepared with 0.2% added propolis was the most acceptable. Furthermore, the bitter taste of the sand-lance meat paste was reduced by adding 2% sweet amber powder.

Cheonggukjang is an ancient Korean food prepared by fermented soybean. It contains high levels of dietary fiber, oligosaccharides, isoflavones, saponin, lecithin, phytic acid, and phenolic compounds, among others. Its many beneficial properties have been reported, such as thrombolytic, anticancer, antimicrobial, hepatoprotective, antioxidant, and cholesterol-lowering effects [202]. Park et al. reported the use of fish-paste containing cheonggukjang powder [117]. The increasing concentrations of cheonggukjang resulted in an increased value of springiness, cohesiveness, and hardness; however, a reduction in brittleness and gumminess values of fish-paste was observed.

4. Shelf-Life Extension of Fish-Paste Products

Fish-paste products may easily spoil due to residual microbes that are not removed by sterilization during the manufacturing process, or by contamination in packaging or the distribution process. For such reasons, even vacuum-packed fried fish-paste products have a shelf-life of fewer than 10 days during cold storage, which is relatively short [121, 122]. Various efforts have been made to develop long-term storage solutions for fish-paste products via physical and chemical methods [118–122]. Although these methods were found to be very effective, for the long-term storage of fish-paste products, they require sensitive and complex manipulation and are costly.

The addition of appropriate food additives to fish-paste products, as an effective preservation protocol, is another strategy. Potassium sorbate is a typical synthetic food preservative and is commonly used in processed foods including fish-paste products. This material is effective in inhibiting the growth of various microorganisms, as it has a slight sterilizing effect. The use of this material is permitted to a concentration of less than 2.0 g/kg in processed fish meat products (Food Code, Ministry of Food and Drug Safety, Republic of Korea). According to the results of Walker, sorbates and sorbic acid exert a very low level of mammalian toxicity, even in chronic studies as up to 10% of the diet did not show any carcinogenic activity [203]. In addition, Thakur and Patel summarized the application of sorbates in the shelf-life extension of fish and fish-based products [204]. The physical and chemical methods, along with natural food preservatives, for the long-term storage of fish-paste products are listed in Table 3 and briefly described below.

4.1. Physical and Chemical Methods. Various efforts have been focused on developing long-term storage solutions for fish-paste products via physical methods, including high pressurization [118], microwave pasteurization [93], high hydrostatic pressure treatment [119], and even irradiation [118, 121]. In addition, it has also been reported that treatment with chlorine dioxide solution at an appropriate concentration, which is harmless to humans, could be used to prevent spoilage and to extend the shelf-life [122].

High hydrostatic pressure technology has gradually gained popularity in the food industry over the last two decades [205]. In 2013, the worldwide market for high hydrostatic pressure equipment was estimated to be $350 million and it is expected to grow. Besides high hydrostatic pressure technologies, several types of radiation have also been tested, including ultraviolet, microwaves, and gamma irradiation treatments. Radiation is generally used to control biological hazards in the production of fish-paste products and to prolong the shelf-life of such products [206, 207]. Gamma radiation exerts potent antimicrobial effects, whereas ultraviolet rays are effective for the surface, but not interior, sterilization of porous dried fish products (e.g., fish-paste products). However, gamma irradiation treatment demands large-scale facilities and higher costs [207, 208].

Miyao et al. reported that growth of the majority of the pathogenic microorganisms present in surimi was inhibited at a high pressure of between 300 and 400 Mpa [118]. Several pressure-resistant strains were isolated from surimi and were identified as *Moraxella* sp., *Acinetobacter* sp., *Streptococcus faecalis*, and *Corynebacterium* sp. It was suggested that

Table 3: Natural food additives and physicochemical methods used to improve the shelf-life of fish-paste products.

Common name	Species	Cooking method	Used as	Fish source for surimi	Metrics	Optimum amount or treatment condition	References
Physical and chemical methods							
High hydrostatic pressure	—	High-pressure treatment or heat treatment in sample tube with vacuum packaging	—	Frozen Alaska pollock	Microbial activity	400 MPa	[118]
High hydrostatic pressure	—	Not cooked	—	Tuna fish paste, Mackerel paste with paprika, mackerel paste with garlic, mackerel paste alone, and salmon paste	Microbial activity	200 MPa	[119]
Co-60 Gamma rays	—	Grilled	—	Commercially available fish meat paste products	TBC, textural, sensory, microbial, physiochemical attributes	7.5 kGy	[120]
Co-60 Gamma rays	—	Fried	—	Commercially available fish meat paste products	TBC, pH, textural, microbial, physiochemical attributes	3 kGy	[121]
Chlorine dioxide (ClO_2)	—	Steamed	—	Commercially available fish meat paste products	VBN, TBARS, pH, microbial, physicochemical, sensory attributes	50 ppm	[122]
Natural food additives							
Red pepper ethanol extract (RPEE) and/chopped fresh red pepper (CFRP)	*Capsicum annuum*	Fried	Ethanol extract and chopped fresh one	Frozen Alaska pollock	TBC, sensory attributes	RPEE: 10%, CFRP: 5%	[123]
Ethanol extract (EE), and water extract (WE)	*Phellodendron amurense*, *Eugenia caryophyllus*, *Pinus rigida*, *Bletilla striata*, and *Paeonia albiflora*	—	—	—	Antimicrobial attributes on putrefactive isolates from fish meat paste products	EE: 2,000 ppm	[124]
Egg white lysozyme (EWL) and/or sodium hexametaphosphate (SHMP), sodium pyrophosphate (SPP)	*Gallus gallus domesticus*	Fried	Powder	Frozen Alaska pollock	Viable cell count, pH, VBN, biochemical attributes	EWL: 5% + SPP: 0.5% + SHMP: 0.1%	[125]
Grapefruit seed extract	*Citrus paradisi*	—	Solution	Commercially available fish meat paste products	Proximate composition, textural, biochemical, rheological, sensory attributes	1,000 ppm	[126]

Table 3: Continued.

Common name	Species	Cooking method	Used as	Fish source for surimi	Metrics	Optimum amount or treatment condition	References
Cinnamon bark extract	*Cinnamomum cassia*	Fried	Extracted solution	Frozen Alaska pollock	Antimicrobial activity	Sprayed diluted extract (1 : 1)	[127]
Alginic acid hydrolysate	—	Boiled	Hydrolysate solution	Frozen Alaska pollock	Relative viscosity, pH, color, rheological attributes	0.3%	[128]
Chitosan hydrolysate	—	Boiled	Hydrolysate solution	Frozen Alaska pollock	Viable cell counts, rheological, sensory attributes	0.3%	[129]
Nisin (N) and/or sucrose fatty acid esters (SFE)	—	Steamed	Powder and solution	Frozen Alaska pollock	Viable cell count, antimicrobial activity	N: 12.5 μg/g + SFE:10 m/g	[130]
Piscicolin KH1	*Carnobacterium maltalomaticum*	Steamed	Solution	Cod fish	Inhibitory assay, protein content, antimicrobial activity	50 AU/g.	[131]
Zein and soy protein isolate (SPI) films containing green tea extract (GTE)	*Zea mays* *Glycine max* *Camellia sinensis*	Fried	Edible film (GC-WPI) with GTE	Commercially available fish meat paste products	TBARS, color, microbial, physical attributes	GTE: 1%	[132]
Gelidium corneum (GC)-Whey protein isolate (GC-WPI) blend film containing grapefruit seed extract (GSE)	*Gelidium corneum Citrus paradisi Bos taurus*	Not mentioned	Edible film (GC-WPI) with GSE	Commercially available fish meat paste products	Water vapor permeability, microbiological analysis, sensory attributes	GSE: 0.1%	[133]

TBC: total bacterial count; VBN: volatile basic nitrogen; TBARS: thiobarbituric acid reactive substances.

damage to the cell membrane and degradation of ribonucleic acids occurred in the high-pressure-treated cells. Malicki et al. investigated the use of high hydrostatic pressure to prolong the shelf-life of traditionally manufactured fish-paste stored under refrigeration (4°C) for 6 weeks [119]. Neither bacteria nor molds or yeasts were detected in the high hydrostatic pressure-treated fish-paste samples at any time point analyzed, irrespective of the pressurization conditions. In conclusion, these studies revealed the effectiveness of high hydrostatic pressure to prolong the shelf-life of traditionally manufactured fish-paste stored under refrigerated conditions for up to 6 weeks.

Kim et al. reported a reduction in the total aerobic bacterial counts in the grilled fish-paste stored at 5°C and irradiated by gamma rays at a level of 2.5 kGy or more [120]. Additionally, the treatment of gamma rays at a level of 7.5 KGy at 30°C showed a significant inhibition in aerobic bacterial growth. Cho et al. investigated the effect of Co-60 gamma irradiation on fried fish-paste and studied the physicochemical properties of fish-paste products stored at low temperature (3 ± 1°C) and room temperature (10–20°C) [121]. There was no obvious difference between the vacuum- and air-packed groups. The irradiation of 3 KGy extended the shelf-life of fish-paste up to 2 times at room temperature and 3-4 times at low temperature. In both studies, the irradiation treatment caused very little textural degradation and no effect on the sensory characteristics of the samples was observed.

Shin et al. investigated the effects of chlorine dioxide (ClO_2) treatment on the physiochemical and microbial properties of fish-paste products [122]. After ClO_2 treatment, fish-paste samples were individually packed and stored at 4°C. The pH and VBN values of fish-paste decreased with increasing ClO_2 concentration. ClO_2 treatment significantly reduced the populations of total bacteria, yeast, and mold during storage. In particular, treatment with 50 ppm ClO_2 significantly decreased the total bacterial count the most among all ClO_2-treated fish-pastes, showing that 50 ppm chlorine dioxide was the optimum concentration to prolong the shelf-life of fish-paste products.

4.2. Natural Food Additives. The use of natural food preservatives rather than chemical and synthetic food preservatives is of worldwide interest. It has been reported that several natural food additives could extend the shelf-life of cooked fish and fish products. Some examples include onion ethanol extract [183], egg white lysozyme [125], grapefruit seed extract [126], chitosan hydrolysate [129], cinnamon bark extract [127], and red pepper extract [123], as well as mixtures of lysozymes, sodium hexametaphosphate, and sodium pyrophosphate.

The shelf-life of fried fish-paste products prepared by adding red pepper ethanol extract was estimated by Yoon et al. [123]. The shelf-life of the fried fish-paste with added 10% red pepper ethanol extract and 5% chopped fresh red pepper was 2 to 3 days longer than that of the commercial fish-paste product, thus demonstrating the most effective preservation effects. According to Ahn et al., the extracts of *Eugenia caryophyllus*, *Pinus rigida*, *Bletilla striata*, and *Paeonia albiflora* exerted strong inhibitory effects on the growth of microorganisms isolated from putrefied fish-paste [124]. Notably, the ethanol extract was more effective than water extract in all tested microorganisms. The inhibition level of each extract was evident at 2,000 ppm ethanol in the fish-paste.

Kim et al. investigated the inhibitory effects of lysozymes, mixtures of lysozymes, and other antibacterial substances such as sodium pyrophosphate and sodium hexametaphosphate on bacterial growth in surimi products [125]. The lysozymes inhibited growth in most of the tested isolates and the mixture of antibacterial substances showed increased effects compared with those when they were used individually. A mixture of 0.5% sodium hexametaphosphate, 0.5% sodium pyrophosphate, and 0.05% lysozyme in imitation crab and kamaboko showed the highest inhibitory activity.

The stabilizing effects of grapefruit seed extract on fish-paste products were investigated by Cho et al. [126]. Textural properties decreased with increasing storage period. The treatment of fish products with grapefruit seed extract prolonged the deterioration of fish-paste product proteins during storage up to 4-5 days. The chemical, sensory, and rheological evaluation revealed that the grapefruit seed extract could be used as an effective additive to extend the shelf-life of fish-paste products.

The predominant bacterium in most of the isolated microorganisms from packed and unpacked spoiled fish-paste products is *Bacillus* sp. [127]. Notably, yeast and molds are not reported in the vacuum-packed products. A hydrolysate of alginic acid has antimicrobial activity, but it has not been used at industrial scale. The alginic acid at a concentration of 0.3% prolonged shelf-life of fish-paste products by 4 days at 15°C and inhibited the growth of *Bacillus* sp. isolated from fish-paste products [128]. According to the results of Cho et al., the chitosan hydrolysate made with chitosanase from *Aspergillus oryzae* ATCC 22787 revealed the strongest antimicrobial activity and inhibited the growth of *Bacillus* sp. isolated from fish-paste products [129]. The addition of chitosan hydrolysate at a concentration of 0.3% resulted in extended shelf-life of up to 6 days at 15°C. Jeong et al. reported that spraying cinnamon bark extract on the surface of the fried fish-paste products could inhibit the growth of spoilage bacteria and mold at room temperature and resulted in prolonged shelf-life [127].

Yamazaki et al. investigated the effects of nisin and sucrose fatty acid esters on the growth of spoilage bacteria in fish-paste products [130]. Nisin exerted antibacterial activity against *Bacillus subtilis* and *Bacillus licheniformis* in a liquid medium at 20°C and resulted in a longer shelf-life for fish-paste products. It was concluded that the addition of nisin could be used as a potential alternative method to prevent spoilage caused by spore-forming bacteria in fish-paste products. The bacteriocin produced by *Carnobacterium maltalomaticum* had the ability to inhibit both *Enterococcus* sp. and *Leuconostoc* sp., which reduce the shelf-life of fish-paste products during preservation [131]. The results showed that the purified bacteriocin, piscicolin KH1 and/or nisin, significantly inhibited the growth of *Leuconostoc mesenteroides* and *Enterococcus faecium* and could be used as a food-grade preservative for kamaboko gels.

Sakai and Yamaguchi examined the possibility of inhibiting lipid oxidation in boiled fish-paste by adding yuzu skin to the surimi [209]. The heat-treated control kamaboko and yuzu skin-added kamaboko (citron kamaboko) were refrigerated at 0°C for 2 days, and, after heating the surimi, the malonaldehyde content in both kamabokos was reduced. These results suggest that the addition of citron skin suppressed lipid oxidation in fish-paste products.

Various packing materials and wrapping techniques have also been employed to keep fish-paste products fresh and free of contaminants for a longer period of time. Lee et al. investigated the processing conditions and quality stability of retort pouched fried-mackerel fish-paste during storage [210]. The mackerel fish-paste was ground with added ingredients, fried in soybean oil, cooled, vacuum-packed in a laminated plastic film, and finally sterilized at 120°C for 20 min in a hot water circulating retort. The reported method showed a good preservation for 100 days at 25 ± 3°C. The sensory evaluation showed no significant differences between the prepared fish-paste products and that of products in the market. Ha et al. examined the optimum storage conditions for maintaining the quality of the fried fish-paste in retort pouches [211]. Both hardness and gel strength increased with increasing sterilization temperature. On the other hand, no differences were observed in elasticity and water-holding capacity.

Lee et al. elucidated the antioxidative effects of soy and/or zein protein films containing green tea extract on the physiological properties of fish-paste products during storage [132]. The soy protein films showed an increase in yellowness, while a decrease in yellowness was observed with the zein films. The lipid oxidation was retarded at day 2 of storage by wrapping the fried fish-paste products with soy and zein protein films containing green tea extract. Lim et al. prepared a *Gelidium corneum* whey protein isolate (GC-WPI) blend film containing grapefruit seed extract and studied the effect of this film on pathogenic bacterial inhibition during storage [133]. The GC-WPI blend was effective in decreasing the populations of *Salmonella typhimurium, Listeria monocytogenes*, and *Escherichia coli* on films treated with 0.1% grapefruit seed extract. These studies suggest that packaging fish-paste products in plant-based protein films containing green tea or grapefruit seed extract could be beneficial to prolong shelf-life.

5. Conclusion

The production of surimi dates back to ancient times. However, advancement in surimi processing technology started in 1960 with the discovery of cryoprotectants, which were helpful in maintaining the gel quality and functionality of fish-paste for relatively longer periods of frozen storage [3]. As the market share of quality-conscious consumers rises, the demand for the use of natural additives rather than chemical ingredients for surimi products will continue to increase. According to Park et al., the worldwide production of surimi-related products reached around 800,000 MT by 2011-2012, while the main fish sources for surimi products include Pacific whiting, Alaska pollock, jack mackerel, Atka mackerel, southern blue whiting, northern blue whiting, and hoki [3].

Surimi is subdivided into high-grade (FA, SA, and A) and low-grade (KA, KB, and RA) types, based on the quality of the raw fish sources. Most of the high-grade surimi is sold in Japan for the production of kamaboko and other high-quality surimi products and in Korea for the production of premium crabsticks. Low-grade surimi is sold in Europe and the United States for the manufacturing of crab sticks and in Korea and Japan for the preparation of other fried fish products [3]. With the technological advancements in the surimi processing industry, it has been possible to use low-grade surimi for the production of fish cakes, fish balls, and other surimi products.

With increasing demand and new processing techniques (e.g., the pH-shift method), the use of other seafood resources, such as small pelagic species and giant squid, for the production of surimi and surimi products was possible [212]. Notably, the production of surimi products is cheaper in Korea than elsewhere, but industry professionals are always searching for the most inexpensive surimi seafood sources. Hence, the production of surimi from aquaculture fish, such as catfish, and carp is growing in demand.

Food additives from animal and seafood sources, such as fish, chicken, beef plasma proteins, and egg white, are considered the most effective protease inhibitors for surimi. However, with the outbreak of avian influenza, mad cow disease, undesirable resulting characteristics, and some religious constraints, there is limited use of these food additives. Additionally, vegetarians in some parts of the world would not wish to consume surimi-based products containing additives derived from animals or even from seafood sources. Hence, there is a need to identify more effective and alternative food-grade ingredients (e.g., plant sources, seaweed, and microalgae) to be used in the preparation of fish-paste products.

Surimi is mainly used for human consumption. As such, the challenges of production cost, composition, nutritional value, and the shelf-life of surimi products can never be neglected. This review has provided an overview of natural and synthetic food additives and preservatives used to enhance the quality, functionality, and shelf-life of fish-paste products. In addition, the improvements in the fish-paste product quality and functionality by various food additives from seafood, plants, mushrooms, animal sources, and functional materials were discussed.

For decades, surimi and surimi-based products have been well known in East Asian countries such as Japan and Korea. However, with advancements in technology, they are attracting attention in other Asian as well as European countries. With the increasing consumption worldwide, the manufacturing and processing of fish-paste products may require new and improved additives to enhance their acceptability in the market. Continuous scientific innovations and improved processing technology will aid in further advancements and improvements in this area.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article and regarding the funding received.

Authors' Contributions

Khawaja Muhammad Imran Bashir and Jin-Soo Kim contributed equally to this work.

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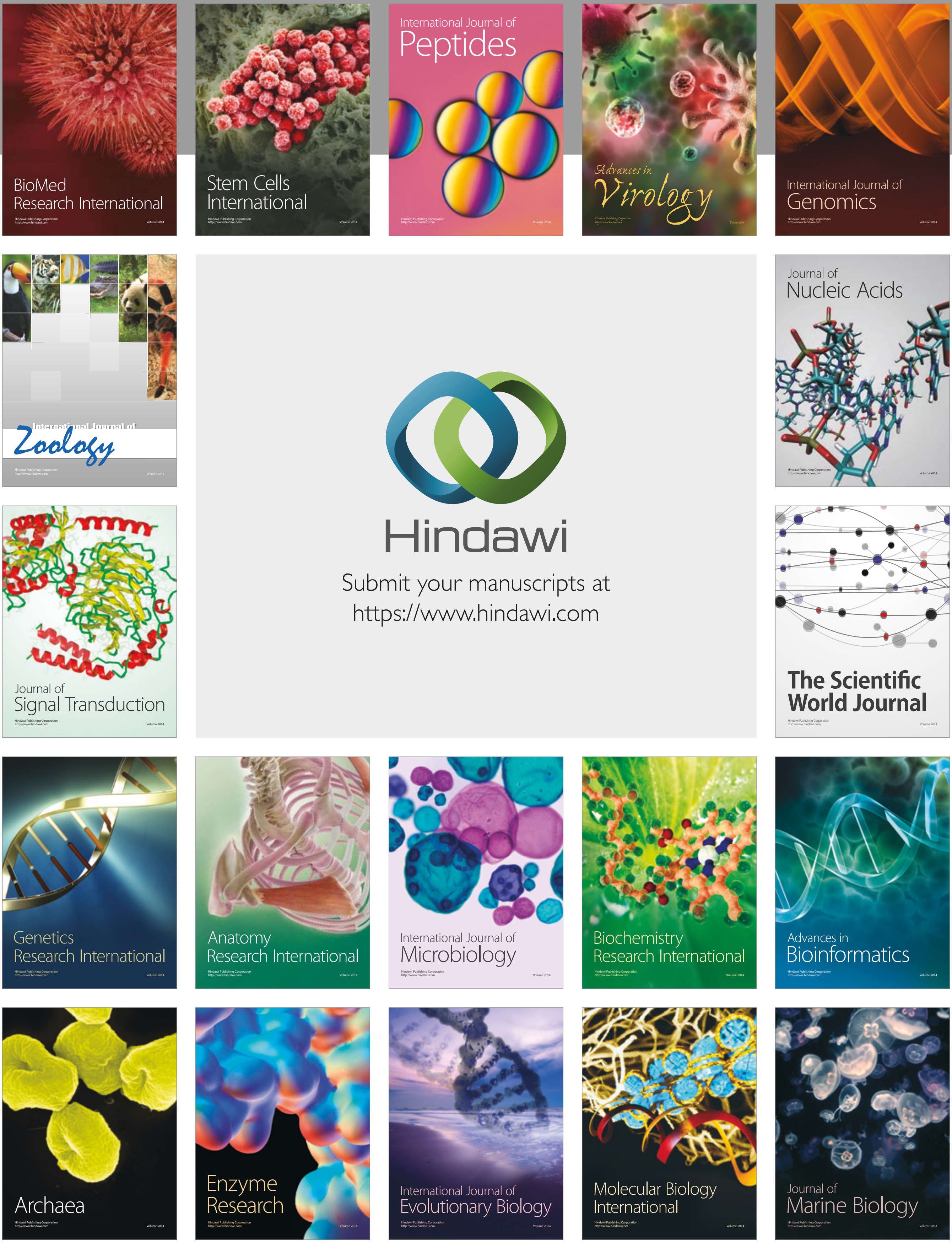
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