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A Review on the Loss of the Functional Properties of Proteins during Frozen Storage and the Improvement of Gel-forming Properties of Surimi

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ABSTRACT

The functional properties of the myofibrillar proteins were protected during frozen storage when a cryoprotectant was added. Some normally used cryoprotectants are sorbitol, sucrose, polydextrose, lactitol, litesse, maltodextrin, trehalose, sodium lactate and mixtures of the above cryoprotectants. Phosphate is normally added to surimi in combination with cryoprotectants to reduce viscosity, increase moisture retention and the protein's ability to reabsorb liquid when the surimi is thawed or tempered and increase the pH slightly, which leads to improved gel-forming ability, gel strength and cohesiveness. Some food additives also can be used to improve the physical properties of and prevent the textural degradation of, surimi gels such as egg whites, Beef Plasma Protein (BPP) and Whey Protein Concentrate (WPC). A new surimi-developing process using an acid and alkaline washing method has shown significant potential for use in increasing the concentration of myofibrillar protein in the surimi.

Key words: Surimi, myofibrillar protein, cryoprotectant, low sweetness sugar, gel-forming properties

INTRODUCTION

In Japan, the term was denoting for a minced fish product, where most of the water soluble components including sarcoplasmic proteins have been removed by leaching with potable water. According to Okada (1992), surimi is the wet concentrate of the myofibrillar proteins of fish muscle that has been mechanically deboned, water-washed and frozen. The Japanese have been improving surimi technology for several hundred years. The development of the industry has recently been supported by an increase in the supply of raw materials, the development of new products and the development of new technologies for manufacturing and preserving the products. The surimi industry has spread to other countries such as Korea, Europe and the United States.

Surimi can be produced from both marine and fresh-water fish, including both white-muscled and dark-muscled fish, such as alaska pollock, blue whiting, croaker, lizardfish, sardine, tilapia and bigeye snapper. Commonly, certain species are used due to their easy capture and low price. The use of alternative species in order to obtain surimi of good gel-forming ability is one of the aims of the fishing industry.

Surimi technology has been widely developed. Significant effort has been directed to developing new products, as well as new technologies for waste-water treatment, the utilization of other fish species, preserving surimi-based products, the utilization of some cryoprotectants and improved gel-forming.

THE IMPORTANCE OF SURIMI

Surimi is a Japanese term referring to the ground fish meat paste formed during the manufacturing process of traditional Japanese product "kamaboko". Introduced more than two decades ago, since 1980s, Surimi is now an important industry in the Southeast Asian region. A 2006 survey found that a total of 80 surimi processing plants are located in the region; including 26 in Thailand, 15 in Vietnam, 3 in Myanmar, 8 in Indonesia and 15 in Malaysia (SEAFDEC, 2009).

Surimi is the primary ingredient in a variety of processed foods such as kamaboko, kani (crab)-kamaboko, chikuwa, satsumage, fish sausages and fish balls, contributing more than 50% to the production yield. Huda and Noryati (2009) reported most of fish balls manufacturer in Malaysia used surimi for their production. Similar trend also begin at fish cracker manufacturer (Huda and Ariffin, 2010). The quality of these products depends very much on the quality of the surimi used. Surimi gels upon kneading. Gel is an important characteristic for surimi-based products. However, it soon loses this ability upon frozen storage. That is to say, the functional properties of the myofibrillar proteins in the raw surimi deteriorate rapidly during freezing: the freezing process causes ice crystals to form, which results in the dehydration of the myofibrillar protein, a pH decrease and a change in salt concentrations. These three effects, in addition to various hydrophobic interactions, denature and/or aggregate the frozen myofibrillar proteins in surimi. Furthermore, the longer the surimi is frozen, the greater is the degree of protein denaturation (United States Patent 5436024, 1995). The formaldehyde level in a given fish muscle has been used as an index of frozen storage deterioration. Myofibril proteins that react with formaldehyde have become denatured and formation of protein aggregates has occurred. Benjakul *et al.* (2004) reported that lizardfish produce high levels of formaldehyde, leading to high levels of protein aggregation, as shown by the considerable loss of solubility during 6 months' storage at -18°C. Several technologies have been applied in attempts to prevent the problem, including the use of cryoprotectants like sugars and sugar alcohols, as well as quick-freezing the surimi into block form. It is essential to provide a cryoprotectant that (1) Maintains the functionality of proteins in frozen surimi, (2) has a low tendency to cause Maillard browning during storage of the surimi at freezing temperatures and during the heating of a surimi-based foodstuff and (3) has a mild taste (United States Patent 5436024, 1995).

Many techniques for improving the texture of surimi-based products have been proposed and implemented, including adjusting the pH of the surimi paste (Rawdkuen *et al.*, 2008; Karayannakidis *et al.*, 2007), application of temperature setting prior to cooking (Alvarez *et al.*, 1997) and using additives like polyphosphate and potassium bromated (Julavittayanukul *et al.*, 2006). Further improvements in both physical and nutritional quality are anticipated: current research focuses on the development of low calorie, low cholesterol value-added products, replacing the cryoprotectants in surimi with low-calorie substitutes.

THE RAW MATERIALS OF SURIMI

The fish normally used for making surimi are alaska pollock or walleye pollock (*Theragra chalcogramma*), new zealand hoki (*Macruronus novaezelandiae*), southern blue whiting (*Micromesistius australis*) and northern blue whiting (*Micromesistius poutassou*). In Asia, several species, such as the croaker (*Pennahai macrophthalmus*), lizardfish (*Sauruda micropectoralis*), barracuda (*Sphyraena* sp.), hairtail (*Trichiurus* sp.), atka mackerel (*Pleurogrammus azonus*), threadfin bream (*Nemipterus bleekeri*) and bigeye snapper (*Priacanthus tayenus*), are commonly used by shore-based surimi manufacturers (Park, 2005).

Pollock is a small cousin of cod and found throughout the North Pacific, north of latitude 30°N from the Gulf of Alaska in the East, throughout the Bering Sea, around the Kamchatka Peninsula in the West Pacific and into the Sea of Japan. Pollock is chosen because of its abundance, accessibility, subtle flavor and low odor and low cost, making this species preferable as a raw ingredient of surimi (Lanier and Lee, 1992).

New Zealand hoki is another popular species used for surimi in Japan and Korea. Most of the hoki caught is currently processed into surimi or other high-quality fillet and fillet-based products. Hoki flesh is normally high in protein, up to 20% and low in oil, at less than 5%. The predominant characteristics of hoki flesh are a mild, slightly sweet flavor and a moist texture. Recent research has shown that at the same protein-to-moisture ratio, hoki surimi has similar functional qualities to the equivalent grades of alaska pollock surimi and that surimi from these two species could be interchangeable when manufacturing surimi-based products (Lanier and Lee, 1992).

Southern blue whiting is a member of the true cod family that lives in the sub-Antarctic waters South of New Zealand. The composition of southern blue whiting muscle (g/100 g sample) is as follows: 79.35% moisture, 18.57% protein, 1.21% ash, 0.78% fat and 0.78% carbohydrate (Stark *et al.*, 2009). Southern blue whiting can be made into surimi with a high functional quality and can form a very firm and cohesive gel. Generally, southern blue whiting surimi is whiter and has lower fishy flavor and odor scores than hoki or Alaska pollock surimi. In the Southern Hemisphere, Southern blue whiting is second only to hoki for use in surimi production (Lanier and Lee, 1992).

Northern blue whiting occupies the North Atlantic off the coast of Norway and the Faeroe Islands and is the most commonly used species for surimi production in this area. Its meat yield rate is 22-27% (Lanier and Lee, 1992). Northern blue whiting offers a high-quality surimi similar to that from southern blue whiting (Park, 2005).

The use of threadfin bream for surimi production has increased dramatically over the past decade and will continue to play a major role in surimi markets in the future. It has been shown to make a high-quality surimi with good gel strength. These fish are benthic, inhabiting marine waters on sandy or muddy bottoms, usually at depths of 20 to 50 m and feeding on small benthic invertebrates and small fish. Because of the white color, smooth texture, strong gel-forming ability and easy processing, threadfin bream surimi is widely used as raw material for Japanese kamaboko and surimi-based crabstick or kani-kama (Park, 2005).

Croaker is the preferred fish of the traditional kamaboko industry. The croaker's myofibrillar proteins are highly stable in frozen storage, making it a good candidate for surimi processing. Croaker is one of the most bountiful near-shore species in Asia. There are more than 60 species of croaker, but the three of interest to surimi producers are blackmouth croaker (*Atrubucca nibe*), white croaker (*Argyrosomus argentatus*) and yellow croaker (*Pseudoscianena polytis*). The meat of blackmouth croaker has a good flavor with a strong gel-forming ability and is most commonly

used in Taiwan's croaker surimi. Average yields are 43%, very high compared to other species used for making surimi. White croaker meat has only a moderately good flavor, but its meat has the best gel-forming ability of all the croaker species and is the main species used in Japanese croaker surimi. Yellow croaker meat has a very good flavor but is said to have a low gel-forming ability (Lanier and Lee, 1992). Croaker surimi from these species is generally darker in color than threadfin bream surimi, but can fetch a high price in Japan (Park, 2005).

Lizardfish has long been considered a high-grade surimi fish and is used for kamaboko processing in Japan. The fresh meat is white in color, has a good flavor and a very high gel-forming ability. However, the freshness and gel-forming ability decrease quickly in storage and the stability of the fish is very low in frozen storage. Thus, the fish must be processed quickly after catching and at low temperatures. Generally, frozen lizardfish cannot be used for frozen surimi. Japan is the only country that is currently using lizardfish for surimi (Park, 2005).

Pike-conger has a rich flavor that demands immediate processing directly into surimi, without leaching. There are five species of pike-conger; the one most used for surimi is daggertooth pike-conger (*Muraenesox cinereus*). Pike-conger has an extremely high meat-yield rate of 68%. Its fat content is also relatively high (Lanier and Lee, 1992).

The largehead hairtail has slightly gray flesh and makes a middle-grade surimi. However, only Japan uses hairtail in surimi. It has a good flavor but a low gel-forming ability. The meat-yield rate is about 50% and it has a relatively high fat content (Lanier and Lee, 1992). Although it has a low gel-forming ability and the surimi is generally darker in color, it is used in Japan for surimi because of its good flavor (Park, 2005).

Atka mackerel is a member of the greenling family and produces a middle-quality surimi. The Japanese use Atka mackerel for surimi, but use only the small fish. The meat is slightly yellowish-gray, with about a 45% meat-yield rate. The fat content of Atka mackerel is relatively high for a surimi fish and has a low gel-forming ability (Lanier and Lee, 1992).

There are 10 species of bigeye, but the purple-spotted bigeye (*Priacanthus tayenus*) is the species most likely to be used for surimi. Bigeye meat is slightly dark but has a high gel-forming ability (Lanier and Lee, 1992).

The use of alternative fish species, other than those above, to obtain surimi with a good gel-forming ability is one of the aims of the fishing industry. Pelagic species like sardine, tilapia, rainbow trout, grass carp are now being considered in surimi manufacturing due to their easy capture and low price.

DEVELOPMENT OF SURIMI TECHNOLOGY

Lanier and Lee (1992) assert that surimi is produced by repeatedly washing mechanically separated fish flesh with chilled water (5-10°C), until most of the water-soluble protein has been removed. The washing procedure is key to for the final surimi quality, not only for removing fat and undesirable materials, such as blood, pigments and odorous substances, but, more importantly, for increasing the concentration of myofibrillar protein, thereby improving the gel-forming ability of the surimi. Then, the raw surimi is mixed with cryoprotectants such as sugars or sugar alcohols. The latter form is quick-frozen into blocks and becomes frozen surimi.

Many studies have been conducted to improve the technology of surimi-making, especially to reduce the loss of the functional properties of myofibrillar proteins during frozen storage and to improve the gel-forming ability. The addition of cryoprotectants is required to retain the functional properties of the myofibrillar proteins. The most commonly used cryoprotectant in the surimi

industry is a 1:1 mixture of sucrose and sorbitol at a concentration of 8% (MacDonald and Lanier, 1994). Phosphates have been used as additives for improving the gel-forming ability of the proteins (Julavittayanukul *et al.*, 2006), along with the pH-shift process (Karayannakidis *et al.*, 2007; Rawdkuen *et al.*, 2008), the addition of whey protein concentrate (Rawdkuen and Benjakul, 2008) and the addition of chitosan (Mao and Wu, 2007).

THE STUDIES OF CRYOPROTECTANTS

The most important step in the making of surimi is the addition of the cryoprotectant. Cryoprotectants are important to stabilize the surimi and protect it during freezing and frozen storage. However, the myofibrillar proteins in the raw surimi lose their functional properties rapidly once they are frozen, a process leading to protein aggregation, textural changes and the loss of gelling and water-holding functionality in the fish (Lainer and Lee, 1992). MacDonald and Lanier (1994) reported that the addition of cryoprotectants is required in order to retain the fish's functional properties. More over, cryoprotectant is not only able to retain functional properties of protein during freezing and frozen storage, but also during drying process (Huda *et al.*, 2000a, 2001). Surimi powder produced also showing higher protein quality (Huda *et al.*, 2000b).

Many compounds, including some low molecular weight sugars and polyols as well as many amino acids, carboxylic acids and polyphosphates, have been found to be cryoprotective (Park *et al.*, 1987; Sych *et al.*, 1991a). Nevertheless, many of them cannot be used for various reasons such as high cost, food regulations that prohibit them, or adverse sensory properties.

Sorbitol and sucrose: Surimi freezing is done commercially using incorporation of sucrose (4%), sorbitol (4%) and polyphosphates (0.2%), which protect fish myofibrillar protein during long periods of frozen storage (Sultanbawa and Li-Chan, 1998). However, one disadvantage of the current commercial cryoprotectant blend is the high level of sucrose and sorbitol, which impart a sweet taste. Yoon and Lee (1990) showed that 4% sucrose plus 4% sorbitol in crystalline or liquid form in red hake (*Urophycis chulos*) surimi, when given as extruded gel products to a sensory panel, were judged to be slightly too sweet. In addition, today's consumer is conscious of caloric content and a low calorie cryoprotectant may be preferred for surimi.

Lactitol: Lactitol is the product of hydrogenation of lactose, thus also a disaccharide polyol (Marshall *et al.*, 2003) and well established as a replacement sweetener for low-calorie foods (MacSweeney, 2009). Lactitol was highly effective in preventing changes from taking place in frozen-stored natural actomyosin extracts of rainbow trout (Herrera and Mackie, 2004). A study by Sych *et al.* (1991a) showed that lactitol in cod surimi (*Godus morhua*) could be reduced from 8% to 5.7-6.4% without a significant alteration of the stabilizing effect. Another study by Sych *et al.* (1991b) showed that lactitol at the 8% level or lactitol at the 4% level maintained the functional properties of the myofibrillar proteins in cod surimi during 4 months of storage at -20°C.

Polydextrose: Polydextrose is an odorless, white-to-light-cream amorphous powder, with virtually no sweetness and an energy value of only 1 kcal g⁻¹ (Roller and Jones, 1996). The use of polydextrose as a cryoprotectant has been patented by Lanier and Akahane (1986). Most of the studies on polydextrose have shown that it is a good cryostabilizer for surimi (Sych *et al.*, 1990, 1991b; Herrera and Mackie, 2004). Furthermore, other research has shown that polydextrose at

the 8% level maintained the functional properties of myofibrillar proteins in cod surimi during 4 months of storage at -20°C (Sych *et al.*, 1991a). Herrera and Mackie (2004) reported that polydextrose was highly effective in preventing changes in frozen stored natural actomyosin extracts of rainbow trout. Park *et al.* (1987) reported that polydextrose maintained a high level of solubility in the myofibrillar proteins at -28°C over several months.

Litesse: Litesse is the brand name for improved forms of polydextrose. Litesse is produced from polydextrose using additional processing to reduce the acidity and bitterness, thereby improving the flavor profile (Nabors, 2001). Litesse is not sweet and is less bitter, astringent and acidic than polydextrose and therefore, in most food systems, litesse does not require neutralization. Sultanbawa and Li-Chan (2001), claimed that the calorie utilization of litesse is 1 kcal g⁻¹, which is 25% that of carbohydrates. Sultanbawa and Li-Chan (2001) reported that 8% litesse was effective in maintaining the gel strength of surimi after eight freeze-thaw cycles.

Maltodextrin: Maltodextrin has the potential to act as cryoprotectant in fish muscle protein. Maltodextrins of varying mean Molecular Weights (MW) (M040, M100, M150, M180, M200, M250) stored isothermally at either -8,-14, -20°C for 3 months were evaluated for cryoprotective ability in alaska pollock surimi. All maltodextrins at -20°C isothermal storage, irrespective of MW, produced good cryoprotective qualities, but higher MW maltodextrins at higher isothermal storage temperatures produced poor cryoprotection. Lower MW maltodextrins likely cryoprotect by a preferential solute exclusion mechanism, similar to sucrose and sorbitol. Higher MW maltodextrins presumably cryoprotect at lower storage temperatures via a reduced water mobility mechanism. The MW of maltodextrins increase the gelling ability of the surimi (Carvajal *et al.*, 1999).

Trehalose: Trehalose is a well-known non-reducing disaccharide synthesized by a wide variety of organisms and it is considered a dietetic sugar (Arnoldi, 2004). Recently, trehalose has been found to have properties protective against thermal inactivation of enzymes; this effectiveness was correlated with its large hydration volume (MacDonald *et al.*, 2000). Osako *et al.* (2005) reported that an addition of 5.0 to 7.5% concentration of trehalose increased the amount of unfrozen water and prevented freezing-induced denaturation of proteins. Other research has shown that trehalose exhibited the greatest protective effects on protein denaturation as shown by the effectiveness Ca²⁺-ATPase activity and protein solubility in comparison with sucrose and sorbitol. The greatest breaking force and deformation were obtained in surimi with 8% trehalose added, in frozen storage for up to 24 weeks (Zhou *et al.*, 2006).

Sodium lactate: Sodium lactate has no sweetness and has a low caloric value. It is currently Generally Recognized as Safe (GRAS) for use as an emulsifier, flavor enhancer, flavoring agent, humectant and pH control agent (MacDonald and Lanier, 1994). Sodium lactate has been demonstrated to be an effective stabilizer against both freeze-thaw and heat-induced denaturation of tilapia (*Tilapia nilotica*×*Tilapia aurea*) actomyosin (MacDonald and Lanier, 1994). Sodium lactate shows a similar cryoprotective effect to sucrose or a sorbitol blend. Sodium lactate at a level of 8% (w/w) effectively prevented the protein denaturation of tilapia surimi during storage at -18°C for 24 weeks (Zhou *et al.*, 2006).

Mixtures of cryoprotectants: Matsumoto reported 4% sucrose and 4% sorbitol to be the optimum cryoprotectant blend (Yoon and Lee, 1990). Additionally, Medina and Garrote (2002) discovered that at 45 and 90 days of frozen storage, surubí (*Pseudoplatystome coruscans*) surimi made with the sucrose-sorbitol blend had a higher gel strength than surimi made with maltodextrin-sorbitol in a ratio 1:1, under different processing temperatures (2 to 18°C), times (1 to 7 min/cycle) and water-to-mince ratios (2:1 to 8:1). However, such a blend yields a taste that is too sweet. Other research reported that the commercial mix of 4% sucrose and 4% sorbitol, as well as other cryoprotectant blends at levels ranging from 4-12%, were all effective in ensuring good gel formation from ling cod surimi after frozen storage at -18°C for 4 months, with the blend containing 4% cryoprotectants (sucrose, sorbitol, litesse and lactitol at a ratio of 1:1:1:1) offering advantages of reduction in sweetness and cost (Sultanbawa and Li-Chan, 1998).

PHOSPHATE

Phosphates are natural compounds; they are salts containing phosphorus and other minerals. The phosphates usually used in surimi are sodium tripolyphosphate (STPP), sodium pyrophosphate (SPP), sodium hexametaphosphate (SHMP), tetrasodium pyrophosphate (TSPP), tetrapotassium pyrophosphate, sodium hexametaphosphate (SHMP) and trisodium phosphate (TSP). The names correspond to the standard system of nomenclature, outlined below. Members of the series having one phosphorus atom are called orthophosphates. The dimers (two P atoms) are the pyrophosphates, followed by the triphosphates, also known as tripolyphosphates (three P atoms) and by the tetraphosphates (four atoms). The members of the homologous series having 5-15 P atoms are sometimes referred to as oligophosphates (Molins, 1991).

The use of phosphates in surimi reduces the viscosity of the paste, allowing for better machinability (Park, 2005). Phosphates increase moisture retention and increase the ability of a protein to reabsorb liquid when the surimi is thawed or tempered. Phosphates increase the pH slightly, which will also lead to an improved gel-forming ability, gel strength and cohesiveness, because of an increase in water-holding capacity at a higher pH. Polyphosphate added at 0.5% provides the greatest gel strength, but 0.3% is optimal for gel strength and flavor with sodium tripolyphosphate trisodium pyrophosphate used in combination (Hui, 2006).

Phosphate is normally added to surimi in combination with cryoprotectants, such as sugar or sorbitol (Sultanbawa and Li-Chan, 2001). Julavittayanukul *et al.* (2006) reported that the type of phosphate (sodium pyrophosphate, PP; sodium tripolyphosphate, TPP and sodium hexametaphosphate, HMP) and the concentration of phosphate compounds (0, 0.05, 0.1, 0.3 and 0.5% w/w) had a varying influence on surimi gels from bigeye snapper (*Priacanthus tayenus*). An increased phosphate concentration generally displays a detrimental effect on gel formation, possibly by chelating calcium ion, required for endogenous TGase. Sodium pyrophosphate (PP) exhibited superior gel-strengthening effects, compared to the others, whereas sodium hexametaphosphate (HMP) was shown to have adverse effects on surimi gelation. The use of PP (0,025%) in combination with CaCl₂ (50 mmol kg⁻¹) at appropriate levels could effectively improve the gel-forming ability of surimi.

THE STUDY OF GEL-FORMING PROPERTIES

Proteolytic degradation of myofibrillar proteins has an adverse effect on the gel-forming properties of surimi. Various food-grade inhibitors, such as egg whites and Beef Plasma Protein

(BPP) have been used to improve the physical properties and prevent the textural degradation of surimi gels (Rawdkuen *et al.*, 2007; Lou *et al.*, 2000). These are also known as food additives. However, alternative food-grade proteinase inhibitors for surimi production are still needed.

Egg whites: Egg whites are frequently used in surimi-derived products. Egg whites make the partially heat-set analog more elastic and stretchable. The amount of egg whites added depends upon the fish species used and the quality of the fish used. Hui (2006) reported, egg whites added at 10% produces a gel with high yield stress; gels containing up to 20% egg whites are softer, but there is a decrease in gel strength and the gel becomes brittle at percentages greater than 20%. Egg whites contribute to the structure of surimi analog gels by filling interstitial spaces in the fish protein network. Benjakul *et al.* (2004) reported that the addition of egg whites up to 3% increased gelling properties of lizardfish surimi regardless of the heating conditions (40/90, 60/90 and 90°C).

There are some negative effects of using egg whites in surimi. Egg whites are an allergen and must therefore appear on the label of surimi analog products. Class II food recalls of analog products have been initiated in the United States because of the failure of companies to list egg whites on the ingredient statement (Hui, 2006). In addition, egg whites must be used carefully because they often generate off-flavors and react with many of the components of the flavor, particularly the aldehydes found in the flavor or extract used (Park, 2005).

Beef Plasma Protein (BPP): Beef plasma protein, which is mostly dried, is used as a gelling agent and/or protease inhibitor. Plasma constitutes about two-thirds of the weight of blood and can be separated from red cells by centrifugation. The liquid plasma is then filtered and spray-dried. Beef plasma, which contains about 70% protein, is widely used in the meat industry for its high solubility and excellent gelling properties. The latter is attributed to the presence of fibrinogen (5%), a superior gelling protein and albumin (65%). Plasma protein can be dissolved in brine and injected into meat. It will form an elastic, irreversible gel when cooked to above 65°C and therefore is suitable for a variety of sectioned, formed and restructured meats that require a strong bind between meat chunks and particles. Another important application of beef plasma is in surimi products. Beef plasma exhibits a remarkable capability to inhibit modori, or gel weakening, during the cooking of surimi, when it is prepared from some fish species or animal by-product meats (Yada, 2004). Lou *et al.* (2000) reported that electrophoretic analysis has shown that myosin degradation, which occurs in control surimi samples heated to above 45°C, is prevented when as little as 0.5% beef plasma powder is added. This strongly suggests that beef plasma contains protease inhibitors, although the nature of such inhibitors has not been elucidated. The BPP may act as a gel-forming component because BPP contains multiple polypeptides, which may facilitate the gelation of surimi proteins. Another potential factor is that BPP contains active transglutaminase, which catalyzes the formation of covalent bonds and hence assists the gel network formation. Benjakul *et al.* (2004) reported that the addition of BPP, up to 3%, showed higher gel strengthening of lizardfish surimi than egg whites under a variety of heating conditions (40/90, 60/90 and 90°C), but resulted in a lower whiteness in the finished product.

After all of the advantages of BPP, surimi added with BPP is not suitable for Muslim consumer due to the Halal issue (Huda *et al.*, 1999). The use of BPP also prohibited in the EU, Japan, Canada and the United States due to the outbreaks of BSE (bovine serum encephalopathy, or mad-cow disease) (Park, 2005).

Whey protein concentrate: Whey Protein Concentrate (WPC) has commonly been used as a protein supplement, foam stabilizer, filler/water binder and as a thickening, emulsifying and gelling agent (Rawdkuen and Benjakul, 2008). Previous studies have shown that WPC increases the shear strain of surimi gels prepared from Pacific whiting and alaska pollock (Chang-Lee *et al.*, 1990; Park, 1994; Piyachomkwan and Penner, 1995; Weerasinghe *et al.*, 1996). Rawdkuen and Benjakul (2008) reported that breaking force and deformation of kamaboko gels of all surimi increased as the levels of WPC added increased (0-3%). The WPC at 3% (w/w) significantly decreased the whiteness of the gels. However, the water-holding capacity of kamaboko gels improved with increasing concentrations of WPC. The microstructure of surimi gels generally became denser with the addition of WPC.

NEW DEVELOPMENTS IN THE SURIMI PROCESS

The washing procedure is very important for the quality of the finished surimi, not only because it removes fat and undesirable materials, such as blood, pigments and odorous substances, but more importantly because it increases the concentration of myofibrillar proteins, improving the gel-forming ability (Lanier and Lee, 1992). Acid and alkaline-aided solubilization has shown potential as a new method for maximal protein recovery from muscle foods. Park (2005) claims that the procedure offers several advantages, including high yields, high-quality proteins, the improvement of functional properties, pollutant reduction, the removal of most lipids and the efficient removal of insoluble impurities. The extraction mechanism of the two processes is to solubilize the muscle protein at low- and high-pH levels to separate soluble proteins, bone, skin, connective tissue, cellular membranes and neutral storage lipids through centrifugation. The proteins recovered by this process have good functionality and in some cases better gelation properties (Rawdkuen *et al.*, 2008) than have proteins recovered by conventional surimi processing (Kristinsson *et al.*, 2005).

In general, lean fish have traditionally been used for surimi production worldwide. Due to increasingly limited fish resources, dark-muscle fish have been gaining popularity as an alternative raw material for surimi production. However, one problem that arises when producing surimi from dark-fleshed fish species is the high lipid and myoglobin content associated with dark muscle fish, resulting in difficulties in making high-quality surimi. Due to the lower pH of dark-fleshed fish, the gel forming ability of the proteins decreases gradually during post mortem handling or storage. To alleviate this problem, alkaline leaching has been developed to raise the pH of the muscle and to increase the efficacy in removing sarcoplasmic protein, lipid and pigments. Balange and Benjakul (2009) discovered that the alkaline-saline washing process for surimi with 0.25% oxidized tannic acid added showed increases in breaking force and deformation in mackerel surimi, improving the gel properties compared with that of surimi produced using a conventional washing process, without adverse effects on sensory properties.

Other studies have shown that acidic wash treatments (pH values of 2.50, 4.00 and 5.50) used in products from sardines (*Sardina pilchardus*) offers a higher recovery of total solids and proteins, while washing in alkaline (pH values of 8.50, 10.00 and 11.50) solutions was more effective in removing lipids. Lightness and whiteness indices improved due to washing and increased further when a thermal process was applied, particularly in the samples washed under acidic conditions. Kamaboko gels washed under acidic conditions showed higher values in firmness as well as cohesive properties and elastic textures. Whiteness showed the highest values at pH 4.00 and 5.50.

Increasing values of lipids and ash removal were indicative of high pH values (10.00 and 11.50) and of low-firmness and cohesiveness of the final product. Sardine samples initially washed at pH 5.50 can lead to high-quality kamaboko gels (Karayannakidis *et al.*, 2007). Rawdkuen *et al.* (2008) reported that a higher protein yield and greater lipid- and pigment-reductions in tilapia muscle were achieved with the acid-alkaline-aided process than with the conventional washing process.

CONCLUSION

Surimi is stabilized minced fish meat that is washed with water and blended with cryoprotectants. The enriched myofibrillar fraction of that protein is the starting material for the surimi, which is used for gel-based products. Low-sweetness sugar has been used by some researchers in surimi processing. Cryoprotectants are additionally required in order to retain functional properties of the myofibrillar proteins, such as the gel-forming properties of surimi, since surimi may lose its functional properties because of the denaturation and/or aggregation of myofibrillar proteins during frozen storage. To improve the physical properties and prevent the textural degradation of the proteins, some food additives permitted by food regulation and new processes in washing methods can be used for manufacturing surimi.

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