Mini Review

Technology for production of surimi powder and potential of applications

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Abstract

Surimi refers to concentrated myofibrial protein extracted from fish flesh by washing process. Surimi powder, is normally prepared in a dried form, and potentially useful as a raw material for preparation of seafood products. Surimi powder offers many advantages in industrial application, such as easy handling, low distribution cost, and physically convenient for addition to dry mixtures. In order to prevent the denaturation of the protein during drying, dryoprotectants such as sucrose and polyols can be added. Surimi powder is classified as fish protein concentrate type A because its protein content is higher than 65%. Surimi powder has good functional properties, such as gelation, water holding capacity, and emulsifying and foaming properties. Gel-based fish products and fish snacks are common products that can be made from surimi powder.

Introduction

The term surimi refers to concentrated myofibrial protein extracted from fish flesh by washing minced meat that has been separated from bones, skin, and guts. During washing with cold water, fat and any other water-soluble contents are removed, whereas insoluble myofibrial protein is isolated. After being mixed with a cryoprotectant, this protein is called surimi (Okada, 1992). Surimi is a primary material used for gelling foods such as kamaboko and fish balls. Surimi generally comes in a block form and is stored frozen.

The Japanese began making surimi hundreds of year ago as a way to preserve fish meat. Today, surimi is a popular food item not only in Japan but also in many other countries due to its unique textural properties and high nutritional value (Park and Morrissey, 2000). It is estimated that around 315,800 million tons of surimi products were produced in the Southeast Asian region in 2005 (Laong and Siriraksophon, 2007). The popularity of surimi-based products among consumers favors the development of surimi manufacturing plants in many countries (Park, 2005).

After deboning of the fish, the sequence processes of making surimi involve mincing, washing and dewatering, refining, screw pressing, addition of cryoprotectant, and freezing (Park and Lin, 2005). The washing technique used is an important key in determining the quality of the surimi. Minced fish flesh is rapidly washed with chilled water (5–10°C), as low temperature water helps preserve the freshness of the raw material. This process removes undesirable matter such as blood, pigments, and other impurities, leaving the myofibril protein. The maximum amount of myofibril protein extracted is desirable because it influences the gel-forming ability of surimi. Next, the extracted myofibrial protein is mixed with sugar or an alcohol sugar as a cryoprotectant. This mix then is quick-frozen into frozen surimi blocks.

The principle factor that determines the quality of surimi is the freshness of the fish (Benjakul *et al*., 2002). Thus, handling of fresh fish is very important, and fresh fish and ice-stored fish are commonly used for surimi production. To prevent deterioration and denaturation of myofibrial protein, proper post-harvest handling is crucial. Freezing often is used to preserve fish during the period of time required for travel between the catch site and the surimi manufacturing plant. Benjakul *et al*. (2004) studied the effect of frozen storage (18°C) on the gel-

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forming ability of four fish species [threadfin bream (*Nemipterus* sp.), purple-spotted bigeye (*Priacanthus tayenus*), lizardfish (*Saurida* sp.), and croaker (*Pennahai macrophthalmus*)] that are commonly used for surimi production in Thailand. They found that the differences in gel-forming ability depended on species and storage time.

The need for surimi powder

Proper frozen storage is very important for maintaining the functional properties of the protein and thus ensuring the quality of frozen surimi. Commercially produced 10 kg frozen surimi blocks are frozen rapidly in a plate freezer for around 2.5 h until the core temperature reaches –25°C (Park and Lin, 2005). The surimi then is preferably stored at –25 °C or below during holding and shipping (Toyoda *et al.*, 1992). The Japanese Association of Refrigeration recommends a storage temperature of 23–25°C for 6–12 months of storage for frozen surimi (Matsumoto and Noguchi, 1992).

Frozen storage costs are high, and the dried form of surimi (i.e., surimi powder) might be one way to decrease expenses in the surimi industry. Surimi powder can be turned into wet surimi by rehydrating it with four times its weight of water, so that wet rehydrated surimi powder would have water content similar to that of a frozen surimi block. The significant difference between frozen surimi and surimi powder is that surimi powder can be kept at ambient temperature without frozen storage; thus, surimi powder has a lower distribution cost compared to that of frozen surimi. Another advantages of surimi powder include ease of handling, more convenient storage, and its usefulness in dry mixtures (Green and Lanier, 1985). Easy handling during manufacturing is very important. In powder form, the weight of surimi is decreased because the water has been removed. Thus, industries could store more surimi powder in smaller areas compared to frozen surimi. Dry mixing also could help industries to modify the formulation of surimi-derived products, resulting in more homogenous blends and easier protein standardization.

Drying methods for surimi powder production

The drying process involves the removal of volatile substances (mostly moisture) from a product (Menon and Mujundar, 1987). The main purpose of drying technologies developed in food industries is to prolong the shelf life of a food product. Drying refers to dewatering, which means removing liquid water from the product (Chen, 2008). In thermal drying, energy transfer from the environment is used to evaporate the moisture from the product's surface, followed by the transfer of internal moisture to the surface of the product. However, both drying and heating can lead to protein denaturation (Carjaval *et al.*, 2005). For a heat-sensitive material such as protein, the heating temperature of evaporation can be lowered by lowering pressure using a vacuum (Menon and Mujundar, 1987). Available drying methods for making surimi powder include freeze drying, spray drying, oven drying, solar drying, and mechanical drying.

The freeze-drying method

The freeze-drying process removes water from the matrix at a very low temperature via the sublimation of frozen water to vapor in a vacuum chamber, so that low temperature and a vacuum atmosphere are the two main principles (Liapis, 1987; Ratti, 2008). During the freeze-drying process, low temperature (–50 to –70 °C) is maintained by condenser cooling (Beurel, 2004). This method is considered to be the most suitable for inhibiting protein denaturation compared to other drying methods because it occurs at a low temperature and the transition of material from fully hydrated to completely dehydrated occurs rapidly (Liapis, 1987). However, freeze drying is more expensive than air drying because of the energy required to maintain the vacuum condition and also to keep the temperature low (Ratti, 2008).

Many studies have used the freeze-drying method to dry fish protein and produce surimi. For example, when Matsuda (1981) dried carp myofibrils using a freeze dryer at a temperature of –40 °C and a vacuum pressure of 0.1–0.02 Torr, the moisture content of the carp myofibrils was under 1% after 5 h of drying. Freeze-dried carp myofibrils with sucrose added showed higher ATP-ase activity during freeze drying than samples with no additives. Huda *et al*. (2001a) evaluated freeze-dried surimi from threadfin bream (*Nemipterus* sp.), purple-spotted bigeye (*Priacanthus tayenus*), and lizardfish (*Saurida* sp.). Surimi from these species was treated with 3.5% sucrose and 0.15% phosphate as cryoprotectants and then freeze dried until the moisture content reached 5%. The freeze-dried surimi made from threadfin bream had better functional properties compared to those of surimi made from purple-spotted bigeye or lizardfish in terms of protein solubility, gelation, water holding capacity (WHC) and foaming and emulsifying properties. Shaviklo *et al*. (2010c) found that freeze-dried surimi made from saithe (*Pollachius virens*) that was treated with cryoprotectant (2.5% sucrose and 0.2% sodium tripolyphosphate) had better gelation (1%) compared to freeze-dried surimi without additives (6%). This

finding indicates that the addition of cryoprotectant prevented the denaturation of myosin and actomyosin, which are responsible for gelation properties of surimi during freeze drying. Ramirez *et al.* (1999) evaluated the emulsifier properties of freeze-dried surimi from tilapia (*Oreochromis nilotica*) and fat sleeper (*Dormitator maculatus*). They found that fat sleeper had better emulsifier properties than tilapia, and both species have potential use as a meat emulsifier.

The spray-drying method

The spray-drying method removes water from products through spray–air contact. Masters (1976) defined spray drying as the transformation of fluid (solution, suspension, or paste) material to a dried form (powder, granule, or agglomerate) by spraying it into a hot drying medium. The process of spray drying starts with the atomization of material into a spray section until the material contacts with hot air, then results in the evaporation of moisture. Spray drying is suitable for drying liquids, even heat-sensitive liquids such as those containing protein (Bhandari *et al.*, 2008). The amount of damaged protein is considered low because of the shorter exposure time of the liquid at higher temperature. The temperature of the inlet ranges from 150 to 300 °C and the outlet temperature ranges from 55 to 100 °C; the temperatures used depend on the material's characteristics. For example, whey protein is dried by using a spray dryer inlet temperature of 150–180 °C and an outlet temperature of 70–80°C (Bhandari *et al.*, 2008). For drying raw surimi with a moisture content of ~80%, water must be added to allow the solution more fluidity and suitable for further process using a spray dryer.

Niki and Igarashi (1982), Niki *et al.* (1983a, 1983b, 1984a, 1984b), Venugopal *et al.* (1994), and Shaviklo *et al.* (2010b; 2011) all have studied spray-dried fish protein powder. For instant, Niki and Igarashi (1982) studied the characteristics of active fish protein powder (AFPP) from Alaska pollock (*Theragra chalcogramma*) by spray drying at different inlet (150–190°C) and outlet (60–80°C) temperatures. Niki and Igarashi (1982) examined whether the addition of different saccharides (sucrose, sorbitol, and glucose) to fish meat could prevent protein denaturation during spray drying. They found that the ATP-ase activity of spray-dried AFPP was highest when sucrose was added, followed by sorbitol and glucose. This means that sucrose had a better cryoprotective effect than sorbitol and glucose in protecting actomyosin from denaturation. Meanwhile, Venugopal *et al.* (1994) studied the properties of spray-dried protein concentrate made

from capelin fish (*Mallotus villosus*) at inlet and outlet temperatures of 200°C and 90°C, respectively. They reported that spray-dried capelin powder had high emulsifying capacity and could absorb 30 ml oil per 100 g powder. Recently, Shaviklo *et al.* (2010b) used a mixture of saithe surimi and water (5× weight) to obtain a solution with about 3% dry matter for feeding into the spray-dryer machine with inlet and outlet temperatures of 190 ± 5°C and 95 ± 5°C, respectively. However, freeze-dried surimi powder made from saithe had better functional properties than spray-dried powder (Shaviklo *et al.*, 2010b).

The oven-drying method

In the oven-drying method, a closed chamber is used to dry an object by heating at a relatively low temperature. The processes involved in oven drying are heating, drying, and baking (Menon and Mujumdar, 1987). Huda *et al.* (2000a) studied the effect of oven drying temperatures of 50, 60, and 70°C on the functional properties of fish protein concentrate (FPC) from lizardfish. This study concluded that a drying temperature of 60°C was the most ambient temperature. Drying at 60°C requires 12 h to reach less than 10% moisture content of FPC.

In another study of fish crackers formulated using surimi powder, Huda *et al.* (2000b) dried threadfin bream surimi after it had been thawed overnight at 4°C. After chopping, surimi samples were transferred to aluminum trays and dried at a 60°C in an oven. During the drying process, the samples were turned over and mixed again every hour to ensure even heat distribution throughout the drying process. The result showed that crackers containing 10% surimi powder were most preferred by panelists.

Other potential drying methods

Other potential drying methods for producing surimi powder are solar drying and mechanical drying. Solar air heaters depend on circumstances such as weather and the climate of the drying location. This drying method is environmentally friendly and less expensive compared to other drying methods (Musa *et al.*, 2003c). Solar drying often is used to dry fish in Bangladesh and can reduce moisture content from 80% to 20% (Sodha *et al.*, 1987). Musa *et al.* (2003b) compared the effects of solar drying vs. oven drying on the WHC and emulsion properties of threadfin bream surimi. They found that solar-dried surimi powder had lower emulsion stability (44%) than oven-dried surimi powder (66%). However, there were no differences in WHC between solar-dried surimi powder and oven-dried surimi powder. Another study showed that solar-dried surimi powder

had lower lightness than oven-dried surimi powder and freeze-dried surimi powder (Musa *et al*., 2003a).

Mechanical drying is another way to produce surimi powder. Mechanical drying refers to ventilating fish granules with natural or heated air to evaporate the water. Chavan *et al*. (2008) used mechanical drying to make texturized dried fish granules using a salt concentration of 12 g/100 g minced meat, a boiling time of 10 min, and a mixing time of 6 min at 100 rpm. The product was stable for up to 4 months due to its high salt concentration and low moisture level (6–7%) after drying at 43–45°C for 12 h.

Protein changes during freezing and drying: The role of dryoprotectant

The freezing process reduces gelling properties and protein functionality due to denaturation of myofibrial protein (Okada, 1992; Park and Morrissey, 2000). Thus, in surimi production, the addition of cryoprotectant plays a significant role in retaining functional properties during freezing and frozen storage (MacDonald and Lanier, 1994). The drying process also can cause denaturation of proteins due to the aggregation of protein when water is removed from the matrix (Carjaval *et al*., 2005). The same sugars and other polyols used as a cryoprotectant in the freezing process also can be used as a dryoprotectant in the drying process (Suzuki, 1981).

The two major factors that induce protein denaturation during the drying process are drying temperature and the loss of water. Generally, protein will denature at temperatures of 60–65°C (Huda *et al*., 1998). The heating process induces the aggregation of protein and leads to gel formation (Le Bon *et al*., 1999). At high temperature, fish protein can lose its three-dimensional structure, which would result in irreversible denaturation and thus to the loss of functional properties.

The loss of water that occurs during drying leads to the aggregation of protein (Lanier, 1992). The mechanism by which water is removed from surimi during drying is similar to that during freezing, but the removal of water during drying is more drastic because bigger amount of water is removed. The existence of a "water replacement" mechanism is one hypothesis to explain how dryoprotectant protects protein (Carpenter *et al*., 2004; Carvajal *et al*., 2005). During drying, dryoprotectant forms hydrogen bonds at specific sites on the surface of the proteins, which substitute or "replace" the thermodynamic stabilization function of the removed water (Maa *et al*., 1999). Via this mechanism, dryoprotectant is charged as a water replacement, thus preventing denaturation of protein induced by drying (Carpenter

et al., 2004). Some of the available dryoprotectants are described below.

Sucrose

To prevent protein denaturation during frozen storage, a mixture of 4% sucrose, 4% sorbitol, and 0.2% phosphate is added to commercial frozen surimi as a cryoprotectant (Sultanbawa and Li-Chan, 2001). Huda *et al*. (2001a) studied the properties of surimi powders made from Malaysian lizardfish, threadfin bream, and purple-spotted bigeye that were treated with sucrose (3.5%) and phosphate (0.15%) as a dryoprotectant prior to the freeze-drying process (Huda *et al*., 2001a). The same proportion of dryoprotectant was also added to make surimi powder from threadfin bream using the freeze-drying and oven-drying methods (Huda *et al*., 2000b). These studies showed that sucrose was potentially used as dryoprotectant for freeze-dried as well as oven-dried surimi powder. Shaviklo *et al*. (2010b) added 2.5% sucrose and 0.2% sodium tripolyphosphate as a dryoprotectant when making surimi powder from local fish in Iceland using the spray-drying and freeze-drying methods. Freeze-dried and spray-dried surimi that contained sucrose and phosphate had better gelation of after drying compared to freeze-dried and spray-dried surimi without additives (Shaviklo *et al*., 2010b).

Sorbitol and polyols

Sorbitol can be used as a cryoprotectant and a dryoprotectant. Sultanbawa and Li-Chan (2001) reported that the use of an individual cryoprotectant at the 8% level (e.g., sucrose, lactitol, litesse, or sorbitol) effectively induced loss of gelling capacity of surimi during frozen storage. Yoo and Lee (1993) studied the thermoprotective effect of sorbitol at levels of 0, 2.8, and 4.0% (weight base) during dehydration in the freeze-drying process. Sorbitol helped to retain the functional properties of surimi during commercial drying because it increased the hydrophobic interaction of the protein-sorbitol complex, which helped stabilize the three-dimensional protein structure (Yoo and Lee, 1993). Osako *et al*. (2005) found that disaccharides such as trehalose also can act as a cryoprotectant. They found that the protective effect of trehalose on freeze-induced denaturation of surimi was similar to that of sucrose and sorbitol.

Properties of surimi powder

During the 1960s, research was focused on the production of FPC as palatable human food due to its nutritional value. Fish materials that are wasted

Table 1. Proximate composition (%) of surimi powder made from different species using different drying methods

Species of fish	Drying method	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	CHO (%)	Reference
Threadfin bream (*Nemipterus* sp.)	Freeze drying	4.6	72.5	1.5	1.5	19.9	Huda *et al.*, 2000b
	Oven drying	5.3	72.6	1.4	1.7	19.0	
Saithe (*Pollachius virens*)	Spray drying	5.8	74.5	3.2	14.3	15.1	Shaviklo *et al.*, 2010c
	Freeze drying	3.9	77.2	2.1	1.9	14.9	
Tilapia (*Oreochromis nilotica*)	Freeze drying	4.6	62	2.9	1.6	8	Ramirez *et al.*, 1999
Fat sleeper (*Dormitator maculatus*)	Freeze drying	4.2	64.7	3.6	1.32	8	Ramirez *et al.*, 1999

because of poor storage can be more efficiently utilized by converting them to FPC. The principle behind this technology involves water removal from fish and concentration of the protein (Suzuki, 1981). The Food and Agriculture Organization (FAO) defines FPC as any stable fish preparation intended for human consumption in which the protein is more concentrated than in the original fish (FAO, 2011). The FAO defines the following three types of FPC: 1) a virtually odorless and tasteless powder with a maximum total fat content of 0.75% and a total protein minimum of 65–80% (FPC type A); 2) no specific limits as to odor or flavor, but definitely having a fishy flavor and a maximum fat content of 3% (FPC type B); and 3) FPC produced under satisfactorily hygienic conditions (FPC type C).

The proximate composition of surimi powder varies among fish species (Table 1). Protein content is relatively high for surimi powder made from threadfin bream and saithe (> 70%), whereas the protein content from tilapia and fat sleeper is around 62–65%. Surimi powder with a protein content of at least 65% is considered to be FPC type A. Protein concentration also corresponds to the emulsifying capacity of the protein concentrate (Blecker *et al.*, 1997).

Conventional FPC is produced by heating fish flesh with an organic solvent to remove fat and water, followed by conversion to powder. However, this process causes FPC to lose its functional properties (especially its rehydration ability). For this reason, FPC is not suitable for processing with other food ingredients (Suzuki, 1981). However, surimi powder that retains its functional properties could be a solution to this problem, as it is more suitable for processing with other ingredients to make fish-derived products.

Functional properties of surimi powder

The functional properties of proteins are affected by the chemical and physical properties of the protein itself, and they can affect a protein's utilization in food preparation, processing, storage, and consumption (Damodaran, 1996). Functional properties of surimi can be classified into three major categories: (1) hydration properties, which include solubility and WHC; (2) surface properties, which include emulsifying and foaming properties; and (3) protein–protein interactions, which are expressed as gelation properties. Table 2 summarizes the functional properties of surimi powder determined in several studies.

Protein solubility

Protein solubility refers to the protein content that is soluble in 3% NaCl solution. It actually can be measured both in water and in 3% NaCl solution, but the solubility of surimi powder is higher in 3% NaCl solution due to its better extraction of proteins (Huda *et al.*, 2000b). Protein solubility is of primary importance because it significantly influences other

Table 2. Summary of functional properties of surimi powder

Fish species	Drying method	Solubility	Gelation	Water holding capacity	Emulsifying capacity	Emulsifying stability	Foaming capacity	Foaming stability	Density	Reference
Lizardfish (*Saurida* sp.)	Oven drying	28.1% in water and 30.2% in NaCl 3%	NA	2.8 mL/g	65%	54%	50%	5%	7.4 mL/10 g powder	Huda *et al.*, 2000a
	Freeze drying	8.1 % in NaCl 3%	4.2%	13.5 mL/g	90% at 2% concentration	77.5% at 2% concentration	28.8%	Decreases after 5 h	2.43 mL/10 g powder	Huda *et al.*, 2001a
Threadfin bream (*Nemipterus* sp.)	Freeze drying	12.4% in NaCl 3%	1.2%	19.5 mL/g	95% at 2% concentration	82.8% at 2% concentration	34.6%	Stable until 8 h	2.26 mL/10 g powder	Huda *et al.*, 2001a
Purple-spotted bigeye (*Priacanthus tayenus*)	Freeze drying	12.3% in NaCl 3%	1.8%	19.7 mL/g	95% at 2% concentration	80.4% at 2% concentration	29.9%	Stable until 8 h	2.36 mL/10 g powder	Huda *et al.*, 2001a
Saithe (*Pollachius virens*)	Spray drying	NA	NA	NA	NA	NA	NA	NA	2.4 g/mL	Shaviklo *et al.*, 2010b
	Freeze drying	26.8% in water	>10%	253.1%	82.5%	76.5%	189.7%	145.5%	4.7 g/mL	Shaviklo *et al.*, 2010c
Capelin (*Mallotus villosus*)	Spray drying	90% in 3% surimi owder concentration	NA	NA	90% at 1.5% concentration	38% at 1.5% concentration	NA	NA	NA	Venugopal *et al.*, 1994
Alaska pollock (*Theragra chalcogramma*)	Spray drying	NA	NA	40 g/g	180 ml/ gram fish meat	NA	NA	NA	NA	Niki *et al.*, 1983b; 1992

*NA: Not measured in the original studies.

functional properties (Vojdani, 1996). Protein solubility is the result of surface activity of the protein, and it relates to its hydrophobic and hydrophilic properties. Some studies (e.g., Huda *et al*., 2000a; 2000b) have used Venugopal et al.'s (1996) method to measure protein solubility. In this technique, 1 g of surimi powder is added to 40 mL of 3% NaCl, and the mixture then is homogenized for 2 min using a Vortex mixer. The aliquots are centrifuged at 6280 g for 5 min. The protein solubility is the percentage of protein content in supernatant from protein content in its original sample. Egg white powder is the primary protein used in food processing, and it generally is used for comparison; it has good foaming properties and excellent gelation properties (Kinsella, 1982; Mine, 1995). Protein solubility in water of freeze-dried egg white powder at pH 7 is 97.23 % (Kakalis and Regenstein, 1986).

Protein solubility of surimi powder varies depending on the fish species used to produce it. Huda *et al*. (2001a) reported that protein solubility from lizardfish was lower than that of threadfin bream or purple-spotted bigeye. Shaviklo et al. (2010b) reported that protein solubility of freeze-dried samples of surimi powder was lower than that of spray-dried surimi powder samples.

WHC

The Oxford Dictionary defines WHC as the amount of water that a particular soil can hold. For proteins, the WHC refers to the ability of the protein to bind a large amount of water by hydrogen bonding to polar amino acid residues via electrostatic interaction with charged amino acids and by entrapment between peptide chains; thus, this property is important for the formation of gels and emulsions (Fisher, 2009). Some researchers (Huda *et al*., 2000a; 2000b) have measured the WHC of surimi powder following the method of Miller and Groninger (1976). Briefly, 1 g of surimi powder is added to 40 mL 3% NaCl solution in a 50 mL centrifuge tube. Samples are homogenized for 5 min using a Vortex mixer and then centrifuged for 5 min at 7500 rpm. The volume of supernatant is subtracted from the original 40 mL and counted as mL of H_2O held by 1 g of protein.

Shaviklo *et al*. (2010b) reported that the WHC of freeze-dried surimi powder was higher than that of spray-dried surimi powder. The lower protein solubility and WHC of spray-dried surimi powder likely was caused by the high drying temperature, which would have led to protein denaturation. Niki *et al*. (1992) reported that the WHC of spray-dried surimi powder from Alaska pollock was 40 mL water per gram powder. The WHC of freeze-dried

lizardfish surimi powder (13.5 mL/g) was lower than that of threadfin bream (19.5 mL/g) and purple-spotted bigeye (19.7 mL/g) surimi powder (Huda *et al*., 2001a). The WHC clearly depends on the drying methods used and the fish species (Huda *et al*., 2001a; Shaviklo *et al*., 2010b). Freeze-dried surimi powder had better WHC than spray-dried surimi powder, and both were better than the WHC oven-dried surimi powder.

Emulsification

The optimum emulsion capacity of a protein occurs when the hydrophilic and hydrophobic proportions are in balance (Damodaran, 1996). Yasumatsu *et al*. (1972) described a useful method for measuring the emulsifying properties of a protein. Five grams of surimi powder are added to 20 mL of distilled water and 20 mL of corn oil. The mixture is blended for 1 min and then centrifuged at 7500 rpm for 5 min. Emulsifying stability is determined by the same procedure, except that prior to centrifugation, the emulsion is heated at 90°C in a water bath for 30 min followed by cooling in tap water for 10 min. The emulsion capacity and emulsion stability are calculated using the same formula, which involves dividing the emulsion volume after centrifugation by the original emulsion volume and then multiplying by 100.

Denaturation of the protein can decrease the emulsification capacity of surimi powder, but adding sugar as a dryoprotectant maintains the hydrophilic residues after drying (Matsuda and Noguchi, 1992). For example, the emulsion capacity of freeze-dried saithe surimi powder with cryoprotectant added was higher than that of freeze-dried surimi powder without cryoprotectant (Shaviklo *et al*., 2010b). Threadfin bream and purple-spotted bigeye had an emulsification capacity that was greater than 80% at 0.8% concentration of freeze-dried surimi powder (Huda *et al*., 2001a). However, spray-dried surimi powder made from Alaska pollock showed much better emulsifying capacity: 1 g of powder could be dissolved in 180 ml oil. Ramirez *et al*. (1999) reported that the emulsion stability of freeze-dried surimi powder made from fat sleeper was better than that of freeze-dried surimi powder made from tilapia. Thus, freeze-dried surimi powder potentially could be used as an emulsifier, but its emulsifying properties vary depending on fish species (Ramirez *et al*., 1999).

Foaming properties

Foams can be defined as a dispersion state of gas in liquid (G/L) or liquid in gas (L/G) materials (Foegeding and Davis, 2011). The strength of the

protein in trapping gases influences the foaming properties of the protein (Belitz *et al.*, 2009). Foaming properties can be determined following Miller and Groninger (1976). In this method, 2 g of surimi powder are added to 100 mL of distilled water and blended at high speed for 1 min. The volume of the mixture is measured. The foaming capacity is calculated as the volume of the mixture after blending compared to the original volume. The foaming stability is the ratio of the foam capacity after a period of time divided by the original foam capacity.

Better foaming properties of surimi powder are related to the stability of the fish protein (Huda *et al.*, 2001a; Shaviklo *et al.*, 2010c). Foaming capacities of threadfin bream and purple-spotted bigeye were 34.6% and 29.9%, respectively (Huda *et al.*, 2001a). Freeze-dried surimi powder made from saithe showed a foaming capacity of 189.7% (Shaviklo *et al.*, 2010c), and freeze-dried surimi powder made from threadfin bream and purple bigeye had stable foaming properties for 8 h (Huda *et al.*, 2001a).

Gelation

Foegeding and Davis (2011) defined a gel as a food system in which the macroscopic property of elasticity is developed once intermolecular linking forms a continuous network. Gelation properties are responsible for food texture, particularly its breaking pattern. Gel formation and physical gel properties or gel strength are two factors that can be evaluated to determine the gelation properties of surimi powder. Gel formation or gelation of surimi powder has been studied extensively. Measurement of gelation can be conducted following Miller and Groninger (1976). Surimi powder is added to 10 mL of distilled water in a test tube at concentration of $1 \pm 10\%$, and the sample is mixed in a Vortex mixer for 5 min. The tubes are heated at 90 °C for 30 min and then placed in a cold room for 30 min. The gelation concentration is determined as the lowest concentration at which the sample does not fall down or slip from an inverted test tube.

Gelation of surimi powder from lizardfish was about 4.2% (Huda *et al.*, 2001a), and that of freeze-dried surimi powder made from saithe was about ± 10 g/kg ~ 1% in water (Shaviklo *et al.*, 2010b). The gel strength of spray-dried surimi powder made from Alaska pollock had a driving force of about 410 g (Niki *et al.*, 1992). The gel strength of frozen surimi made from Alaska pollock with 4% sorbitol, 4% sucrose, 0.3 % sodium tripolyphosphate, and 2% NaCl added had a gel strength of about 233.8 g.cm (Nielsen and Pigott, 1994).

Potential application of surimi powder in food products

Today, food technology is growing and adapting to the needs of manufacturing and the potential market. The processing of surimi into a dried form so that it can be used in dry mixing is now preferred by food manufacturers. Surimi itself is a raw material currently used to produce many seafood products. Surimi also is utilized commercially to imitate high-value marine products, such as crab meat, scallops, and shrimp (Aguilera and Rademacher, 2004). Surimi powder that maintains the functional properties of protein also is a potentially useful raw material for making seafood products. Besides gel-based products, surimi powder may prove useful for making friable food products such as crackers.

Gel-based products

Gel-based products refer to food products that require gelation or gel formation to acquire textural properties. Gel-based products from fish include kamaboko, fish sausage, and fish balls (Spinelli and Dassow, 1982; Huda *et al.*, 2010b). Like egg white and β-lactoglobulin in milk, surimi can form a thermo-irreversible gel (Lanier *et al.*, 2005). In addition to gelation and protein solubility, WHC (to entrap water in the matrix) and emulsification (to form and stabilize the fat emulsion) are important functional properties for making gel-based products (Kinsella, 1982).

Surimi powder has high gel strength and excellent bending capacity (Niki *et al.*, 1983b; 1992). However, the gelling ability differs among fish species due to variability in cross-linking of myosin chains (Chan *et al.*, 1992). Although the gelation properties of surimi powder are not as good as those of frozen surimi, spray-dried and freeze-dried surimi powder from Alaska pollock, freeze-dried surimi powder from threadfin bream, and freeze-dried surimi powder from saithe are potentially useful raw materials for gel-based products such as fish balls and fish sausage. Fish balls made from surimi powder had lower textural quality compared to fish balls made from frozen surimi, but fish balls made from surimi powder had sensory acceptance that was equal to that of fish balls made from frozen surimi (Huda *et al.*, 2003).

The ingredients used in gel-based products also are important, as they influence the characteristics of the final product. The addition of starch is very important because it is a functional ingredient needed for making seafood surimi, as it helps to form a network structure in surimi-starch gels (Park, 2005). Around 4–12% starch is added in the sausage

manufacturing process (Essien, 2003). The amilose and amilopectin in starch are responsible for gelation of food products in the presence of water (Morris, 1990). A modified starch, which can perform better in terms of stabilizing gelatinization, is recommended for making sausage and other gel-based product from surimi powder. A cross-linked starch could help in the formation of gels better than a natural starch (Chilton and Collison, 1974; Morikawa and Nishihari, 2000). Raju *et al*. (2003) reported that gel strength of fish sausage made from minced fish meat was 245 g cm.

Non-gel-based products

Non-gel-based products refer to products that do not require high gelation to influence the textural performance. Friable products and emulsion products are examples of non-gel-based products. Many friable food products are made from fish, including fish crackers, or keropok, in Malaysia (Huda *et al*., 2010a). A little or no elasticity is needed in such products, whereas they do need to be crisp (Mohamed *et al*., 1983). WHC also is an important functional property for such products due to the rehydration process used in making crackers (Huda *et al*., 2009).

Developing snack products from surimi powder as part of a dry mix represents a big opportunity in food industries. Application of surimi powder in friable or snack-based products has been studied previously, such as in snack extrusion (Gogoi *et al*., 1996), fish crackers (Huda *et al*., 2000c; 2001b), corn fish snacks (Shaviklo *et al*., 2010a), and fish cutlet mix (Shaviklo *et al*., 2011). Consumers prefer fish-based snacks due to their nutritional value. Corn fish snacks, which are fortified with 7% surimi powder from saithe, are more nutritious than regular corn snacks (Shaviklo *et al*., 2010a).

Processing of fish crackers involves mixing fish flesh with starch and water. Huda *et al*. (2009) used surimi powder obtained from threadfin bream and processed using the oven-drying method to make fish crackers. Fish flesh was replaced by surimi powder with the addition of water until the moisture content was similar to that of fish flesh. Shaviklo *et al*. (2011) prepared a fish cutlet mix by mixing freeze-dried surimi powder made from saithe with potato flakes and other ingredients. The dry fish cutlet mix was stable at ambient temperature (27 ± 2ºC) for 6 months.

Emulsion products, such as mayonnaise and porridge, are other products that have low gelation properties but high emulsifying and foaming properties. Sathivel *et al*. (2005) studied the use of freeze-dried protein powder from arrowtooth flounder (*Atheresthes stomias*) in mayonnaise. Solar-dried surimi powder also has the proper functional properties to be used as a raw material for making high protein cereals (Musa *et al*., 2002).

Conclusion

The functional properties of surimi powder vary depending on the fish species and the drying method used. The addition of dryoprotectants such as sucrose, sorbitol, and polyols can prevent protein denaturation during drying. Gelation and emulsifying properties of surimi powder are important factors to consider when evaluating the use of surimi powder as a primary raw material for making gel-based products such as fish balls and fish sausage. Surimi powder also adds to the nutritional value of fish snack products. Further research is needed to explore the potential uses of surimi powder in various food products and their quality, including texture properties and consumer acceptance of the products.

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