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REVIEW

Development of fish protein powder as an ingredient for food applications: a review

Amir Reza Shaviklo

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Abstract The increasing awareness that dried fish protein can be applied for food fortification and production of value added/functional foods has encouraged the food industry to examine different methods for developing fish protein ingredient from different raw materials. Fish protein powder (FPP) is a dried and stable fish product, intended for human consumption, in which the protein is more concentrated than in the original fish flesh. Quality and acceptability of FPP depend on several factors. The fat content of the FPP is a critical issue because when it is oxidized a strong and often rancid flavour is produced. Protein content of FPP depends on the raw materials, amount of additives and moisture content, but it contains at least 65 % proteins. FPP is used in the food industry for developing re-structured and ready-to-eat food products. The FPP maintains its properties for 6 months at 5 °C but loses them rapidly at 30 °C. Deterioration of the FPP during storage is prevented by lowering the moisture content of the product and eliminating of oxygen from the package. The FPP can be applied as a functional ingredient for developing formulated ready-to-eat products. This article reviews methods for extracting fish proteins, drying methods, characteristics and applications of FPP and factors affecting FPP quality.

Keywords Fish protein powder · Protein ingredient · Food fortification · Functional food

Abbreviations

FPP	Fish protein powder
FP	Fish protein
FPI	Fish protein isolate
PI	Protein isolates
FPH	Fish protein hydrolysate

A. R. Shaviklo (✉)
Department of seafood processing, Iranian Fisheries Research Organisation, P. O. Box: 14155-6116, Tehran, Iran
e-mail: shaviklo@gmail.com

Introduction

Demands for fish protein ingredients including dried fish protein to develop functional food or ready-to-eat products are gradually growing in the world (Thorkelsson et al. 2009). The white flesh and low fat content fish are considered the most suitable species for developing fish protein ingredients (Hultin et al. 2005; Park and Lin 2005). While, there are other fish protein sources that can be used for producing protein ingredients "i.e." dark muscles/underutilized/low value fish species and fish by-products for human consumption (Arason et al. 2009). The quality and characteristics of fish protein ingredients are highly dependent on the source of the raw materials and the processing methods (Arason et al. 2009; Shaviklo et al. 2010a). This work reports the processing methods which were used for developing FPP, physicochemical properties of such product and its application in the food industry.

FPP a functional value added product

The FPP is a dried and stable fish product, intended for human consumption, in which the protein is more concentrated than in the original fish flesh (Shaviklo et al. 2010a). It is an excellent source of highly digestible amino acids, but production costs normally limit its use (Venugopal et al. 1996). The FPP can be used in the food industry as a binder, dispersing agent and emulsifier in preparing herring roes, fillet blocks and re-structured products from beef, pork and chicken due to its strong interactions with other proteins and its high gelation ability (Ramirez et al. 1999; Chung et al. 2000; Carvajal et al. 2005; Pires et al. 2012). Dried fish protein can also be used for producing formulated seafood and enrichment of food products (Shaviklo et al. 2010a, b, 2011a, b, c). The FPP, kept above 0 °C has many advantages in food trade such as ease of handling, low distribution costs, convenient storage and ease in mixing with other ingredients

(Green and Lanier 1991; Matsuda and Noguchi 1992; Shaviklo et al. 2010a). The FPP can be turned into wet mince/leached mince (surimi) by adding four times the weight of water and has excellent functional properties such as the ability to form *kamaboko* gels (Niki et al. 1983).

Types and quality of the raw materials used for developing FPP

Underutilized/low value fish species and the rest raw materials of fish processing (by-products) are sources for developing fish protein ingredients (Arason et al. 2009; Thorkelsson et al. 2009). The FPP has been developed from a number raw materials including: whole myctophid (*Benthosema pterotum*) (Shaviklo 2012), Cape hake (*Merluccius paradoxus*) sawdust and cut-offs from the fish portioning (Pires et al. 2012), saithe (*Pollachius virens*) fillet (Shaviklo et al. 2010a, 2012), Channel catfish (*Ictalurus punctatus*) roe (Sathivel et al. 2009), sardines (*Sardina pilchardus*) head (Nurdiyana et al. 2008), arrowtooth flounder (*Atheresthes stomias*) fillets (Sathivel et al. 2004), Croaker (*Otolithus argenteus*) fillet (Chavan et al. 2008), pollock (*Theragra chalcogramma*) viscera, heads, frames, trimmings, and liver (Sathivel and Bechtel 2006), pink salmon (*Oncorhynchus gorbuscha*) and red salmon (*Oncorhynchus nerka*) heads (Sathivel et al. 2006), whole herring (*Clupea harengus*) (Sathivel et al. 2004), herring head and gonad (Sathivel et al. 2004), cut-offs and backbone of saithe and cod (*Gadus morhua*) (Gunnarsson et al. 2004), Chinese grass carp (*Ctenopharyngodon idella*) (Herrmann et al. 2006), mackerel (*Scomber australasicus*) fillet (Chung et al. 200), threadfin bream (*Nemipterus* sp.), purple-spotted bigeye (*Priacanthus tayenus*), and lizardfish (*Saurida* sp.) fillets (Huda et al. 2001a), tuna (*Euthynnus affinis*) fillets (Muraleedharan and Gopakumar 1998), tilapia (*Oreochromis nilotica*) and fat sleeper (*Dormitator maculatus*) fillets (Ramirez et al. 1999), capelin (*Mallotus villosus*) Venugopal et al. (1994), trout (*Cyanoscion nothus*) fillet (Montejano et al. 1994), Alaska pollock (*Theragra chalcogramma*) fillet (Niki et al. 1992), carp (*Cyprinus carpio*) fillet (Matsuda 1983), and fish Bombay duck (*Harpodon nehereus*) fillet (Warrier and Ninjoor 1981).

The quality of the raw materials is very important when processing FPP (Shaviklo et al. 2012), thus, proper post-harvest handling of fresh fish/by-products is critical to prevent deterioration and denaturation of myofibrial proteins (Arason et al. 2011). Freezing is recommended to preserve fish/fish by-products during the period of fishing travel in tropical areas.

Extraction of fish proteins

Several methods are used to separate proteins from fish flesh (Fig. 1). They can be classified as repeated water washing and refining, pH-shift method, solvent extraction method, heat treatment, enzyme/acid hydrolysis and a combination of various methods.

Repeated water washing and refining

Surimi is fish mince in which most water soluble proteins have been washed out. It contains 16 % water insoluble protein, 75 % moisture and 8–9 % freezing stabilizers or cryoprotectants (Venugopal 2006). The water insoluble proteins are elastic and make it possible to shape or form surimi in different formulated fish products through further processing (Min et al. 1988). Figure 2 illustrates surimi processing stages.

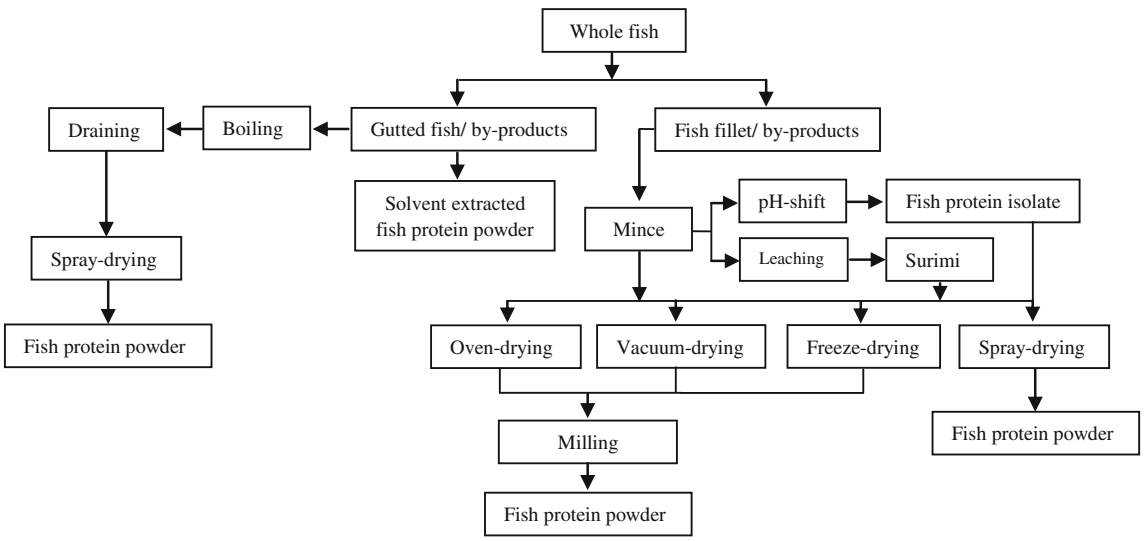

Fig. 1 Methods for developing fish protein powder (adapted from Windsor 2001; Sathivel et al. 2004; Shaviklo et al. 2010a, 2012)

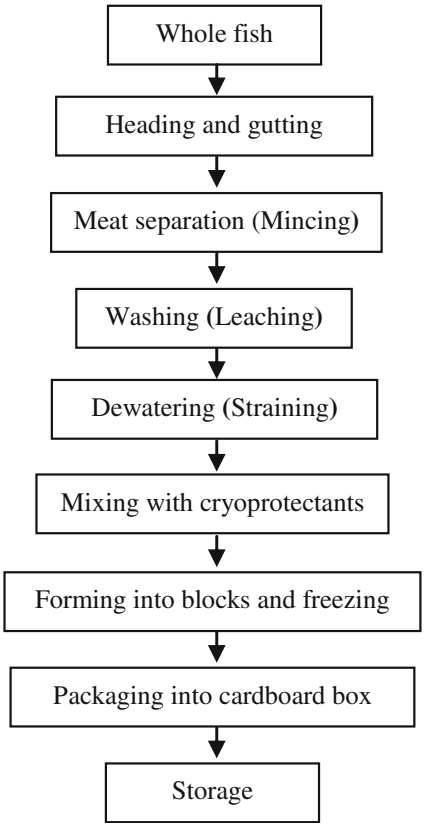

Fig. 2 Flow diagram of surimi processing (adapted from Park and Lin 2005)

The raw materials used for extracting myofibrillar proteins should be fresh and kept chilled. Fish flesh is separated from fish fillets by a fish bone separator (Min et al. 1988). The leaching process involves mixing mince with cold water and removing the water by screening and dewatering. The number of washing cycles and water volume varies with fish species, freshness of fish, type of washing unit, and the desired quality of the product, but the process is usually repeated 2–4 times (Park and Lin 2005). Residues of the scales and connective tissues are removed by a refiner/strainer before a final dewatering under a screw press. The screw press, which commonly has 0.5 mm perforations, squeezes water out with compression to 82 to 85 % moisture, which is similar to that in a fish fillet (Min et al. 1988). The leached fish flesh, which has been mixed with cryoprotectants in a silent cutter, is formed into 10 kg blocks, put into plastic bags, and then placed onto a stainless steel tray for freezing. After freezing, two 10 kg blocks of frozen surimi are packed into a cardboard box. The frozen surimi should be maintained at −20 °C (Park and Lin 2005; Venugopal 2006). To extract myofibrillar proteins from oily or dark muscle fish, such as sardines and mackerels, alkaline leaching must be applied to negate the effects of oils and haem proteins (Hultin et al. 2005). Haem proteins, such as myoglobin and haemoglobin, account for the red colour of dark muscles. Fat oxidation in the dark muscle which causes an offensive, rancid odour is prompted by haem proteins (Thorkelsson et al. 2008).

Isolating fish proteins using the pH shift method

Several studies have been carried out during recent decades to recover protein from fish by-products and low value fish species in order to develop food for human consumption (Kristinsson et al. 2005; Rustad 2007). Using the pH shift method was patented by Hultin and Kelleher (1999). However, the technology was described in details in three recently published books (Park and Lin 2005; Shahidi 2006; Borresen 2008). The basic outline of the pH shift method is simple (Fig. 3). Once the fish has been minced or chopped to a small particle size, the fish flesh is solubilised in an acid or an alkali by using five to ten times the volumes water with acid or alkali added to obtain approximately pH 2.5 or 11 (Hultin and Kelleher 1999). The mixture is then centrifuged to remove oil and other insoluble materials. Precipitation of proteins is accomplished by adjusting the pH to the isoelectric point of the myofibrillar proteins, around 5.2 to 5.5 (Hultin et al. 2005). Protein isolates (PI) is then sedimented by using a high speed centrifuge. Fish protein isolates (FPI) should be stabilized against freezing using appropriate cryoprotectants (Thawornchinsombut and Park 2006; Campo-Deano et al. 2010; Shaviklo et al. 2010c). Like surimi and mince, FPI can be kept frozen until further use.

Solvent extraction method

Solvent extracted fish protein was mainly studied and applied in the 1970's and 1980's (Liston and Pigott 1971; Windsor 2001). However, some interest in this technology has been reported recently (Hussain et al. 2007; Ibrahim 2009; Khoshkhoo et al. 2012). It is mainly based on the use of alcohol solvents to remove water, fat and fishy-tasting components of raw fish (Fig. 4).

Solvents most successfully used to extract fish proteins are ethanol and propanol, but ethylene dichloride is also used. The choice between alcohol solvents is based on cost (Windsor 2001). Normally the solvent is recovered and reused. There are three types of solvent extracted fish proteins. Type A: a virtually odourless and tasteless powder having a maximum total fat content of 0.75 %. Type B: a powder having no specific limits as to the odour or flavour, but definitely having a fishy flavour and a maximum fat content of 3 %. Type C: normal fish meal produced under satisfactory hygienic conditions (Windsor 2001; Sen 2005). The quality of the solvent extracted fish protein depends on the raw materials and processing conditions. When prepared from lean fish, such as hake, the colour of the product is light gray to yellowish brown. The colour of solvent extracted fish

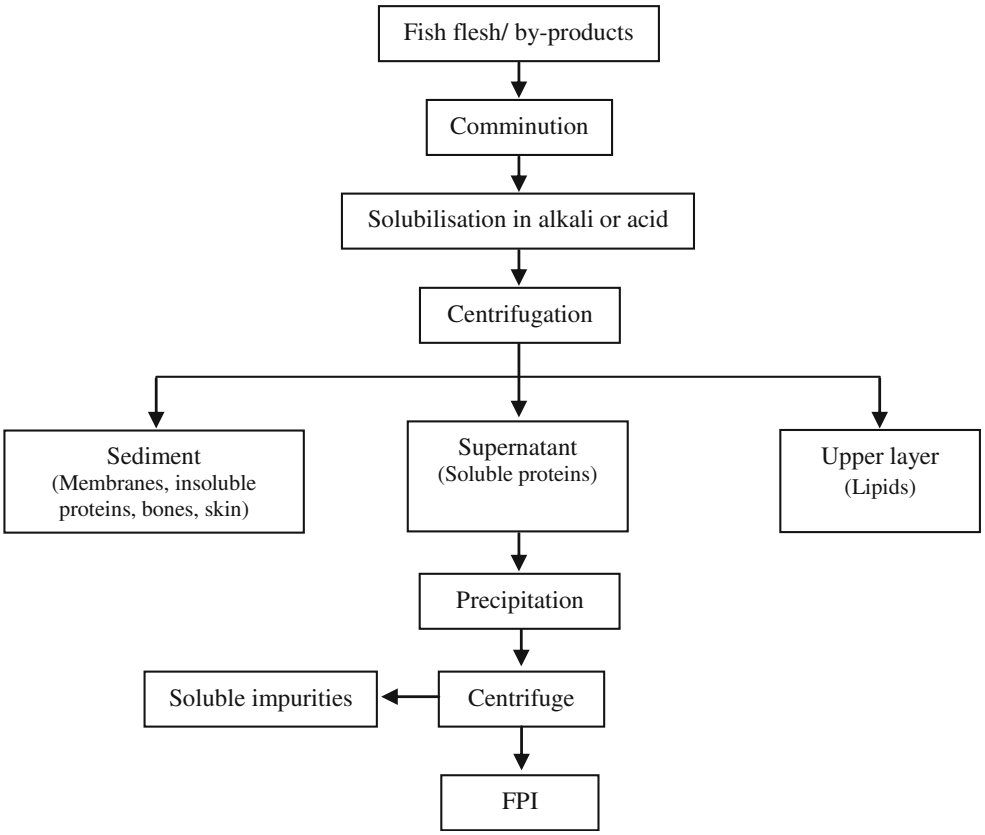

Fig. 3 pH-shift process for production fish protein isolates (FPI) (adapted from Hultin et al. 2005)

protein prepared from fatty species like anchovy and herring, however, tends to be of a darker gray (Stillings and Knobl 1970). This characteristic is not desirable and limits the use of solvent extracted fish protein in certain foods (Venugopal 2006). The product is stable for 6 months at 5 °C when packed in a hermetically sealed container. However, a major factor limiting the use of solvent extracted fish protein is the lack of functional properties (Liston and Pigott 1971; Windsor 2001).

Heating treatment

Protein separation from fish flesh is done by applying a heating process. A clearly described method has been documented (Sathivel et al. 2004). Fish flesh/by-products are minced. Then they are mixed with an equal volume of distilled water (23 °C) and homogenized in a high speed blender for 2 min. The mixture is continuously stirred for 60 min at 85 °C. During heating, fat cells are ruptured, releasing oil into the liquid phase. The heated suspension is centrifuged at 2560 × g for 15 min, resulting in three separate phases: the semi-solid phase at the\bottom containing insoluble protein, the heavy liquid phase in the middle containing soluble proteins, and the light liquid phase at the top containing crude lipids. The heavier liquid middle layer and insoluble proteins are separated, collected, and dried by freeze/spray drying (Fig. 5). The FPP developed by this method had desirable nutritional and functional properties and contained 63–81.4 % protein. The emulsifying and fat adsorption capacities of all FPP samples were higher than those of soy protein concentrate (Sathivel et al. 2005, 2009).

Enzyme/acid hydrolysis

Protein extraction from fish is carried out by the enzyme/acid hydrolysis (Hoyle and Merritt 1994). The processing steps for FPH are not complicated. Raw materials including whole fish/fish by-products are ground and suspended in water, then pH is adjusted before the enzyme is added to the slurry. Hydrolytic enzymes such as alcalase are applied to break the peptide bonds in proteins (Kristinsson and Rasco 2000). Sometimes the raw material is first heated in order to denature the endogenous proteases. The reaction takes one to several h, depending on the activity of the enzyme employed, the temperature of the process and other factors (Guerard et al. 2010). A critical issue of enzyme catalyzed process is stopping of reaction; so the added enzymes are then inactivated by pH or heat treatment at the end of the batch reaction. After separation of solids, the aqueous layer is clarified, and then dried or concentrated (Kristinsson and Rasco 2000; Guerard et al. 2010).

FPH, a value added fishery product, possesses excellent nutritional properties and biological activities for food and feed (Hoyle and Merritt 1994). Functional properties of FPH

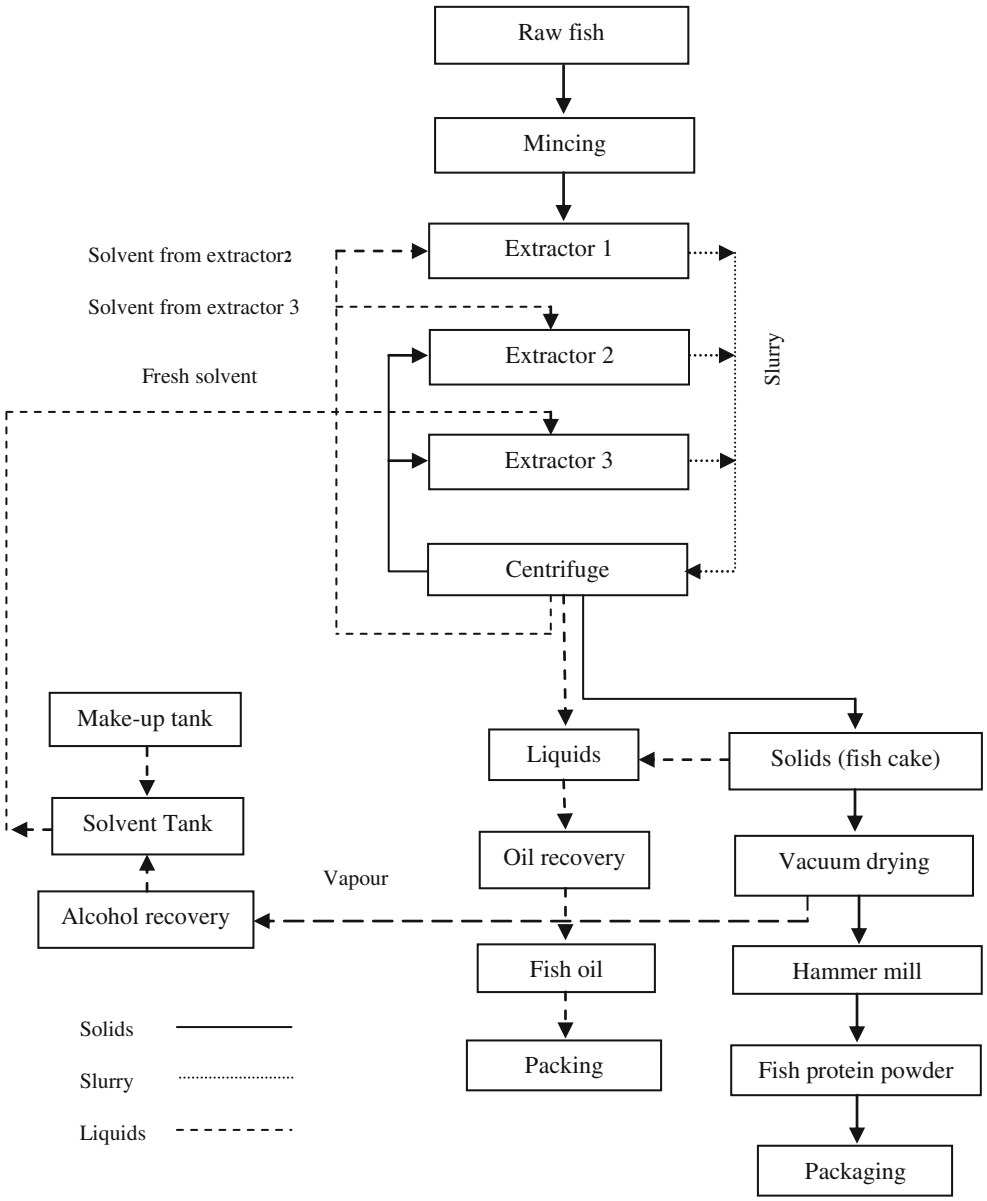

Fig. 4 Flow diagram of solvent extracted fish protein processing (modified from: Windsor 2001)

are influenced by the degree of hydrolysis (Kristinsson and Rasco 2000). Proteins separated by partial enzyme hydrolysis are known to possess anti-oxidation properties against peroxidation of lipids and fatty acids (Kim et al. 2001).

Combination of various methods

A process involving gamma-irradiation (200 Krad) and heat treatment (60 °C, 10 min), for the preparation of FPP from a tropical fish Bombay duck (*Harpodon nehereus*) was described (Warrier and Ninjoor 1981). The procedure enabled the precipitation of 75 % of proteins from fish flesh which accounted for 80 % of myofibrillar proteins. The solubility of FPP was 3 % in water and 15 % to 5 % NaCl. Among enzymes tested for FPP solubilisation, pronase was found to be the most effective both with respect to the extent and the rate of hydrolysis. The FPP had good functional properties in terms of emulsifying capacity and water holding capacity (Warrier and Ninjoor 1981).

Another method for developing FPP has been investigated (Muraleedharan and Gopakumar 1998). Homogenization of the leached mince in water (1:3) followed by acidification of the dispersion with 1 % acetic acid produced a weak gel which was diluted with water and spray dried to get a bright yellow powder having a faint fishy odour. The resulting powder contained 5 % moisture, 1.2 % lipid and 89.5 % protein and had excellent functional properties. The product packed in polyester/polyethylene laminate pouch, did not undergo significant browning for 3 months during storage at ambient temperature (Fig. 6).

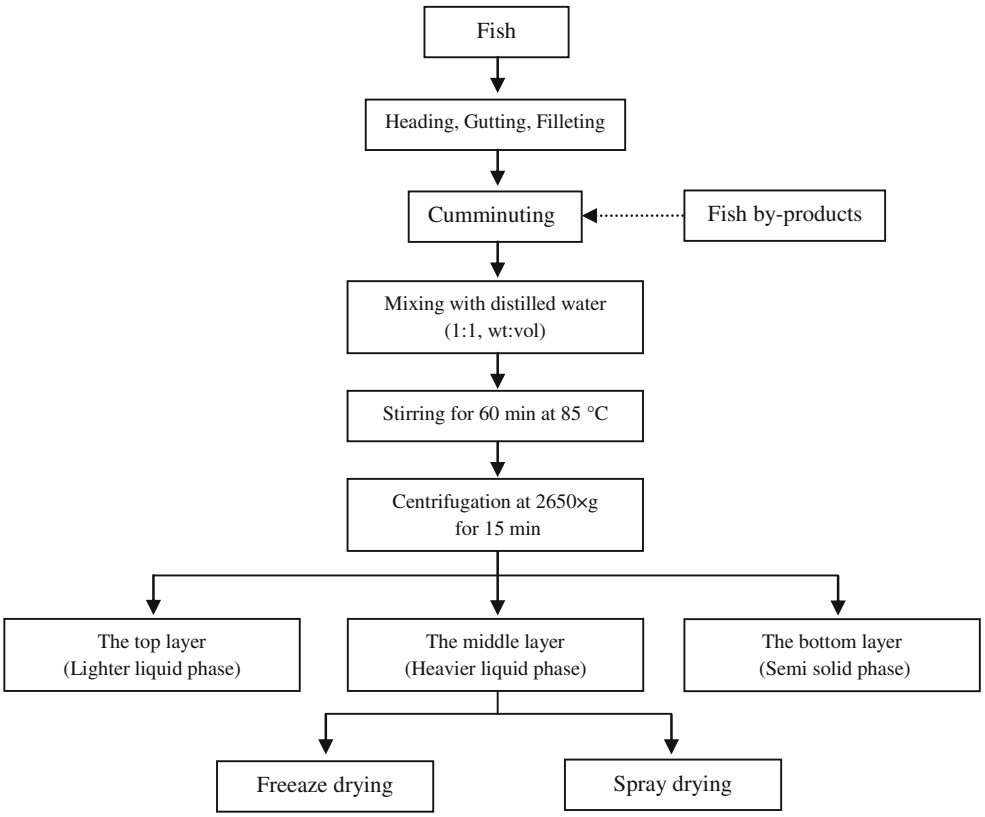

Fig. 5 Flow chart for the preparation of soluble protein concentrate (adapted from Sathivel et al. 2004)

Developing FPP

The increasing need for producing high quality and convenience fishery products at a competitive cost has led to the employment of several drying methods (Shaviklo et al. 2011a). The methods used by different authors are: freeze drying, spray drying and oven-drying.

Freeze drying

Freeze drying is often used to prepare protein powders. The freeze drying process consists of freezing the product and subsequent drying in a vacuum chamber. The drying process is done in two phases: primary drying which removes frozen water through sublimation and secondary drying which removes non frozen bound water (Carvajal et al. 2005; Cordova-Murueta et al. 2007). Freeze drying often presents stability problems due to the conformational instability of many proteins when subjected to freezing and dehydration stress. Therefore, proteins must be stabilized against both of these fundamentally different stresses (Crowe et al. 1990; Sathivel and Bechtel 2006). Lyoprotectants including saccharides, amino acids and sugar alcohols are used to stabilise the proteins during the freeze drying process (Arakawa et al. 2001; Carvajal et al. 2005; Shaviklo et al. 2011a, 2012; Huda et al. 2012).

Freeze drying does not damage the functionality of the myofibrillar proteins (Suzuki et al. 1992; Montejano et al. 1994). Therefore, freeze dried fish protein has versatile structures which increase its application possibilities (Ramirez et al. 1999). In the production of freeze dried fish protein mixing of fish flesh with additives, plate temperature in the freeze dryer and packaging and storing of the product are critical steps (Matsuda 1983). Lyoprotectants should be mixed thoroughly with leached mince to protect proteins against denaturation (Matsuda 1971). A plate temperature of 55 °C is recommended for developing FPP (Matsuda 1971, 1983; Shaviklo et al. 2010a, 2012). It is possible to store FPP for a long time if it is vacuum packed or inert gas packaging is used and the products are kept at temperatures below 15 °C, but the functionality loss rapidly at 30 °C (Matsuda 1979; 1983). However, low temperature storage (−18 °C) can preserve excellent functionality of freeze dried fish protein for up to 9 months (Carvajal et al. 2005). Freeze drying is the most expensive methods than the other drying methods because of the energy required to keep the vacuum condition and the low temperature (Ratti 2008).

Spray drying

Spray drying is the most common method for drying food proteins. It is done at higher temperatures than freeze drying and is therefore more detrimental to protein quality (Carvajal et al. 2005). To develop FPP, leached mince with lyoprotectants should be homogenised in a colloidal mill (Niki et al. 1982). Then the slurry is spray dried to obtain a

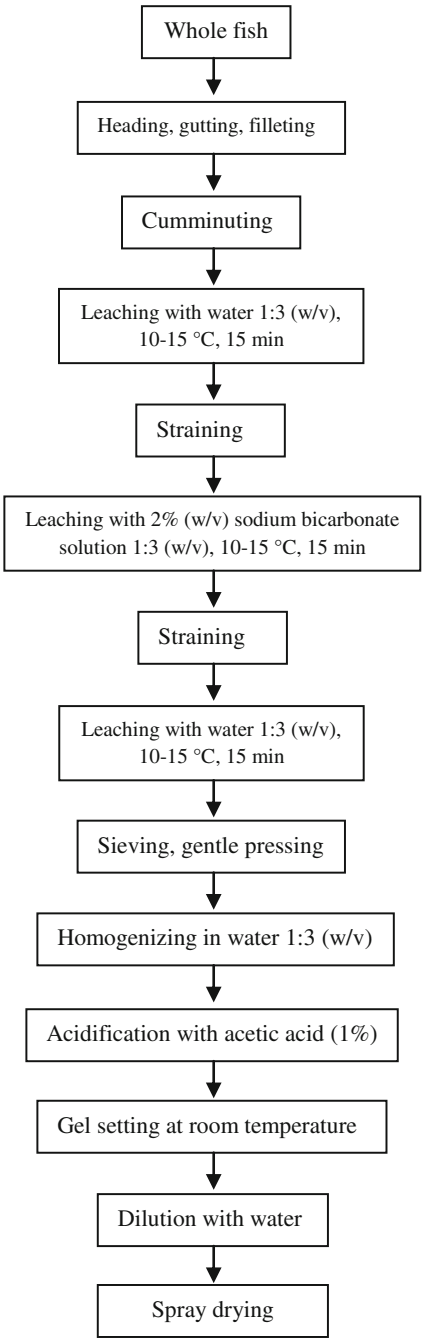

Fig. 6 Flow chart for the preparation of tuna protein powder (adapted from Muraleedharan and Gopakumar 1998)

product with excellent functional properties (Niki and Igarashi 1982; Shaviklo et al. 2010a).

When producing FPP by spray drying one of the most significant problems is the recovery of FPP. The recovery of the FPP is affected by the viscosity of fish flesh and the temperature of spray drying and recovery rate increasing with reduced moisture (Niki and Igarashi 1982). The particle size of the FPP is also affected by the viscosity of the fish flesh sol. High viscosity allows big drops of fish flesh sol to grow and produces large FPP particles. The big drops collide with the wall and the bottom of the drying-chamber resulting in decreased recovery of FPP (Niki et al. 1983). Fish flesh sol viscosity can be reduced by adding carbonic acid, reducing the pH to the isoelectric point of the protein. During drying carbonic acid is decomposed instantly into carbon dioxide and water, and is not retained in the FPP (Niki and Igarashi 1982). Therefore pH of FPP becomes neutral and denaturation of fish protein (actomyosin) is decreased (Niki et al. 1983).

Spray dried fish protein maintains its properties for 6-months at 5 °C. The low moisture content of FPP and the elimination of oxygen from the package prevent deterioration of the product during storage (Niki et al. 1983). Successful development of FPP has been reported by several authors, but the quality of spray dried fish protein totally depends on the type and pre-treatment of fish protein (Bragadottir et al. 2007; Sathivel et al. 2009; Shaviklo et al. 2010a).

Oven drying

Using oven drying, a low-cost technology, for developing dried fish protein has been reported (Chavan et al. 2008). Fish croaker mince was drier at 43–45 °C for 12 h and the prototypes demonstrated food functional properties. In another study the effect of oven drying temperatures at 50, 60, and 70 °C on the functional properties of FPP from lizardfish was studied (Huda et al. 2000). Drying at 60 °C for 12 h to reach less than 10 % moisture content of FPP was recommended. However, the functional properties of oven dried product were poorer than that reported for spray dried or freeze dried fish proteins (Cordova-Murueta et al. 2007; Chavan et al. 2008; Huda et al. 2012).

A processing technique called the very low temperature (VLT) method was also examined to develop FPP. The VLT method employs the latest technology and is efficient for maintaining the high protein and original taste, as well as the moisture level, of the products. Fish mince is dried for about 12 to 14 h at 32 °C and was finished off at 50 °C for approximately 1 h. The material is then ground before vacuum packing (Herrmann et al. 2006).

Characteristics of FPP

Physiochemical properties

The proximate compositions of FPPs depend on fish species and added ingredients (Cordova-Murueta et al. 2007; Sathivel et al. 2009; Shaviklo et al. 2010a). The FPP has been classified as fish protein concentrate since the protein content of FPP prototypes mostly is higher than 65 %

(Barzana and Garcia-Garibay 1994; Sen 2005). The lower content of proteins and the higher content of carbohydrate in FPPs containing additives are due to the addition of different amount of additives such as sucrose to the leached mince (as lyoprotectant) to protect proteins during drying (Table 1). Moisture content and water activity values of spray dried and freeze dried saithe protein powders varies owing to the influence of additives and using different drying methods (Shaviklo et al. 2010a). Foods with a_w values less than 0.3 are largely protected against lipid oxidation, non-enzymatic browning and enzymatic activity. Microorganisms also cannot grow under a_w 0.6 (Fontana 1998). Density of FPPs also depends on particle size, ingredients and drying temperature (Huda et al. 2012; Shaviklo et al. 2012).

Colour is an important quality attribute of fish protein ingredient. The colour of FPP varies from light gray to creamy, or pinkish depending on the type of fish used, method of extraction and also the particle size (Table 2). Freeze dried FPP made from leached saithe had a pinkish colour. While spray dried leached saithe had white colour indicating the influence of drying method on the FPP quality (Shaviklo et al. 2010a). The importance of the colour of solvent extracted fish protein becomes more acute when it comes in contact with water and/or oil because it darkens, which obviously is not desirable. The colour of solvent extracted fish protein has two origins: (1) the melanin present in scales, which are insoluble in alcohol; and (2) the red pigment of the blood (haemoglobin) in combination with protein which is mostly alcohol soluble. During the manufacture of solvent extracted fish protein, blood pigments principally removed by centrifugation; however, the melanin from the scales remains in the final product (Windsor 2001).

The pH of the fish flesh is one of the most important factors in drying fish mince and surimi (Niki and Igarashi 1982). Functional FPP can be produced from fish flesh of neutral pH, but it is not possible to produce FPP with appropriate functionality from fish flesh of acidic or alkaline pH (Geirsdottir 2005; Shaviklo et al. 2012). Therefore, FPI is very susceptible to drying process. Studies on freeze drying saithe PI (Shaviklo et al. 2012) and Cape hake PI (Pires et al. 2012) and drying of herring PI using heat pump fluidized bed dryer (Geirsdottir 2005) revealed poor functional properties of the prototypes. The results indicated that the dried samples had an intense rancid odour with a dark yellowish or gray colour. The FPI powder did not form a gel and did not hold water very efficiently (Geirsdottir 2005; Shaviklo et al. 2012). Similar results are reported for drying fish protein hydrolysate (Bragadottir et al. 2007).

The FPP prepared from enzyme hydrolysis of saithe (*Pollachinus virens*) had higher solubility because of smaller peptides with increased availability of polar residues to form

Table 1 Proximate composition of fish protein powders

Sample	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Carbohydrate (%)	pH	a_w	Density (g/mL)	Source
Freeze dried saithe protein isolate	1.41	94.04	0.62	2.71	0.00	5.50	0.03	3.91	Shaviklo et al. 2012
Freeze dried Fish protein isolate with 5 % sucrose and 0.2 % phosphate	2.81	71.51	0.42	3.90	20.31	6.14	0.07	4.72	Shaviklo et al. 2012
Spray dried saithe surimi with additives (2.5 % sucrose and 0.2 % phosphate)	5.82	74.52	3.22	1.41	15.12	7.13	0.29	2.43	Shaviklo et al. 2010c
Freeze dried saithe surimi without additives	5.14	92.80	2.44	1.62	0.00	6.81	0.15	1.34	Shaviklo et al. 2010c
Freeze dried saithe surimi with additives (2.5 % sucrose and 0.2 % phosphate)	3.91	77.24	2.12	1.91	14.52	6.92	0.12	1.70	Shaviklo et al. 2010c
Freeze dried Lizard fish surimi	5.23	73.41	1.90	1.90	17.50	NA	NA	2.43	Huda et al. 2001a
Freeze dried Threadfin bream surimi	5.62	72.90	1.92	2.22	17.42	NA	NA	2.26	Huda et al. 2001a
Freeze dried Purple spotted bigeye surimi	6.43	72.82	1.83	1.81	16.81	NA	NA	2.36	Huda et al. 2001a
Freeze dried tilapia surimi	4.64	62.05	2.90	1.60	8.00	NA	NA	NA	Ramirez et al. 1999
Freeze dried fat sleeper surimi	4.21	64.71	3.61	1.32	8.00	NA	NA	NA	Ramirez et al. 1999
Spray dried tuna surimi	5.49	89.50	1.23	2.08	NA	NA	NA	NA	Muraleedharan and Gopakumar 1998
Spray dried fish protein from Threadfin bream soluble protein	5.43	93.14	1.14	2.62	NA	NA	NA	NA	Venugopal et al. 1996
Freeze dried whole herring soluble protein	5.30	76.22	3.90	14.81	NA	NA	NA	NA	Sathivel et al. 2004
Freeze dried arrowtooth flounder fillet soluble protein	10.64	81.43	3.04	4.83	NA	NA	NA	NA	Sathivel et al. 2004
Freeze dried pollock frame soluble protein	5.82	78.90	2.91	12.50	NA	NA	NA	NA	Sathivel et al. 2006
Freeze dried pollock trimming soluble protein	8.11	71.01	3.63	17.32	NA	NA	NA	NA	Sathivel et al. 2006

NA not measured in the original study

Table 2 Colour characteristics of fish protein powders

Sample	Lightness (L*)	Redness (a*)	Yellowness (b*)	Whiteness (L-3b*)	Source
Freeze-dried saithe protein isolate	36.61	−2.50	6.90	15.81	Shaviklo et al. 2012
Freeze-dried Fish protein isolate with 5 % sucrose and 0.2 % phosphate	39.32	−2.71	6.11	21.12	Shaviklo et al. 2012
Spray dried saithe surimi with additives (2.5 % sucrose and 0.2 % phosphate)	47.84	−1.36	2.42	40.60	Shaviklo et al. 2010c
Freeze dried saithe surimi without additives	39.40	−0.11	6.70	19.12	Shaviklo et al. 2010c
Freeze dried saithe surimi with additives (2.5 % sucrose and 0.2 % phosphate)	41.22	−0.44	6.22	22.51	Shaviklo et al. 2010c
Freeze dried Lizard fish surimi	85.59	0.30	16.38	36.45	Huda et al. 2001a
Freeze dried threadfin bream surimi	89.57	0.19	12.22	52.91	Huda et al. 2001a
Freeze dried purple spotted bigeye surimi	88.33	0.23	13.16	48.85	Huda et al. 2001a
Freeze dried pollock frame soluble protein	76.01	−1.2	18.90	69.31	Sathivel et al. 2006
Freeze dried pollock trimming soluble protein	68.90	−3.01	16.91	64.53	Sathivel et al. 2006
Freeze dried whole herring soluble protein	82.82	3.52	12.52	45.30	Sathivel et al. 2004
Freeze dried arrowtooth flounder fillet soluble protein	86.31	2.21	2.80	77.90	Sathivel et al. 2004

hydrogen bonds with water. FPP samples exhibited an excellent ability of fat absorption (Bragadottir et al. 2007).

The Functional properties and the lipid stability of FPPs (Table 3) are affected by the type of drying process and physicochemical changes occurring in proteins during drying seem to affect the quality of the dehydrated product. Therefore, the same raw material may end up as a completely different product, depending on the type of drying method and processing conditions (Shaviklo et al. 2010a, 2012).

Fish proteins should be protected against denaturation during freezing/drying (Park and Lin 2005). Dryoprotectants (Suzuki et al. 1992) or lyoprotectants (Carpenter et al. 1997; Carvajal et al. 2005) are ingredients such as sucrose and polyphosphate which are used for this purpose. A sufficient concentration of sucrose along with a small amount of polyphosphate can protect fish proteins from denaturation during drying and storage (Carvajal et al. 2005), due to the forming of hydrogen bonds with proteins, acting as a replacement for the hydration shell (Carpenter et al. 1997). Adding about 5 % sucrose and 0.2 % or less polyphosphate to the washed fish mince to develop functional FPP has been recommended (Niki et al. 1982; Matsuda 1983). The freeze dried saithe protein containing lyoprotectant had superior functional properties and stability than spray dried saithe protein with the same amount of lyoprotectant (Shaviklo et al. 2010a).

Lipid oxidation is a critical issue when drying of fish proteins. Therefore, rancid flavour is the main problem of FPP and makes it unacceptable for further use (Thorkelsson et al. 2008; Shaviklo et al. 2010a). An increased TBARS level during drying of FPP was reported (Shaviklo et al. 2012). TBARS levels for spray dried and freeze dried FP

Table 3 Properties of fish protein powders

Sample	WHC (%)	Protein solubility in water (%)	Viscosity (Pa)	Gelation (%)	EC (%)	ES (%)	FC (%)	FS (%)	TBARS (μmol/Kg)	Source
Freeze dried saithe protein isolate without additives	287.40	20.80	0.13	>10	78.51	76.50	155.44	100.31	90.50	Shaviklo et al. 2012
Freeze dried Fish protein isolate with 5 % sucrose and 0.2 % phosphate	253.15	26.81	0.27	>10	82.45	76.55	189.72	145.54	82.25	Shaviklo et al. 2012
Spray dried saithe with additives (2.5 % sucrose and 0.2 % phosphate)	335.21	26.32	0.22	2.00	61.35	47.51	197.51	117.52	15.27	Shaviklo et al. 2010c
Freeze dried saithe without additives	326.02	36.62	0.10	6.00	50.24	39.23	152.54	122.53	28.47	Shaviklo et al. 2010c
Freeze dried saithe with additives (2.5 % sucrose and 0.2 % phosphate)	359.21	46.60	0.27	1.00	83.40	60.45	185.34	172.42	13.41	Shaviklo et al. 2010c

WHC water binding capacity, *EC* emulsification capacity, *ES* emulsification stability, *FC* foaming capacity, *FS* foaming stability

containing additives were 15.5 and 13.3 μmol/kg, respectively. However, TBARS levels of freeze dried saithe surimi without additives were significantly higher (28.7 μmol/kg) than that reported for additive-added samples, indicated the positive effects of additives on preventing lipid oxidation (Shaviklo et al. 2010a). The exact mechanisms by which lyoprotectants (additives) exert their antioxidative effects are not clearly understood but it is ascribed to the ability of lyoprotectants to form an amorphous matrix within cells upon drying (Pereira et al. 2003; Santivarangkna et al. 2008).

Advanced lipid oxidation (90.5 μmol/kg) was also reported for saithe protein isolates powder (Shaviklo et al. 2012). Although, the pH-shift process has been reported to reduce lipids and active prooxidants from FPI (Hultin et al. 2005) there were still a small amount of lipids in the product enough to lead to significant development of oxidation products. Lipid oxidation in FPP developed form FPH is very important because all the lipids cannot be removed from the product when prepared in a large scale. However, the problems with lipid oxidation can be reduced due to mild processing conditions (Kristinsson and Rasco 2000).

Sensory attributes of freeze/spray died FPP assessed in terms of odour and flavour have been reported (Shaviklo et al. 2010a, 2012). The FPP prototypes were described by the following attributes: dried fish odour and flavour, fish liver oil odour and flavour, rancid odour and flavour and seaweed and chemical flavour. Freeze dried saithe PI had the highest intensities of fish liver oil odour and flavour and rancid flavour and odour comparing to surimi powders due to advanced lipid oxidation in FPI powder (Shaviklo et al. 2010a, 2012). Apart from *flavour instability*, the FFP may have a gritty texture when processed with alcoholic solvents. This defect is detectable in the mouth even after the very fine grinding. Solvent extracted FP has also a chalky flavour (Iaqer 1969; Windsor 2001). However, a major factor limiting the use of such product is the lack of functional properties (Windsor 2001; Ibrahim 2009; Khoshkhoo et al. 2012). Flavour reversion is also the main problem with solvent extracted FP even at a low fat content. It may develop fish or fish meal flavour during storage of the products. Rancid flavour occurs in FPP with high fat content (3 %) and makes it unacceptable for further use (Windsor 2001; Khoshkhoo et al. 2012).

Nutritive value of FPP

The nutritive value of fish proteins is comparatively high due to the essential amino acid favourable pattern. Fish proteins are rich in all the essential amino acids (particularly methionine and lysine), in contrast with most proteins from plant sources, which lack adequate amounts of one or more essential amino acids (Venugopal 2006). The in vivo digestibility of raw fish flesh proteins is in the range of 90–98 %. Protein efficiency ratio (PER) of fish proteins, an index of protein quality, is slightly above that of casein, the major milk protein. The net protein utilization (NPU) of fish flesh is 83, as compared with values of 80 and 100 for red meat and egg, respectively (Skaara and Regenstein 1990; Sen 2005).

There are no significant differences in the amino acid composition of fish flesh and FPP (Venugopal 2006). An investigation on amino acid and mineral analysis of freeze dried Cape hake protein isolated from by-products from alkaline solubilisation revealed that the amino acid content of raw Cape hake and the Cape hake protein powder were similar. However, raw Cape hake was richer in glutamic acid and glycine than Cape hake protein powder but Cape hake protein powder had a higher level of lysine. The essential amino acid (EAA) content of Cape hake protein powder exceeded the requirements for adult humans. Lysine and threonine content of Cape hake protein powder exceeded the EAA requirements for infants (Pires et al. 2012).

The mineral content of fish flesh is lower than those of proteins powders prepared from by-products (Sathivel et al. 2004, 2006; Pires et al. 2012). Types of raw materials and the preparation process of FPPs may be responsible for these differences (Pires et al. 2012).

An evaluation of the nutritional properties of freeze dried protein powders from whole herring, herring body, herring head, herring gonad and arrowtooth flounder fillets indicated that the FPP samples had excellent nutritional properties and contained 63–81.4 % protein. All FPP samples had desirable essential amino acid profiles and mineral contents (Sathivel et al. 2004).

The FPP is a valuable protein supplement to improve the protein quality and quantity of indigenous diets, particularly the diets of pre-school children and other vulnerable groups. It is used to help increase the weight and height of children (Frokjaer 1994; Owusu-Amoako 2001; Sen 2005). A study of the intake of FPP on 144 preschool children revealed that after 7 weeks of once-daily supplementary feeding, there were significant increases in the weight and height of children (Owusu-Amoako 2001). The FPP has been also proven to be very valuable in treating severe malnutrition of children under five, 'i.e.', Kwashiorkor (Vakily et al. 2012). It could help to increase the protein content of the diet of the low-income classes and also as a valuable source of protein for infants and children under five (Vakily et al. 2012).

Nutritive studies have shown the remarkable beneficial effect of adding FPP to the diet. Its use is particularly beneficial to growing children and pregnant or nursing mothers (Frokjaer 1994; Sen 2005). Twelve g of FPP a day will supply the needed protein to a child; a small FPP plant processing 50 t of raw fish a day could provide enough FPP for three quarters of a million children (Windsor 2001).

Application of FPP in convenience foods

Using FPP as an ingredient in food systems depends on whether it is feasible to stabilize the residual lipids by suitable processing methods (Thorkelsson et al. 2008). However, potential uses of fish protein ingredients are impacted by functional properties of proteins such as water holding capacity, gelation, foam stability and emulsion capacity (Thorkelsson et al. 2009). Fishery-derived ingredients may have a negative impact on sensory characteristics despite improving nutritional and functional quality of the products (Shaviklo et al. 2013). Studies on the effects of enriching foods with fish ingredients on sensory quality report negative effects both on flavour and odour if they are used at inappropriate levels. Therefore, the level of enrichment should not affect acceptance and sensory properties of the product (Shaviklo et al. 2011a, b).

Using FPP for producing formulated seafood and other food products has been investigated (Carvajal et al. 2005; Musa et al. 2005; Shaviklo et al. 2010b, 2011a, b, c; Shaviklo 2012). Applications of FPP as a binder in restructured meat (Chung et al. 2000), as emulsifier in muscle foods (Ramirez et al. 1999) and the development of value added products from FPP (Sathivel et al. 2005) have been reported. These protein powders can be used in the preparation of edible films or as a dipping solution before battering or breading of fillets and fish fingers (Pires et al. 2012).

Nutritive value of cereal proteins could be increased when combined with a FPP. Thus, the addition of 3 % of FPP to wheat flour (protein content, 10.4 %) increased its protein content to 12.4 % with an increase of NPU from 50 to 67 (Venugopal 2006). However, successful fortification of puffed corn snack (Shaviklo et al. 2011a), ice cream (Shaviklo et al. 2011b), bread (Adeleke and Odedeji 2010), biscuits (Ibrahim 2009), mayonnaise (Sathivel et al. 2005), crackers (Huda et al. 2001b) with FPP have been reported.

A work on the application of FPP for seasoning of extruded corn snacks revealed a further option for utilization of this ingredient. Seasoning of extruded puffed corn snakes with 18 % FPP were liked by Iranian children aged 7–12 years old. The products were also stable for 4 months at ambient temperature (Shaviklo et al. 2013).

A high-protein, wet yellow noodle by the incorporation of FPP as a protein source was developed. The physicochemical and sensory properties of the noodle were also evaluated. There was no significant difference in the colour, hardness and elasticity between the control and noodles incorporated with 5 % FPP. Thus, a value of 5 % FPP was considered the maximum concentration acceptable for incorporation into the noodles (Chin et al. 2012).

The fish bouillon powder was also processed from myctophid protein along with different spices. It can be used as flavouring when consuming rice, noodles etc (Shaviklo 2012). The effect of fortification with different levels of FPP on chemical properties and sensory quality of a Persian ice cream with 0, 3 and 5 % FPP during storage at −18 °C for 4 months was investigated. All the products had the same levels of fat, lactose, acidity and pH. The fortified ice creams had similar sensory quality after production, but it was changed significantly after 2 months of storage. Development of ice cream fortified with FPP could be an effective way to enhance nutritional and functional value of ice cream (Shaviklo et al. 2011b).

A high protein extruded corn-fish snack containing 7 % FPP was developed. It was seasoned with cheese powder, vegetable oil, salt, and colorant. Consumers' acceptance of 6–16 years old children were studied in two communities (Iceland and Iran). The consumers liked the product but Iranian children favoured it more than Icelandic children. The majority of the children's parents expressed their willingness to choose this product when buying snacks (Shaviklo et al. 2010b).

In another study, an extruded corn-fish snack containing 3 % FPP was produced to study quality changes and storage stability of the product during 6-month storage at 27±2 °C. The product was stable during the study period. It was concluded that extrusion of corn grits with FPP can be utilised to produce high-protein products that would be an option to provide nutrient snacks for consumers (Shaviklo et al. 2011a).

Acceptability of bread fortified with 5, 10, 15 and 20 % FPP were studied. The results of the sensory evaluation indicated no significant differences among the samples. The prototypes were accepted by the Nigerian consumers (Adeleke and Odedeji 2010). It was found that 5 % FPP is the best level of fortification of biscuits (Ibrahim 2009). FPP at the level of 5 % can be applied as a potential emulsifier in mayonnaises (Sathivel et al. 2005). Crackers fortified with 10 % FPP were accepted by Malaysian consumers (Huda et al. 2001b).

A convenient ready-to-reconstitute cutlet mix containing 30 % FPP was developed to improve the nutritive quality of the product. The FCM packed in a polyethylene bag and cardboard box was stable during 6-month storage. There were no changes in colour, moisture gain and water activity, and TBARS values remained low. The FCM was accepted by Iranian consumers (Shaviklo et al. 2011c).

A traditional Pakistani weaning food (*Khitchri*) was incorporated with different levels of FPP. The protein efficiency ratio (PER), net protein utilization (NPU), true digestibility (TD) and biological value (BV) were estimated for each level. Values such as NPU, BV, PER and TD show remarkable improvement in weaning food incorporated with 10 % FPP indicating that the addition of 10 % FPP to the prototypes can result in superior nutritional quality. The authors concluded that the FPP could be an ideal source of protein for enriching the weaning food (Hussain et al. 2007).

Marketing and economic aspects

Fishery resources are limited and there are necessary to optimise the utilisation of the low value/underutilized fishes and by-products. Such raw materials are usually used for fish meal production. But they may be converted to highly valuable products, in some cases, even higher in value than fish fillets (Arason et al. 2011).

Adding value to the underutilized fish and fish by-products through developing FPP is highly profitable (Shaviklo 2012). Prices of underutilized fish/fish by-products are relatively low because of the availability of such raw material in bulk at a relatively cheap price. However, it is difficult to obtain a definite idea of FPP commercial price. It takes approximately 5–10 kg fish/by-products to make 1 kg FPP. The production cost will depend obviously on the type and cost of the raw material and the process used and the market depends upon the price and functional properties of FPP.

The FPP is an article of commerce in several countries. Freeze dried leached mince is commercialized in Japan and applied in the food industry (Pires et al. 2012). In China, FPP is produced from farmed fish and used for supplementing children's diets (Herrmann et al. 2006). A number of surveys are available in the economics of production and marketing of FPP. These were carried out in the early 1970s and are irrelevant today (Sen 2005). Recently an economic analysis of production and marketing of FPP to China revealed that manufacturing and commercialization of FPP may provide a niche market for seafood industry. The FPP is a relatively new product in China. At first, FPP was not readily accepted as a good protein source for children, as many children did not like the taste of this product. Thus, meat protein and vegetables were mixed with FPP to reduce its fishy taste (Pei 2004). However, the FPP has started to gain market share and is being gradually accepted by young Chinese parents (Herrmann et al. 2006).

Sensory attributes of FPP are similar to dry fish (Venugopal 2006; Shaviklo et al. 2010a). Therefore, the FPP can be successfully marketed in the areas where fish powder from dried fish is used in tasty, spicy dishes consumed with the staple dish. However, fish protein ingredients cannot compete with plant and dairy proteins on the functional ingredient market (Thorkelsson et al. 2009). However, production of FPP may have a double effect on food and seafood industries. Firstly, in being added to the foods, it increases the content of nutrients in the diet. Secondly, it improves the utilization of fishery resources and fish protein consumption per capita (Vakily et al. 2012; Shaviklo 2012). The market for fish protein ingredients is not big, but it will grow (Thorkelsson et al. 2009). The FPP could be a means of increasing fish consumption in countries/areas where there is no tradition of consuming fresh or frozen fish (Shaviklo 2011).

Conclusions

Extracting proteins from fish processing by-products, by-catch and other underutilized fish, provides an avenue to increase utilization of harvested catch. This review study presented that fish protein can be dried successfully and dried fish protein can be potentially applied as functional ingredients and nutritional supplements. The FPP is a good source of high-quality amino acids and could compete industrially with other protein ingredient such as soy protein isolate and egg albumin. This study indicated opportunities to produce value-added products from fish processing by-products and low value fish.

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