



Overcoming current challenges in commercial applications of fish protein isolates in food and feed systems: a review

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Abstract Over the past 2 decades, the number of scientific papers on properties of fish proteins recovered from various aquatic resources, including the rest raw materials obtained from seafood processing have grown dramatically. Whereas the fish protein isolate (FPI) is a new source of animal protein that can be used to develop value-added food products as well as animal feed enrichment. But to date, very few practical studies have been done on the application of FPI in food and feed systems, and it may have caused the lack of commercial development of this product. Therefore, in order to optimal utilization of aquatic and raw materials in addition to the fight against malnutrition and protein deficiency in poor countries more attention to this technology will be caused this product commercialized. However, for realizing this potential in FPI, several challenges have to be solved. Therefore, this article explores in depth the researches into the use of FPI in food systems and discusses the challenges that this protein source is faced in developing food products. The authors believe that in order to overcome the current challenges in commercial applications of protein isolates in food systems, the following issues should be paying attention and further researches being carried out based on them: industrial process scale-up, production costs, choosing the optimum pH for protein extraction, solubility of proteins, lipid and protein oxidation, the ratio of FPI in

food systems, storage stability, sensory defects of FPI, marketing, and economic aspects and future trends of the use of FPI.

Keywords Fish protein isolates · Commercial applications · Value-added products · Sensory evaluations

Introduction

The needs for the animal protein sources in the world has resulted in the maximum exploitation of aquatic by-products, including low-value or small fish species, as well as the rest raw materials from seafood processing for food application (Nolsøe and Undeland 2009; Kim and Venkatesan 2014). Industrial processing of seafood commonly generates significant amounts of by-products including heads (9–12%), viscera (12–18%), skin and fins (1–3%), filleting trimmings and cut-offs (15–20%), bones (9–15%), abdominal contents and scale (5%) (Torres et al. 2007; Rustad et al. 2011). The amounts of by-products are relatively as much as 57% (w/w) of the weight of the total catch after filleting (Meeker 2009). Therefore, non-utilization or underutilization of fish by-products not only leads to increasing cost of disposal of these products, but also resulting in a loss of potential revenues. In this regard, the food industry has tried to expand various technologies in order to use of these by-products and reduce the costs derived from its disposal (Shavandi et al. 2019). However, the reality is that considerable amounts of fish by-products are hardly recovered in most the countries, especially in Iran. Legal constraints and people's concerns about the use of waste and misconceptions about their inability to use in human foods have caused them to accumulate in nature and lead to environmental problems (Borda et al. 2018).

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Fish and fishery by-products are rich in high-quality proteins that can be recovered by different methods (Hultin et al. 2005; Shaviklo 2015). Recovering fish proteins by acid-alkaline solubilization processes or pH-shift is one of these methods (Batista 1999). FPI can be used as additives/ingredients in food formulations in order to increase nutritional values or improving functional properties (Shaviklo et al. 2012a; Shabanpour and Etemadian 2016). So, that is the appropriate method for creating value-added products, raising productivity and increasing per capita fish consumption (Shaviklo 2008). Over the past 2 decades, many efforts have been made to recycle proteins from dark muscle fish and fatty fish as well as remaining raw materials from aquatic processing using pH-shift technology (Hultin et al. 2005). Extracted protein is called FPI and is typically used as an intermediate raw material in the food industry and value-added products manufacturing (Shaviklo et al. 2012a). FPI can be used to develop superfoods/functional foods with acceptable sensory attributes and nutritional qualities. It can also serve as a vehicle not only for improving the dietary content of ω -3 PUFAs, but the fortification with several useful ingredients (Ananey-Obiri and Tahergorabi 2018). The use of FPI as an emulsifier has also been reported (Nolsøe and Undeland 2009). The FPI may apply as a nutritive binder in the feed industry (Gehring et al. 2009).

The overall concept of the process is very simple (Fig. 1). At first, the raw material is homogenized in the water at 5–9 times its weight. Then the alkali/acid is added to obtain pH 10.5–11.5 or pH 2.5–3.5. The solution is centrifuged. This causes the oil to be placed on the top of the suspension, the membranes of the lipids are removed as a result of changes in density and other insoluble impurities such as bone, skin, are deposited on this stage. The precipitated muscle proteins are then collected. The easiest way to deposit proteins is to bring their pH closer to the isoelectric point, which is about 4.5–5.5 for most proteins. Mostly all muscle proteins are insoluble in this condition (Hultin et al. 2005). Using this technology has several advantages (Ingadottir 2004; Shaviklo 2006, 2017a): (a) Whole ungutted fish can be used; (b) The low-value and underutilized fish species, like myctophid, which are currently not directly used for human consumption, are applied; (c) The functional properties of proteins are maintained and often improve in the alkaline process; (d) All membrane lipids are separated and thus increase the stability of the protein against oxidation; (e) In this method, water consumption is lower compared to the surimi production.

In general, the factors affecting FPI quality are the type and quality of raw materials, the ratio of fish weight to water, homogenization the mix of water and fish, processing and extraction times, temperature, the pH used to

extract proteins and moisture reducing method (Nolsøe and Undeland 2009). It is also reported that the thermal processing of FPI may increase lipid oxidation (Shaviklo et al. 2012b; Matak et al. 2015). And this can lead to unpleasant rancid odor and flavor and detrimental color changes (Shaviklo et al. 2010a; Tahergorabi et al. 2013). In a recent research it was noted that the application of the FPI is strongly dependent on its sensory attributes and it depends on the quality of raw materials (Abdollahi and Undeland 2018). The present review focuses on the current and potential applications and also sensory evaluations of recovered proteins from processing by-products for human food and animal feed. Furthermore, possible drawbacks and future perspectives of the use of these FPI in food and feed systems will be discussed.

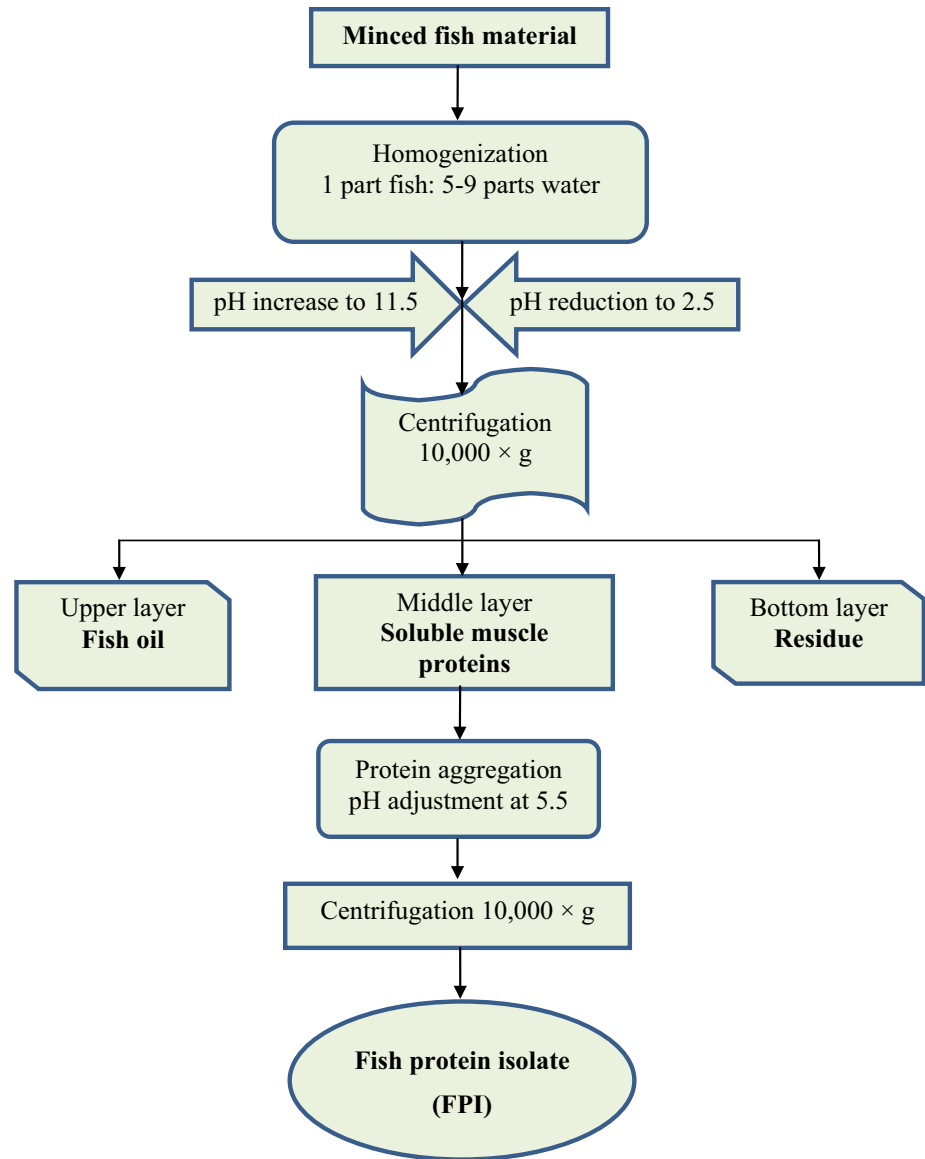
Application of fish proteins isolates products in food systems

The world's harvest of fishery and aquaculture products has increased considerably in recent years, reaching about 171 million tons in 2016, of which 151 million tons utilized for human consumption. This growth in the global supply of fish for human consumption is mainly due to a gradual increment in population growth and for the coming decades, it is expected that this product will compensate the stagnation of fishing catches and satisfy the growing demand for seafood and freshwater fish (FAO 2018). In addition, other factors that have contributed to rising consumption include better utilization, reductions in wastage, improved distribution channels, urbanization, rising incomes and growing demand linked to population growth (Shavandi et al. 2019). On the other hand, significant nutritional value and the health benefits of fish proteins are generally known. These properties suggest the protein of fish as a valuable pure material for the preparation of various food products (Borda et al. 2018). But, very little information has been published to apply fish protein isolated from different source of raw materials in food systems.

Fish protein solution

Fish protein solution (FPS) is a semi-solid protein colloid in water, which is prepared using the acid/alkaline aided process. It may also include salt and other optional materials (e.g., NaCl and polyphosphate) based on the final use (Shaviklo et al. 2012a). The FPS containing 1–5% proteins is used for injection into the fillet. This may increase the fillet weight and yield, as well as the microbial stability of the fillet (Valsdottir et al. 2006; Einarsdottir et al. 2007). The use of FPS as a fat blocker in the battering of the

Fig. 1 Flow diagram for recovering fish protein isolate by isoelectric precipitation (adapted from Hultin et al. 2005)



breeding process can reduce the uptake of oil by the product (Nolsøe and Undeland 2009). It has been reported that the use of FPS in food systems can increase water holding capacity (Thorkelsson et al. 2008). However, the use of FPS is an opportunity to use in the food industry based on the desired goals and further researches in this field.

Fish protein isolates

The FPI is a wet concentrated protein and its proximate composition depends on the type and quality of raw materials. Table 1 indicates proximate analysis of different FPIs. It strictly depends on the source of raw materials, protein extraction and dewatering processes (Hultin et al. 2005; Shaviklo 2017b). The production of FPI based products requires a comprehensive study on the stability of

raw materials and the sensory properties of the final product (Shaviklo et al. 2010a). As mentioned earlier, there are few published reports on the use of FPI in various food systems. In this article, they are referred to in the order of publication.

Shaviklo (2006) evaluated the physicochemical and sensory properties of protein isolated from cod, saithe, and Arctic Char by-products. He explained that the full use of FPI in the formulation without the addition of fish mince/surimi is not possible and the product does not have the proper texture and palatability. However, these defects did not observe in fish ball and fish burger made from FPI and fish mince and the prototypes were accepted by the panelists.

Pires et al. (2009) reported Frankfurter type's sausage production from proteins isolated from hake processing by-

Table 1 Proximate analysis of different FPIs

Analysis (%)	Haddock (%WW)	Saithe (%WW)	Rainbow trout (%DW)	Myctophid (%WW)	Silver carp (%DW)	Common carp (%WW)	Tuna (%WW)
Moisture	80.1	86.6	3.5	83.1	3.1	74.6	69.7
Protein	19.8	12.7	75.6	15.9	76.5	18	23.6
Fat	0.1	0.1	2.4	0.5	4.3	0.5	5.7
Ash	0.1	0.4	4	0.5	4.6	2.3	0.9
Source	1	2	3	4	5	6	7

WW wet weight, DW dry weight

1. Shaviklo et al. (2010b), 2. Shaviklo et al. (2012b), 3. Lone et al. (2015), 4. Oliyai et al. (2015), 5. Zhong et al. (2016), 6. Shabanpour and Etemadian (2016), 7. Shaviklo et al. 2016

products. In the product formulation, 0–40% of hake protein isolate was used. In order to reach the desired value of FPI, the Response Surface Methodology (RSM) was used. The results indicated that increasing the amount of FPI in the formulation reduced sensory scores. Therefore, for the optimal sample selection, the highest sensory scores were considered. As a result, the formulation was selected with 20% FPI. The researchers concluded that the protein isolated from hake processing by-products using the alkaline aided process can be used to make Frankfurter fish sausages up to a maximum of 20%.

In another study by Shaviklo et al. (2010a), a protein isolated from haddock fish processing waste was used for the formulation of fish balls. The amount of added FPI was 25% and 50% in the prototypes. Other additives were added in equal amounts in each formulation including fresh onions, baking powder, wheat flour, dried milk powder, sunflower oil, fresh garlic, and salt. Frozen samples were stored at -18°C for up to 8 weeks. The effect of FPI on fish balls sensory properties were investigated using quantitative descriptive analysis (QDA) and a trained sensory panel. The results of statistical analysis (Fig. 2) shows that in samples containing FPI, grainy and rubbery texture and soapy flavor attributes were dominant. During the storage time the scores of negative attributes indicating lipid oxidation like rancid odor and flavor were increased in FPI containing samples. Fish balls with 25% isolate and 75% mince showed similarities with the control sample from a sensory point of view. Therefore, the use of this amount of FPI (25%) was recommended to be added to the formulated fishery products.

Ibrahim (2015) also reported chemical composition, minerals, amino acids, bioavailability and sensory characteristics of meat/and fish balls containing FPI. The FPI ratio in meatballs was 25 and 75%. Sensory evaluation of the examined meat and/or fish balls with or without FPI was investigated in term of odor, texture, flavor, and acceptance. The data showed that FPI affected the sensory

properties of the prototypes. FPIs with higher levels of FPI had the highest score for general acceptance and flavor. But the grainy texture was detected in them. Hence, the recommended result was the use of 25% FPI in meatballs as already suggested by Shaviklo et al. (2010a).

In another research study, a protein isolated from the tuna fish processing by-products was added to the product formulation to improve the sensory quality of the fish burger made from silver carp (Shaviklo et al. 2016). The optimal amount of tuna isolate was determined in the formulation (20%) using D-optimal Mixture Design model. Other additives included vegetables, wheat flour, bread powder, oil, and so on. The effect of tuna protein isolates (20%) on the sensory changes of the fish burger compared to the control (silver carp mince burger) was investigated during the 6 months storage at -18°C . For this purpose, quantitative descriptive analysis (QDA) and a trained sensory panel were used. The PCA (Principal component analysis) graph (Fig. 3) showed that the storage time affected the sensory properties of the burger containing isolate (containing 20% tuna protein isolate and 50% silver carp mince) and control (silver carp mince). The isolate burger and control samples had the same sensory properties until the end of the second month of the storage. The two groups of samples were completely separated from the fourth month of storage and were located in the lower and upper half of the graph. This category represented the difference between the samples. Changes in sensory characteristics revealed the degradation of lipids and proteins in isolate burger samples. Accordingly, the intensity of the rancid odor and flavor and frozen storage odor and flavor increased in the isolates burger samples during storage and at the end of 6 months. The grainy texture was also detected in the isolate burger, but was not significant (Shaviklo et al. 2016).

In a recent study carried out by Moosavi-Nasab et al. (2018) two levels of 2 and 4% of fish protein isolated from lantern fish (*Benthosema pterotum*) were used in the

Fig. 2 Principal component (PC) analysis describing sensory quality scores of haddock balls as evaluated by a trained sensory panel. (A₀₋₈) Control sample with 100% mince. (B₀₋₈) Sample containing 75% mince and 25% isolate. (C₀₋₈) Sample containing 50% mince and 50% isolate; *O* odor, *A* appearance, *F* flavor, *T* texture; Numbers 0–8 indicate storage weeks (Shaviklo et al. 2010a)

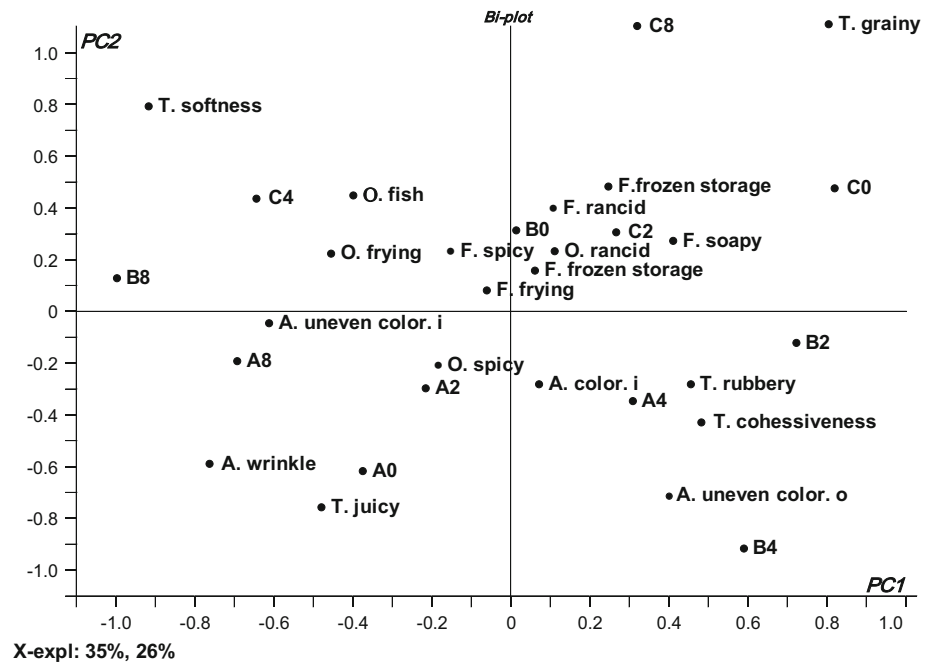
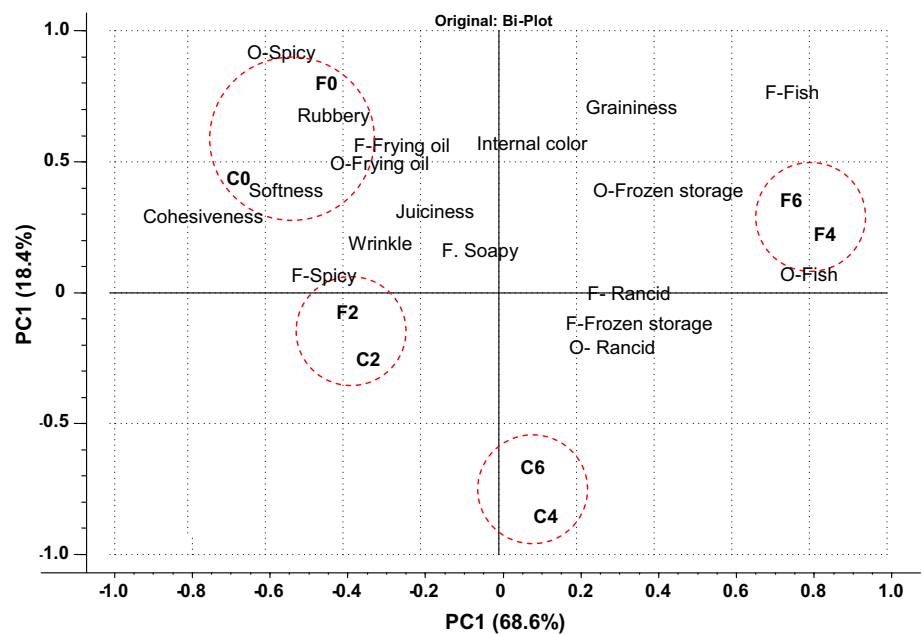


Fig. 3 Principal component (PC) analysis describing sensory quality scores of silver carp mince burger (C₀₋₆) and isolate mince burger containing 20% tuna protein isolate and 50% silver carp mince (F₀₋₆) stored 6 months at -18°C as evaluated by a trained sensory panel. *O* odor, *F* flavor. Numbers 0–6 indicate the storage months (Shaviklo et al. 2016)



formulation of fish sausages. They reported that the product with 2% FPI had the greatest overall sensory acceptance.

Fish protein isolated from yellow stripe trevally (*Selaroides leptocephalus*) was used as an emulsifier to prepare meat sausage and its concentration effect (1%, 2% and 3%, w/v) was studied in comparison with soy protein isolate (SPI). FPI was more effective at reinforcing the protein matrix of the sausages than SPI, and the product had a lowered cooking loss and better textural attributes. The effective concentration of FPI to improve product stability was 2%. This study recommended that FPI was promising

in the preparation of emulsified meat products (Chee-tangdee 2017).

Ochoa et al. (2017) evaluated the efficacy, safety and acceptance of a FPI in the nutrition of Peruvian children (n 441) less than 36 months of age. In their study, 50% of the animal protein was replaced with FPI instead of the standard protein in the lunch meal, 5 times/week, for 6 months. The control group took the same standard diet with animal protein from beef, chicken, pork, beef liver or egg, without the fish protein. Consumption was similar in both groups and there was no significant difference in growth between

them. It was noted that the FPI was safe, well tolerated and well accepted by the children. Therefore, the authors concluded that FPI could be a potential source of animal protein at lower cost.

Fish protein isolates powder

Fish protein powder (FPP) is a dried and stable fish product, intended for food application, in which the protein is more concentrated than in the original fish flesh (Shaviklo 2015). Several attempts have been made to dry FPI. But advanced lipid oxidation was observed in the dried isolates. Accordingly, poor functional properties and sensory attributes were noted in the prototypes. However, the mince powder as a control sample was less oxidized and had higher functional properties such as water binding capacity, gel-forming ability, emulsification, foaming properties and color and lower sensory scores for rancid odor and flavor than the FPI powders (Shaviklo et al. 2012a). So, to apply FPI powder in food systems further studies on how to prevent oxidation of fish flesh during pH-shift and drying processes are needed.

Application of FPI in animal feed industry

The functionality and gel-forming ability of FPI is well documented (Hultin et al. 2005; Kristinsson et al. 2005; Nolsøe and Undeland 2009). FPI is able to immobilize water and particulates within a stable gel network (Lanier 1986). Therefore, applying FPI as a binder may lead to improve feed quality and properties of extruded/pelleted feeds. Furthermore, the feed durability and stability will be extended during handling and transportation.

Quality improvement of pellet for broiler grower diets with fish protein isolated from rainbow trout using pH-shift technology was studied by Gehring et al. (2009). They revealed that FPI incorporated at less than 5% of the diet may be beneficial to the broiler industry as a pellet binder and nutritive feed additive. Furthermore, the use of FPI in pellet formula increased pellet mill relative electrical energy usage and decreased pellet mill production rate. On the other hand, it seems that FPS can be used like fish silage in direct feeding of animals.

Restrictive factors in the commercial application of FPIs

In the FPI commercial application, there are several factors that each of them alone can restrict the development of this product (Table 2). They are briefly referred to in this study.

Industrial process scale-up

An industrial process is a system that converts a prototype into a product. Both prototype and product have to have intended features and usability in the food industry (Harmsen 2013). In this regard due to the fact that studies of isolating proteins from fish have been limited to laboratory scale, the results cannot become indicators of production on an industrial scale (Shaviklo 2017a, b). Hence, in order to achieve reliable industrial scale results, the food industry's concerns about the quality and properties of the product should be considered (Nolsøe and Undeland 2009). Therefore, it is necessary to assess the economic feasibility of producing FPI on an industrial scale (Shaviklo 2017b).

Production costs

The impossibility of generating FPI on a commercial scale has led to an uncertainty in the cost of the product. The price of raw materials needed to produce FPI is cheap due to the use of low-value fish/fish by-products. However, it is difficult to obtain a definitive idea of the FPI's commercial price. To produce 1 kg of FPI, about 5–10 kg of fish raw materials is needed and this influence the production cost of the final product. Comparing to surimi development, the production cost of FPI might be higher because of the need for continues advanced homogenizer and centrifuge/decanter machinery. However, it is anticipated that by choosing the right and economical machinery as well as the localization of the technology needed, FPI prices could be competitive with other aquatic protein sources (Shaviklo 2017b).

Choosing the optimal pH for extracting/precipitation of proteins

The most important factor in protein extraction is pH. The pH-shift method by acid/alkaline aided process causes the deposition of proteins at the isoelectric point (4.5–5.5) to give highly functional and stable protein isolates (Hultin et al. 2005). This method is able to overcome some of the problems such as using dark muscle, small and low-value species or by-products (Hultin and Kelleher 2000). Although, several studies have confirmed the preferences of alkali extraction on acid extraction, it is necessary to determine and select this material based on the type of raw material. For example, one of the different response reasons to the acid and alkali process can be expected for warm water species compared to cold water species, because their proteins are more heat stable due to their living environment (Ingadottir 2004; Kristinsson et al. 2005, 2006; Nolsøe and Undeland 2009; Shaviklo et al. 2017).

Table 2 Challenges and strategic researches needs to commercial production of FPI and related products

Challenges	Strategic research needs
Industrial process scale-up	Developing and implementing scale-up process
Production costs	Choosing the right and economical machineries, localization of technologies
Choosing the optimum pH for extracting/precipitation of proteins	Process optimization based on the type of raw materials
Lipid and protein oxidation	Protecting lipids and protein pre-during and after processing against oxidation using antioxidants
Ratio of FPI in food systems	Formula optimization of the intended food system
Storage stability	Using appropriate cryoprotectants to stabilize FPI during frozen storage
Sensory defects and consumer survey	Quality improvement of FPI during processing, ingredient optimization, applying flavor enhancers and masking agents
	Optimizing the use of low-value/underutilized fish, adding value to low-value fish and fish by-products through the development of FPI
Marketing and economic aspects	Considering the cost of production; the type and price of raw materials, marketing and financial feasibility studies
Future strategic researches	Improve the knowledge on the best levels of protein isolates from fish processing in food systems that will lead to the fast development of food industry, improve the knowledge of the molecular structures of FPI

Adapted from Shaviklo (2017b)

Lipid and protein oxidation

FPI is highly sensitive to oxidation. This causes undesirable odor, flavor, color, and texture changes, and loss of nutritional value. Fat oxidation is considered to be one of the main reasons for the decline in quality and one of the biggest concerns about frozen seafood. Another important issue for keeping FPI frozen is protein degradation (Petty and Kristinsson 2004; Hultin et al. 2005). The use of natural antioxidant (e.g., tocopherol) and cryoprotectant of proteins (e.g., sorbitol) could be used for improving the quality of frozen/dried FPI products (Shaviklo et al. 2010b, 2012b). Therefore, extensive studies should be conducted in this regard.

The ratio of FPI in the food system

Food products are complex systems. Therefore, any changes in their formulation can make significant changes in their sensory characteristics and shelf life. On the other hand, proteins in food can interact with flavoring compounds and may change sensory characteristics. The maximum use of FPI for fillet enrichment and food formulation are 5 and 25% respectively (Shaviklo et al. 2010a). However, in order to develop FPI application in foods, the optimal FPI ratio in different food systems should be taken into account (Shaviklo et al. 2010a; Shaviklo 2017b).

Storage stability

The FPI is an intermediate product used to enrich or formulate ready-to-eat foods. To supply this product to the

processing units, it should be frozen and transformed in the recommended conditions. It may take several days to several months to keep frozen FPI in the cold storage until the product is consumed. During this time, the quality of the product is affected by the process of freezing and storage temperature. These changes involve the coagulation of the proteins, as well as the lipid oxidation, which results in the loss of functional properties and texture and alteration of sensory properties. Therefore, FPI should be preserved during frozen storage and much more researches should be carried out in this field (Thawornchinsombut and Park 2006; Shaviklo et al. 2010b; Shaviklo 2017a, b).

Sensory defects and consumer survey

The soapy/chemical flavor is one of the most important FPI sensory attribute that has been identified by expert panels in manufactured products (Shaviklo et al. 2010a, 2017). Several methods are used to cover the soapy/chemical flavor of the FPI. Adding spices and herbs to isolate products is a practical and economical approach for solving this problem. However, the isolation process must be redesigned in order to eliminate this defect.

Sandy/grainy texture is another FPI attribute that is detected in formulated products (Shaviklo et al. 2010a, 2017). Apart from modifying the isolation process, various methods such as size reduction can be used to improve FPI texture. Accordingly, this method is based on reducing the particle size of the food in unit operation. But the shape and size of these particles, as well as their distribution, affect the taste, texture, and appearance of the desired food (Shaviklo 2017b). In our observations, when

the FPI is homogenized or crushed, the appearance and taste of the product will change. Its color is brighter and the taste becomes soapy (Shaviklo et al. 2010a).

Marketing and economic aspects

The aquaculture and fisheries production are important issues to all governments due to providing food security. However, fish resources are limited and it is necessary to optimize the use of low-value/underutilized fish. Such raw materials are usually used to produce a fish meal for animal feed. But they may be converted to very valuable products (Shavandi et al. 2019). Adding value to low-value fish and fish by-products might be very profitable through the development of the FPI (Shaviklo 2016). The cost of production clearly depends on the type and price of the raw materials and equipment and machinery used. And the market share depends on the cost and functional characteristics of the FPI. However, fish protein cannot compete with vegetable and dairy proteins in the world market (Thorkelsson et al. 2008). FPI production may have a dual effect on the food and seafood industry. In the first step, being added to foods increases the nutrient content of the diet. Second, it improves the use of fishery resources and per capita protein consumption (Shaviklo 2016). The market for fish protein is not big, but it will have a good growth trend in the future (Thorkelsson et al. 2008; Shaviklo 2017a, b). Therefore, marketing and financial feasibility studies are recommended. On the other hand, it is said that seafood proteins tend to result in allergic reactions in sensitive individuals affecting marketability of the products (Matak et al. 2015). Therefore, the potential allergenicity of the isoelectric precipitation technology from aquatic sources should be investigated.

Future strategic management

In 2018, the world's population was about 7.5 billion people, and by 2050 it is estimated to reach 10 billion people. The growing number of earth's population simultaneously means increasing the need of the people for food. Therefore, there are many management challenges in this regard, which should be thought of them. Lack of living space, along with the continued growth of the population, water and food shortages, climate change and its consequences are some of the problems that the world faces today. At present, a glance on the status of the majority of world fishery activities, confirms the overfishing that leads to resource depletion. Serious depletions are indicating poor management quality in worldwide and decline of any effort. So, if in the past, our technological methods were not systematic and sustainable, today we have a duty to take a more responsible approach to protect our vulnerable

natural environment by changing our food production and processing methods (Borda et al. 2018). Therefore, the maximum utilization of the fishery by-products for human food might be considered as a strategic management tool by the policymakers. In this regard, pH-shift method is a well-recognized technology for recovering proteins from low-value fish/fishery by-products and the current obstacles in commercial production and applications of protein isolates in food systems should be overcome.

Conclusion

The utilization of aquatic resources, especially underutilized fish, and fish processing by-products are one of the most important tasks of the fisheries industry. In the meantime, it is important to extract fish protein using the pH-shift technology that has previously been used to extract protein from other animal and plant sources. Over the past 2 decades, the issue of improving the quality of fish protein isolates has been underestimated, and this has limited the commercial use of it in the food industry. Therefore, applied research should be done to develop the application of this product in various food systems and animal feed industry. In order to overcome the current challenges in commercial application of protein isolates, the following issues should be paying attention and further researches being carried out based on them: industrial process scale-up, production costs, choosing the optimum pH for extracting/solubilization of proteins, lipid and protein oxidation, the ratio of FPI in food systems, storage stability, sensory defects of FPI, consumer surveys, marketing and economic aspects.

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