Chapter 3

Development and Characterization of Fish-Based Superfoods

Daniel Ananey-Obiri and Reza Tahergorabi

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.73588

Abstract

The importance of superfoods has been well recognized in connection with health promotion, disease risk reduction, and reduction in health care costs. Fish processing generates large quantities of the by-products which are usually discarded. However, these by-products contain nutritious protein and ω-3 rich oils. Isoelectric solubilization/precipitation (ISP) is a relatively new method that can be used to recover fish protein isolate (FPI) from fish processing by-products or other low-value meat materials. FPI can be used as a main ingredient in the development of superfoods with functional ingredients such as ω-3 rich oils, dietary fiber, and salt substitute. These functional ingredients have demonstrated health benefits especially for cardiovascular disease. Therefore, this book chapter focuses on the development of superfoods from ISP-recovered FPI by incorporating such ingredients as ω-3 oil, dietary fiber, and salt substitute.

Keywords: superfoods, fish, isoelectric solubilization/precipitation, ω-3 oil, dietary fiber, salt substitute

1. Introduction

Consumers' increasingly awareness and demand for healthful foods has hit a global status, thus, requiring appropriate and timely response from stakeholders in the food processing field. Beyond the nutritional values from food intake, consumers are looking for food products that would doubly provide them with health benefits. Among other factors, higher health care cost, recent developments in scientific discoveries linking dietary habits with many diseases can be attributed to this increasing demand for functional foods by consumers [1].

Market trend in functional foods and superfoods is soaring and projections show exponential increase in demands in the future.

Colloquially, superfoods have been described as foods that are appealing and are able to deliver more calories per bite [2]. Superfoods have indigenously been referred to as functional foods [3], even now, there is still a thin line separating the two definitions. Several phrases have been used to define functional foods and these definitions vary accordingly, from continent to continent. For instance, in Europe, "a food product can only be considered functional if together with the basic nutritional impact it has beneficial effects on one or more functions of the human organism thus either improving the general and physical conditions or/and decreasing the risk of the evolution of diseases" [4]. Conversely, in the US, functional food is defined as "food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains [5]. According to Siró et al. [4], this is not a legal definition and the US has not defined functional foods for regulatory purposes. Tahergorabi et al. [6] gave a comprehensive description of what functional food should possess. They characterized functional foods as modified compositions and/or processing conditions to prevent or limit the presence of certain potentially harmful components to human health, and/or inclusion of certain desirable substances, present either naturally or added, with proven health benefits. The fundamental implication from this pool of definitions is that, functional foods have characteristic properties, which in addition to their nutritive qualities, provide health benefits when consumed. The many purported health benefits associated with superfoods/functional foods can be attributed to compounds found in these foods [1]. Bioactive compounds found in both plants and animals are responsible for the many health claims of superfoods and functional foods.

In commercial fish processing, about 60–70% of the live fish weight are probably discarded as processing by-products with just a little percentage being marketed as fillet [7]. Fish processing by-products are the remainder of the fish after processing that are not considered as fitting for human consumption, and it includes the frames, heads, skins, bones, scales, visceral from the fish. They are sometimes used in animal feeds and fertilizers, or ultimately at land filled sites. These "neglected" fish parts present opportunity to recover useful macromolecules that would have otherwise been discarded. Fish processing by-products are good sources of protein and Fat. They contain bioactive compounds such as proteins, peptides, amino acids [8] and fatty acids. Peptides are produced from hydrolysis of protein. Peptides are known to have antioxidative, antihypertensive and antithrombotic effects [9]. Fish oils produced from marine fish such as salmon, cod, and sardine which are the common sources of omega-3 polyunsaturated fatty acid (ω-3 PUFA). It is known that, ω-3 PUFA oil and the proteins are the bioactive compound that gives fish its "superfood" status [6]. The main ω-3 PUFAs found in aquatic animals are eicosapentaenoic acid (EPA, 20:5 ω3), and docosahexaenoic acid (DHA, 22:6 ω3), while linoleic acid (La, 18:2 ω6) and arachidonic acid (AA, 20:4 ω6) are the main ω-6 PUFA in aquatic animals [10]. US Food and Drug Administration (FDA) as well as, the European Food Safety Authority approved a health claim for reduced risk of cardiovascular diseases (CVDs), and if so, sudden death [11] for foods containing omeg-3 PUFAS, especially EPA and DHA. EPA and DHA are known to have antioxidant properties [12].

The benefits derived from superfoods/functional foods can be obtained not just from natural foods but from novel foods as well [1]. This chapter will succinctly review the development of functional foods from seafood protein and other functional ingredients.

2. Recovery of proteins from fish processing by-products

There are several methods for recovering protein from fish. The method of recovery affects the quality of the protein and oil, and their functionality. Fish protein isolates (FPI), fish protein hydrolysates (FPH), and surimi among others are resulting products of the various methods used in the recovery process. FPH can be produced by breaking down of the peptide bonds of the fish protein using proteolytic enzymes [13], as well as chemical methods. FPH has been used in developing many products with functional properties. For instance, the resulting protein concentrate can be dried to form a stabilized product, fish protein powder (FPP) [14]. Formulations and ready-to eat foods have been developed from FPP. However, the cost of production of FPP has placed a limit on its use [14]. Additionally, one grievous concerned about foods developed from FPH is off flavor and bitter taste associated with these foods [10, 12].

Surimi (**Figure 1**) is a concentrate of myofibrillar protein from minced fish flesh that has been deboned mechanically, and washed. It has been a long principal food ingredient in Japan diets, and has now become an integral part of many other countries diet [15, 16]. However, surimi manufacturing cannot be applied to fish processing by-products. If used, the resultant protein will have poor texture, off-odor and off-color [17]. Novel extractive technology which uses pH at basic and acidic ranges to solubilize and precipitate the protein is currently been used and it is patented [18].

Protein recovery using pH-shift also known as isoelectric solubilization/precipitation (ISP) has recently been used in developing fish protein products. ISP processing allows selective and efficient recovery of nutritious protein muscles, separation of lipids and removal of materials that are not intended for human consumption such as bone, scales, skin, etc. [19]. FPIs

Figure 1. A block of frozen surimi (usually formed in 10 kg blocks).

have been recovered using ISP both in a batch mode at the laboratory scale [20, 21] and on pilot scale [22]. ISP has also recently been used to recover protein muscle from chicken meat [6]. FPI is a concentrated fish protein that contains 90% of the dry material as protein content. FPI has constantly being used in literature to mean muscle protein that has been recovered with protein shift (ISP). It is uncooked and definitely not eaten in its form but like FPP can be used in formulation of many food products. The overall process of fish muscle recovery using ISP involves solubilization and precipitation using a pH known as Isoelectric point (pI).

The pI is specific and differs from protein to protein, and isoelectric focusing is often done to identify the pI. At this pH, the protein ions exist in equilibrium, that is they have zero net charge and are called zwitterions. The protein side chain can assume different electrostatic charges depending on the condition it is subjected to. This comes to suggest that, change in environment of the fish protein affects its solubility. That is, fish muscle solubility can be "turned" on or "turned" off depending on the surrounding environment that they are placed in. Addition of an acid to a solution leads to the dissociation of the acid producing hydronium (H_3O^+). At this low pH, the negatively charged side chains on glutamyl or aspartyl receive the hydronium and becomes protonated. This makes the solution more positively charged. When a base is added, it as well dissociates giving off hydroxide ion (^-OH). The side chains on tyrosyl, tryptophanyl, cysteinyl, lysyl, argininyl or histidinyl residues become deprotonated by giving off its hydrogen ion. This makes the surface of the solution more negatively charged. This has been attributed to the solubilization of fish muscle protein during protonation of glutamyl and aspartyl (pKa = 3.8 and 4.2 respectively) residue at acidic pH and the subsequent deprotonation of tyrosyl, tryptophanyl, and cysteinyl, (pKa = 9.5–10.5, 9.1–10.8, and 9.1–10.8, respectively) residue at basic pH. When equilibrium is reached, and protein solution attains homeostasis, the final status of a protein surface electrostatic charge at a given pH is referred to as the net charge. The accumulation of net positive or negative charge encourages protein–protein electrostatic repulsion and increased hydrodynamic volume due to expansion and swelling [23]. Protein–protein hydrophobic interaction decreases as the protein-water interaction increases. As a result of protein becoming more polar, the protein surface become surrounded with water, making it water soluble. It is however, likely to adjust the pH of a protein solution so that the number of negative charges and positive charges balances, and hence, the protein molecule assumes a net zero electrostatic charge.

The above description forms the theoretical substance for isoelectric solubilization/precipitation (ISP) that allows mechanistic understanding of pH-induced protein solubility and precipitation. The ability to recover a protein from any animal sources including fish is generally dependent on the knowledge of its pI. The initial ISP recovery process, encompasses homogenization of the fish to release the protein from the muscles and subsequent solubilization and precipitation using a pH known as Isoelectric point (PI). The homogenate is transferred into a beaker and the pH is adjusted to 11.50 ± 0.05 with 10 and 1 N NaOH. Solubilization of the protein occurs at a basic pH of 11.50 and it is then followed by centrifugation, resulting in three layers; top deposit of fish oil, middle layer of fish muscle protein solution, and bottom deposit of insoluble (bones, skin, scale, insoluble protein, membrane lipids, etc.). The middle fish protein layer is collected and pH adjusted to 5.5 ± 0.05 with 10 and 1 N HCl to allow the protein to precipitate. It is centrifuged into two layers: top, process water; bottom layer, precipitate-fish protein isolate. The summarized process is presented in **Figure 2**.

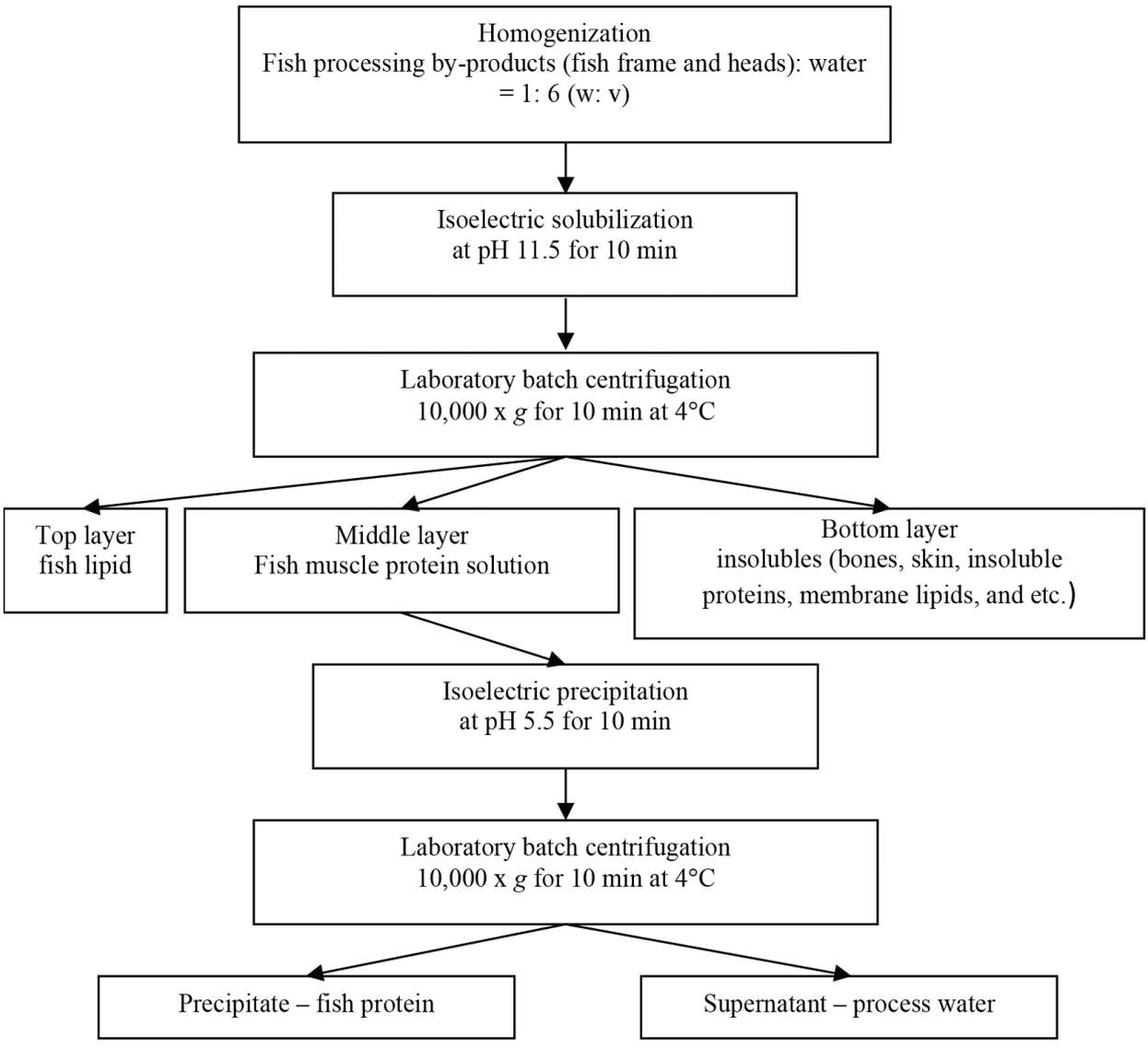

Figure 2. Flow diagram for fish protein isolate recovery using isoelectric solubilization/precipitation. Reproduced from Tahergorabi et al. [40].

3. Nutritional properties of recovered proteins by isoelectric solubilization/precipitation

Isoelectric solubilization/precipitation allows efficient and selective recovery of fish proteins and oil without changing the nutritional and functional value of the food products [19]. Evidentially, this process of recovering protein and fats does not affect the composition of ω-3 or ω-6 PUFA, and consequently, the ω-3/ω-6 ratio [24]. Also, the fatty acid composition of the fish is not altered after it has been recovered with ISP at both basic and acidic pH, as it remains fairly the same as in the starting fish [25]. The other known processes and conditions, unlike ISP, involves heating which affect protein degradation as well as endogenous antioxidants and fatty acids [26]. Hence, protein recovered by ISP significantly reduces protein degradation and fat oxidation.

Krill, salmon and fish processing by-products, have significant portion of their DHA and EPA bound to phospholipids (PLs), as well as triglycerides. Unlike triglycerides, the extraction of PLs from marine products still remains a challenge. The polar head and non-polar tail (amphipathic nature) of PLs from fish does not allow their efficient recovery [27]. Notwithstanding, ISP has successfully been used to enhance the recovery triglycerides that have no electrical polarity [19].

Protein recovery yield with ISP ranges from 42 to 90%, as it has been reported in literature [18, 23]. Protein nutritional quality is assessed by the presence of all the nine essential amino acids (EAAs), its digestibility and bioavailability. Protein recovered by ISP at basic pH was assessed and found to possess greater content of EAAs including lysine and threonine [28], making it a higher nutritional quality than ISP at acidic pH [27]. Proteins recovered by ISP have higher content of EAAs and non-Essential amino acids, and they also have higher ratio of total EAAs: total amino acid [29]. Protein bioavailability (BV) is an extension of digestibility, and it is defined as the amount of protein than can be assimilated and used in supporting the needs of the human body. Egg protein is the commonly used reference protein as it has BV of 100%. Milk, beef, fish, corn, and rice proteins have BV of 93, 75, 75, 72, and 59%, respectively [6]. Relatively, FPIs recovered with ISP have BV higher than soybean concentrate and it is equal to milk protein (BV is 93%) [30].

ISP treatment at both basic and acidic pH efficiently reduces the content of minerals such as Ca, P and Mg from recovered proteins without getting rid of the exoskeleton before processing [24, 25]. These minerals remain in the insoluble fraction after ISP, and can be used in preparing animal feed.

4. Assessment of impact of ω-3 PUFA incorporation on fish-based protein for superfoods

Humans are not able to insert double bonds in fatty acids molecules in positions closer than the 7th carbon bond from the methyl group because they do not have the necessary enzymes [31, 32]. Fish can be classified based on whether it stores its lipid in the liver or in the flesh. The former and latter groups of fish are known as lean fish (e.g. Cod fish) and fatty fish (e.g., Mackerel, tuna, salmon), respectively [33]. The amount of oil varies among fish in the same class. Fatty fish have comparatively higher amount of DHA and EPA oils than lean fish. ω-3 PUFAs are made up of long chains of carbon atoms with a methyl group at one and an acid group at the other end. They can be classified as saturated, as with no double carbon–carbon bonds, or unsaturated, that is with at least one double carbon–carbon bond. The position of the first double carbon–carbon bond from the methyl group end of an unsaturated fatty acid determines whether the saturated fatty acid would be called ω-3 or ω-6. ω-6 fatty acids, thus, the first double carbon–carbon bond is six carbon atoms away from the methyl group of the fatty acid chain. Similarly, ω-3 PUFA has the first double carbon–carbon bond three carbon atoms away from the methyl end. ω-3 PUFAS contains two healthy oils namely; EPA and DHA [34]. The third form ω-3 PUFA, ALA (α-linolenic acid) is predominantly obtained from plants sources such as leafy vegetables, flaxseeds, walnuts. ALA can be converted to long chain EPA and DHA [35] but synthesis of EPA and DHA from ALA is characterized by low amounts. Gender factor

also affects conversion capacity of ALA to EPA and DHA. Women are able to synthesize more EPA and DHA from ALA because of estrogen effects as compared to men [10]. EPA and DHA can help in the protection against cardiovascular diseases (CVD) [36].

The western diet is typified by high amount of ω-6 PUFA, and trans-fatty acids dietary intake as well as decreased intake of ω-3 PUFA. A disproportionate ratio of ω-6 to ω-3 is at 15–20 to 1 as against the recommended 1 to 1 [37–39]. The current trend is to take dietary ω-3 PUFA supplement in the form of pill or capsule to make up for the large gap. Fish is not only known to provide a good source of protein (18–25% protein) but most varieties of fish are also low in cholesterol (15–25% mg/100 g), making fish highly suitable source of ω-3 PUFAs [12]. There is therefore, a logical justification for the fortification of fish-based protein to increase the content of dietary ω-3 fatty acid.

4.1. ω-3 PUFAs content in fish-based superfoods fortified with ω-3 PUFAs rich oil

Fat contents of FPI recovered with ISP are woefully low, usually below 2/100 g ("as-is" basis), and with this, meeting the recommended dietary intake of ω-3 PUFAs will be difficult. Tahergorabi et al. [40] examined the impact of fortification of FPI gels recovered with ISP using ω-3 PUFAs-rich oils. The oils were obtained from both plant and animals sources including flaxseed, fish, algae, krill, or their blend (Flaxseed, algae: fish, 8:1:1). These oils are good sources of ω-3 PUFAs, and hence their selection [41, 42]. The pastes were formulated with 10/100 g of ω-3 PUFAs- rich oils before cooking to form gels. The fortification increased ($P > 0.05$) the total content of ω-3 PUFAs (34–51%) of the gels, higher than gels that were not fortified (20%). The highest ($P > 0.05$) ω-3 PUFAs content was in gels fortified with flaxseed (51%), followed by blend (49%), krill (46%), and fish oil (34%). The EPA, DHA, ALA contents increment was characterized by variations in the fatty acid (FA) in total fatty acids. Krill and fish oil- fortified gels resulted in the greatest ($P > 0.05$) content of EPA (24 and 16%, respectively), with other fortified gels containing less than 3% of EPA. Results obtained from krill and fish oil are promising because, both oils are very good sources of EPA and DHA whereas algal oils contain DHA as their main ω-3 PUFA [43].

The differences in FA compositions of the gels resultantly affect the ratios of ω-6/ω-3 and unsaturated/saturated FAs (UFAs/SFAs). The lowest ω-6/ω-3 FAs ratio was seen in gels fortified with algae, krill, and fish oils (0.07, 0.11, and 0.12, respectively), followed by gels with added blend and flaxseed oil (0.29 and 0.32, respectively). The highest ($P < 0.05$) ratio of ω-6/ω-3 FA was seen in gels fortified with flaxseed and blend due to the high content of LA (linolenic acid) in flaxseed as compared to much lower LA content in the other oils. Despite the recorded highest ratio of ω-6/ω-3 with flaxseed oil, it is still much lower than the recommended 1/1 ratio [44]. It is still yet better to consume fish protein isolates fortified with any of the five oil types used in the present study, more advisably those fortified with flaxseed oil. This would help lessen the gap between ω-6 and ω-3 PUFAs in Western diets. On the other hand, gels fortified with flaxseed and blend showed the highest ($P < 0.05$) UFAs/SFAs ratio, 8.0 and 6.1 respectively; and the lowest ($P < 0.05$) ratio was recorded for fortification with krill, algae, and fish oils, 3.8, 3.5, and 2.3, respectively. Although the latter three oils resulted in lower UFAs/SFAs ratios in the gels, they still contained 2–4 times as much UFAs as SFAs.

4.2. Color properties of fish-based superfoods fortified with ω-3 PUFAs rich oils

The assessment of physicochemical properties of a new developed protein product is necessary for consumer acceptability. Consumers are tuned to certain original physical and chemical properties of proteins and are likely to reject products that do not meet their requirements. In the same vain, consumers may reject a product irrespective of its quality, if it does not appeal to their senses. Maintaining high sensory attributes has been one of the challenges confronting the development of functional and superfoods. Color as an attribute of fish and fish products is a strong determinant of consumers' acceptability. In as much as FPI recovered with ISP possess quality characteristic properties, its esthetic appearance has been a rough edge that needs to sharpened.

Whiteness of color in sea-foods is a desirable attribute and variable when it comes to quality assessment of such foods. In spite of the many touted qualities of protein and oil recovered by ISP, heat set gels made from fish protein isolate develop poor color due to dark pigments that are extracted and recovered with the proteins [45]. These dark pigment results in high yellowness (b*), thus, lowering the whiteness of the heat set gel. Numerous research studies have been geared towards improving the whitening attribute of heat set gels developed from proteins. Titanium dioxide (TiO_2) is a well-known whitening agent used in the cosmetic and food industry. Titanium dioxide has been used to improve the color attribute of gels developed from proteins recovered by ISP, in fish [46] and chicken proteins [47]. It does so by blocking/scattering light and giving white appearance [48]. Gels that have been treated with TiO_2 have color attribute improved beyond that of products that are not treated. Incorporation of ω-3 fatty acid into heat set gels developed from FPI have yielded positive results, improving color attributes. This discovery simply implies that, fortifying FPI with ω-3 PUFAs contributes to color improvement without having to add TiO_2. Fish protein isolate pastes were fortified with different types of ω-3 PUFAs oils, and gels subsequently were prepared [49]. The quest was to improve the color, whilst concurrently improving their nutrition and texture. The same observation was made by Pérez-Mateos et al. [50] when they fortified surimi with ω-3 from three different sources. Usually, vegetable oils are used in surimi-based products for color improvement [51]. Oils addition to products proportionally increase their lightness (L*) because of light scattering, thus, improving whiteness [50]. In measuring the whiteness of gel, values for the CIE (commission international d'Eclairage of France) color system using L*, a* (redness), and b* tristimulus color are determined and used to calculate the whiteness of the gel. Gel whiteness is calculated by the following equation [52]. The color of the gels was generally improved after it was formulated with ω-3 PUFAs oils.

4.3. Texture properties of fish-based superfoods fortified with ω-3 PUFAs rich oils

The texture of fish and fish product is a salient physicochemical property that determines the quality of fish and fish products. Texture measures the mechanical properties in the form hardness/firmness, resilience, cohesiveness, springiness, adhesiveness, and viscosity by vision, hearing, somesthesis, and kinesthesis of human sense [53]. Torsion test, Kramer shear test, and texture profile analysis (TPA) test are three possible methods that can be used to determine texture. Torsion test is the basic test due to its objectivity in measuring mechanical properties of protein-based gels [54]. Critical quality parameters for restructured gelled products are gel strength and cohesiveness. Cohesiveness as defined as "the extent to which a material can be

deformed before it ruptures" and hardness as the force necessary to attain a given deformation" [55]. Trout protein gel fortified with or without ω-3 PUFAs oils were compared. Heat-set gels were fortified with flaxseed, fish, and algae oil and texture of the gels were measured using texture profile analysis (TPA) [49]. There was a general improvement in gel texture, particularly with algae oil. These results indicate the possibility of developing superfood products from ISP recovered FPI with acceptable texture properties using ω-3 PUFAs oils.

5. Role of salt substitute and ω-3 PUFAs rich oil in fish-based superfoods

Dietary sodium chloride has been a major component of many food products. The major mineral, sodium, has been correlated with hypertension and many cardiovascular diseases. In spite of this revelation of adverse effect of consuming this sodium related salt on triggering CVDs, it still remains a major dietary component in diets because of its undeniable taste. Therefore, during food processing, the sodium can be reduced or replaced to reduce salt-related CVDs. Salt substitute (potassium) is currently being exploited as a potential substitute for sodium in diets as it provides a non-pharmacological approach in lowering blood pressure. Potassium, unlike sodium has antihypertensive properties and are much higher recommended maximum intake level than sodium (sodium—2300 mg/day, potassium—4700 mg/day) [56].

Potassium Chloride-based salt substitute was used to extract myofibrillar proteins to obtain fish protein paste, a procedure described by Jaczynski and Park [57]. The fish protein paste was then chopped at low speed for 5 min in a universal food processor. The level of the salt substitute was found to be optimal and similar to salt (NaCl) in terms of texture and a color development likewise the protein gelation and reduction of water activity in heat-set fish protein gels [49]. The salt substitute contained 68/100 g of KCl and L- lysine mono-hydrochloride and calcium stearate. The resulting concentration of fish protein isolate is equivalent to 20 g of NaCl per 1000 g batch. It was then fortified with different ω-3 PUFAs oils and the fish protein heat-set gels were subsequently prepared. Gels made with salt substitute with different ω-3 PUFAs oil were analyzed for their sodium and potassium content. Sodium content was reduced with concurrent increase in potassium content in the gel.

6. Physicochemical properties of fish-based superfoods fortified with dietary fiber

The European community defined dietary fiber as a carbohydrate polymer with three or more monomeric units, which are neither digested nor absorbed in the human intestine and according to the American Association of Cereal Chemists (AACC) defined it as an edible part of plants or analogous carbohydrates, that are resistant to digestion and absorption in the human small intestine and can be partially or completely fermented by bacteria. Oligosaccharides, polysaccharides, lignin, and other plant sources provide fiber. Dietary fiber intake protects individuals against CVDs, diabetes, hypertension, obesity, stroke and certain gastrointestinal diseases [58, 59]. The

health benefits of dietary fiber have been made to be understood by many countries, and they have developed guidelines, and have also allowed for fortification of food products with dietary fiber. The fortification of food with dietary fiber has been imperative, and has been encouraged, because most diets in the western countries are deficient in dietary fiber. Daily dietary recommendation for most European countries and for countries like Australia, and the New Zealand and the USA are in the order 30–35 g for men and 25–32 g for women [60]. The Dietary Guidelines Advisory committee (2010), find out that the average intake among Americans is only 15 g. The same can be said about other countries, as having low average intake of dietary fiber. Additionally, dietary fiber possesses gelling characteristics that have technological implications in food manufacturing and final food product. Dietary fiber has wide range of functionalities such as gel-forming abilities, cryoprotectant, thickener and stabilizer [61]. Cellulose is a polymer of linear glucose monomer (β 1–4 linkage) chain and it is the commonly used dietary fiber in food fortification. It is added in foods in powdered form. Powered cellulose is used in food fortification, and it has been used in baked goods as non-caloric bulk agent. Long chain-chain cellulose (> 110 μm), due to their porous nature, retains more water and oil than short chain fibers.

Naturally, the addition of dietary fiber to fish protein (surimi) is not common, and thus, limited literature report on it. Notwithstanding, soluble fibers such as carrageen, chicory root insulin, garrofin, guar, and xanthan have previously been added to surimi [62, 63]. The use of these soluble fibers resulted in loss of gel elasticity and strength coupled with gel hardening, and increase in brittleness of surimi protein [64]. This is not the case of surimi fortified with powdered cellulose as they tend to improve thermal gelation of surimi proteins [65]. In the fortification of surimi with powdered cellulose powder, the protein concentration and moisture content were maintained constant but variable concentrations of insoluble fiber, and silicon dioxide (SiO_2) were added to the surimi paste as an inert filler [66]. Insoluble fiber and SiO_2 were then added to the surimi pastes to a final total concentration of 8/100 g. The ingredients were chopped to ensure thorough mixing. The resulting pastes were subjected to texture analysis, color analysis, etc. Textural properties (shear stress and strain) of surimi fortified with 2, 4, and 6 g/100 fiber had greater ($P > 0.05$) gel strength than those that were not treated with fiber [66]. The color of the surimi fortified with fiber showed good color properties including slight whitening effect except for 8/100 g of fiber fortification. As demonstrated by differential scanning calorimetry, added fiber did not interfere with the thermal transitions of surimi myosin and actin.

Powdered cellulose is an obvious choice for fortification of surimi with dietary fiber because of its bland flavor and whiteness, as these characteristics do not alter the color and flavor of surimi. They do not interfere with the natural characteristics of the products that are fortified. They instead added whiteness to the color of the surimi product.

7. Conclusions

Superfoods/functional foods can be developed from seafoods including fish protein (ISP) isolate and surimi recovered with isoelectric/precipitation (ISP) with acceptable sensory and nutritional qualities. Fish protein isolates recovered with ISP can serve as a vehicle not just for improving dietary content of ω-3 PUFAs, but the fortification with several useful ingredients. The overall ω-3 PUFAs oil content in fish can be improved by incorporating ω-3 PUFAs

oil into the fish, improve the color, texture, rheology of the fish product. It also allows the use of salt substitute to increase the potassium content of the fish whiles reducing sodium content. Interestingly, ISP can be used to recover proteins from different sources including food processing-by products which otherwise would have been difficult to recover using conventional methods. Surimi can be prepared using the conventional water-process, as well as using ISP. It is possible to fortify surimi products with dietary fiber and obtain good color and textural properties. The benefits of recovering fish proteins are numerous, they are reported to contribute to ash content of the product, and thus, fluoride content of the products [43].

Acknowledgements

This work was supported, in part, by the Agriculture Research Program and the Department of Family and Consumer Sciences at North Carolina Agriculture and Technical State University, Greensboro, N.C., USA, through the USDA Evans-Allen Project No. NC.X-311-5-18-170-1.

Conflict of interest

The authors declare no conflict of interest.

Author details

Daniel Ananey-Obiri and Reza Tahergorabi*

*Address all correspondence to: rtahergo@ncat.edu

Food and Nutritional Sciences Program, North Carolina Agricultural and Technical State University, Greensboro, NC, USA

References

[1] Milner JA. Functional foods: The US perspective. The American Journal of Clinical Nutrition. 2000;**71**:1654-1659

[2] Rozin P. The meaning of food in our lives: A cross-cultural perspective on eating and well-being. Journal of Nutrition Education and Behavior. 2005;(37):107-112. DOI: 10.1016/S1499-4046(06)60209-1

[3] Lunn J. Superfoods. Nutrition Bulletin. 2006;**31**:171-172. DOI: 10.1111/j.1467-3010.2006.00578.x

[4] Siró I, Kápolna E, Kápolna B, Lugasi A. Functional food. Product development, marketing and consumer acceptance — A review. Appetite. 2008;**51**:456-467. DOI: 10.1016/j.appet.2008.05.060

[5] Thomas PR, Earl RO. Opportunities in the Nutrition and Food Sciences: Research Challenges and the Next Generation of Investigators. Washington, D.C.: National Academies Press; 1994

[6] Tahergorabi R, Matak KE, Jaczynski J, Animal D, Sciences N, Box PO. Fish protein isolate: Development of functional foods with nutraceutical ingredients. Journal of Functional Foods. 2015;**18**:746-756. DOI: 10.1016/j.jff.2014.05.006

[7] Gehring CK, Davenport MP, Jaczynski J. Functional and nutritional quality of protein and lipid recovered from fish processing by-products and underutilized aquatic species using isoelectric solubilization/precipitation. Current Nutrition & Food Science. 2009;**5**:17-39. DOI: 10.2174/157340109787314703

[8] Harnedy PA, Fitzgerald RJ. Bioactive proteins, peptides, and amino acids from macroalgae. Journal of Phycology. 2011;**47**:218-232. DOI: 10.1111/j.1529-8817.2011.00969.x

[9] Hamed I, Özogul F, Özogul Y, Regenstein JM. Marine bioactive compounds and their health benefits: A review. Comprehensive Reviews in Food Science and Food Safety. 2015;**14**:446-465. DOI: 10.1111/1541-4337.12136

[10] Chen YC, Nguyen J, Semmens K, Beamer S, Jaczynski J. Enhancement of omega-3 fatty acid content in rainbow trout (*Oncorhynchus mykiss*) fillets. Journal of Food Science. 2006;**71**:383-389. DOI: 10.1111/j.1750-3841.2006.00115.x

[11] Giltay EJ, Gooren LJG, Toorians AWFT, Katan MB, Zock PL. Docosahexaenoic acid concentrations are higher in women than in men because of estrogenic effects. The American Journal of Clinical Nutrition. 2004;**80**:1167-1174

[12] Ganesan B, Brothersen C, McMahon DJ. Fortification of foods with omega-3 polyunsaturated fatty acids. Critical Reviews in Food Science and Nutrition. 2014;**54**:98-114. DOI: 10.1080/10408398.2011.578221

[13] Kristinsson HG, Rasco BA. Fish protein hydrolysates: Production, biochemical, and functional properties. Critical Reviews in Food Science and Nutrition. 2000;**40**:43-81. DOI: 10.1080/10408690091189266

[14] Shaviklo GR, Thorkelsson G, Arason S, Kristinsson HG, Sveinsdottir K. The influence of additives and drying methods on quality attributes of fish protein powder made from saithe (*Pollachius virens*). Journal of the Science of Food and Agriculture. 2010;**90**:2133-2143. DOI: 10.1002/jsfa.4062

[15] Shaviklo AR. Development of fish protein powder as an ingredient for food applications: A review. Journal of Food Science and Technology. 2013;**52**:648-661. DOI: 10.1007/s13197-013-1042-7

[16] Tina N, Nurul H, Ruzita A. Surimi-like material: Challenges and prospects. International Food Research Journal. 2010;**17**:509-517

[17] Sanmartín E, Arboleya JC, Villamiel M, Moreno FJ. Recent advances in the recovery and improvement of functional proteins from fish processing by-products: Use of protein

glycation as an alternative method. Comprehensive Reviews in Food Science and Food Safety. 2009;**8**:332-344. DOI: 10.1111/j.1541-4337.2009.00083.x

[18] Hultin HO, Kelleher SD. Process for Isolating a Protein Composition from a Muscle Source and Protein Composition. 6,288,216 B1; 1999

[19] Gehring CK, Gigliotti JC, Moritz JS, Tou JC, Jaczynski J. Functional and nutritional characteristics of proteins and lipids recovered by isoelectric processing of fish by-products and low-value fish: A review. Food Chemistry. 2011;**124**:422-431. DOI: 10.1016/j.foodchem.2010.06.078

[20] Choi YJ, Park JW. Acid-aided protein recovery from enzyme-rich Pacific whiting. Journal of Food Science. 2002;**67**:2962-2967. DOI: 10.1111/j.1365-2621.2002.tb08846.x

[21] Kim YS, Park JW, Choi YJ. New approaches for the effective recovery of fish proteins and their physicochemical characteristics. Fisheries Science. 2003;**69**:1231-1239. DOI: 10.1111/j.0919-9268.2003.00750.x

[22] Mireles DeWitt CA, Nabors RL, Kleinholz CW. Pilot plant scale production of protein from catfish treated by acid solubilization/isoelectric precipitation. Journal of Food Science. 2007;**72**. DOI: 10.1111/j.1750-3841.2007.00407.x

[23] Kristinsson HG, Hultin HO. Changes in conformation and subunit assembly of cod myosin at low and high pH and after subsequent refolding. Journal of Agricultural and Food Chemistry. 2003;**51**:7187-7196. DOI: 10.1021/jf026193m

[24] Chen YC, Tou JC, Jaczynski J. Amino acid, fatty acid, and mineral profiles of materials recovered from rainbow trout (*Oncorhynchus mykiss*) processing by-products using isoelectric solubilization/precipitation. Journal of Food Science. 2007;**72**. DOI: 10.1111/j.1750-3841.2007.00522.x

[25] Lansdowne LR, Beamer S, Jaczynski J, Matak KE. Survival of *Escherichia coli* after isoelectric solubilization and precipitation of fish protein. Journal of Food Protection. 2009;**72**:1398-1403

[26] Nolsoe H, Undeland I. The acid and alkaline solubilization process for the isolation of muscle proteins: State of the art. Food and Bioprocess Technology. 2009;**2**

[27] Chen YC, Jaczynski J. Gelation of protein recovered from whole antarctic krill (*Euphausia superba*) by isoelectric solubilization/precipitation as affected by functional additives. Journal of Agricultural and Food Chemistry. 2007;**55**:1814-1822. DOI: 10.1021/jf0629944

[28] Taskaya L, Chen YIC, Beamer S, Tou JC, Jaczynski J. Compositional characteristics of materials recovered from whole gutted silver carp (*Hypophthalmichthys molitrix*) using isoelectric solubilization/precipitation. Journal of Agricultural and Food Chemistry. 2009;**57**:4259-4266. DOI: 10.1021/jf803974q

[29] Chen Y-C, Tou J, Jaczynski J. Amino acid and mineral composition of protein and other components and their recovery yields from whole antarctic krill (Euphausia superba) using isoelectric solubilization/precipitation Introduction. Journal of Food Science. 2009;**74**:H31-H39. DOI: 10.1111/j.1750-3841.2008.01026.x

[30] Bridges KM, Gigliotti JC, Altman S, Jaczynski J, Tou JC. Determination of digestibility, tissue deposition, and metabolism of the omega-3 fatty acid content of krill protein concentrate in growing rats. Journal of Agricultural and Food Chemistry. 2010;**58**:2830-2837. DOI: 10.1021/jf9036408

[31] Lee HJ, Park SH, Yoon IS, Lee G-W, Kim YJ, Kim J-S, et al. Chemical composition of protein concentrate prepared from Yellowfin tuna *Thunnus albacares* roe by cook-dried process. Fisheries and Aquatic Sciences. 2016;**19**:12. DOI: 10.1186/s41240-016-0012-1

[32] Arts MT, Brett MT, Kainz M JTA-TT. Lipids in Aquatic Ecosystems; 2009

[33] Calder PC, Yaqoob P. Omega-3 polyunsaturated fatty acids and human health outcomes. BioFactors. 2009;**35**:266-272. DOI: 10.1002/biof.42

[34] Rizliya V, Mendis E. Biological, physical, and chemical properties of fish oil and industrial applications BT - seafood processing by-products: Trends and applications. In: Kim S-K, editor. Seaf. Process. By-Products Trends Appl. New York, NY: Springer New York; 2014. pp. 285-313. DOI: 10.1007/978-1-4614-9590-1_14

[35] Ungerfeld R, Dago AL, Rubianes E, Forsberg M. Response of anestrous ewes to the ram effect after follicular wave synchronization with a single dose of estradiol-17beta. Reproduction, Nutrition, Development. 2004;**44**:89-98. DOI: 10.1051/rnd

[36] Kris-Etherton PM, Harris WS, Appel LJ. Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. Circulation. 2002;**106**:2747-2757. DOI: 10.1161/01.CIR.0000038493.65177.94

[37] Eaton SB, Konner M. Paleolithic nutrition. A consideration of its nature and current implications. The New England Journal of Medicine. 1985;**312**:283-289. DOI: 10.1056/NEJM198501313120505

[38] Eaton SB, Konner M, Shostak M. Stone agers in the fast lane: Chronic degenerative diseases in evolutionary perspective. The American Journal of Medicine. 1988;**84**:739-749

[39] Simopoulos AP. Omega-3 fatty acids in health and disease and in growth and development. The American Journal of Clinical Nutrition. 1991;**54**:438-463

[40] Tahergorabi R, Beamer SK, Matak KE, Jaczynski J. Chemical properties of ω-3 fortified gels made of protein isolate recovered with isoelectric solubilisation/precipitation from whole fish. Food Chemistry. 2013;**139**:777-785. DOI: 10.1016/j.foodchem.2013.01.077

[41] Kassis NM, Beamer SK, Matak KE, Tou JC, Jaczynski J. Nutritional composition of novel nutraceutical egg products developed with omega-3-rich oils. LWT- Food Science and Technology. 2010;**43**:1204-1212. DOI: https://doi.org/10.1016/j.lwt.2010.04.006

[42] Kassis NM, Gigliotti JC, Beamer SK, Tou JC, Jaczynski J. Characterization of lipids and antioxidant capacity of novel nutraceutical egg products developed with omega-3-rich oils. Journal of the Science of Food and Agriculture. 2012;**92**:66-73. DOI: 10.1002/jsfa.4542

[43] Gigliotti JC, Davenport MP, Beamer SK, Tou JC, Jaczynski J. Extraction and characterisation of lipids from antarctic krill (*Euphausia superba*). Food Chemistry. 2011;**125**:1028-1036. DOI: 10.1016/j.foodchem.2010.10.013

[44] Simopoulos AP. Evolutionary aspects of omega-3 fatty acids in the food supply. Prostaglandins, Leukotrienes, and Essential Fatty Acids. 1999;**60**:421-429

[45] Taskaya L, Chen Y, Jaczynski J. Texture and colour properties of proteins recovered from whole gutted silver carp (*Hypophthalmichthys molitrix*) using isoelectric solubilisation/precipitation. Journal of the Science of Food and Agriculture. 2009;**89**:349-358. DOI: 10.1002/jsfa.3461

[46] Taskaya L, Chen Y, Jaczynski J. Color improvement by titanium dioxide and its effect on gelation and texture of proteins recovered from whole fish using isoelectric solubilization/precipitation. LWT- Food Science and Technology. 2010;**43**:401-408. DOI: 10.1016/j.lwt.2009.08.021

[47] Tahergorabi R, Beamer SK, Matak KE, Jaczynski J. Effect of isoelectric solubilization/precipitation and titanium dioxide on whitening and texture of proteins recovered from dark chicken-meat processing by-products. LWT- Food Science and Technology. 2011;**44**:896-903. DOI: 10.1016/j.lwt.2010.10.018

[48] Feng X, Zhang L, Chen J, Guo Y, Zhang H, Jia C. Preparation and characterization of novel nanocomposite films formed from silk fibroin and nano-TiO_2. International Journal of Biological Macromolecules. 2007;**40**:105-111. DOI: 10.1016/j.ijbiomac.2006.06.011

[49] Tahergorabi R, Beamer SK, Matak KE, Jaczynski J. Functional food products made from fish protein isolate recovered with isoelectric solubilization/precipitation. LWT- Food Science and Technology. 2012;**48**:89-95. DOI: 10.1016/j.lwt.2012.02.018

[50] Pérez-Mateos M, Boyd L, Lanier T. Stability of omega-3 fatty acids in fortified surimi seafoods during chilled storage. Journal of Agricultural and Food Chemistry. 2004;**52**:7944-7949. DOI: 10.1021/jf049656s

[51] Park JW. Ingredient technology for surimi and surimi seafood. In: Park JW, editor. Surimi Surimi Seaf. Boca Raton, FL: Taylor & Francis; 2005, pp. 649-707

[52] Kristinsson GH, Theodore EA, Demir N, Ingadottir B. A comparative study between acid- and alkali-aided processing and surimi processing for the recovery of proteins. Journal of Food Science. 2005;**70**:298-306

[53] Hagen Ø, Solberg C, Sirnes E, Johnston IA. Biochemical and structural factors contributing to seasonal variation in the texture of farmed Atlantic halibut (*Hippoglossus hippoglossus* L.) flesh. Journal of Agricultural and Food Chemistry. 2007;**55**:5803-5808. DOI: 10.1021/jf063614h

[54] Tahergorabi R, Sivanandan L, Beamer SK, Matak KE, Jaczynski J. A three-prong strategy to develop functional food using protein isolates recovered from chicken processing by-products with isoelectric solubilization/precipitation. Journal of the Science of Food and Agriculture. 2012;**92**:2534-2542. DOI: 10.1002/jsfa.5668

[55] Szczesniak AS. Texture is a sensory property. Food Quality and Preference. 2002;**13**:215-225. DOI: 10.1016/S0950-3293(01)00039-8

[56] Geleijnse JM, Witteman JC, Bak AA, den Breeijen JH, Grobbee DE. Reduction in blood pressure with a low sodium, high potassium, high magnesium salt in older subjects with mild to moderate hypertension. BMJ 1994;**309**:436-440

[57] Jaczynski J, Park JW. Physicochemical changes in Alaska pollock surimi and surimi gel as affected by electron beam. Journal of Food Science. 2004;**69**:C53-C57. DOI: 10.1111/j.1365-2621.2004.tb17855.x

[58] Anderson JW, Baird P, Davis RHJ, Ferreri S, Knudtson M, Koraym A, et al. Health benefits of dietary fiber. Nutrition Reviews. 2009;**67**:188-205. DOI: 10.1111/j.1753-4887.2009.00189.x

[59] InterAct C. Dietary fibre and incidence of type 2 diabetes in eight European countries: The EPIC-InterAct Study and a meta-analysis of prospective studies. Diabetologia. 2015;**58**:1394-408

[60] Stephen AM, Champ MM-J, Cloran SJ, Fleith M, van Lieshout L, Mejborn H, et al. Dietary fibre in Europe: Current state of knowledge on definitions, sources, recommendations, intakes and relationships to health. Nutrition Research Reviews. 2017;**30**:2830-2837. DOI: 10.1017/S095442241700004X

[61] Sofi S, Singh J, Rafiq S, Rashid R. Fortification of dietary fiber ingriedents in meat application: A review. International Journal of Biochemistry Research & Review. 2017;**19**:1-14. DOI: 10.9734/IJBCRR/2017/36561

[62] Sánchez-Alonso I, Solas MT, Borderías AJ. Technological implications of addition of wheat dietary fibre to giant squid (*Dosidicus gigas*) surimi gels. Journal of Food Engineering. 2007;**81**:404-411. DOI: https://doi.org/10.1016/j.jfoodeng.2006.11.015

[63] Cardoso C, Mendes R, Vaz-Pires P, Nunes ML. Effect of dietary fibre and MTGase on the quality of mackerel surimi gels. Journal of the Science of Food and Agriculture. 2009;**89**:1648-1658. DOI: 10.1002/jsfa.3636

[64] Cardoso C, Mendes R, Nunes ML. Effect of transglutaminase and carrageenan on restructured fish products containing dietary fibres. International Journal of Food Science and Technology. 2007;**42**:1257-1264. DOI: 10.1111/j.1365-2621.2006.01231.x

[65] Sánchez-Alonso I, Haji-Maleki R, Borderias AJ. Wheat fiber as a functional ingredient in restructured fish products. Food Chemistry. 2007;**100**:1037-1043. DOI: 10.1016/j.foodchem.2005.09.090

[66] Debusca A, Tahergorabi R, Beamer SK, Matak KE, Jaczynski J. Physicochemical properties of surimi gels fortified with dietary fiber. Food Chemistry. 2014;**148**:70-76. DOI: 10.1016/j.foodchem.2013.10.010