The United Nations University
FISHERIES TRAINING PROGRAMME

P.O. Box 1390, Skulagata 4
120 Reykjavik, Iceland

Final Project 2006

QUALITY ASSESSMENT OF FISH PROTEIN ISOLATES USING SURIMI STANDARD METHODS

Gholam Reza Shaviklo

Iranian Fisheries Organisation (SHILAT)
No.250, West Fatemi Street
Tehran, Iranshaviklo@gmail.com

SupervisorDr. Ragnar Johannsson
MATIS ehf
ragnar@matis.is

ABSTRACT

Fish protein isolate is a kind of protein ingredient which is prepared from different kinds of raw material, without retaining the original shape of the muscle. It is generally not consumed directly and is used as raw material for production of value added products. In this study, the quality attributes of fish protein isolates (FPI) made from raw material of filleting processes of cod (*Gadus morhua*), saithe (*Theragra chalcogramma)*, and Arctic charr (*Salvelinus alpinus*) were determined based on the Codex Code of Practice for frozen surimi (FAO/WHO 2005). The results were compared to the attributes of conventional surimi and other fish protein isolates made from fish fillets. The results indicated that although quality attributes of these products, such as: gel strength, gel forming ability and whiteness were different to conventional surimi, or FPI made from fresh fillets, it is still a good source of protein for the production of ready to eat fish products. The texture, taste and flavour of FPI products, which were produced in this study, were acceptable but they could be improved by adjusting different ingredients and spices according to the target market.

Key words: Fish protein isolate (FPI), protein isolate (PI), surimi, gel strength, cod, saithe, Arctic charr, gel forming ability, whiteness.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Production of fish protein ingredients is growing throughout the world. Increased demands for traditional raw materials for production of fish protein ingredients are leading to great pressure on fish stocks (Hultin *et al.* 2000). This has led to over-fishing of many of the more traditional species and has required governmental intervention to prevent the collapse of important species (Hultin *et al*. 2005). There are several methods to produce fish protein ingredients such as surimi, minced fish, and fish protein isolate, etc. Surimi, the largest source of fish protein ingredients, is obtained from mechanically de-boned fish flesh which is washed with water and blended with cryoprotectant (Figure 1). It can be used as a versatile raw material for producing many kinds of value added seafood products (Shaviklo 2000). Surimi is usually produced from low value white flesh fish, like Pacific whiting and Alaska pollock, with a typical yield of 25-28% of the body weight of the fish (Park *et al.* 1997).

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

Surimi processing has been unsuccessful from unconventional raw materials, such as fatty pelagic species, in part because of the abundance of oxidatively unstable lipids and many pro-oxidants (especially hem proteins), which result in colour and oxidation problems (Hultin 2002). Most attempts to make surimi from materials rich in dark muscle have resulted in products with poor gelation and considerable problems with colour and lipid oxidation. Separation of undesirable constituents of these materials such as bones, scales, skin, and fat from the desirable muscle proteins has also met with numerous difficulties (Hultin *et al.* 2005).

To solve the problem of utilisation of unconventional raw material (dark muscle fish, fatty fish) and also fish by-products (fish cut offs, fish frames etc.) a process was developed to economically produce functional protein isolates from these kinds of raw materials. This technology uses the pH-dependent solubility properties of fish muscle proteins for their separation and recovery from other components of muscle which are not desirable in a final product. Figure 2 shows fish protein isolate (FPI) made from Arctic charr fish frames.

A significant difference between the conventional and alkaline aided fish protein isolates, in relation to yield, is that in the alkali-aided process sarcoplasmic proteins

(haemoglobin, myoglobulin and proteolytic enzymes) and other proteinous materials are not removed (Kim *et al.* 2003).

Figure 2: Fresh FPI made from Arctic charr frames (it could be packed like frozen surimi).

This process offers a new technology to recover and use protein from more than 50 million tons of underused aquatic species (Kristinsson *et al*. 2005) and a considerable amount of fish flesh remaining on fish frames after filleting operations (Hultin *et al.* 2000). Quality assessment is the key to time saving and better quality control, so in this work quality attributes of these new products have been studied. Since knowledge of rheological and physiochemical changes of fish muscle protein prepared under alkali and acid solubilisation is limited the results from this work are expected to give important information for quality improvement of fish protein isolates from by-products of filleting operations and development of value added products from this new source of fish protein.

1.1 Assessment of FPI attributes

Fish protein isolate is a protein concentrate which is prepared from fish muscle without retaining the original shape of the fish muscle. Generally it is not consumed directly, but used as raw material for the production of value added products or as an ingredient in the food industry. As there are no quality standards for the evaluation of fish protein isolates and because of the similarity of this product to surimi, the methods which have been described in the Codex Code of Practice for frozen surimi (FAO/WHO 2005) developed by the US and Japanese governments are used for quality assessment of FPI. The quality of surimi is determined based on a number of characteristics, some more important than others. Quality is assessed using raw surimi tests and cooked surimi tests. Among all properties related to surimi quality there is no doubt that gel properties, namely gel strength, and whiteness are of primary interest in surimi production and trade which were considered for FPI evaluation in this study.

Objectives

The objectives of this study were:

- To review processing and technology of FPI and surimi;
- To assess quality of FPI using surimi standard methods;
- To evaluate quality attributes of FPI made from the rest raw material of filleting processes of cod, saithe, and Arctic charr, and comparing the results to attributes of conventional surimi or FPI made from fresh fillets;
- Using the results, to improve the quality of FPI and its products.

2 PRODUCTION OF FISH PROTEIN INGREDIENTS

Demand for fish protein ingredients is growing worldwide. The quality and characteristics of these products are highly dependent on the source of muscle protein and the processing procedures applied. Species with white flesh and low fat content are considered most suitable for manufacturing protein ingredients, but there are other protein sources that are suitable for manufacturing protein ingredients. Dark muscle fish species currently make up 40-50% of the total fish catch in the world. There is great interest in using the large quantities of these low value, fatty, pelagic fish for human food (Park and Lanier 2000). Also there is a very little usage of the skeletons of fish after filleting and the flesh collected from this source for human consumption (Hultin *et al*. 2000). There are several methods to produce fish protein ingredients from different raw materials. In this chapter the processing of FPI and conventional surimi are described, and the standard methods used for quality assessment of surimi.

2.1 Conventional surimi

Surimi originated in Japan where it has been a traditional food source for centuries. For many years the industry was dependent on supply and availability of fresh fish. The discovery of adding cryoprotectants to surimi in order to prevent protein denaturation during freezing revolutionised the industry (Park and Lanier 2000) which was no longer dependent on fluctuations in supply of fresh fish.

Surimi is minced fish in which all water-soluble proteins in the fish muscle have been washed out and thus contains only 15-16% water insoluble proteins, 75% moisture and 8-9% freezing stabilisers. The water insoluble proteins are elastic and make it possible to form surimi into fish cakes and crab sticks through further processing. However, freezing reduces elasticity. Use of freezing stabilisers is therefore a condition for stabilisation of the surimi quality during long periods of frozen storage, often more than 1 year (Shaviklo 2000).

2.1.1 Raw material

A variety of fish species are used for surimi production from cold water whitefish like Alaska pollock, and tropical species such as threadfin bream (Guenneugues and Morrissey 2005) to farmed species like Chinese carp (Shaviklo 2000). The use of fish species with high dark/red muscle and fat content has met with some complications such as low grade protein gels, colour problems and lipid oxidation (Park and Lanier 2000). The reason for poorer gelling ability of products from species with darker muscle has been related to high photolytic activity, low muscle pH which can lead to accelerated protein denaturation, a high concentration of sarcoplasmic proteins, higher lipid content and a high concentration of hem proteins in the muscle.

2.1.2 Processing methods

Surimi processing consists of several steps that are described in Figure 3. For surimi production raw material should be fresh and kept chilled. Heading and gutting of fish should be done as soon as possible. Fish flesh is separated from the bones and skin using a fish bone separator machine. This should be done at a low temperature to minimise the deleterious effect of frictional heat on the product. The most important step of surimi processing to ensure maximum gelling, as well as colourless and odourless surimi, is efficient washing. The leaching process involves mixing mince meat with cold water (5ºC) and removing water by screening and dehydration. This process is usually repeated three times. Before the final dewatering under a screw press, undesirable material particles, such as scales, and connective tissue are removed by a refiner. The screw press, which commonly has 0.5 mm perforation, squeezes water out with compression to level 82-85% moisture, which is similar to that in a fish fillet. 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 surimi (Shaviklo 2000).

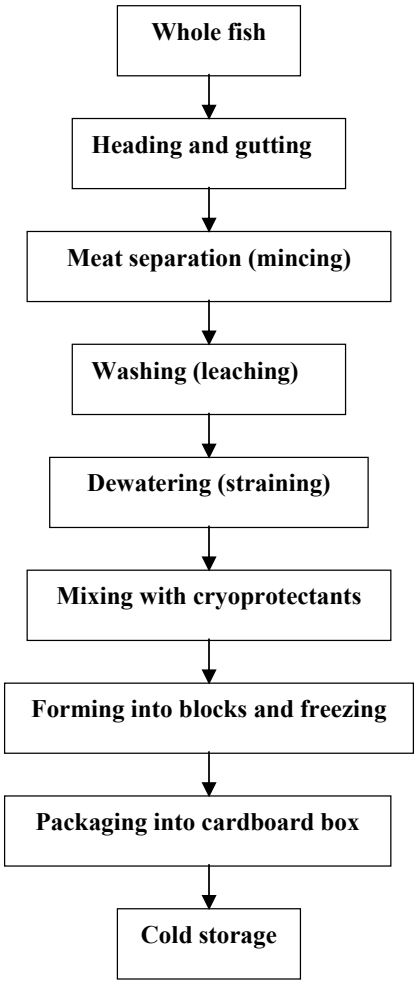

Figure 3: Flow diagram of surimi processing.

The addition of cryoprotectants is important to ensure maximum functionality of frozen surimi because freezing includes protein denaturation and aggregation. Sucrose (10-12%) serves as the primary cryoprotectant in the production of surimi. Sodium polyphosphate (0.1%) and sodium pyrophosphate (0.1%) are commonly used as synergists to the cryoprotective effects. The washed fish flesh, which has been mixed with cryoprotectants in a silent cutter, is formed into a 10 kg block, put in a plastic bag, and then placed onto a stainless steel tray for freezing. Surimi blocks are placed in a contact freezer and held for approximately 2½ hours or until the core temperature reaches -25ºC. After freezing two 10 kg bocks of frozen surimi are packed into a cardboard box. The frozen surimi should be maintained constantly at -20ºC. Care should be taken, especially during transportation and distribution, to keep the frozen surimi close to the mentioned temperature (Shaviklo 2000).

To make surimi from oily or dark or muscle fish, such as sardine and salmon, certain steps must be applied to negate the effects of oils and hem proteins. Hem proteins, such as myoglobin and haemoglobin, account for the red colour of dark muscle. In addition, fat oxidation in the dark muscle is prompted by hem proteins which causes an offensive, rancid colour (Park *et al*. 2005a).

2.2 Surimi based products

As a source of protein ingredient, surimi from various species has been used in different countries for producing surimi based products such as fish cakes, fish balls, fish burgers, fish sausages, fish noodles, imitation crab sticks and imitation shrimp tails (Park *et al.* 2005a). Processing steps of surimi based products, which could be used for FPI, are described in Figure 4.

2.2.1 Fish cakes

The Kamaboko, or Japanese fish cake, is the most typical surimi based product in Japan (Shaviklo 2000). The term often refers to all surimi based products in this market. The processing of Kamaboko can be done manually (traditionally by trained artisans) or by using machinery (for mass production). The shape and texture of Japanese fish cakes varies, depending on the geographical region in Japan and elsewhere. After forming, the surimi paste is subjected to a low temperature setting process, 20-40ºC for 30-60 minutes, depending on the species and size of product. During this process, the gel-forming ability of solubilised myofibrillar proteins is enhanced, which yields a strong and elastic gel. Cooking by either steaming or baking is carried out to complete the gelation of fish proteins. Another type of Kamaboko is called moulded Kamaboko. The moulding technique is applied in the utilisation of low grade surimi that commonly has a low gelling ability. The process is almost the same as for regular Kamaboko, but surimi paste is poured into a plastic mould and cooked at 90ºC (baking/steaming) after setting at 10-15ºC for 1 hour. The finished products are packed, pasteurised and chilled before entering their marketing channel (Park 2005b).

2.2.2 Fish balls

Fish balls are the most popular surimi based products in Southeast Asia. Ingredient preparation for fish ball manufacturing is similar to that for Kamaboko. In Japan and some other Asian countries, typical ingredients used for fish balls, in addition to surimi, are salt, sugar, monosodium glutamate (MSG), starch, and water. In those markets no flavours or protein additives are added to the formulation, while in some other countries a variety of protein additives and spices are used in fish ball formulation (Shaviklo 2006b). Once the paste has been prepared, it is extruded (formed) into a ball shape using a special device and dropped into warm water (20-40ºC, depending on the species) and allowed to set for 30-60 minutes.

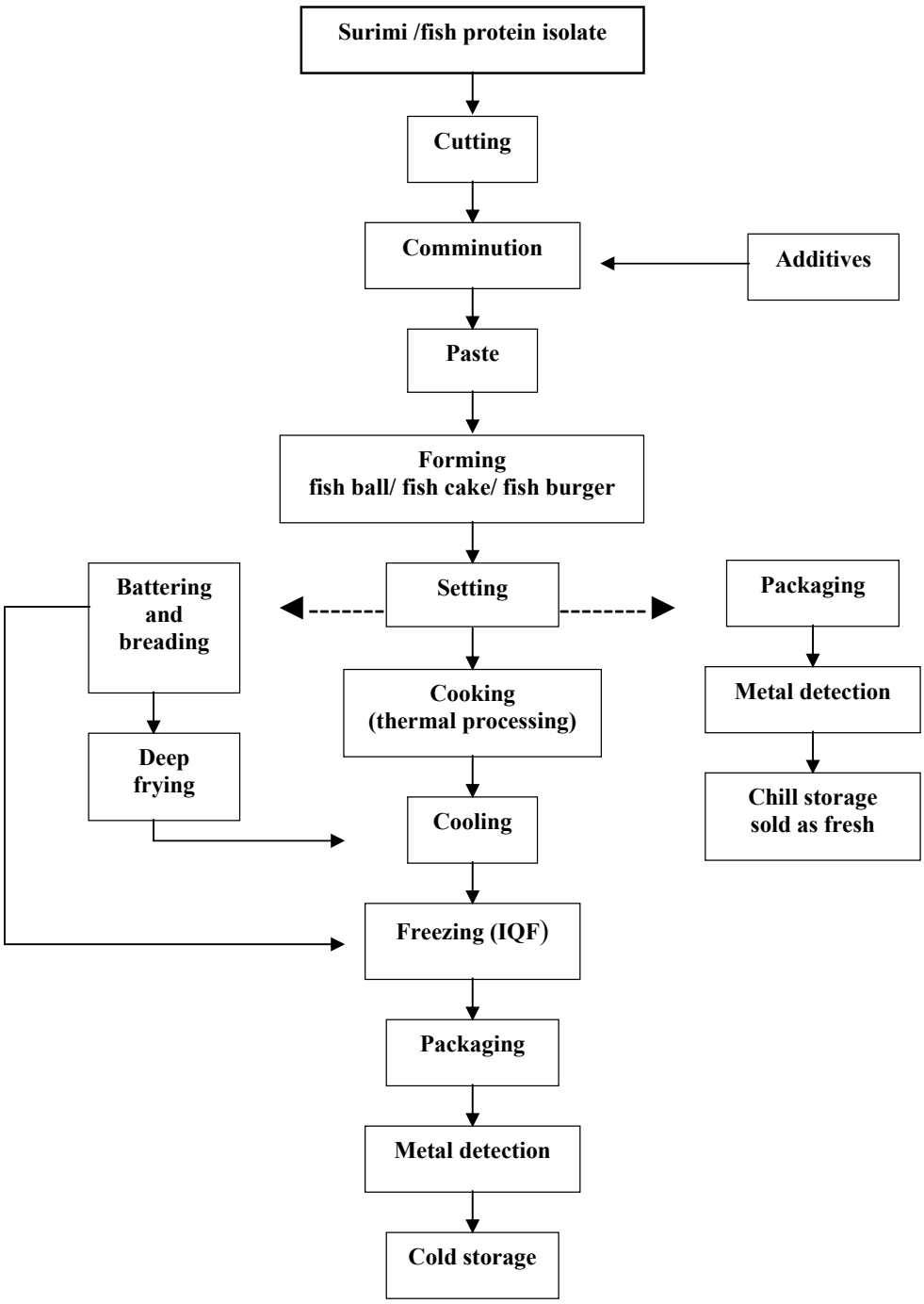

Figure 4: Processing flow of fish value added products from surimi/ FPI

The forming process is still done manually in some Asian countries. Once fish balls are set, they are placed in hot water (95-98ºC) for 10-30 minutes (until the core temperature reaches 80ºC), followed by chilling under tap water. After draining the water, the fish balls are then packed in a poly bag before checking with metal detection. Unlike cooked fish balls, raw fish balls, which are partially set, are sold in a poly bag containing cold water. Consumers perceive them as fresher and tastier. The most challenging endeavour is to deal with a shorter shelf life and to prevent oversetting while in the market (Park 2005b).

2.2.3 Other value added products

Value added surimi products are processed by mixing surimi with different ingredients such as vegetable proteins, starches, wheat flour, spices etc. and forming fish paste into the intended shape of the product. The paste can be shaped by hand or by a continuous mechanical forming machine. Fish burgers, fish cakes, fish nuggets, fish bars and fish patties are value added products which are processed this way. Battering, breading and frying are further processes of these products. Demand for these kinds of products in Southeast Asia and in the Middle East is increasing (Shaviklo 2000, 2006b).

2.3 Fish protein isolates

In order to utilise marine resources and upgrading the by-products of fish filleting, a systematic study was made of the recovery of proteins by chemical extraction (Batista 1999). The overall process concept is simple. The proteins of the muscle tissue are first solubilised. The solubilisation can be accomplished in 5-10 volumes of water with alkali added to obtain approximately pH 10.5 or higher, or with acid added to about pH 3.5 or lower. It is usually necessary to choose the pH at which the consistency of the solution decreases to a value that allows the removal of undesirable materials. The mixture is then centrifuged. This allows the light oil fraction to rise to the top of the suspension. At the same time, the lipids of the membrane are removed due to density differences compared to the main protein solution. Other insoluble impurities, such as bone or skin, are also sedimented at this stage. The muscle proteins are then precipitated and collected by a process such as centrifugation.

The easiest way to precipitate proteins is by adjusting the pH to a value near the isoelectric point of the majority of the proteins that is about 5.2-5.5. Strangely, almost all the muscle proteins become insoluble under theses conditions. This includes the sarcoplasmic proteins, which are mostly washed away during conventional surimi manufacture. The non-protein soluble materials from the muscle tissue remain in the supernatant fraction after centrifugation and can subsequently be removed. The water remaining in the collected protein contains the same concentration of impurities found in the supernatant fraction. Additional washes of the sedimented protein at the same pH can be used to decrease the concentration of these soluble impurities if necessary. The overall process is illustrated diagrammatically in Figure 5 (Hultin *et al*. 2005).

2.3.1 Quality of FPI

Protein gels made from protein isolates recovered with the new process from several species have been shown to have equal and sometimes significantly better gelation properties than those produced using conventional surimi processing techniques (Hultin *et al.* 2005, Undeland *et al.* 2002, Choi and Park 2002, Kristinsson and Demir 2003). The process has also been shown to improve other functional properties. The process has given excellent results for some cold water species as well as temperate and warm water species. According to Kristinsson and Hultin (2003) the alkali treatment of cod muscle proteins improved functional properties (emulsification and gelation) of cod myosin and myofibrillar proteins.

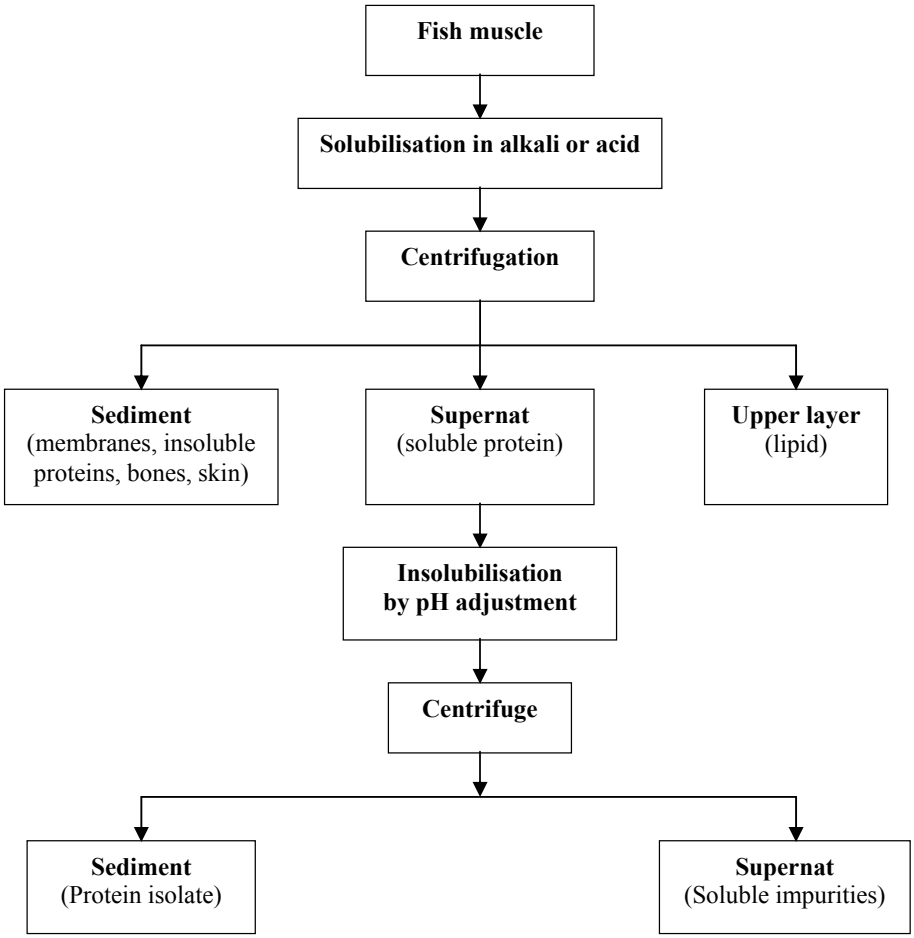

Figure 5: Scheme of process using pH shifts for production fish protein isolate (Hultin *et al*. 2005).

A different response to the acid and alkali process can be expected for warm water species compared to cold water species, in part because their proteins are more heat stable due to their living environment. A study performed on threadfin bream actomyosin indicated that aggregation occurred at higher temperatures than was seen for cold water species such as cod and Pacific whiting (Yongsawatdigul and Park 2003). Kristinsson and Demir (2003) compared the acid and alkali-aided processes to surimi processing of channel catfish, Spanish mackerel, croaker and mullet. They demonstrated that the two FPI processes led to higher protein recoveries and lipid reduction than lab scale conventional surimi processing but also that the alkali process resulted in significantly improved gelling ability, colour and oxidative stability (due to the removal of hem proteins) compared to the acid treatment and surimi process.

Theodore *et al*. (2003) showed that using the alkali-aided processes on catfish led to protein gels of greater strength when compared to using the acid-aided process and conventional surimi process over a wide range of pH (pH 6-8) and ionic strengths (0-600 mM NaCl). In addition, Kristinsson and Crynen (2003) demonstrated that both myofibrillar and sarcoplasmic proteins of muscle (from channel catfish) are positively affected in terms of gelation ability after alkali-treatment, but negatively affected after acid-treatment. The molecular phenomena responsible for these differences are under investigation.

2.3.2 Advantages of the acid and alkali-aided processes

The acid and alkali-aided processes have several advantages over the conventional surimi process when isolating functional and quality protein from fish muscle (Hultin *et al.* 2005):

(1) Whole fish with skin and bones can be utilised in the acid and alkali-aided processes because proteins are selectively separated and recovered from undesirable muscle components.

(2) Low cost species and fish by-products can be used in these processes which, at present, are not used directly for human food.

(3) This process is faster because it eliminates the washing and refining steps.

(4) Functional properties are retained, and often improved, in the alkali process. The effect on functionality is highly dependent on the species and type of functional property.

(5) With the new process, food safety is also improved. Microorganisms may be removed in the first centrifugation step, thus preventing their build-up in the product.

(6) The process removes essentially all of the membrane lipids, thereby stabilising the edible protein against oxidation.

(7) By removing the lipids, this method reduces fat-soluble toxins (e.g., polychlorinated biphenyls or PCBs) in the product.

(8) It also provides for increased yield of protein from fish muscle. More than 70% of the protein can obtained from the muscle tissue using this method. In some cases, protein yields greater than 90% can be obtained.

(9) Besides the obvious commercial value of having better yields, the improved yield results in less protein in the wastewater during industrial processing, so that environmental pollution is decreased and the cost of pollution control will be lower.

2.3.3 Factors affecting FPI attributes

- Raw material

Depending on the species used, the functional and compositional properties of FPI vary. It is, therefore, important for processors to understand the relationship between the physiochemical functions of fish and the functional and compositional properties of FPI. The freshness of fish/raw material is a critical factor in the production of FPI (Ingadottir 2004). The use of acid and alkali-aided processes has made it possible to produce quality protein ingredients from dark muscle species. A major problem facing any protein extraction and recovery process is proteolysis by endogenous proteases. Post-mortem fish muscle is prone to proteolysis but the problem varies with species and season. The effect of photolytic activity on muscle protein gels has a detrimental

effect on their quality due to rapid degradation of myofibrillar proteins, in particular myosin. Photolytic activity and types of proteases vary among species.

Proteolysis can be a problem during the acid and alkali-aided processes. The former process is thought to be more problematic since low pH levels can activate contaminating gut enzymes (pepsin) and also certain lysosomal muscle enzymes (Kristinsson and Rasco 2000). Undeland *et al.* (2002) found that proteolysis occurred when herring proteins were held at pH 2.7, while no proteolysis occurred at pH 10.8. Choi and Park (2002) also reported photolytic degradation of muscle proteins during acid-aided processing of Pacific whiting.

- Homogenisation of fish muscle tissue

Homogenisation of fish muscle tissue to a fine particle size is an important step in FPI production. If the tissue is simply ground, as in normal surimi processing, solubilisation will be incomplete. Homogenisation of the tissue to produce fine particles also has the advantage that it allows rapid mixing of the soluble cellular components and the added wash water (Hultin *et al*. 2005). It has been reported that different homogenisation times may affect muscle protein solubility which could in turn lead to variations in protein recovery (Ingadottir 2004).

- Ratio of fish to solution (viscosity)

For production of FPI usually one part of fish muscle is homogenised with 5-9 parts of water. The concentration of the muscle tissue in the homogenate is important because the consistency of the material depends on the amount of protein present (Hultin *et al*. 2005). The viscosity of muscle protein homogenates at low and high pH in the acid and alkali processes is important since low viscosity is necessary to separate insoluble material from soluble proteins via centrifugation. Viscosity of a protein solution is believed to be affected by factors like protein concentration, pH, salt, and raw material which can in turn affect the size, shape, flexibility and hydration of the proteins (Ingadottir 2004).

- Extraction time

Time of extraction should be adjusted to have a maximum rate of extraction. Hultin *et al*. (2005) reported that a 20 minute extraction time of ground mackerel muscle, produced somewhat less than 80% extraction of soluble protein

- Time and temperature of processing

Quality and stability of a final product is affected by the time and temperature of processing (Hultin *et al* 2005). The time and temperature of the raw material between filleting and gathering fish flesh from filleting operation and processing can be considered to be two of the most important factors that affect the final FPI quality (Ingadottir 2004).

- Solubility of proteins

Almost all muscle tissue proteins are soluble at a pH of 3.5-10.5. The actual solubility, however, may vary somewhat, depending on the species and the muscle type. Hultin *et al*. (2005) reported that more than 98% of cod and mackerel light muscle proteins are solubilised. The solubility of the proteins of mackerel red muscle varies from 75 to almost 100%. The variability may be related to post mortem age and time of exposure to pH values below 6.6 (Hultin *et al*. 2005). A change in solubility can be obtained in various ways, for example, by varying ionic strength, ion types, pH, and/or temperature, thus affecting the hydrophobic and/or ionic nature of the proteins. In order to find the most appropriate pH to solubilise and recover proteins from a protein solution a solubility curve can be constructed (protein concentration vs. pH). For example, a study done by Choi and Park (2002) showed that solubility of Pacific whiting proteins was lowest at pH 5.0 which indicated a suitable pH to precipitate the proteins.

- Presence of hem proteins

Fat oxidation in dark muscles is prompted by hem proteins, which cause an offensive rancid odour (Guenneugues and Morrissey 2005). Solubility of hem proteins in FPI especially for dark muscle species is very important. Rapid handling and pH control are necessary to keep the haemoglobin sufficiently soluble (Hultin *et al*. 2005), so it can be removed from the soluble fraction. Haemoglobin is much more stable at alkaline pH than it is at acid or even neutral pH. This is reflected in its much lower pro-oxidant activity at high pH than at acid pH (Hultin *et al*. 2005).

- Water holding capacity (WHC)

Water holding capacity is an important attribute of muscle protein gels as it not only affects the economics of their production but also their quality. Water holding capacity can be defined as the ability of a protein gel to retain water against a gravitational force.

- Protein denaturation

It is a commonly held view that denaturing of fish muscle proteins has a detrimental impact on their functional properties. Denaturation often results in negative changes in protein functionality such as enzyme activity or loss of functional properties. Loss of protein functionality has been correlated to loss in ATPase activity, a common indicator of muscle protein denaturation (Ingadottir 2004).

3 MATERIAL AND METHODS

3.1 Sample preparation

3.1.1 Preparation of raw FPI

The rest raw materials of cod (*Gadus morhua*), saithe *(Pollachius virens)*, and Artic charr (*Salvelinus alpinus*) from filleting were collected for production of FPI using a combination of acid and alkali-aided processes at Iceprotein ehf facilities in Saudarkrokur. The isolate process took place in a new designed processing line using a Decanter NX-400 LPX for isolating and dewatering purposes. The products were then mixed with cryoprotectants (5% sucrose, 4% sorbitol, and 0.3% sodium tripolyphosphate) and were frozen and kept at -20ºC. The samples were transferred to Matis facilities under chilled conditions for quality assessment. For assessment of drip loss in FPI containing different amounts of water, FPI was prepared from fresh cod fillets. The primary moisture of the sample was reduced manually. Blue whiting surimi was also evaluated for drip loss.

3.1.2 Preparation of cooked FPI

To prepare FPI gel, the following equipment and materials were used:

- Stephan Vertical Cutter /Mixer;
- Balances for accurate weighing of material;
- Manual sausage stuffer;
- Sausage casing (tub);
- Ice bath;
- Thermometer;
- Knife;
- Salt
- Sodium bicarbonate for adjusting pH;
- Vacuum packaging machine with a heat sealer, plus appropriate plastic bags.

Frozen FPI was transferred to the fridge to increase its temperature to approximately -5°C. Test samples were prepared as follows:

A. Comminution: Sample volume necessary for FPI paste preparation depends on the capacity of the mixing instrument used. 500 g of FPI was crushed with a silent cutter, then 3% of salt was added, and the mixture ground and mashed into homogenised paste for 10 minutes.

B. Stuffing: The homogenised paste was stuffed into a plastic tube 18 mm in width, and then both ends of the tube were tied. The test material was kept in the fridge for 1 hour.

C. Heating: The test material was heated in hot water of 84-90°C for 30 minutes.

D. Cooling: Immediately after completing the heating treatment, the test material was put in cold water to be cooled completely. The test material was kept in the fridge for 24 hours.

3.2 Quality assessment

Codex criteria for frozen surimi (FAO/WHO 2005) were used for quality assessment of fish isolate proteins. All measurements were repeated three times and average values calculated. Fish balls/fish cakes and fish burgers were processed manually for evaluation of functional properties and gel strength of fish protein isolates.

3.2.1 Raw FPI tests

- Moisture

A sample for moisture content was taken from the interior part of an FPI block to ensure that there was no freezer burn (surface dehydration) of the sample. The test sample was put in a polyethylene bottle, sealed and thawed so that the temperature of the sealed sample increased to room temperature. The AOAC method was used to measure the moisture of the samples. Calculation of the moisture was done according to the following formula to the first decimal place.

$$\textbf{Moisture (\%)} = \frac{\text{Pre-dry weight (g)} - \text{after- dry weight (g)}}{\text{Pre-dry weight (g)}} \times 100$$

- Pressure Induced Drip

Pressure Induced Drip is an important factor to estimate the water content of FPI and the quality of the protein in the product. 50 g of the test sample were defrosted and transferred to a circular cylinder with an inner diameter of 35 mm and 120-150 mm in length, made of stainless steel and a perforated plate with holes 1 mm in diameter in the bottom. Pressure was applied with a 1 kg cylindrical rod 34 mm in diameter and left for 20 minutes. The weight of the dripped liquid was measured and the percentage of the weight of the test sample calculated to the first decimal place.

- pH

To measure pH, 90 ml of distilled water was added to 10 g of the test sample and homogenised. The pH of the suspension was measured with a glass electrode pH meter. Sodium bicarbonate was used for adjusting the pH of the samples.

- Objectionable matter

The term “objectionable matter” as used here means skin, small bones and any objectionable matter other than fish muscle. In this method 10 g of the test sample is spread to the thickness of 1 mm or less, and the number of visible objectionable matters more than 2 mm in diameter is noted. Objectionable matter smaller than 2 mm shall be counted as one half but any objectionable matter smaller than 1 mm shall be disregarded.

3.2.2 Cooked FPI tests

- Determination of gel strength by puncture test

The gel strength or gel forming ability is one of the most important factors for quality evaluation of FPI. The puncture test, which is a convenient and easy method to use, was applied to determine this attribute (Park 2004). The test was performed between 24 and 48 hours after cooking and after equilibrium with room temperature had been reached. The casing of the inspection sample of cooked FPI gel (Figure 6) was removed and samples were cut into test specimens, 15-25 mm in length. They were measured using a Texture Analyzer. A spherical plunger, 5 mm in diameter was dropped at 60 mm/minute. The test specimen was placed on the sample deck of the tester so that the centre of the test specimen would come just under the plunger. The penetration force in g and the deformation at breakage in mm was measured and recorded. Six test specimens were prepared from the same inspection sample of FPI gel and each of them was tested. The average values for all the samples were calculated.

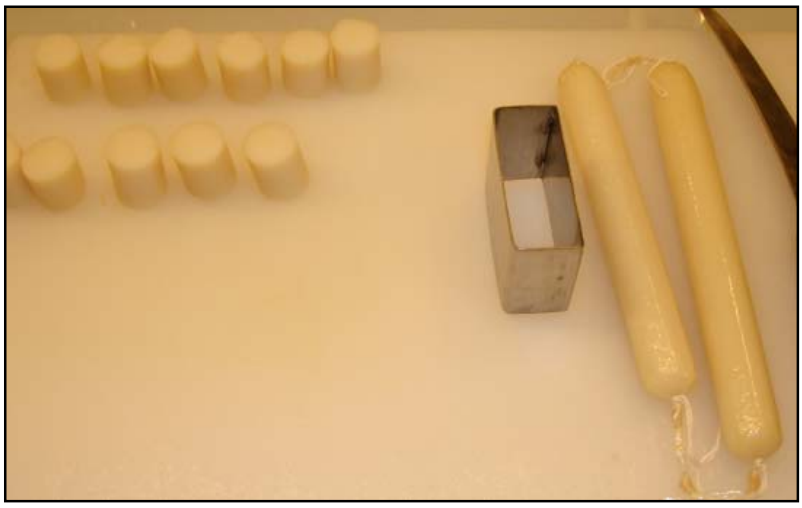

Figure 6: Specimens of cooked cod FPI for measuring gel strength, whiteness and sensorial tests.

- Whiteness

The colour and whiteness of FPI gel is another important factor which affects the quality of this product especially for East Asian markets. The inspection sample of FPI gel (Figure 6) was cut into flat and smooth slices 15 mm in thickness or more. The samples were evaluated immediately with a colour-difference meter instrument by measuring the values of L*(lightness), a* (red-green colours) and b* (yellow-blue colours) to the first decimal place. Three or more sliced pieces were tested. Whiteness, as an index for the general appearance of surimi gel, can be calculated as: Whiteness = L* - 3b*.

- Determination of water holding capacity by measuring expressible moisture

Water holding capacity of FPI is easily determined by measuring expressible moisture of cooked FPI gel. A small amount of test sample (around 2 g) was placed between 6 filter papers and pressed by pressure equipment (Texture Analyzer) under a fixed pressure (10 kg/cm²). The expressible water is calculated according to the following formula to the first decimal place:

$$\textbf{Expressible water (\%)} = \frac{\text{Pre-pressed weight (g)} - \text{after- pressed weight (g)}}{\text{Pre-pressed weight (g)}} \times 100$$

Water holding capacity is calculated as follows:

$$\textbf{Water holding capacity (\%)} = \frac{\text{Expressible water content (g)}}{\text{Total moisture content of pre-pressed sample (g)}} \times 100$$

- Sensorial tests for measuring gel strength and elasticity of FPI

Sensory evaluation is convenient and easy to use for the determination of gel strength and elasticity of FPI if it is performed by trained panellists. In this case, sensorial tests of the samples were done by the author who has been trained in Japan and Singapore. Folding the test samples by hand and biting samples by the front teeth are commonly used in Japan and South East Asia for sensory valuation of surimi.

The folding test (Figure 7) is conducted by folding a 5 mm thick slice of gel slowly in half and in half again while examining it for signs of structural failure (cracks). Three or more slice pieces of the same inspection sample were folded completely in half for 5 seconds and changes in the shape were evaluated using five stage merit marks according to Table 1. The average values for three trials were calculated.

Figure 7: Folding test used for measuring the gel strength of cooked FPI gel.

Table 1: Scoring of folding test.

Merit	Mark property
5	No crack occurs even if folded in four.
4	No crack occurs if folded in two but a crack(s) occur(s) if folded in four.
3	No crack occurs if folded in two but splits if folded in four.
2	Cracks if folded in two.
1	Splits into two if folded in two.

The biting test was done by biting 5 mm thick slices of the gel sample with the front teeth to evaluate the resilience and elasticity of cooked FPI. More than three sliced pieces of the same inspection sample were tested by a panellist. Scoring of the biting test is given in Table 2.

Table 2: Scoring of biting test.

Merit mark	Gel quality
10	Extremely strong
9	Very strong
8	Strong
7	Slightly strong
6	Fair
5	Slightly weak
4	Weak
3	Very weak
2	Extremely weak
1	Incapable to form gel

- Functional properties of FPI during processing

Functional properties can be defined as the effect an ingredient has on either the organoleptic properties of a food (flavour, odour, texture, appearance, etc.) or on the processing properties of the food (pumpability, extrudability, resistance to tear or breakage, etc.). This definition indicates that a functional property is affected by the ingredient added to the food and by the manufacturing process. All measurements of organoleptic and/or physical properties should be made on a cooked product. The assessment of the appearance, flavour/odour and texture of FPI products is necessary in order to improve the quality of FPI. To determine effects of setting temperature/ time on gel strength of the cod, saithe, and Arctic charr FPI samples, fish balls and fish cakes containing 5%, 10% and15% starch were prepared. Treatments with starches were divided into two different setting categories:

1) Setting at room temperature (20ºC) for 12-24 hours
2) Heating at 90ºC for 15 minutes. For the 90ºC treatments the samples were submerged in a 90ºC water bath. Heated gels were immediately chilled to less than 5ºC in ice water for 1 hour.

3.2.3 Statistical analysis

All experiments with fresh and cooked FPI were repeated three times. Data were analysed for the degree of variation and significance of difference based on the analysis of variance (ANOVA) to determine if significant differences ($p \leq 0.05$) existed between treatments.

4 RESULTS

4.1 Raw FPI

The optimum pH of FPI to make a strong gel has been reported to be 7.5-7.8 (Halldorsdottir 2006), so pH of cod and saithe samples were adjusted to 7.6-7.7 by using sodium bicarbonate. The primary pH of cod and saithe PI were 6.7 and 7.1 respectively.

As the gel strengths of cod and saithe PI were weak, the pH of Arctic charr was adjusted to 7.3-7.4 in an attempt to improve gel quality.

The moisture content of the cod and saithe samples was 85.0% and 83.5% respectively, while the moisture content of the Arctic charr PI gel was 72.5%.

Pressure induced drip was by far the highest in the cod PI sample while it was lowest for the Arctic charr PI sample. The quality atributes of raw FPI are presented in Table3.

No objectionable matters were detected in the samples of raw fish isolate protein.

Table 3: Quality attributes of raw FPIs.

FPI sample	Moisture (%)	Pressure induced drip (%)
Cod	85.0±0.3	44.7±0.07
Saithe	83.5±0.1	25.4±0.08
Arctic charr	72.5±0.4	19.2±0.06

Effects of water content, cryoprotectant and freezing on pressure induced drip:

Water content can be one of the main factors affecting drip loss in FPI. Therefore, the effects of this factor in pressure induced drip of FPIs made from cod fillets and frozen blue whiting surimi was studied. The results, which are given in Table 4, demonstrate that pressure induced drip of fresh FPIs free from cryoprotectants and containing 85.5%, 84.7% and 78% moisture were 8.18%, 5.54%, and 0% respectively. This attribute in blue whiting surimi containing 76.6% moisture was 1.68%. The surimi sample had the lowest level of drip loss among samples except cod PI containing 78% moisture.

Table 4: Effect of water content in pressure induced drip (pressing for 20 minutes).

Samples	Moisture %	Pressure induced drip (%)
Fresh cod PI made from fish fillets	85.5±0.4	8.23±0.4
Fresh cod PI made from fish fillets	84.7±0.4	5.57±0.03
Fresh cod PI made from fish fillets	78±0.4	0
Fresh cod PI made from fish fillets including cryoprotectant.	80±0.4	4.18±0.03
Frozen cod PI made from fish fillets including cryoprotectant.	80±0.4	9.36±0.45
Frozen blue whiting surimi	76.6±0.4	1.68±0.18

The effect of freezing on pressure induced drip of FPIs was also assessed in this work. The results indicate that freezing can increase this attribute in FPI. Drip loss in frozen cod PI containing cryoprotectant and 80% moisture was almost double that of fresh cod PI containing the same amount of moisture and cryoprotectant (Table 4).

The trend of time in drip loss of different samples of fish protein isolates and blue whiting surimi was studied. The results indicate that more than 90% of the water content of the samples was removed in the first 20 minutes and the higher the water content the higher the drip loss (Table 5).

Table 5: Pressure induced drip (g) of test samples at different times (min).

Time (min)	Test samples					
	Cod PI (1)	Cod PI (2)	Cod PI (3)	Cod PI (4)	Cod PI (5)	Surimi (6)
1	1.45±0.25	0	0	0.57±0.22	3.24±0.26	0
2	0.74±0.05	0.97±0.12	0	0.28±0.04	0.3±0.03	0
3	0.35±0.03	0.53±0.08	0	0.26±0.02	0.17±0.01	0
4	0.33±0.04	0.36±0.08	0	0.14±0.06	0.15±0.01	0
5	0.31±0.03	0.21±0.02	0	0.16±0.05	0.07±0.01	0.37±0.05
10	0.5±0.15	0.34±0.0	0	0.39±0.13	0.31±0.12	0.17±0.04
15	0.27±0.02	0.28±0.04	0	0.19±0.02	0.18±0.04	0.19±0.06
20	0.14±0.02	0.08±0.0	0	0.08±0.0	0.08±0.0	0.1±0.01
25	0.17±0.02	0.07±0.0	0	0.04±0.02	0.06±0.0	0.08±0.03
30	0.32±0.30	0.24±0.01	0	0.06±0.0	0.09±0.01	0.07±0.01
40	0.31±0.27	0	0	0	0	0.11±0.02
50	0.28±0.29	0	0	0	0	0.08±0.01
60	0.15±0.04	0	0	0	0	0.09±0.02
90	0.18±0.05	0	0	0	0	0.09±0.03
120	0.25±0.21	0	0	0	0	0.02±0.0
Total drip	5.75	3.08	0	2.17	4.65	1.37

1-Fresh PI made from cod fillets containing of 85.8% moisture.
2- Fresh PI made from cod fillets containing of 84.7% moisture.
3-Fresh PI made from cod fillets containing of 78% moisture.
4-Fresh PI made from cod fillets including cryoprotectants containing of 80% moisture.
5-Frozen PI made from cod fillets including cryoprotectants containing of 80% moisture.
6-Frozen blue whiting surimi with 76.6% moisture.

4.2 Cooked FPI

Gel strength measured by the puncture test was much weaker either for saithe or for Arctic charr than cod PI which was the strongest among all the samples. The results of cooked FPI attributes are given in Tables 6 and 7.

Water holding capacity was highest in saithe (18.2%), followed by Arctic charr (7.6%) and cod (5.3%).

The folding values of cod, saithe, and Arctic charr PI were 3, 2, and 1 while biting test values for the samples were 6, 3 and 2 respectively.

Table 6: Quality attributes of cooked FPI.

FPI	Puncture test	Moisture (%)	Expressible moisture (%)	Water holding capacity (%)	Sensorial tests(1)	
					Folding test	Biting test
Cod	274.3±0.08	85±0.3	10.7±0.55	5.3±0.07	3±0.0	6±0.0
Saithe	198.5±0.09	83.5±0.1	32.5±0.18	18.2±0.12	2±0.0	3±0.0
Arctic charr	29.5±0.08	72.5±0.4	13.3±0.09	7.6±0.07	1±0.0	2±0.0

(1) Performed by one expert.

Cod PI had the whitest value among all the samples. Arctic charr PI had a pinkish colour, while saithe PI had a grey colour. Values of the whiteness test for cod, saithe, and Arctic charr PI were 73.5, 38.3 and 32.3 repectively (Table 7). Figure 8 illustrates the whiteness, folding, and biting values of FPIs.

Table 7: Whiteness values of cooked fish protein isolates.

Sample	Values			Whiteness
	L*(lightness)	a* (red-green)	b* (yellow-blue)	
Cod (cut off)	71.1±0.17	-3.9±0.17	-0.88±0.04	73.5±0.11
Saithe (cut off)	61.7±0.09	-2.7±0.15	7.7±0.50	38.3±0.16
Arctic charr (fish frame)	76.2±0.06	3.3±0.45	14.8±0.51	32.3±0.50

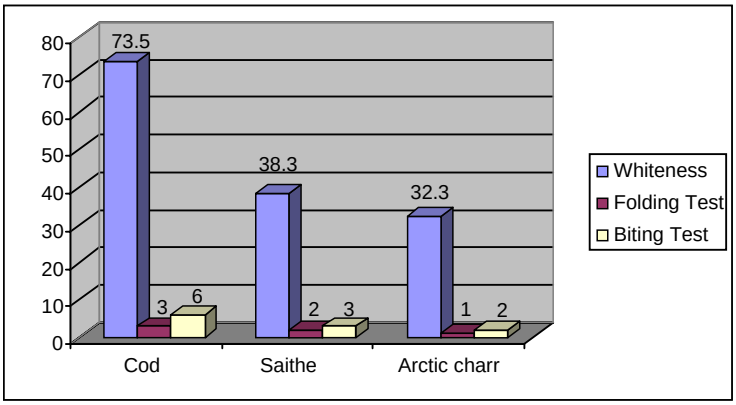

Figure 8: Whiteness, folding, and biting values of FPIs.

4.3 Functional properties of FPI products

Fish balls and fish cakes from cod and saithe samples with 5% and 10% starch did not form gel but samples with 15% starch formed gel in hot water and at room temperature. All prepared samples of Arctic charr PI formed gel with different textures. For evaluation of Arctic charr PI during processing, different formulations of fish balls and fish burgers were used. For the initial preparation of fish balls and fish burgers a formulation, which was used by Shaviklo (2006b) to produce fish balls from silver carp surimi, was adopted. Arctic charr PI and ingredients were ground and mixed in a microprocessor, then the fish paste was formed into fish balls manually and fish burgers by using a batch forming machine. Deep frying was used to cook the products.

The texture of the products was soft because of the weakness of the gel forming ability of the FPI. To improve the texture of the products the formulation was changed. The last formulation of these products (Table 8) was evaluated by more than 10 colleagues and Matis company staff. All evaluators scored the products well and most of them found the fish burgers tastier than the fish balls. A few people were of the opinion that the fish burgers were a bit hot (spicy), but the majority expressed their satisfaction with the flavour. Figures 9, 10 and 11 show products prepared from Arctic charr PI.

Table 8: Formulation of fish balls/fish burgers used in this study.

#	Ingredients	First* formulation(%)	Second formulation(%)	Third formulation(%)
1	Arctic charr PI	64	63	61
2	Potato starch	4	-	6
2	Dried potatoes	-	5.5	-
	Wheat flour	7	-	8.5
3	Fresh white egg	1.8	2	2
4	Salt	0.9	1	1
5	Fresh onion	12.3	12	10.55
6	Fresh garlic	0.7	0.8	0.7
7	Bread crumbs	7.66	11.4	8.6
8	Curry	0.9	0.7	0.87
9	White pepper	0.18	0.1	0.18
10	Vegetable oil	0.56	0.5	0.6
11	Dried skimmed milk	-	3	-

* Adopted from Shaviklo 2006b.

Figure 9: Fish burgers and fish balls prepared from Arctic charr PI before setting/thermal processing.

Figure 10: Fried fish balls prepared from Arctic charr PI.

Figure 11: Fried fish burgers prepared from Arctic charr PI.

5 DISCUSSION

5.1 Raw FPI

Quality and characteristics of a FPI are highly dependent on the source of fish protein and the processing procedures applied. Moisture content of conventional surimi usually varies from 73-76% (Park and Lin 2005a). Moisture of cod and saithe PI samples exceeded 83% and should be decreased to be in the same range as in surimi.

The amount of drip usually reflects the extent of denaturation of the protein and water content. Biscalchin *et al*. (2003) investigated drip (%) of surimi from red and Nile tilapia. Drip in surimi from red tilapia was 9.7% after 30 days of storage and 17.4% at 180 days. At the same conditions, drip loss of Nile tilapia was 9.6% and 13% respectively. According to the results (Table 5) the drip (%) depends on water content of FPI.

The results indicate that the amount of drip directly depends on the quality of the raw material which is used for producing FPI. In this study two samples of cod PI made from fresh fillets and fish cut offs with the same moisture (85%) had different values of drip loss. The amount of drip in a sample of cod PI made from fish cut offs was more than five times that of PI made from fresh cod fillets which emphasises the importance of freshness and kind of raw material on end product quality (Tables 3 and 4).

No drip was observed after 120 minutes of measurement in fresh PI made from cod fillets containing 78% moisture. This level of moisture (78%) could be considered as a control point during dewatering of FPI in the processing line. Drip loss in frozen cod PI containing cryoprotectant and 80% moisture was almost double that of fresh cod PI containing the same amount of moisture and cryoprotectant. The temperature and method of freezing is another control point that should be considered in production of FPI.

In this study, there were no objectionable matters (impurities) in the FPIs, while in conventional surimi there are usually about 5-10, indicating that FPI processing can separate and remove all impurities from the products. Park *et al*. (2005a) reported 13 objectionable matters in conventional surimi and 15 impurities in recovered surimi (Table9).

5.2 Cooked FPI

5.2.1 Gel strength

The formation and characteristics of muscle gels are highly dependent on fish species, the quality and kind of fish flesh (fillet, cut off, frame) which is used for processing and heating procedures. Gel strength and gel forming ability of the three samples of FPI which were measured by puncture and sensorial tests were not as good as conventional surimi qualities and quality of FPIs made from fish fillets, because they were produced from filleting by-products. Several authors reported the same results for surimi and FPI (Hultin *et al.* 2005, Park *et al*. 2005a, Choi and Park 2002).

The type and freshness of the raw material can affect dramatically the quality of fish protein isolates. Park *et al.* (2005a) compared attributes of conventional surimi to recovered surimi. Quality attributes of recovered surimi using decanter technology to recover fine insoluble particles from wash water such as moisture, impurities, gel strength and colour were lower than attributes of conventional surimi (Table 9).

Table 9: Comparison of quality attributes of recovery-grade and primary-grade surimi (Park *et al*. 2005a).

Attributes	Primary grade surimi(1)	Recovery-grade surimi (2)
Moisture	75.6	78.6
Impurities /10 g	13	15
Gel deformation (cm)	1.51	1.5
Gel breaking force(g)	575	231
Colour L* value	81.5	80.9
Colour a*value	4.5	4.4

1-Surimi produced by conventional method.
2- Surimi produced by using decanter technology [Decanter used to recover fine insoluble particles from wash water and to replace the conventional screw press]

Similar results were also reported by Hultin *et al*. (2005) and Choi and Park (2002) who studied the effects of different kinds of raw material on alkali-aided FPI quality (Table 10). They reported that cod PIs made from fish fillets, minced fish and fish frames had different puncture test and folding test values. In their study, cod PI made from fish fillets had the highest puncture test value and PI made from cod frames the lowest. Hultin *et al.* (2005) also studied the effects of fish freshness on gel strength and reported different values of puncture tests for herring PI. In their report, PI from fresh herring had the highest level of gel strength (810 g×cm) and PI of herring prepared after 6 days of icing had the lowest level (287.5 g×cm). The puncture test value for PI made from frozen herring was 668 g×cm. It showed that freshness and freezing can affect FPI quality (Table 10).

Table 10: Puncture test and fold test values of different kinds of Alkali-aided FPI.

Kind of FPI		Punch test values (g×cm)	Fold Test value
Cod (1)	Fillet	693	5
	Minced	234	5
	Frame	27.7	2
Herring (1)	Fresh	801	5
	Aged 6 days	287.5	3
	Frozen	668	5
Farmed catfish (1)	Fillet	816	5
Pacific whiting (2)	Fillet	696	-

1- Hultin *et al*.2005.
2- Choi and Park 2002.

According to the Lanier *et al.* (1991) guidelines, cod PI was evaluated grade B, and saithe PI and Arctic charr PI grade C and grade D respectively. These low grade FPIs like low grade surimi can be used for manufacturing products (like moulded products) when gel strength is not an important factor.

The moisture of products also affects gel strength. Reppond and Babbitt (1997) reported that the moisture content of pollock surimi decreased punch force linearly. The moisture of cod and saithe PI samples in this study were calculated more than 83% that should be decreased to less than 78% to form a good gel. Halldorsdottir (2006) reported the same result for FPI.

It seems that FPI samples in the range of pH 7.6-7.7 do not give a good gel strength, so it is recommended to adjust the pH to around 7.1-7.2 during fish protein isolate production.

Fat content is a critical factor which can affect gel strength in surimi (Park *et al.* 2005a) and FPI. Surimi has less than 1% fat content while there was more than 9% fat in Arctic charr PI, which caused weak gel strength in this product.

5.2.2 Water holding capacity

Water holding capacity can be defined as the ability of a protein gel to retain water against a gravitational force. The level of water retained in a gel is affected by the same factors that affect the formation of a good protein gel: pH and ionic strength (i.e. salt). Water holding capacity and expressible moisture usually reflects the extent of denaturation of the protein and water content. In this study water holding capacity of saithe PI was 18.2%, higher than Arctic charr PI (7.6%) and cod PI (5.3%). Kristinsson and Liang (2006) measured expressible moisture of gels made from Atlantic croaker surimi and Atlantic croaker PI made from fish fillets. They reported 9.7% expressible moisture for Atlantic croaker surimi and 6.1% for Atlantic croaker PI which are lower than of FPI made from by-products. Ingadottir (2004) reported 5-6% press losses for surimi and isolate gels from tilapia. She also measured 2-4% water holding capacity for tilapia protein isolate made from fish fillet.

5.2.3 Whiteness and colour

The colour and whiteness of products depend on fish muscle colour, the kind of raw material used and fish freshness. In this study FPI samples had different colour and whiteness values. The highest values of a* (red-green colours) and L* (lightness) and the lowest value of whiteness in the test samples related to Arctic charr PI. Cod PI made from fish cut offs was whiter than Rock fish PI and Pacific croaker PI made from fish fillets and surimi from Atlantic croaker and cat fish studied by other researchers (Table11).

Surimi usually has L* values well above 50 and positive but low values of a* and b* (yellow-blue colours) (Lanier *et al*. 1991). Reppond and Babbitt (1997) found the L* and a* values increased linearly with increased moisture content in Alaska pollock surimi. According to their study the b* value decreased linearly while whiteness increased with increasing moisture content in Alaska pollock surimi.

Kristinsson *et al*. (2005) studied the colour characteristics of FPIs. Their results are as follows:

- Connective tissue can increase the L* value of FPI;
- Yellowness values could be in part be influenced by the retention of lipids;
- Redness values are influenced by co-precipitation of hem proteins;
- Denaturation and oxidisation of haemoglobin causes a yellow-brownish colour in products;
- High a* values could be attributed to hem proteins in the final product.

The colour of fish flesh and therefore FPI depends on the species and also fish feed. It seems the pinkish colour of Arctic charr PI comes from astaxanthin in the fish flesh (Moretti *et al.* 2006).

Table 11: Whiteness values of cooked fish protein isolates.

Sample	Values			Whiteness
	L*(lightness)	a* (red-green)	b* (yellow-blue)	
Cod (cut off)	71.1±0.17	-3.9±0.17	-0.88±0.04	73.5±0.11
Saithe (cut off)	61.7±0.09	-2.7±0.15	7.7±0.50	38.3±0.16
Arctic charr (fish frame)	76.2±0.06	3.3±0.45	14.8±0.51	32.3±0.50
Rockfish (fish fillet) (1)	76.20	-0.04	5.67	59.18
Pacific whiting (fish fillet) (2)	70.11+0.27	1.6+0.04	4.63+0.08	60.7±4.52
Atlantic croaker (3)	72.3+1.2	-3.1+0	6.2+ 0.4	56.2±0.03
Atlantic croaker surimi (4)	77.6+0.8	-2.0+0	8.3+0.3	52.7±0.1
Cat fish surimi (5)	70.4+1.1	-0.9+0.2	0.7+0.4	68.3±0.1

1- Yongsawatdigul and Park 2004, alkaline-aided process.
2- Choi and Park 2002, acid-aided process.
3- Kristinsson and Liang 2006.
4- Kristinsson *et al.* 2005.
5- Ensoy *et al.* 2004.

Hultin *et al*. (2005) reported that FPIs from both acid-aided and alkali-aided processes [using fresh fillets] had higher ($p<0.05$) whiteness scores than surimi. The alkali-aided process recovers proteins of higher whiteness ($p<0.05$) than the acid-aided process (Kristinsson *et al*. 2005).

5.3 Functional properties of FPI products

One of the most important functional properties of muscle proteins is their ability to form gels upon heating. As mentioned, the purpose of processing FPI products (fish balls and fish burgers) was not sensory evaluation of the product but to evaluate the functional properties of FPIs.

The formulation which was used to prepare fish balls and fish burgers was improved because of the weakness of the gel forming ability of Arctic charr PI. The texture was improved by adjusting the amount of PI, potato starch and wheat flour. The colours of the fish balls and fish burgers were brown to yellow, without any fish smell and tasted similar to products which were produced from silver carp surimi (Shaviklo 2006b). A few people found the fish burgers produced from Arctic charr PI to be a little bit hot, but most were satisfied with the flavours. Some of those tasting the fish burgers felt they were a bit on the soft side. Compared to hamburgers which have a tough texture,

it should be kept in mind that the texture of fish burgers from any kind of fish species will always be soft unless a considerable amount of vegetable proteins, starch, or other additives are added to the formulation. For product development, the target market and expectations of consumers should be considered.

6 CONCLUSION

Fish filleting operations in Iceland generate large amounts of cut offs annually (Arason 2006), which could be utilised to produce fish protein isolate, provided that the proper process is used. Quality assessment of fish protein isolate from rest raw material of cod, saithe and Arctic charr filleting processes showed that quality attributes such as gel strength, gel forming ability and whiteness are considerably different to conventional surimi and FPI made from fresh fillets. However it is a good source of protein for manufacturing products which do not need a high level of gel strength, such as fish balls (not Japanese style), fish burgers, fish nuggets and other ready to eat fish products. The texture, taste and flavour of FPI products, which were produced in this study, were acceptable but they could also be improved by adjusting different ingredients and spices according to the target market and specified consumers. Further studies on chemical composition, functional properties and storage stability are necessary in order to obtain a better characterisation of these products.

6.1 Recommendations

A better understanding of the quality properties of fish protein isolates made from different raw materials could contribute to the improvement of the products and optimal utilisation of fish protein resources. Based on the results of this study the following recommendations can be made:

- Preventing time/temperature fluctuations during the handling and processing steps for preserving fish freshness;
- Using a vacuum mixer for homogenising raw material which has a considerable amount of fat and haemoglobin to prevent oxidation;
- Adjusting pH to 7.1-7.2 during processing of FPI for better gel forming ability;
- Using a screw press or decanter for dewatering FPI for adjusting the moisture of the product to less than 78%;
- Adding appropriate cryoprotectant to FPI to preserve proteins from denaturations.

Further research is recommended on the following:

- Freezing stability of FPI;
- Determination of shelf life of FPI;
- Sensory evaluation of FPIs by a trained panel;
- Feasibility study of product development.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to the United Nations University, the Icelandic Ministry of Fisheries, Marine Research Institute and UNU-FTP, especially Dr. Tumi Tomasson and Mr. Thor Asgeirsson, for providing this opportunity for me to study in this programme and their support during the course, and Ms. Sigridur Kr. Ingvarsdottir, the programme officer, for her valuable assistance. I am deeply grateful to all lecturers, especially Mr. Sigurjon Arason, for sharing their knowledge with us during the 6 month training course in Iceland. My sincere thanks to my supervisor, Dr. Ragnar Johannsson and his colleagues Ms. Margret Geirsdottir, Mr. Sigurdur Hauksson and Mr. Irek Klonowski for their excellent guidance.

LIST OF REFERENCES

Arason, S. 2006. Utilization of Fish By products in Iceland. UNU-FTP.2006-2007. Iceland.

Batista, I. 1999. Recovery of proteins from fish waste products by alkaline extraction. Eur Food Res Technol .210:84–89.

Biscalchin-Gryschek, S.f., Oettere M. and Gallo C.R. 2003. Characterization and frozen storage stability of minced Nile tilapia and red tilapia, *Journal of Aquatic Food Product Technology*, Vol.12 (3).

Choi, Y.J. and Park J.W. 2002. Acid-aided protein recovery from enzyme-rich pacific whiting. *Journal of Food Science.* V. 67, No. 8, 2002.

Ensoy, U., Kolsarici N. and Candogan k. 2004. Quality characteristics of spent layer surimi during frozen storage. *Journal of Eur Food Res Technol* (2004) 219: 14-19.

FAO/WHO. 2005. Codex code for frozen surimi. In: Park, J.W. editor, *Surimi and Surimi Sea Food,* Boca Raton: Taylor and Francis Group.P.869-885.

Guenneugues, P and Morrissey MT. 2005. Surimi resources. In: Park, J.W. editor, *Surimi and Surimi Sea Food,* Boca Raton: Taylor and Francis Group.P.3-32

Halldórsdóttir, S. 2006. Approving methods to stimate gel strength of fish protein, University of Iceland . Rekjavik. Icaland.

Hultin, H.O., Kelleher and Stephen D. 2000. High efficiency alkaline protein extraction, US Patent 6136959, Issued on October 24, 2000.

Hultin, H.O. 2002. Recent advances in surimi technology.In: Fingerman M, Naghabhushanam R, editors. Recent advances in marine biotechnology. Vol.7.Enfield, N.H: Sceince publisher. P. 241-251.

Hultin, H.O., Kristinsson, H.G., Lanier T.C. and Park J.W. 2005. Process for recovery of functional proteins by pH shifts. In: Park, J.W. editor, *Surimi and Surimi Sea Food,* Boca Raton: Taylor and Francis Group.P.107-139.

Ingadottir, B. 2004. The use of acid and alkali-aided protein solubilisation and precipitation methods to produce functional protein ingredients from Tilapia, Master Thesis, University of Florida.

Kim, Y.S., Park, J.W. and Choi. Y.J. 2003. New approaches for the effective recovery of fish proteins and their physicochemical characteristics, *Journal of Fishery Science* 2003, 69: 1231-1239.

Kristinsson, H.G. and Rasco, B. A. 2000. Hydrolysis of Salmon Muscle Proteins by an Enzyme Mixture Extracted from Atlantic salmon (Salmo Salar) Pyloric Caeca. *Journal of Food Biochemistry* 2000, *24*, 177-187.

Kristinsson, H. G. and Demir, N. 2003. Functional Fish Protein Ingredients from Fish Species of Warm and Temperate Waters: Comparison of Acid and Alkali-Aided Processing Vs. Conventional Surimi Processing. *Advances in Seafood Byproducts, Fairbanks, AK*; Alaska Sea Grant College Program.

Kristinsson, H. G. and Hultin, H.O. 2003. Effect of Low and High pH Treatment on the Functional Properties of Cod Muscle Proteins. *Journal of Agricultural and Food Chemistry* 2003, *51*, 5103-5110.

Kristinsson, H. G., and Crynen, S. 2003. The Effect of Acid and Alkali Treatments on the Gelation Properties of Sarcoplasmic and Myofibrillar Proteins of Channel Catfish. *IFT Annual Meeting, Chicago*; Abstract 87-3.

Kristinsson. H.G., Theodore, A.E., Demir, N. and Ingadottir, B. 2005. A comparative study between acid and alkali-added processing and surimi processing for the recovery of proteins from channel cat fish muscle, *Journal of Food Science*-Vol.70, Nr.4,2005.

Kristinsson. H.G. and Liang Y. 2006. Effects of pH- shift processing and surimi processing on Atlantic croaker muscle protein. *Journal of Food Science*-Vol.71, Nr.5, 2006.

Lanier, T.C, Hart K. and Martin R.E. 1991. *Manual of standard methods for measuring and specifying the properties of surimi*, University of North Carolina Sea Grant College Programme. Raleigh, NC.

Moretti, V. M.; Mentasti, T.; Bellagamba, F.; Luzzana, U.; Caprino, F.; Turchini, G. M.; Giani, I.; Valfrè, F.2006. Determination of astaxanthin stereoisomers and colour attributes in flesh of rainbow trout (*Oncorhynchus mykiss*) as a tool to distinguish the dietary pigmentation source. Food Additives & Contaminants, Nov2006, Vol. 23 Issue 11, p1056-1063.

Park Jae W., Yongsawatdigul J. and Lin T.M. 1994. Rheological behaviour and potential cross-liking of pacific whiting surimi gel. *Journal of Food Science.* Volume 59, No. 4, 1994. P.773-776.

Park, J.W., Lin, T. M. and Yongsawatdigul, J. 1997. New Developments in Manufacturing of Surimi and Surimi Seafood. *Food Review International* 1997, *13*, 577-610.

Park, J. W. and Lanier, T. C. 2000. Processing of Surimi and Surimi Seafood. In *Marine Freshwater Products Handbook*; R. E. Martin, Ed.; Technomic Publishing Company: Lancaster, NH.

Park, J.W.2004. Surimi Gel preparation and texture analysis for better quality control. In: Sakaguchi M. editor. More efficient of fish and fisheries products. Hardbound, p.333-341.

Park Jae W, Yongsawatdigul J., Lin TM. 2005a. Surimi: Manufacturing and evaluation. In: Park JW editor. Surimi and surimi sea food, Boca Raton: Taylor and Francis Group.P.33-106.

Park Jae W. 2005b. Surimi sea food: products, markets, and manufacturing. In: Park JW, editor. *Surimi and surimi seafood*, Boca Raton: Taylor and Francis Group.P.375-434.

Pérez-Mateos, M. and Lanier T.C. 2006. Comparison of Atlantic menhaden gels from surimi processed by acid or alkaline solubilization. *Journal of Food Chemistry* 101 (2006) 1223–1229.

Reppond, K.D. and Babbitt JK. 1997. Gel properties of surimi from various fish species as affected by moisture content. *Journal of Food Science*. Volume 62, No. 1, 1997. P.33-36.

Shaviklo, Gholam Reza. 2000. *Production Manual of Surimi and surimi based products*. Naghsh-e Mehr publication. Tehran. [In Persian]

Shaviklo, Gholam Reza. 2006a. Sensory Evaluation of Surimi attributes made from local species. Iranian Fisheries Organization. Jan. 2007. [In Persian] {http://www.iranfisheries.net/persian/page-view.asp?pagetype=articles&id=479}

Shaviklo, Gholam Reza. 2006b. Fish balls production. Iranian Fisheries Organization. Jan. 2007. [In Persian] {http://www.iranfisheries.net/persian/page-view.asp?pagetype=articles&id=611}

Shaviklo. Gholam Reza.2006c. An introduction to quality improvement of sea food products, Iranian Fisheries Organization, Jan. 2007. [In Persian] {http://www.iranfisheries.net/persian/page-view.asp?pagetype=articles&id=63 }

Theodore, A., Kristinsson, H.G.; Crynen, S. 2003. The Effect of pH and Salt on the Gelation Properties of Catfish Surimi and Catfish Protein Isolates from Acid and Alkali-Aided Processing. *IFT Annual Meeting, Chicago*; Abstract 76A-10.

Undeland, I. A., Kelleher, S. D.and Hultin, H.O. 2002. Recovery of Functional Proteins from Herring (*Clupea Harengus*) Light Muscle by an Acid or Alkaline Solubilization Process. *Journal of Agricultural and Food Chemistry*, *50*, 7371-7379.

Yongsawatdigul, J. and Park, J. W. 2003. Thermal Denaturation and Aggregation of Threadfin Bream Actomyosin. *Journal of Agricultural and Food Chemistry*, *83*, 409-416.

Yongsawatdigual J. and Park J.W. 2004. Effects of alkali and acid solubilisation on gelation characteristics of rockfish muscle proteins. *Journal of Food Science*. Volume 69, No. 7, 2004. P.C499-C505.