# Fish Protein Concentrate: A New Source of Dietary Protein[1]

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## ABSTRACT

The concept of fish protein concentrate (FPC) is based on the more efficient use of our fishery resource by converting under-utilized fish to acceptable products for human consumption. FPC is not a single product. It is rather a family of products produced by different processes. Each member in the family of products has different characteristics and can be used for different purposes. Although a variety of processes has been developed, most have been based on solvent extraction of whole fish to remove lipids and water. FPC produced by solvent extraction of fish of several different species contains between 75% and 95% protein, which is particularly high in quality. This type of product can be used in foods to improve markedly their nutritional quality without significantly changing their other characteristics. FPC produced by some solvent extraction methods, however, has limited functional properties. New processes are being developed which use enzymes, various solvents, or a combination of enzymes and solvents. Products from some of these processes have improved functional properties and these FPCs appear to be particularly promising for use in foods for their functional attributes. Several problems still remain to be solved and research is needed to determine how FPCs can be produced and utilized most efficiently and effectively. There is, however, a commercial industry emerging and indications are that FPCs will find a significant place in the market.


## INTRODUCTION

Fish protein concentrate (FPC) has been defined as any low-cost, stable, wholesome product of high nutritive quality, hygienically prepared from fish, in which the protein and other nutrient materials are more concentrated than they were in the fresh fish. This definition might include products of varying characteristics ranging from tasteless, odorless, light-colored, flour-like materials, through coarse meals having a fish taste and odor to highly-flavored, dark-colored pastes or powders resembling meat extracts.

A major point to emphasize is that FPC is not a single product. It is rather a family of products produced by different processes. Depending on the process that is used, the members of the family of products will have different characteristics and can be used for different purposes. Some FPCs are designed solely to be used for nutritional purposes because of their exceptionally high nutritional quality but limited functional properties. Others have desirable functional properties and are designed to be used in foods for these attributes rather than strictly as nutritional ingredients.

A variety of processes has been developed for producing FPC, and these may be classified as either chemical, biological, or physical. In the chemical processes, solvents are used to remove water and lipids from fish, and the remaining protein and minerals are subsequently dried and ground. Biological methods involve the use of either enzymes or microorganisms to release protein from the oil and water. In the physical methods, mechanical means, such as presses, are used to remove oil and water.

The purposes of this paper are to review briefly the development of FPC, to point out some of the problems related to the production and use of FPC, and to give a "state of the art" report on progress that has been made recently in solving these problems.

## EARLY DEVELOPMENTS

Prior to the early 1960's, several groups and organizations throughout the world were involved in processing FPC of one kind or another (1). For the most part, these processes involved solvent extraction. In this country, companies such as VioBin, General Foods, Lever Brothers and the J. Howard Smith Company were engaged in FPC to some degree. VioBin, however, was the only company that was involved in the commercial production of FPC for humans. Outside the United States, there was activity in countries such as Chile, Morocco, Germany, Canada, South Africa, Sweden and Peru.

The U.S. National Marine Fisheries Service (formerly the Bureau of Commercial Fisheries) began a basic FPC research program in 1961. The program was designed to investigate simultaneously several different methods of FPC manufacture. Subsequently, however, a decision was made that the basic research programs would be interrupted, and that we would concentrate on developing one commercial method for manufacturing FPC. One of the reasons for this decision was a ruling of the Food and Drug Administration (FDA) that essentially precluded the use of whole fish in the manufacture of FPC. Our objective, therefore, was to develop one method, to produce and exhaustively test the product, and to apply for FDA approval of the product.

The process developed was based on solvent extraction of whole fish, and it was essentially a three-stage crosscurrent batch extraction process (2). Red hake was used as the raw material, and isopropyl alcohol was used as the solvent. FPC prepared by this process was exhaustively tested, and it was found to be highly nutritious, safe and wholesome, and entirely satisfactory as a dietary supplement for humans. In 1966 we applied to the FDA for approval of FPC as a food additive. A similar petition was submitted at the same time by the VioBin Corporation for another process for making FPC from hake.

On February 2, 1967, the FDA amended the food additive regulations and in general approved both processes. The amendment specified, however, that only hake or hakelike fish could be used in the manufacture of FPC. In addition to this restriction, the regulations also contained certain other limitations. The most serious of these was that FPC produced from whole fish could only be sold in one-pound packages, and it could not be used in manufactured foods. A restriction was also included that limited the maximum amount of fluoride in FPC to 100 ppm. This meant that in some cases the bones, where most of the fluoride is located, had to be partially removed.

## RECENT DEVELOPMENTS

### Modifications in the Isopropyl Alcohol Extraction Process

Several modifications and improvements have recently

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been made in the basic isopropyl alcohol extraction process. The crosscurrent batch extraction procedure has been replaced by a countercurrent batch extraction system (2). This countercurrent process is more applicable to commercial processing, and it results in a product similar to that produced by the original process.

Improvements have also been made in the recovery of isopropyl alcohol. Previous work indicated that amines were accumulating in the solvent because of inadequate purification during recovery. These amines were subsequently deposited in the FPC during reuse of the isopropyl alcohol, which resulted in undesirable flavor and odor characteristics. Adequate and effective solvent recovery systems have recently been designed by the Esso Research and Engineering Corporation, under contract with National Marine Fisheries Service (3). Using adequately recovered isopropyl alcohol, the amine content in the resulting FPC is low and does not contribute significantly to the flavor and odor.

Additional work is needed on the recovery of oil, which is extracted during processing of FPC. With fish containing high amounts of oil, this byproduct could be of significant economic value. Some fish such as menhaden contain up to 25% oil. Limited laboratory work indicates an excellent food-grade quality oil can be recovered.

### FPC From Other Species of Fish

The approval of the use of only hake or hakelike fish as a raw material severely limited the commercial production of FPC. There are only a few places in the world where the hake resource is large enough to support a FPC plant of commercial size. To overcome this obstacle, we turned our attention to research on other species of fish with a view toward enlarging the resource base.

In this research, we used the basic isopropyl alcohol process, but, for fish containing high amounts of lipids, the number of extraction stages was increased from three to five. Using this process FPC was prepared from several kinds of fish, including menhaden, herring, anchovies, alewives, ocean pout and sardines. The percentage composition of samples prepared from these fish was as follows: protein, 78% to 88%; lipids, 0.1% to 0.5%; ash, 10% to 20%; and volatiles, 2% to 6%. The protein quality of these FPCs was equal to or higher than that of casein, as determined in rat-feeding studies (4). In general, the research showed that FPC that met FDA specifications could be produced from a variety of fish.

A petition to increase the kinds of fish that can be used for the manufacture of FPC was submitted to the FDA in December 1969. To date, approval to use menhaden and herring of the genera *Clupea* has been granted. We believe this broadening of the resource base for FPC manufacture in the United States is a major advance toward the establishment of an FPC industry. Although this is a major step forward, approval for other kinds of fish and other processes is needed. In this respect, we expect that further changes in the present FDA regulations will be forthcoming.

### FDA Restriction on the Use of FPC in Foods

As previously mentioned, the FDA ruled that FPC was safe, wholesome and suitable for human consumption. They did, however, limit the sale of FPC to one-pound packages at the retail level and specified that FPC was intended to be used in food products made in the home. In effect, this prohibits the use of FPC in manufactured food products.

Although at the present time this ruling severely restricts the use of FPC, we do not consider it a serious long-term problem. In response to suggestions to remove the restriction, the FDA has indicated that anyone desiring to market FPC should formally submit a proposed marketing plan. This should include such information as the intended use, the amount of FPC that would normally be consumed by users, and most importantly how the product would be labeled.

In this connection, the Food and Drug Directorate (FDD) of Canada published regulations on FPC in October 1970. Their regulations do not consider FPC a food additive, and they contain no restrictions on the packaging and on the use of FPC in manufactured foods. The FDD regulations differ in several other respects from those of the FDA. Perhaps, however, the above mentioned is the most significant difference.

### Quality of FPC From Different Sources

As previously mentioned, FPC that meets all FDA specifications has been prepared from several species of fish. There was, however, variability in the chemical and physical characteristics of the FPCs. For large-scale production and use, we believe that FPC must be reasonably consistent in quality, as well as conforming to the FDA specifications. Quality in this case means not only chemical and nutritional quality, but also physical and organoleptic quality.

The species of fish that is used in FPC manufacture can affect the chemical composition of the final product. Some fish, such as menhaden, contain a higher proportion of bones to protein than do other fish, such as hake. Thus, FPC made from whole menhaden may contain about 20% ash and 78% protein, whereas that made from hake may contain 13% ash and 85%. Providing the lipids are efficiently extracted during processing, FPC from both fish will contain less than 0.5% lipid.

We have found that the variations in ash and protein in FPCs can be eliminated largely by removing most of the bones during processing. This has been accomplished by passing the raw fish through a deboning machine prior to solvent extraction. The machines are available commercially, and they efficiently separate the bones and skin from the flesh. Up to about 90% of the whole fish can be recovered in the bone-free fraction. The efficiency of separation varies somewhat between different species of fish.

FPC that is processed from deboned fish consistently contains about 90-95% protein. Also, by this procedure, the FPC consistently contains less than 100 ppm of fluoride, which is the maximum level established by the FDA. Most of the fluoride in fish is located in the bones (5), and the removal of bones during processing results in FPC with a markedly reduced fluoride content. It is interesting to note, however, that the fluoride content of FPC made from nondeboned fish is not necessarily related to the ash content. We have found, for example, that FPC processed from non-deboned menhaden contained about 60 ppm of fluoride and 20% ash. On the other hand, FPC made from non-deboned hake contained only two thirds as much ash and two to six times more fluoride.

The color of FPC prepared from different species of fish varies also. When prepared from lean fish, such as hake, the color of FPC is light gray with a yellowish tan cast. The color of that prepared from anchovy and herring, however, tends to be a darker gray. This characteristic is not desirable and it would limit the use of FPC in certain foods.

Based on a limited amount of work, it appears that the color can be significantly lightened by water extraction of the ground fish prior to alcohol extraction. Much of the pigment is removed during water washing, which results in FPC that is lighter and varies less in color from one species to another. The color of FPC might also be improved by treating either the fish during processing or the finished FPC with a bleaching agent.

### Use of FPC in Foods

We have done a considerable amount of work on the use of FPC for nutritional purposes in a variety of foods. Several studies have been conducted in which FPC was used in such products as bread, pasta, crackers, cookies, soups, tortillas and beverages (4). These studies have shown that the quantity and quality of the protein in these products can be substantially improved by the use of FPC. Foods containing 5% FPC were found to be very acceptable, and usually indistinguishable from unsupplemented products. Differences in the organoleptic characteristics of foods were sometimes found when higher levels of FPC were used, especially from certain species of fish. The color of the products was most often altered by the use of high levels of FPC. Also, with bread, decreases in loaf volume were found as increasing amounts of FPC were used in the formulation. We have recently found that these decreases in volume can be minimized or prevented by modifying the baking techniques and by the use of glycolipids in the formulation. This observation was previously reported by Pomeranz et al. (6).

## Availability of FPC

In the past, progress on the introduction and utilization of FPC has been impeded because of a lack of sufficient quantities of product. There was no FPC industry in the world capable of producing FPC in sizable quantities on a continuing basis. Several possibilities now exist for production of product on a large scale.

The National Marine Fisheries Service is currently building an FPC plant in Aberdeen, Washington. The isopropyl alcohol extraction process developed by the Service will be used in this experiment and demonstration plant, which will have a raw fish input capacity of up to 50 tons per day. It is expected to be in operation in early 1971. The purposes of this plant are to demonstrate the feasibility of producing FPC on a large scale using the extraction process developed by the Service, to obtain engineering and cost data, to experiment with variations of the basic process, and to provide product for use by private industry and Government agencies.

Cardinal Proteins, Ltd., Nova Scotia, Canada, has constructed a plant with a maximum input capacity of about 200 tons of fish per day. The plant will use an isopropyl alcohol extraction process.

Alpine Marine Protein Industries, Inc., has an FPC plant in New Bedford, Massachusetts. This company has produced a considerable amount of FPC for use by the U.S. Agency for International Development.

Astra Nutrition, Boa, Sweden, is currently producing "eviscerated fish protein" or EFP 90. They have a land-based plant in operation, and currently are converting a 25,000-ton ship into a floating protein factory. The novel approach taken by Astra is the production of FPC from eviscerated fish. This is accomplished by mechanically cutting the fish in small segments that are then washed to remove viscera and blood. Earlier this year, the National Biscuit Company of the U.S. and Astra Nutrition of Sweden formed the Nabisco-Astra Nutrition Development Corporation. Astra is producing the protein and Nabisco is developing products enriched with it and market testing these products. Several other companies have also indicated that they plan to build plants to produce FPC.

## New and Modified Processes

Most of the previous work conducted on processing was concerned with an isopropanol extraction process. This general process results in a highly nutritious product that can be added to foods easily. The FPC, however, retains few of the functional characteristics of the native protein. Thus, more recently we have broadened our research to produce other FPCs with improved functional properties.

Results indicate that extraction with a combination of hexane and isopropyl alcohol markedly improves protein solubility. Also, FPC with markedly improved functional especially oil emulsifying capacity, can be produced by extracting fish with isopropyl alcohol at room temperature instead of at 70 C. These and other developments indicate that modifications of the solvent extraction process can result in products with greatly improved functional properties.

Research by personnel at our Seattle Laboratory has been directed toward the development of an aqueous extraction process (Spinelli, unpublished data). In this process, the myofibrillar protein in ground, deboned fish is separated from the soluble sarcoplasmic protein and oil by a series of extractions with dilute sodium chloride solutions and water. The myofibrillar fraction is then dried and ground. The product is not completely stable because it contains some reactive lipids. These can be removed by extracting with isopropyl alcohol; however, this step denatures the protein. To improve the stability, personnel at Seattle have also used a short enzyme digestion of the myofibrillar protein from the aqueous extraction process. The partially digested protein is then isolated and dried. The final product is relatively stable as well as having the desired functional properties.

We have also conducted research on the production of soluble fish protein concentrates through enzymatic hydrolysis of whole fish (Hale, unpublished data). The enzymes generally are added to a well mixed slurry of comminuted fish, and the pH and temperature are controlled at near the optimum levels. The period of reaction is typically between 5 and 24 hr. The protein hydrolysates are recovered and spray dried. Generally the products are totally water soluble. The nutritive quality of these FPCs is usually somewhat lower than that of FPCs produced by solvent extraction. Some, however, have a protein quality equal to that of casein. Several products with different combinations of nutritive value, appearance, taste and cost have been produced by varying both the enzymes and the conditions of digestion.

Several other approaches have been used to produce FPCs that have quiate different characteristics (7). Some will remain laboratory curiosities, while others show excellent potential as protein ingredients in processed foods. Research on the processing and application of protein from marine sources has only recently received increased emphasis. These efforts, however, still remain at a comparatively low level. Intensified research is needed to learn how marine proteins can be most effectively utilized to realize their full potential.

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