

FISH PROTEIN CONCENTRATES

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Fish protein concentrates have been used in various parts of the world for several centuries. It has only been within the past 30 years, however, that the production of FPC has been investigated on a scientific basis.

Today several pilot plants and full-scale industrial plants have been built. Most of these plants produce FPC by solvent (usually isopropyl alcohol) extraction procedures.

The FPC's produced are, in general, bland tasting and vary in color from white to dark tan. They contain between 75 and 95 percent high-quality protein and they exhibit limited functional properties according to standards set by industry for high protein foodstuffs. The characteristic of limited functional properties far from being a drawback, is in many circumstances advantageous since FPC can be added to existing food products, markedly improving the nutritional quality without significantly altering other characteristics, although in some instances the addition appears to improve the shelf life of final baked products.

One must not assume, however, that all solvent extracted FPC's nor even all isopropyl alcohol extracted FPC's, are completely alike. On the contrary, significant differences in odor, lipid content, stability, taste, nutritional value, and functional properties are obtained depending upon the processing conditions and the species of fish used.

Experimental work is now being conducted to produce FPC with various solvents, and with enzymes, microorganisms, or combinations of enzymes and solvents. The products resulting from these processes have improved functional properties. Some of these appear to be particularly promising for use in certain foods because of their functional attributes.

Although many problems still remain to be solved and additional research is required to show how FPC can be utilized more efficiently, an FPC industry has been started.

INTRODUCTION

Fish protein concentrates (FPC's) are defined as those products obtained from fish in which the protein is more concentrated than the original raw material. FPC's may range from light-colored, bland powders to dark powders having intensely fishy tastes, or they may be pastes with a similar wide range of colors and tastes. Both powders and pastes may be water soluble or insoluble and may be high in nutritive value or only intermediate in nutritive value.

FPC's may be prepared by a variety of methods most of which can be classified as chemical (solvent extraction) or biological (enzymatic and microbial) procedures.

During the last 20 years most efforts have involved the use of solvents, usually isopropyl alcohol, and several pilot plants and a few full-scale industrial plants have been constructed. The type of FPC produced by solvent extraction is a bland, nearly odorless, lightly-colored, water-insoluble but highly nutritive powder, intended for use as a protein supplement.

The biological procedures, in general, have not advanced beyond the laboratory or small pilot plant stage. The FPC's produced, however, usually have more desirable functional characteristics than the solvent produced FPC's. That is, in addition to having good nutritive properties, they have other attributes, such as water solubility, which may lead to wider market appeal.

If FPC's are to be widely used, markets must be defined; therefore, marketing studies have been conducted.

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This paper reviews the resources available to make FPC, the laboratory and pilot plant solvent extraction and enzymatic procedures under investigation at the Fishery Products Technology Laboratory at College Park, Maryland, commercial procedures for making FPC's, the characteristics of the FPC's produced, and the potential domestic and foreign markets for FPC's.

The use of FPC as a new source of protein depends upon the fish supply. Before an industry can be started, a continuing supply of raw material must be available. The growth of world fisheries in the last 100 years has been remarkable. The world catch rose from 2 million metric tons in 1850 to 64 million metric tons in 1968. However, questions have been raised regarding the future growth in landings and the maximum annual sustainable yield that can be realized.

Many scientists have occupied themselves with predicting the potential maximum sustainable yields of fish that can be harvested from the sea. The estimates vary widely and should only be regarded as indications of the magnitude of the resource.

Kastavan and Holt (1) concluded that an annual harvest of 500 million metric tons was a reasonable estimate of the potential sustainable annual harvest. This estimate was based on the primary organic production in the sea.

Chapman (2) estimated a much higher annual yield based on the carbon that is fixed annually into living matter in the ocean. He concluded that 2 billion metric tons of fish are available annually that are "large enough and useful enough to form the basis of practical commercial harvest."

More recently, a consideration of 17 estimates led Shaeffer and Alverson (3) to conclude that a sustainable world potential existed for 180 million metric tons annually with foreseeable extensions of present harvesting techniques. A Panel on The Commission on Marine Science and Engineering and Resources arrived at a similar figure and concluded that if fishing were broadened to include other species, locations, and equipment than those presently used, annual production could be realistically expanded to 400 to 500 million metric tons before expansion costs became excessive. Even further increases might be achieved given significant

technological breakthroughs in the ability to detect, concentrate and harvest fish on the high seas and in the deep ocean.

Although these estimates vary widely, they do indicate that the amount of food in the sea that can be used to alleviate the dearth of food on the land is indeed sizable. It is obvious, however, that there is not an unlimited supply of fish in the ocean and careful judgment must be exercised to ensure wise use of the resource.

Obviously, the majority of the harvest will continue to be used in traditional forms, such as fresh and frozen fish, and fish meal. However, there is a large unutilized resource that could be processed into FPC.

PROCESSING

Research

Chemical Methods.--Chemical methods use solvents to remove water and lipids from fish. The primary purpose in removing water and the highly reactive lipids is to produce a stable and organoleptically acceptable product for human consumption. Numerous chemical methods have been developed in various parts of the world to produce FPC. References to most of these methods are given in a recently compiled Bibliography published by the Library of Congress (4). Among the chemical methods developed are those of the following groups: VioBin Corporation, General Foods Corporation, Lever Brothers Company, United Nations, Canada, Fishery Research Institute of South Africa, and Astra of Sweden.

In 1961, the U.S. National Marine Fisheries Service (formerly the Bureau of Commercial Fisheries) began a research program to investigate various methods of producing FPC. Primary emphasis was given to the development of a commercial method of FPC manufacture based upon solvent extraction. Based on the earlier work conducted by others, isopropyl alcohol was chosen as the solvent. It was known to be highly effective in the removal of water and lipids from raw fish. It was prepared by a synthetic process which would guarantee its purity and, in addition, isopropyl alcohol was known to be safe, to be reasonably priced, and to be an effective bacteriostat.

Initially the fish used in the manufacture of FPC was red hake. Subsequently, a variety

of fish has been used to produce FPC by isopropyl alcohol extraction and the research has demonstrated that a satisfactory FPC can be produced from a variety of fish.

A modified cross-current batch extraction system was developed first. In this system fish were comminuted and mixed with azeotropic isopropyl alcohol at room temperature with a ratio of solvent to fish of 2:1 by weight. After agitation, the solid and liquid were separated in a centrifuge. The wet solids were then re-slurried with fresh alcohol and extracted continuously at about 70° C. in a system where the extract was continuously drawn off, filtered, evaporated, and the condensed overhead pumped back into the extractor. The solids were then separated from the liquid in a centrifuge. The solids were desolventized in a vacuum oven at 160° F. for 18 to 22 hours.

Subsequently, a system closely approximating a commercial batch countercurrent process was developed. In this process a four-stage countercurrent procedure with an overall ratio of solvent to fish of 2:1 was used. The first stage extraction was performed at room temperature, while the second, third, and fourth stages were performed at 70° C. The solid-liquid slurry from each stage was separated by centrifugation and the final solids were desolventized as in the original process. Theoretically the processing of a large number of batches of fish would be required before this countercurrent system would at-

tain steady state operating conditions, that is, before the composition of the liquid and solids in each stage would not change from batch to batch. However, experience indicated that the system essentially reached steady state conditions after the fourth batch and definitely after the fifth stage.

FPC from a variety of fish has been processed using the aforementioned systems. In Table 1, the proximate composition of FPC produced from a variety of fish is shown. The species of fish that are 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 percent ash and 78 percent protein, whereas that made from hake may contain 13 percent ash and more than 80 percent protein. Providing the lipids are efficiently extracted during processing, FPC from both fish will contain less than .5 percent lipid.

The variation in ash and protein in FPC's can largely be removed by separating most of the bones from the flesh during processing. This can be accomplished by passing the raw fish through a deboning machine prior to solvent extraction. These machines are available commercially and they efficiently separate the bone and the skin from the flesh. Up to about 90 percent of the whole fish can be recovered in the bone-free fraction. The

Table 1 - Proximate analyses of fish protein concentrate (FPC) prepared by isopropyl alcohol extraction of various species of fish (expressed as percent of sample)

Species of fish used	Crude protein (N x 6.25)	Volatiles	Ash	Lipids
Red hake-FPC	80.9	7.7	13.5	0.18
Atlantic menhaden-FPC	78.5	3.8	19.4	0.18
Atlantic herring-FPC	87.5	5.9	10.8	0.19
Northern anchovy-FPC	80.0	6.1	16.8	0.07
Ocean pout-FPC	86.0	1.5	15.0	0.24
Alewife-FPC	86.0	2.3	15.7	0.09
Moroccan sardines-FPC	79.7	4.4	-	0.21
Red hake-FPC, non-deboned	87.2	1.9	12.8	0.46
Red hake-FPC, deboned	92.2	4.0	5.3	0.14

efficiency of separation varies somewhat between different species of fish. As shown in Table 1, FPC processed from deboned fish contains higher amounts of protein than the non-deboned.

Table 2 shows data on the nutritive value of FPC's produced from a variety of fish. In general, all FPC's have a nutritive quality equal to or higher than that of casein. Also listed in Table 2 is the nutritive value of FPC prepared from deboned fish. From limited results available, it appears that the quality of the protein in FPC prepared from deboned fish is slightly higher than that of FPC made from non-deboned fish.

be attributed to the diet or to the FPC. These studies have shown that FPC prepared by isopropyl alcohol extraction is safe, wholesome, and in addition has high nutritive quality.

Laboratory research is continuing on the use of other solvents and combinations of solvents to extract lipids and water from the whole or partially deboned fish. The purpose is to develop new processes that can produce products with varied characteristics. These products are to be used as nutritional supplements but would have improved functional properties. For example, they might be used in processed meats as both a meat extender and a fat binder.

Table 2 - Nutritive quality of fish protein concentrate (FPC) prepared by isopropyl alcohol extraction of various species of fish

Species of fish used	Average daily weight gain (g)	Average daily food intake (g)	Protein efficiency ratio ^a
Red hake-FPC	5.21 ± 0.13	14.8 ± 0.2	3.19 ± 0.09
Atlantic menhaden-FPC	4.60 ± 0.19	13.9 ± 0.4	3.05 ± 0.06
Atlantic herring-FPC	5.32 ± 0.15	15.0 ± 0.3	3.15 ± 0.05
Northern anchovy-FPC	5.18 ± 0.12	14.6 ± 0.3	3.25 ± 0.03
Ocean pout-FPC	4.68 ± 0.21	13.8 ± 0.5	3.06 ± 0.04
Alewife-FPC	5.28 ± 0.15	15.2 ± 0.2	3.17 ± 0.07
Moroccan sardine-FPC	4.98 ± 0.14	15.7 ± 0.2	2.96 ± 0.05
Red hake-FPC, non-deboned	5.94 ± 0.14	15.1 ± 0.4	3.27 ± 0.04
Red hake-FPC, deboned	5.73 ± 0.37	14.2 ± 0.8	3.36 ± 0.08
Casein	4.35	13.0	3.00

^a Values adjusted to a casein value of 3.00.

An exhaustive evaluation has been made of FPC prepared from a variety of fish by the isopropyl extraction method. This evaluation included a determination of the physical, chemical, and sensory properties of the FPC's, a determination of the protein quality and of the microbiological and toxicological safety. The final product has no fishy flavor or odor and consists of a fine, free flowing, lightly colored powder. Toxicological studies have been conducted with rats and mice over several generations in which FPC was the sole source of protein. The studies are now nearing completion and the data indicate no untoward results have occurred that can

Biological Methods.--The biological methods of FPC preparation are based on the use of enzymes to convert fish protein into a stable concentrate with desirable properties. The enzyme systems employed may be the natural enzymes in the fish, commercially available enzymes, or enzymes supplied by living cultures of microorganisms. Development of biological processes is being pursued because an enzymatically produced product can have special properties which make it particularly suitable for certain applications. The production costs may also be less since the basic processing equipment may be simple and quite adaptable to ship-board or remote area use.

Numerous methods have been developed for the biological production of FPC. Several methods are referred to in the bibliography published by the Library of Congress. In this paper, only the research conducted by the National Center for Fish Protein Concentrate will be presented.

In-house Research.--The primary objective has been to develop a process for a totally water-soluble product which will offer distinct advantages for use in such foods as soups and beverages. Although processing costs have been considered throughout the work, the major concern has been for improvement of the amino acid pattern and nutritive value of the soluble product. The basic process outline includes enzymatic digestion of a whole fish slurry with control of pH and temperature, screening out of bones and scales, separation of undigested solids by centrifugation and spray drying of a clarified hydrolysate to yield a soluble product consisting of peptides, polypeptides and some free amino acids. An alternate product which is easily dispersible but only partially soluble is prepared by eliminating the centrifugation step.

In early experiments with a specially prepared fish protein substrate, the relative proteolytic activities of 23 commercially available enzyme preparations were compared. Papain, ficin, bromelin, pepsin, and trypsin from two or more manufacturers each and several preparations of bacterial and fungal enzymes were tested. Based on a one-hour hydrolysis at pH 7 and 40° C. used in initial tests, preparations of the enzyme ficin were most active. In a second set of experiments 24-hour digestions were carried out at conditions of pH and temperature considered near optimum for each enzyme preparation. Based on enzyme concentrations required to solubilize 60 percent of the insoluble solids the fungal enzyme Pronase was most effective. Papain, pepsin, and pancreatin showed the most promise when activity per unit cost of enzyme was considered.

Initial hydrolysates of whole fish were prepared from pre-sterilized slurries of red hake (*Urophycis chuss*) but the soluble products were critically low in tryptophan and the aromatic amino acids. Both yields and amino acid profiles were improved by hydrolyzing

raw hake and utilizing the native enzymes in conjunction with added commercial enzyme preparations.

An extended series of 5-liter hydrolysate batches were prepared from raw hake using a variety of enzyme preparations and processing conditions. The results were analyzed and although essential amino acid contents of solubles were improved by elimination of pre-cooking, they were not adequate for good nutritive value. Tryptophan concentrations were low in hydrolysates prepared under acid conditions and histidine recovery was poor in those prepared under neutral to slightly alkaline conditions. Attempts to overcome the problem with a two-stage hydrolysis were not successful.

Experiments with newly acquired alkaline proteases of *Bacillus subtilis* revealed that fairly good recoveries of both tryptophan and histidine could be obtained in soluble FPCs hydrolyzed at pH 8.5 and above. Hydrolysis with pancreatin above pH 8.5 also gave good yields and better histidine recovery than did earlier runs at pH 8. Pancreatin and the alkaline protease Alcalase* were chosen for evaluation in replicate runs. Both hake and a fatty fish, alewife (*Alosa pseudoharengus*),

Table 3 - Nutritive quality of hydrolysates produced from red hake and alewife by enzymatic hydrolysis

Enzyme used	Protein efficiency ratio	
	Actual	% of casein
	Red Hake	
Pancreatin, 0.50%	2.89 ± 0.07 ^a	82.2
Alcalase, 0.35%	2.63 ± 0.10	74.8
Autolysis	2.87 ± 0.07	81.7
	Alewife	
Alcalase, 0.5%	3.44 ± 0.06	97.2
Alcalase, 0.3% ^b	3.34 ± 0.07	94.4
Autolysis	3.40 ± 0.08	96.0

^a Standard error of the mean.

^b Produced by digestion of presscake. All other samples were produced by digestion of raw fish.

*Supplied by Enzyme Development Corp., New York, and manufactured by Novo Industries, Copenhagen. The use of manufacturers' and trade names throughout this article is for informational purposes only and does not imply endorsement.

were hydrolyzed and chemical analyses, material balances and protein efficiency ratios (PERs) were determined.

Yields of soluble products from hake and alewife were in the range of 12-14 percent of wet fish weight. Partially soluble products were also prepared from both species by autolysis and from alewife presscake by hydrolysis with Alcalase. These products included undigested solids, except bones and scales removed by screening, and were obtained in high yields but residual fat was also high.

The PERs determined by feeding studies with each of the hydrolysates are listed in Table 3. The soluble product from alewife had a PER essentially equal to that of casein, a level that we have not reached with a totally soluble product of red hake. Although the soluble hake products were inferior to casein as a sole source of protein, they were nearly equal to casein as a supplement to wheat flour protein as is shown in Table 4.

do not include marketing costs and profit margins.

Contractual Research.--Additional work on biological methods for FPC has been done under contract. At Columbia University, hundreds of microorganisms were screened for lipolytic, proteolytic and organoleptic suitability for fish fermentation. A fungus, *Geotrichum candidum*, and a yeast, *Candida lipolytica*, were determined to be most promising for menhaden fermentation. Both microorganisms utilized for lipids and non-protein nitrogen contained in menhaden and effected a reduction in fat content and a net increase in protein content of the ferment while yielding a product with a neutral to pleasant aroma. These results have been reported in a publication by Burkholder et al. (5).

At the Massachusetts Institute of Technology, the solubilization of solvent-extracted FPC by enzymatic hydrolysis has been in-

Table 4 - Supplement value when added to wheat flour of hydrolysates produced from red hake

Enzyme used	Sample 2%, wheat flour 8% of protein in diet ^a		Sample 4%, wheat flour 6% of protein in diet	
	PER	% of wheat flour	PER	% of wheat flour
Pancreatin	2.17 ± 0.05 ^b	171	2.85 ± 0.05	224
Alcalase	2.09 ± 0.07	165	2.74 ± 0.05	216
Autolysis	2.26 ± 0.12	178	2.87 ± 0.08	226
Casein	2.28 ± 0.03	180	3.02 ± 0.07	238

^a Diets contained 10 percent protein of which the supplements provided 2 or 4 percent and the remaining 6 or 8 percent was supplied by wheat flour.

^b Standard error of the mean.

Suggested process outlines have been developed for biological processes utilizing raw whole fish and fatty fish press cake. Material balances obtained experimentally were used in conjunction with a newly-developed computer program to estimate production costs for the two types of products. It is estimated that plants processing 200 tons/day of fish costing 1¢ per pound could produce a totally soluble product for less than 19¢ per pound. A plant of similar size could produce a partially soluble product from press cake for about 12¢ per pound. These figures are based on operating costs including amortization, but

investigated. Several enzymes were evaluated in batch studies and a continuous system was developed in which an ultra-filtration membrane was used to remove hydrolytic products while retaining the enzyme and insoluble solids for continued reaction. It appears that this approach may not be feasible because of the instability of proteolytic enzymes under suitable reaction conditions. A large continuous system is now being assembled which will employ a relatively inexpensive *B. subtilis* enzyme and will produce sufficient products for evaluation including PER determinations.

Production

Most large-scale research efforts have involved solvent extraction methods. A wide variety of solvents has been investigated for use in making FPC. These range from non-polar solvents, such as hexane, to very polar solvents, such as methyl alcohol, and from chlorinated hydrocarbons to ketones and esters. It is interesting to note, however, that every commercial or proposed commercial solvent extraction procedure makes use of isopropyl alcohol somewhere in the process.

A description of the major commercial or near commercial operations will serve to illustrate the extensive use of isopropyl alcohol for making FPC.

The FPC Experiment and Demonstration Plant, Aberdeen, Washington.--The Experiment and Demonstration Plant constructed in Aberdeen, Washington, was authorized by the 89th Congress in Public Law 89-701. It is designed to demonstrate the feasibility of commercially producing FPC, by the counter-current isopropyl alcohol extraction technique developed by the National Marine Fisheries Service. Construction was completed in March 1971. The process used in this plant is that previously described as a four-stage countercurrent extraction with the IPA-water azeotrope. The plant is designed to process 50 tons of raw fish per 24-hour period into $7\frac{1}{2}$ tons of FPC. At present, the plant is designed to process lean varieties of fish and several hundred tons of fish have been processed into large tonnages of acceptable FPC. After demonstrating the process with lean fish, the plant will be modified to process fatty fish. The phases of the process used in the plant are as follows:

Storage.--The fish unloading and storage system is based on the use of refrigerated brine. In this system, 150 tons of fresh fish can be stored at 32° F. in chilled brine. The storage tank is constructed of redwood and contains 12 separate, 750-cubic-foot galvanized, steel-lined compartments. Fish are conveyed to the tanks by a fish pump and belt conveyor system.

Comminution.--The fish are carried from the refrigerated storage in large tote boxes, weighed, and then conveyed to a Rietz disintegrator for comminution. After comminution, the fish can be deboned if such is

needed to assure that the final product will meet the 100 ppm fluoride restriction. The comminuted fish are then placed in one of the two slurry tanks.

Extraction.--The fish-IPA mixture contained in the slurry tank is then continuously pumped through the four extractors in which the oil and water are removed. The material moves through the extractors at approximately 30 gallons per minute. During the extraction phase, the solids are removed by a combination shaker screen and pulp press arrangement.

Solvent Recovery.--The liquid portion, called miscella, is then further processed for solvent and by-product recovery. The IPA is purified and recovered by distillation.

Desolventizing.--The solid material, which contains some water and isopropyl alcohol, is dried and desolventized in a series of four Strong-Scott driers.

Milling.--The material is then finely milled and bagged in 50-pound polyethylene-lined bags.

Throughout the process stringent sanitary and safety controls are maintained and monitored by a team of chemists and microbiologists located at the plant site.

The product from the EDP will be packaged in 50-pound quantities and will be made available to industry for research.

Nabisco-Astra Nutritional Development Corporation.--This Corporation, with headquarters in New York City, is a joint venture between the National Biscuit Company, U.S.A., and the Astra Company of Sweden. Astra Nutrition has developed a process for making IPA-FPC and Nabisco is experienced in the production and marketing of protein-enriched food products. The two companies united to form the Nabisco-Astra Nutritional Development Corporation.

The process for making EFP-90 (eviscerated fish protein) as it is called, is a modified IPA process (6).

Fish are cut into segments, washed to remove viscera and blood, and slurried in water and cooked. The cooked material passes through a deboner, a desludging centrifuge, a hot water treatment, and a second centrifuge. From there it enters a continuous extractor where fat is removed by isopropyl

alcohol. On discharge, the IPA is centrifuged to clarify it for return to the solvent recovery system. The extracted fish is passed through a steam-heated agitating desolventizer where any remaining solvent is removed. As a final operation, the material is dried in a steam heated unit, milled to a fine consistency and placed in appropriate containers. The EFP-90 contains between 92-94 percent protein with an IPA residue of less than 100 ppm. At present, herring is used to make EFP-90. Reportedly, the EFP-90 is offered for sale at about 49¢ per pound.

Cardinal Proteins, Ltd.--Cardinal Proteins, Ltd., Nova Scotia, Canada, has constructed a multimillion dollar IPA-FPC plant with a capacity of 200 tons of fish daily. This plant, located in Canso, Nova Scotia, uses the IPA process, as developed in Halifax, Canada. In this system, the initial slurry is acidified with phosphoric acid.

The plant is located next to an established fish processing plant. Cardinal expects to meet one-third of its daily requirement for raw material by fluming cod and haddock trimmings directly from the processing plant. These trimmings currently are being used in fish meal production. However, this material, having been handled under sanitary conditions, is considered superior to fish normally used for making fish meal. Canadian FDD regulations permit the use of sanitary fish trimmings, which is considered economically beneficial and a wise use of the resource. No firm cost figures for IPA-FPC are available at this time.

Societe Nationale Farine Alimentaire Poisson (SONAFAP), Agadir, Morocco.--The Agadir plant uses batch extraction procedures. This plant operated for a few weeks in 1965 and for several months in 1966. About 170 tons of product were produced using hexane and ethyl alcohol, but because of poor odor and color the product was unacceptable. The plant remained idle until about a year ago when operations were once again resumed and an acceptable FPC was made by IPA extraction of sardines (*Sardinia pilchardus*).

This plant will be used to produce IPA-FPC for acceptability studies in Morocco. No cost figures are available.

Alpine Marine Protein Industries, Inc.--Alpine Marine Protein Industries, Inc., New Bedford, Massachusetts, whose plant was re-

cently sold to another company, used a two-solvent system. The process was based on the VioBin method of extraction of whole fish with ethylene dichloride resulting in a dehydrated and partially defatted material. This material was further extracted with IPA in a continuous countercurrent procedure. The final solids were dried, steam stripped, and milled.

This company, prior to cessation of operations, produced a considerable amount of FPC for use by the U.S. Agency for International Development.

UTILIZATION

To be an effective nutritional supplement, FPC should be supplied in a form that people will readily accept. One means of accomplishing this is to incorporate FPC into foods that people are accustomed to eating. In this respect, we must keep in mind that FPC, by itself, is not a food. Rather it is a supplement that is designed to be added to food products to enhance their nutritive quality. Thus, a major effort has been made to obtain basic information on the use of FPC in various food products.

Sidwell et al. (7) have extensively studied several generic foods to determine suitable levels of incorporation of solvent-extracted FPC as related to alterations in formulations and changes in the characteristics of the resulting food products. Excellent results have been obtained in incorporating FPC into a variety of such products as bread, pasta, and crackers. These studies have shown that the quantity and quality of the protein in these products can be substantially improved by the use of FPC. With most products, little change in the physical and sensory characteristics of the foods occurred when 5 percent FPC was used in the formulation. Foods containing 5 percent FPC were very acceptable, and usually indistinguishable from unsupplemented products. Differences in the organoleptic characteristics of foods were some times found when higher levels were used, especially from certain species of fish. The color of the products was most often altered by the use of higher levels of FPC. In most cases no more than 6 to 8 percent FPC would be recommended from the standpoint of nutrient return per unit of cost. In general, these studies and others have demonstrated that the technological problems related to the incorporation of FPC into food products for

nutritional purposes are not particularly difficult to solve.

Limited food research studies have been carried out with enzymatically produced FPC's. The studies indicated that the FPC's are highly flavored. For most food applications a bland product is desirable and a good soluble protein would command a premium price. With additional development, biological FPC's from whole fish can be of real value for uses where good nutritional quality and special functional properties are required.

MARKETING

The distribution and marketing of foods containing FPC--or any protein supplement--is a difficult and complex problem that involves a host of interrelated factors. Social, economic and cultural considerations must be taken into account. Each particular country or location must be analyzed separately.

United States.--According to a report by Hammonds and Call, the market for FPC's depends upon price-functionality relationships (8). An FPC with functional properties would command a higher price than a non-functional FPC.

Hammonds and Call assumed a price range for FPC of between 28.8 to 53.8¢ per pound of protein. They state that this price range would place FPC costwise between soy flour (12.6 to 16.4¢ per pound of protein) and non-fat dry milk (55.6 to 69.4¢ per pound of protein). Furthermore, since this range is neither clearly lower than that of present protein ingredients, nor clearly higher, the functional characteristics of FPC then becomes crucial in determining the market potential.

The study showed, in summary, that the maximum market potential for protein ingredients is approximately 3.1 billion pounds yearly at the present time. FPC could become an important commodity in this market if the organoleptic, functional, physical, and nutritional characteristics were satisfactory. Obviously, the price would also have to be competitive with other protein ingredients.

Other Countries.--Outside the United States, the competitive market for FPC will be subject to essentially the same type of economic analysis as reported by Hammonds and Call. Some countries, however, have plans to require FPC supplementation in bread and baked goods. This could lead to a sizable market for FPC.

A study was recently conducted in Chile under a contract from the Agency for International Development. The purpose of the study was to analyze the feasibility of commercial production and marketing of FPC. The report of the study noted that there are still some uncertainties regarding the cost of producing FPC. Based on available data, however, it appeared that FPC could be produced profitably for a selling price of 25 to 30¢ per pound. At this price, the report concluded that FPC would be highly competitive with other protein alternatives. At present levels of consumption, about 18,000 metric tons of FPC would be required to fortify bread and pasta in Chile. Although a note of caution was indicated because of several uncertainties, the conclusions of the study were optimistic and indicated that FPC could be produced and marketed successfully.

A recent report concerning the economics of solvent-extracted FPC, however, indicates a less optimistic outlook than the study conducted by AID (9).

SUMMARY

An FPC industry has been started, and plants are now in operation. Isopropyl alcohol is used, in each instance, as at least one of the solvents to remove water and lipids. The isopropyl alcohol extracted-FPC is essentially a "non-functional" product, but has a place on the world market as a high quality nutritional supplement. FPC's with improved functional properties, such as produced biologically or by modified chemical means, are desirable and research is underway for their development.

There is a market for FPC's, but their price and characteristics will govern the extent of usage.

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