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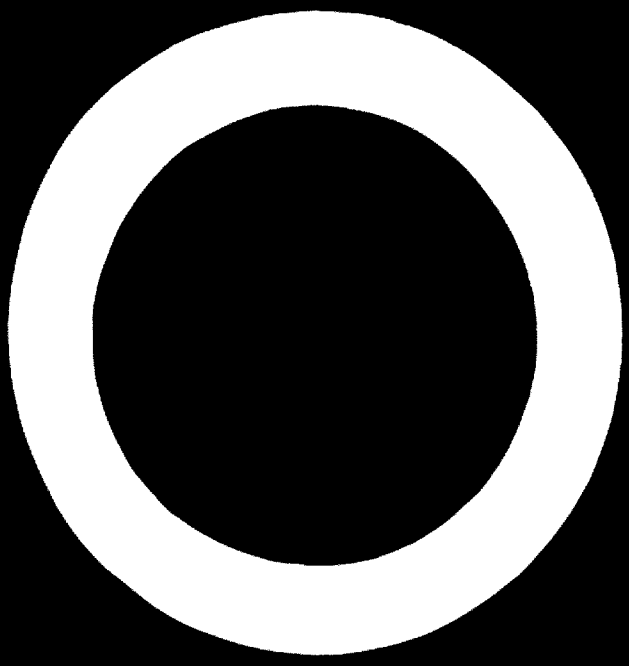
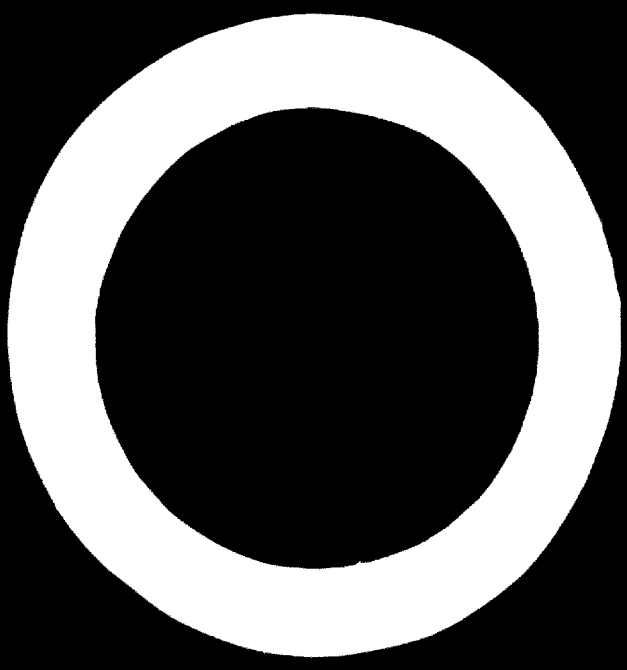
PRODUCTION OF FISH-PROTEIN CONCENTRATE

UNITED NATIONS





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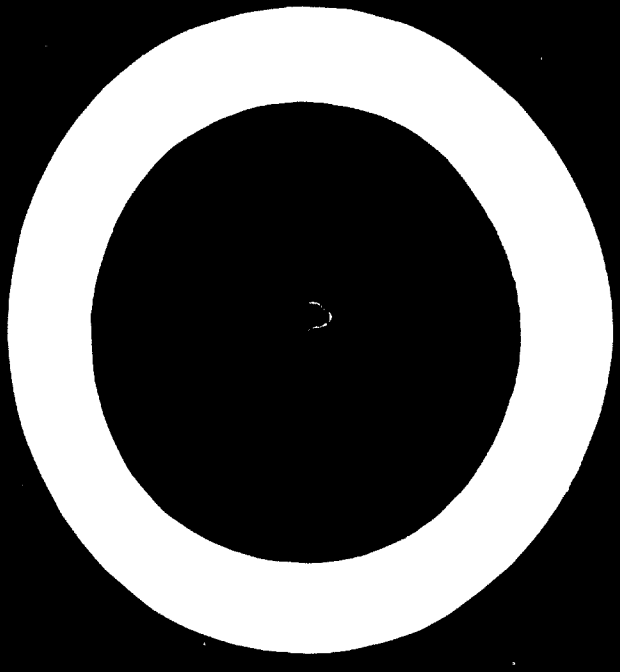

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

PRODUCTION OF FISH-PROTEIN CONCENTRATE

Report and proceedings of the
Joint UNIDO/FAO Expert Group Meeting
Rabat, Morocco, 8–12 December 1969

Part II PROCEEDINGS OF THE MEETING

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Preface

The joint UNIDO/FAO Expert Group Meeting on the Production of Fish-Protein Concentrate (FPC), held in Rabat, Morocco from 8 to 12 December 1969, addressed itself to two principal questions: (*a*) commercial production of fish-protein concentrate (FPC) products and their distribution to people having the greatest need for such products; and (*b*) the development of a commercial enterprise to produce FPC in Morocco, taking into account the efforts made so far.

A report of the meeting, published by UNIDO as ID/60, Vol. I, includes general recommendations on FPC, recommendations for the SONAFAP plant in Morocco, a summary of discussions, statements describing the situation in Morocco and efforts made elsewhere to produce FPC.

The present publication, Volume II, covers the proceedings of that meeting, including papers presented to the meeting. The authors review various aspects of the research done in the field with the main emphasis on the testing, processing methods, production and utilization of FPC as a viable source for supplementing the diets of humans.

The paper "Fish-protein concentrate—history and trends in production", by Oswald A. Roels, describes the early efforts of other agencies of the United Nations—notably FAO and UNICEF—and of individual countries to produce an FPC suitable for human consumption, and includes brief descriptions of the extraction methods and other processes developed for the production of FPC.

The next two papers, "Utilization and quality control of fish-protein concentrate", by George D. Kapsotis, and "The nutritional effectiveness and acceptability of fish-protein concentrate", by C. O. Chichester, F. Mencher-berg, and E. Yáñez, give the results of tests conducted with humans and with animals to determine the protein efficiency, nutritive value and acceptability of FPC used as a supplement in diets.

The paper on "Potential resources for the industrial production of fish-protein concentrate", by Rudolf Kreuzer, provides data on the world-wide production of fisheries and indicates the various ocean resources for possible industrial utilization in the production of FPC.

Eight papers describe in detail the operations and processing methods of plants producing FPC in Canada, Chile, Morocco, Norway and the United States. These are "Production of fish-protein concentrate from Moroccan

sardines", by John Blake; "Description of operational FPC plants", by James S. Tolin; "Description of the demonstration plant of the United States Bureau of Commercial Fisheries", by George M. Knobl, Jr.; "Production of low fat fish meal in Norway", by Gerdt Lövold; "The Halifax isopropanol process for the manufacture of FPC", by David R. Idler; "Aspects of planning FPC production facilities", by Arnold Carsten; "An experiment using isobutanol for the production of fish-protein concentrate in Chile", by P. Hevia, Fernando Acevedo Bonzi, and S. Kaiser; and "Proteolysate of sardines", by B. De Gero and O. Skiredj.

The paper "Observations on fish processing", by Noel R. Jones, relates the various operations used for the freezing, storage and canning of fish at sea, and describes other processes for preserving fish such as fermenting, salting, drying and smoking, along with the characteristics, quality and nutritive value of the products obtained. Another method of preserving the essential nutritive elements of fish, which has been used for centuries in Viet-Nam and has recently been introduced in the Ivory Coast, is discussed in the paper on "The production and use of *nuoc mam* in the Ivory Coast", by A. Faubeau.

A paper on the "Analysis, testing and uses of fish-protein concentrate", by Virginia D. Sidwell, Bruce R. Stillings, and George M. Knobl, Jr., compares the chemical composition, nutritive value and sensory evaluation of foods, such as bread, pasta, crackers, cookies and beverages, supplemented in varying amounts with FPC made from different species of fish.

The paper on "The US/AID programme for evaluating and promoting FPC", by J. B. Cordaro, gives the results of feasibility studies sponsored by the United States Agency for International Development for the location of an FPC industry, and describes further experiments made in Chile, the Republic of Korea and Morocco to obtain reliable data on consumer acceptance, product stability and packaging requirements of FPC-fortified food products, with the long-term aim of introducing FPC into the food system in countries where the traditional diets are low in protein.

The concluding paper, "Utilization of FPC: an analysis to help formulate national nutrition policy", by Gerald D. Bernstein, Sidney M. Cantor, and Solomon H. Chaffkin, analyses the economic aspects of using FPC as a fortification agent—its cost by comparison with lysine, casein and other protein sources—to serve as an aid to governments in formulating their nutrition policies.

The data included in this publication are in general as presented at the meeting in December 1969, and were presumably the latest figures available to the respective authors at that time.

Opinions expressed in signed articles are those of the authors und do not necessarily reflect the views of the United Nations Secretariat.

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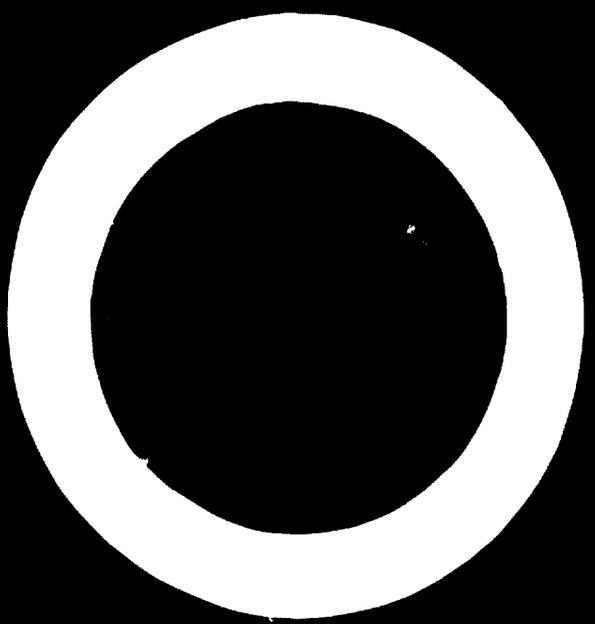

EXPLANATORY NOTES

Reference to dollars ($) is to United States dollars. One cent (¢) equals $ 0.01.
Reference to tons is to metric tons unless otherwise indicated.
Three dots (...) in tables indicate that data are not available or are not separately reported.
A dash (–) in tables indicates that the amount is negligible.
Details and percentages in tables do not necessarily add to totals, because of rounding.
Numerals in square brackets [ ] refer to the references gathered at the end of the article.

The following abbreviations are used in this volume:

BHT	Butylated hydroxy toluene
BU	Brabender unit
BV	biological value
c.i.f.	cost, insurance and freight
EDC	ethylene dichloride
FPC	fish protein concentrate
IPA	isopropyl alcohol
NPU	net protein utilization
PER	protein efficiency ratio
ppm	parts per million
RNV	relative nutritive value

The following acronyms are used in this publication:

United Nations and specialized agencies

UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
FAO	Food and Agriculture Organization of the United Nations
WHO	World Health Organization
PAG	Protein Advisory Group of FAO/WHO/UNICEF

Other organizations

AOAC	Association of Official Agricultural Chemists
BCF	Bureau of Commercial Fisheries, Fish and Wildlife Service, United States Department of the Interior

FDA	Food and Drug Administration, United States Department of Health, Education, and Welfare
ICES	International Council for the Exploration of the Seas
SONAFAP	Societe Nationale de Farine de Poisson (National Fish Meal Company, Agadir, Morocco)
TNO	Organisatie v. Toegepast Natuurwetenschappelijk Onderzoek (Netherlands Organization for Applied Scientific Research), Zeist, Netherlands
USAID	Agency for International Development, United States Government

INTRODUCTION

The papers presented at the joint UNIDO/FAO meeting provide a wide view of the many aspects of the development, preparation and use of fish-protein concentrate (FPC).

The papers deal primarily with FPC prepared by solvent extraction of ground whole fish, and they reflect the active research and development programme currently going on. This is evident, for example, from the several similar but still differing definitions of FPC put forward by the various authors.

Basically, the term FPC covers a number of products, made in different ways, which have in common that they are made from fish and contain a more concentrated amount of protein than was present in the raw material. This led to the definition suggested by the Ad Hoc Working Group on the potential of FPC for developing countries, at a meeting held in London from 9—10 November 1970, to suggest the following definition as a basis for discussion:

> "Fish-protein concentrate is taken to be a stable product suitable for human consumption prepared by a process involving the removal of water from whole fish or parts thereof." (PAG Document 2.8/30, 2 December 1970.)

Regardless of how it is prepared, the nutritive value of the product is unquestioned. As summarized by C. O. Chichester, F. Monckeberg and E. Yáñez:

> "First, as a supplemental food in wheat, corn or other cereal diets, FPC offers an excellent protein for fortification. Where it can be incorporated with cereal mixtures—material to which it does not have to contribute a functional property (for example, in bread pasta, cookies and the like)—the product is acceptable to most populations at values approximating 10 per cent of the total mixture. Second, the cost of the raw material appears to be lower than that for most other good protein sources. Finally, the stability of the protein is excellent in that it is able to retain its nutritional qualities without special attention being paid to conditions of storage."

In the final analysis, however, FPC will only be of use if it finds its way into the human diet, not as an occasional supplement on a give-away basis but on a continuous commercial basis. It must be remembered that FPC, in common with other food-protein concentrates, is a food ingredient, not a food

per se. Its use, therefore, depends on its incorporation into acceptable foods at a price admissible to the consumer. Thus opens the whole problem of marketing food products. The papers by Sidwell, Knobl and Cortaro outline some of the steps that have been taken towards marketing trials, and give the results of market studies made in Chile and the Republic of Korea.

A much greater step has been taken recently with the development of a large and still growing market for FPC in specialized animal feed stuffs, particularly in "calf starters", which are milk substitutes used in early calf feeding. These products require a high quality, odourless and tasteless animal protein concentrate. FPC precisely fills this need. The volume of the market is such that plants can be run profitably to meet the market demand. This, in turn, will hasten the use of FPC in human foods since the slow step-by-step process of entering the human food market can now be undertaken without concern over idle plant capacity or the necessity for a long-term subsidy of some sort while a profitable market in human food is being obtained.

1 FISH PROTEIN CONCENTRATE—HISTORY AND TRENDS IN PRODUCTION*

ACUTE SHORTAGE OF HIGH-QUALITY PROTEIN

Despite the increase in world food production during the 1960s, the *per capita* production in the developing countries was declining [1] to such an extent in some areas as to cause serious concern. The deficient quality of food, notably the lack of proteins, was an even more critical factor than the insufficient quantity, measured in calories.

A report of the Advisory Committee on the Application of Science and Technology to Development, submitted to the United Nations Economic and Social Council in 1968, noted that one third of the populations of developing countries suffered from an unbalanced diet consisting of too many calories in proportion to proteins. Varying but undeniable instances of a gap between nutritional requirements and actual consumption of protein were widely evident in these areas and showed signs of increasing. The report concluded:

> "If the situation worsens, the physical, economic, social and political development of the populations involved may be completely arrested. Protein-calorie malnutrition not only increases susceptibility to acute and chronic infections, but also causes a compensatory reduction in the capacity for physical activity and promotes apathy. These direct effects on adult populations impede the economic productivity and development of countries which are desperately in need of improving the status and potential of their peoples, quite apart from the human suffering involved.
>
> "The growing nutritional deficiencies have even greater impact on young children in developing countries. In some countries, as many as one third die before reaching school age, and for most of the survivors physical growth and development are impaired. Moreover, there is increasing evidence of associated retardation in mental development, learning and behaviour, due in particular to malnutrition in early childhood. Thus, the nutritional deficiencies existing at the present time in many developing countries already are jeopardizing the future for many millions of the world's people."

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* Paper presented to the meeting by Oswald A. Roels, Professor, Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York, USA.

Among proposals to increase the availability of protein, the report recommended that until improvements were made in conventional agriculture in the developing countries the diet be supplemented by protein-containing foods of unconventional origin, such as oil-seed meal, fish-protein concentrate, single-cell products and the effective use of synthetic essential amino acids and non-specific nitrogen sources. This would require greater emphasis on nutrition education and on the processing, marketing and promotion of food products. [2]

More effective use of fisheries

The animal protein shortage could be overcome rapidly by a more efficient use of present fisheries. The annual world catch of fish amounts to about 50 million tons, containing about 10 million tons of animal protein. This fish could provide as much as 40 per cent of the total animal protein requirement of the entire human race. Only a small percentage, however, is used directly in human nutrition. The large commercial fisheries of the world produce mainly fatty fish, such as herring, menhaden and anchovies. Most of these fish are now used in the preparation of feed for poultry, swine and cattle, and an appreciable quantity is employed as fertilizer. Fish protein, used in this way, will eventually increase the amount of animal protein available to man but only after passing through a long and inefficient food chain.

An example of such a food chain occurs in connexion with the Humboldt Current, which flows northward along the coast of northern Chile and Peru. This Current is an area of extraordinary productivity and supports the life of millions of tons of anchovies. For centuries the anchovies have been food for a huge population of fish-eating birds that nest on the rocky islands and promontories along the coast. The excrement from these birds is called guano. It has long been used as fertilizer and was one of Peru's most valuable natural resources as well as one of its major exports. The inefficiency of this food chain lies in its many time-consuming stages: the birds eat the fish, the birds defecate in caves along the shore, and the fecal matter, guano, is collected and shipped long distances across the ocean where it is used to fertilize fields. The fields produce crops which, in turn, support either cattle or pigs that are destined to be eaten by man. The protein efficiency of such a food chain is in the order of 10^{-6}. In other words, one million pounds of fish caught by the birds eventually will yield one pound of protein for human consumption. The inadequacy of this trophic chain has led to its abandonment for the more efficacious and remunerative system of harvesting anchovies directly.

In recent years the Peruvian anchovy fisheries have become one of the world's most rapidly expanding fishing industries. Their catch increased from 89,000 tons in 1955 to 10 million tons in 1967—1968. The fish is now converted into fish meal to be used as feedstuff for animals. Hence, the food chain has been shortened to three stages: from the fish to the pig to man. Approximately 1,000 pounds of anchovies currently produce one pound of protein for human use, or a thousandfold increase of efficiency over the guano food chain. Still, even in this shortened food chain the protein yield is low

and could be improved by a factor of at least ten if fish were consumed directly by man.

The preservation of fresh fish, however, and particularly of fatty fish, presents a problem, especially in tropical climates. In many developing countries where protein deficiencies are greatest, the high cost of refrigeration puts fresh fish out of reach of the consumers who need it most and tends to discourage the fishing industry. For example, in the 1950s in the former Belgian Congo the annual yield of sea fisheries was restricted to 6,000 tons because of the low capacity of the ice factory in Ango-Ango [3] the only serviceable fishing port.

Although drying, salting and drying, and smoking are inexpensive ways to preserve fish, they have disadvantages from the standpoint of quality.

The preparation of fish flours for human consumption could make better use of the resources of fisheries, especially by converting fatty fish into an inexpensive edible protein. The cost of processing fish protein could be reduced by eliminating the need for refrigeration or canning. Finally, fish flour represents an improvement from the hygienic and nutritional standpoint over dried and smoked fish.

Fish flour for human consumption

Nearly twenty years ago agencies of the United Nations—notably UNICEF and FAO—drew attention to the important contribution that fish flour could make to human nutrition as an inexpensive protein with very high biological value. This was stressed by Autret in his address to the Third International Congress of Nutrition in Amsterdam in September 1954, in which he pointed out the importance not only of its high protein value but also of its calcium and vitamin B_{12} content. For child and infant feeding a cheap fish flour offers advantages with respect to price and storage by comparison with canned, dried and salted fish. Autret also called attention to the acceptability tests being conducted among the populations of certain developing countries, and indicated that preferences varied markedly from country to country when it came to a flavoured or flavourless flour. Children, however, did not seem to show a preference. [4]

The argument for the development of fish flours with full fish flavour for human consumption is based on economic considerations. The wholesale price of fish meal for animal food in 1969 was about 0.9 ¢ per lb. Since it contained 65 per cent protein, the cost of the protein in the meal was approximately 14 ¢ per lb. If such protein could be utilized directly for human consumption with relatively little increase in cost, few other sources of protein could compete with it.

Several attempts were made in the 1950s to produce inexpensive fish flours for human consumption. These products had a strong fish flavour. For this reason they were accepted by consumers in African countries where the staple food is usually a bland starch, and the fish flour was used to prepare a sauce that added flavour to the diet.

In many developing countries the population groups that require high protein supplementation to their diet live essentially in a substistence economy. They grow and produce their own food and have little or no means to buy food. In the African countries where such an economy pertains, salt is a regular purchase. Hence, when fish flour was introduced as a new type of condiment, it sold well, even in areas such as Rwanda and Burundi where the population is traditionally vegetarian.

Ghana

In Ghana, the Government fisheries service built a pilot plant in Accra in 1951 to produce fish flour for human consumption. [5, 6] The fish used was *Sardinella aurita*, which is caught in the coastal waters from June to September. The product was prepared by autoclaving the fresh fish, pressing it to remove part of the oil, and drying the remaining cake. It sold for 21¢ per kg in 1955, but the small pilot plant could not produce enough to satisfy the demand. A larger factory for the manufacture of fish flour was then planned for construction at Tema Harbor.

The product prepared at the Accra plant contained up to 8 per cent fat. This high fat content might be expected to cause rancidity and peroxidation. After storage at room temperature for nine months, [7] however, the peroxide in the Accra fish flour was less than 0.5 per cent, and there was no detectable rancid flavour. The product was then analysed for natural tocopherols; it contained the equivalent of 18 mg tocopherol acetate per kg or 224 mg per kg of fat in the fish flour, a quantity sufficient to prevent the oxidation of fats.

Uganda

The Uganda Fish Marketing Corporation (TUFMAC) constructed a plant much like the one in Ghana on the shores of Lake George. [8] (A detailed description of the process and of the equipment used has been published by TUFMAC.)

The product from the Uganda plant contained 72.8 per cent protein, 3.2 per cent oil, 15.4 per cent ash, and the remainder was moisture. The cost of the preparation was 2.5¢ per kg of fresh fish in 1956.

Congo/Rwanda-Burundi

A pilot plant for the production of fish flour for human consumption was built in Usumbura in 1956 on the north shore of Lake Tanganyika, Burundi. [9] Two sardine-like species of fish from Lake Tanganyika (*Stolothrissa tanganicae* and *Limnothrissa miodon*) were treated by a process very similar to that used in Ghana. The product was offered for sale in two packages, 100 g for home consumption and 5 kg for institutional use. It contained 68 per cent protein, 8 per cent water, up to 11 per cent oil, and 12.5 per cent ash. The oil content of the product varied, depending upon the physiological cycles of the fish and seasonal changes in their environment. The oil

content was an asset in this area, where a vitamin A deficiency is endemic and is caused in part by the low fat content of the diet. The biological value was excellent, and the product was very well accepted in Rwanda and Burundi. Like the Ghana fish flour, the product from the Usumbura plant, although high in fat, apparently contained sufficient natural antioxidants to prevent rancidity and peroxidation, even when it was stored during long periods of time in a tropical climate. It was protected from moisture, however, by polyethylene bags.

Solvent Extracted Fish or Fish Meal

Several attempts have been made to prepare tasteless fish protein products that could be incorporated into staple foods such as bread. The simplest approach has been to remove the fish lipids by solvent extraction.

South Africa—extraction with ethanol

One of the early efforts in this area was undertaken by the Fish Industries Research Institute of South Africa in collaboration with a private firm, Marine Oil Refineries of Africa. They prepared a deodorized fish protein concentrate by the extraction of whole fish (*Trachurus trachurus*) with ethanol [10, 11]. Up to 8 per cent of this deodorized, defatted fish flour was incorporated in the formulae for bread baked in Johannesburg. But when it was discovered that the population groups who needed the protein supplement most did not buy bread, this highly motivated government sponsored effort was abandoned.

Chile—extraction with hexane/ethanol

The development of the South African process led to the establishment of a United Nations co-sponsored fish protein concentrate plant in Chile.

In his report to the Nutrition Congress in Amsterdam Autret enumerated the following reasons for selecting Chile as a suitable country for initiating experiments to determine the acceptability of such flours: the country's extensive fish resources, the "fish consciousness" of the population, the availability of FAO technical and promotion assistance, the fact that the Chilean diet is lacking in animal protein, and the general receptivity of the local authorities to the project [4].

Autret described preparatory experiments in Chile in which the fish flour was mixed into a number of foods, such as vegetable soup, potato soup, tagharins (pasta), cochayuyo (edible algae), fried potatoes and lettuce, beet leaves pie, beans, beef stew, boiled potatoes, cocktail crackers, coffee cake and white bread. These combinations were judged in preliminary tests by a limited number of persons, who found the preparations generally acceptable, except for the tagharins, the cochayuyo and the beef stew (the texture of these was not considered normal). The beet leaves pie, the crackers (25 per cent fish flour), the coffee cake (10 per cent fish flour) and the bread (10 per cent fish flour) were unanimously accepted.

These preliminary tests were followed by a larger trial involving 140 school children, five to fourteen years old. Every day for six weeks each child received, as part of his school lunch, an 80 g bread roll made at a commercial bakery of flour containing 10 per cent fish flour. Each bread roll contained 6.1 g of fish flour, which provided the child with a daily supplement of 4.4 g protein, 335 mg calcium, 329 mg phosphorus and 3 mg iron; the roll itself supplied 6.5 g protein. The only difference from normal bread was a slightly darker colour; smell, taste, form and consistency of crust and crumb were normal.

The bread was very well accepted by the children. There was no rejection or complaint, and no digestive trouble occurred.

On the basis of these results, the Chilean Government requested UNICEF and FAO to help them set up a plant for the manufacture of edible fish flour to be used mainly in supplementary feeding programmes.

Later, UNICEF assisted the Government of Chile in the production of fish protein concentrate by providing the supervisory engineering services and the necessary processing equipment, which was installed at the IPESA (Industria Pesquera de Altamar) plant at Quintero. A report on the operation of the plant, the biological value of the product, and all cost details was prepared by Layton E. Allen, the senior engineer for UNICEF. [12]

The plant used fresh hake (merluzza), which is a lean, edible fish, and employed a process combining hexane and ethanol for the extraction of fat and for deodorization. The plant was equipped with a horizontal, steam-jacketed, air sweep, raw fish dehydrator with scraper, agitator and condenser; a horizontal, steam jacketed rotary extractor with integral cloth filters and the necessary connections for a vacuum solvent flow and steam stripping; a solvent recovery and storage system, an alcohol purification system; a hammer mill for the dehydrated meal; a hammer mill, flour sieve and packing arrangement for the deodorized product; and the necessary hoppers, conveyors, bucket elevators and cyclones to transport the materials between operations.

The raw fish was first heat-dried in a horizontal, steam-jacketed vessel, agitated by a steam-heated cage of tubes. The meal was extracted with ethanol or with hexane/ethanol. Meal-drying temperature could be controlled over a range of 70° to 100° C by adjusting the rate of air circulation. Under these conditions, drying required about six hours per batch of two tons of whole, fresh merluzza, including time for charging and discharging. The ground meal was defatted and deodorized by the batch in a jacketed rotary extraction vessel through successive washings with solvent. Most of the solvent was removed from the drained cake by agitation and heating under vacuum. The partially dried cake was then stripped of residual solvent by reduced-pressure steam under vacuum. Maximum temperature during this operation was 80° C. The yield of dried, deodorized concentrate was about 16 per cent of the original fresh fish. The product contained, on an average, 3.5 to 10 per cent moisture, approximately 80 per cent protein (N × 6.25), 1.6 to 3 per cent fat, and the remainder was ash. The fluoride content varied from about 150 to

200 ppm, and the lysine content approached 9 per cent. Total cost of the hexane/ethanol process was estimated to be $268 per ton of defatted and deodorized fish flour. It was based on prices in Quintero, Chile, in December 1961, and included the price of raw fish, the fish oil recovered, electricity, steam, water, labour, solvents and packaging supplies.

A recent publication describing the Quintero fish-protein concentrate [13] quoted the price for the product as 35¢ to 55¢ per kg, but indicated that the exact cost was hard to calculate since the plant was built with the technical and financial aid of UNICEF, owned by the Government of Chile and operated by private industry.

North America

The VioBin process—extraction with ethylene dichloride

At about the same time that the Quintero FPC process was developed in Chile, the VioBin Corporation, Monticello, Illinois, was experimenting with fish extraction using ethylene dichloride. This solvent extracts the oil and removes the water from fish by azeotropic distillations. (VioBin had been using this process to extract oil and water from the liver, pancreas and other organs of cattle and pigs on a contract basis for the pharmaceutical industry.) This fist method of extraction applied to fish yields a product with a content of approximately 73 to 75 per cent protein, 15 to 18 per cent ash, 1.5 per cent fat, 0.5 per cent crude fibre, and 8.0 per cent moisture, when lean fish is used. The product is now offered as a milk substitute in animal feeds, and sells for about 15¢ per lb (as of March 1969) if bought in fifteen-ton lots.

The advantage of this type of partially defatted fish protein is that it can be used to feed chickens and pigs, for example, until slaughter time without impairing the flavour of the meat. Regular fish meal cannot be fed to animals for several weeks prior to slaughter because it gives the meat a fishy taste.

VioBin submits this product to a second process of extraction with isopropanol in order to remove the last traces of fat and fish flavour.

The VioBin process, now licensed to several companies, is used by Alpine Marine Protein Industries, Inc. to produce 1,000 tons of fish-protein concentrate for human consumption for the Agency for International Development of the United States Government at approximately 42¢ per lb, or 60¢ per lb of protein.

Alpine Marine Protein Industries, Inc. operates a plant in New Bedford, Massachusetts, with a processing capacity of over 100 tons of fresh fish per day. The plant can produce 20 tons a day of animal feed-grade (non-deodorized) fish-protein concentrate, or 16 tons a day of human food-grade fish-protein concentrate. The company has had difficulty in fulfilling its contract with the Agency for International Development, because the United States Food and Drug Administration regulation prescribes that only hake can be used for the human food-grade product. The hake supply has become scarce and expensive, partly as a result of the demands of the New Bedford plant.

The Cape Flattery Company of Seattle, Washington, has built a solvent extraction plant for treating hake with the VioBin process—i.e. ethylene dichloride extraction—on board a 196-foot surplus US Navy landing ship. The plant on board the ship went into service early in September 1968; it can process 8 tons of fish per hour, or about 200 tons daily. The firm plans to produce a high-grade fish meal using ethylene dichloride as the sole solvent. This fish meal would be used for feeding chickens, pigs and other animals prior to slaughter.

Bureau of Commercial Fisheries—extraction by the isopropanol process

It is difficult to sell foods and food additives, however, until they have been approved and accepted for human consumption. In the United States, the Food and Drug Administration has traditionally ruled out the use of whole fish as human food on aesthetic grounds, because of the incorporation of the intestinal contents in the product, although the practice is allowed for sardines, shellfish and the like.

Recently, the United States Bureau of Commercial Fisheries, under the direction of Dr. Donald Snyder, demonstrated that solvent-extracted whole fish—that is, fish-protein concentrate—is a wholesome food with high nutritional value, especially as a protein supplement. [14] The Bureau of Commercial Fisheries uses a multi-stage isopropanol extraction process to remove both water and oil from the fish, and obtains a bland and finely ground product. A detailed description of the isopropanol extraction process developed by the Bureau of Commercial Fisheries is given in the brochure *Marine Protein Concentrate.* [14]

After intensive toxicological and biological evaluation, the Food and Drug Administration passed a regulation on 2 February 1967 admitting the wholesomeness of the product, but restricting its preparation to fish-protein concentrate made from whole hake and hake-like species of fish, prepared by solvent extraction of fat and moisture with isopropanol or with ethylene dichloride followed by isopropanol. [15]

The Food and Drug Administration's specifications for fish-protein concentrate are the following: it must be made from hake or hake-like fish; it should have a minimum protein content of 75 per cent; it should have a maximum water content of 10 per cent, a maximum fat content of 0.5 per cent, a maximum fluoride content of 100 ppm, a maximum isopropanol content of 250 ppm, a maximum ethylene dichloride content of 5 ppm; and it should be free of pathogenic organisms.

The Food and Drug Administration act states that fish-protein concentrate is supposed to be an additive intended for use in the household only as a protein supplement. The additive must be packed in consumer-size units not exceeding one pound in weight. This regulation effectively prevents the use of FPC in formulated foods at the manufacturing level. The United States Food and Drug Administration approval of whole FPC, achieved through the determined efforts of the United States Bureau of Commercial Fisheries,

was nevertheless extremely important despite its punitive aspects, and several firms in the United States and outside are now seriously considering the production of protein foods utilizing whole fish. [16]

The Bureau of Commercial Fisheries has recently awarded a $2 million contract to Southwest Engineering, Inc. to build a pilot demonstration plant at Aberdeen, Washington. The plant will be operated by Star-Kist Foods, Inc. and will use the isopropanol process.

The Cardinal Proteins Company is building a plant in Canada that will use the United States Bureau of Commercial Fisheries process for the production of 30 tons of fish-protein concentrate per day from red hake. This concern plans to debone the fish with a specially developed Japanese deboning machine prior to isopropanol extraction. This should bring the protein content of the FPC up to approximately 90 per cent and considerably reduce the difficulty of high fluorine content. The plant is under construction in Canso, Nova Scotia; it receives significant support from the Canadian Government. The Canadian Department of Commerce and Industry is actively promoting the use of the fish-protein concentrate to be produced by Cardinal Proteins in various Canadian enterprises.

The Guttmann-Vandenheuvel-Gunnarsson process

As early as 1945 the Fisheries Research Board of Canada in its laboratories at Halifax, Nova Scotia, initiated a study for the preparation of fish-protein concentrate. In 1954 this group studied isopropanol extraction of fish to produce a tasteless and odourless protein product. In 1957—1958 pilot-scale trials of the isopropanol extraction of whole fish were started. The Halifax process was tested on a pilot scale with cod fillets, whole cod, eviscerated cod, cod trimmings and whole herring. The process, known as the Guttmann-Vandenheuvel-Gunnarsson process, is described in detail in article 10 of these *Proceedings* by Dr. David R. Idler of the Fisheries Research Board of Canada, and by Idler and Power in the Canadian Fisheries Report No. 10, 1968. [17, 18]

Processes developed by private companies

Lever Brothers Company has developed and patented a process utilizing fresh ground fish that is drum-dried and subsequently extracted with ethanol.

General Foods Corporation has developed and patented a process in which raw fish is slurried in water, and the pH of the mixture is lowered by the addition of acid. An antioxidant is added to the slurry. After stirring in water for fifteen minutes, the suspension is screened and pressed. The press cake is then extracted with tertiary butyl alcohol or other similar alcohol.

Peru—extraction by the Verrando process

An interesting process to prepare solvent-extracted fish-protein concentrate has been developed in Peru and is generally referred to as the Verrando

process. It has been described in some detail by the WHO/FAO/UNICEF Protein Advisory Group (PAG). [19] In this process fish meal is extracted with hexane vapour in a vacuum. Its developers claim that it extracts the fat very efficiently and produces a fish-protein concentrate with less than 1 per cent fat in a single-stage operation, using only 1.5 times as much solvent as the weight of the raw material. The product is manufactured from merluzza or from anchovy or other fish.

The plant employs a batch process and requires 1,700 litres of n-hexane to extract one ton of raw material. A 28-inch vacuum is produced in the extractor and in the remainder of the circuit. The product is extracted for 90 minutes with hexane vapour. After removal of solvent, the product is packed in polyethylene and Kraft paper bags and is offered to the local market at $240 per ton, c.i.f. The PAG document referred to also includes complete amino acid analysis and gross composition, including the results of nutritional tests.

The product was authorized by the Government as a food supplement for human use in Peru, and was used for the enrichment of bread at the 4 per cent level. Industrialización de Productos Agrícolas S.A. utilizes FPC in the preparation of a mixture containing corn meal, malt sprut, mineral salts, vitamins and condiments. This mixture contains 50 per cent FPC. Mr. Verrando has also developed a powdered soup and a special type of enriched and seasoned macaroni.

Sweden

Astra Nutrition in Sweden also produces a completely defatted fish-protein concentrate at Bua, a fishing village south of Gothenburg. The Astra plant produces one and one half tons of protein concentrate per hour. Astra Nutrition utilizes herring meal as raw material, extracts its fat and deodorizes it with isopropanol. The defatted fish-protein product contains 80 to 85 per cent protein, 10 to 15 per cent minerals, 5 to 8 per cent water and less than 1 per cent liquid. The product has high biological value. Extensive biological evaluation of the product has been made through both animal and human testing.

Germany

A process was developed in Germany during the Second World War in which ground whole fish was stirred in 0.5 per cent acetic acid. This slurry was then pressed and the press cake extracted with ethanol. Following ethanol extraction, the press cake was hydrolyzed with alkali and filtered. This yielded a protein solution which was neutralized with acetic acid and spray-dried. The product is a pure white, water-soluble powder which was used as an egg white substitute in Germany, where it was manufactured on a large scale during the Second World War.

Vogel and Company in Germany uses another process to extract fish with ethanol after acid or alkali treatment. The fish is subsequently re-extracted with acetone and dried *in vacuo*.

Great Britain

Cavanagh and Inman produce a fish-protein concentrate by extracting fish with solvent mixtures of acetone, ethyl acetate and ethanol.

Other processes for production of FPC

New research has been undertaken recently in the laboratory of the Lamont-Doherty Geological Observatory of Columbia University and elsewhere in an effort to improve these products. [16]

Fish-protein hydrolysates

Chemical hydrolysates

A process using chemical hydrolysis yields a product containing 90 to 99 per cent fish protein. It is extremely low in oil (less than 0.1 per cent) and of high biological value. The product is water-soluble up to 20 per cent weight/volume. The process follows a number of very simple steps: chemical hydrolysis is followed by filter press separation of the aqueous phase from the oil-plus-skin-and-bone phase, the aqueous solution is then purified, and the resulting liquid is spray-dried.

Enzymic hydrolysates

Various types of enzymic hydrolysis are also under study. The United States Bureau of Commercial Fisheries in its laboratory at College Park, Maryland, has undertaken a study of the utilization of various commercially available proteolytic enzymes for the preparation of fish-protein hydrolysates, and the Agri Consult Company in Sweden has developed what they call the Tilamin process, which is essentially analogous. These processes are also relatively simple: whole fish is finely ground with a buffer, a commercially available proteolytic enzyme is added, and the fish is digested. At the end of the digestion period, the mass is de-sludged in a centrifuge and the aqueous and oily phases are separated. The aqueous phase is then dried by various means, yielding a protein hydrolysate consisting essentially of fish amino acids and small peptides.

Trytophan tends to be low in fish-protein hydrolysates.

The Rohm and Haas Company in Philadelphia, Pennsylvania, has developed an experimental proteolytic enzyme which hydrolyzes solvent-extracted, completely deodorized and defatted fish-protein concentrate. The enzyme is called "experimental enzyme 56". Its pH optimum is 10.0. Rohm and Haas claim that up to 85 per cent of the original protein nitrogen can be solubilized by incubation of solvent-extracted FPC with this enzyme. They recommend a temperature of 60° C for the enzymic digestion. The resulting enzymatic digest is filtered and the filtrate, containing small peptides and free amino acids, is spray-dried. The product is colourless and almost tasteless, and contains 87 per cent protein.

Fermentation processes

Proteolytic micro-organisms

Dr Victor Bertullo of the University of Uruguay has developed a method to prepare a fish protein hydrolysate using a proteolytic yeast, *Hansenula montevideo*. Molasses is added to the whole ground fish. The mixture is then inoculated with the yeast culture and fermented for 18 to 24 hours at 30° to 32° C with slow stirring. An initial filtration removes scales and bones and the oil is removed by centrifugation. The mixture is concentrated by low temperature evaporation until it reaches 50 per cent solids and then is spray dried. This yields a product containing 70 to 72 per cent protein, 5 to 6 per cent moisture, 12 to 14 per cent ash and approximately 5 per cent fat. A pilot plant utilizing this process is now in operation in Uruguay.

The Reliance Chemicals Corporation produces protein meal from fish by utilizing fungal enzymes to digest and liquefy the fish and to neutralize the fish taste and odour. The fish meat is cooked for five to fifteen minutes at 60° to 70° C. The fungal proteolytic enzyme is added with wheat bran, brewers' yeast and sugar. The fermentation is carried on for eight hours at 52° to 56° C. The product is then heated to 70° C and dried.

The Central Food Technological Research Institute in Mysore, India, has prepared protein hydrolysates from fish using papain as the proteolytic enzyme.

The Prolsa Company of Israel prepares a fish protein hydrolysate by fermenting fish with *Lactobacillus plantarum* in a culture medium containing rye bran, ground barley, wheat bran, grass meal and carrot flour.

Lactobacillus plantarum has high proteolytic activity at pH 4.

Lipolytic micro-organisms

Another process now under development at the Columbia University laboratory has as its goal to produce acceptable human foods from abundant and inexpensive fatty fish, by fermentation with lipolytic micro-organisms capable of reducing the fat content of the fish by about 90 per cent and producing a pleasant flavour reminiscent of certain foodstuffs commonly acceptable in western society. [20] The object of this fermentation programme is: to utilize an abundant and inexpensive fish, to produce a food with pleasant aroma and flavour, to maintain or increase the protein content of the product without impairing its biological value, and to reduce the fat content of the raw material, thereby ensuring the shelf life of the product.

The best results were obtained with an imperfect fungus, *Geotrichum candidum*, to ferment fish. This fungus shows very considerable lipolytic activity when fermented with menhaden, which has a high fat content. The fermentation product has a sweet, ester-like aroma with no trace of the smell of the starting material, although the flavour reversed after one month's storage. There was a significant gain in amino nitrogen and a simultaneous reduction of non-protein nitrogen during fermentation.

Maximal lipase production and growth were achieved within 36 hours under aerobic conditions with mild agitation in a 0.15 *M* phosphate-buffered fish medium, pH 7.5.

A variety of other lipolytic organisms have been found suitable for this work, among them the yeast *Candida lipolytica*. The work is sponsored by the United States Bureau of Commercial Fisheries.

Peroxide preventing fermentation

In collaboration with Professor Paul Gyorgy, the author has developed a process for simultaneous fermentation of soybeans and fish with *Rhizopus oligosporus*. This process is adaptable to cottage industry. The flavour of soybeans fermented with *Rhizopus oligosporus* is already acceptable in Indonesia, where fermented soybeans (*tempeh*) are well known. When *tempeh* is fermented in the presence of fish in a ratio of three parts of soybean to one part of fish, acceptable products with high biological value are obtained. Moreover, the fish is protected from rancidity and peroxidation by the natural antioxidant in the *tempeh*. [21]

Detergent processes

In another development detergents are being used to extract fish oil from fish in an aqueous system. [22] The University of Chile in Santiago recently published the results of the extraction of fish oil and fish meal with sodium lauryl sulphate in an aqueous system. They used fish meal prepared from eviscerated hake (*Merluccius gayi*) and extracted it with a solution of 5 per cent aqueous sodium lauryl sulphate. An analogous process was reported by J. J. Connell of the Torry Research Station in Aberdeen, Scotland. [23] Connell had used detergents earlier to extract protein from fish, obtaining products with a negligible lipid content, but he feared the effects of the remaining detergents in the product. Ionic detergents bind very strongly to fish protein and might be toxic.

The United States Bureau of Commercial Fisheries is also actively engaged in the study of the use of detergents for the extraction of lipid from fish to prepare fish-protein concentrate.

FISH-PROTEIN PRODUCTS

Three principal types of fish-protein products have been considered here:

Fish-flavoured protein products

These products have fish flavour and contain some fish oils. The Ghana, Uganda and Congo/Rwanda-Burundi products come under this heading. The residual oil content in these products may be an advantage in areas where the fat content of the diet is too low. Fish hydrolysates such as nuoc-mam and nuoc-nhum from Viet-Nam, other traditional fish pastes and fish hydrolysates from the East, and furikake in Japan might be classified under this

heading. The *tempeh*-fish mixture now under development could also come into this category.

These products are highly flavoured and add taste to bland staple diets. Their price is low, and given proper production controls they may well be the best solution for people living in subsistence economies.

Solvent-extracted fish-protein concentrates

These products are bland, sometimes rather gritty because of their bone and skin content, and therefore difficult to incorporate into foodstuffs. Recent developments aim at removing skin and bones to overcome this obstacle. The products lack "functional properties" such as solubility, whipability, water-binding and fat-binding capacity—all very important in modern food technology and economics. Attempts are being made to improve the functional properties of these products. The products are best adapted for incorporation into bread, macaroni, pasta and similar foodstuffs. They lend themselves well to protein supplementation for school lunch programmes, hospitals, maternal and child health centres and the like. A major drawback is their high price. Solvent extraction processes generally require sophisticated plants, frequently not adaptable to primitive environments. Their major contribution in the near future will be to improve the protein nutrition of urban populations and, in general, of people living in a monetary economy.

These protein concentrates can be prepared from either fish meal or fresh fish. Several small-scale plants now produce them and others are planned. The experience of the few existing small plants has taught that such operations should be integrated into a large-scale fishery and manufacturing operation such as the fish reduction plants in Peru, where an average-size fish meal plant has a capacity to handle 2,000 tons of fresh fish a day and operates its own fishing fleet. If the fishery and the FPC plant are independent operations, serious problems may arise.

New products under development

It is too early at this stage to predict the economic future of the fish-protein hydrolysates or what the products from the fish-fermentation processes will be. The major objective of those who are developing these processes is to reduce the cost of producing fish-protein concentrate.

Potential development of world fisheries

One might argue that the fish resources of the oceans are not well known and could be depleted if the demand for fish-protein concentrate increases too rapidly. Moreover, present fishing technology is antiquated. Nevertheless, just as mankihd has gone through a hunting and gathering stage and then turned to agriculture and domestication of animals for food production, it should not be long before rational and serious planning of marine harvests is introduced.

R. D. Gerard and J. L. Worzel [24] recently developed a project that opens up new possibilities for aquaculture. Their proposal is to pump up cold sea-water from 800 metres deep through large-diameter pipes into a condenser area, located on shore to intercept the flow of moisture-saturated trade winds. When this air is cooled, much of its moisture is condensed. This condensed water will be conducted to storage tanks for use as drinking water. The deep sea-water, which has been utilized as a source of cold for moisture condensation, will flow into closed-off lagoons near shore, where it will act as a fertilizer. This deep cold water, below the euphotic zone, is ten to fifteen times as rich in the inorganic nutrients necessary to initiate the photosynthetic process as the surface waters of the euphotic zone, since nutrients in the surface waters are depleted by photosynthetic activity. The marine food chain will be started off by stimulating primary production. Primary production is the synthesis of complex organic molecules from simple mineral salts, carbon dioxide and water, organized in living cells or protoplasm, by radiant energy from the sun. This synthesis will increase primary production in the coastal lagoons enormously, so that they can then be utilized as ponds for breeding all kinds of fish or shellfish. Japanese yellowtail fish are now raised at high density and with sequential cropping; annual yields are 280 tons per hectare.[25]

Such a brine-pump project is now in operation on the island of St. Croix in the Virgin Islands. This location was chosen because 1,000-metre-deep sea-water is less than one and a half kilometres from the shore of this island.

The brine-pump project aims at creating an artificial upwelling, just as the Humboldt Current creates an upwelling off the west coast of the South American continent. Its implications for potential protein production in the sea are difficult to estimate at this time. The scheme is not limited to utilizing lagoons or closed-off areas along the shore.

A major project for utilizing the brine pump was envisaged for 1970 in the open sea. An underwater mining company, planning to harvest minerals from the sea bottom, will employ huge pumps to bring up their product from the sea floor. A by-product of this will be nutrient-rich water and genuine marine pastures downstream from the mining operation. The economic problem of pumping deep water for aquaculture will not arise since the deep water will be a by-product of the mining operation.

The economic argument against artificial upwelling put forward in the report of the Secretary-General of the United Nations [26] does not apply in this instance. To pump water from the deep to the euphotic zone, where the nutrient-rich water is available for the photosynthetic process, requires only the energy necessary to raise the water about 18 feet—that is, enough to overcome the friction in the pipes and a small difference in density.

It is hoped that the brine pump will contribute substantially towards increasing the availability of protein resources from the sea, and that, along with the development of suitable forms of fish preservation, it will help to eradicate protein malnutrition.

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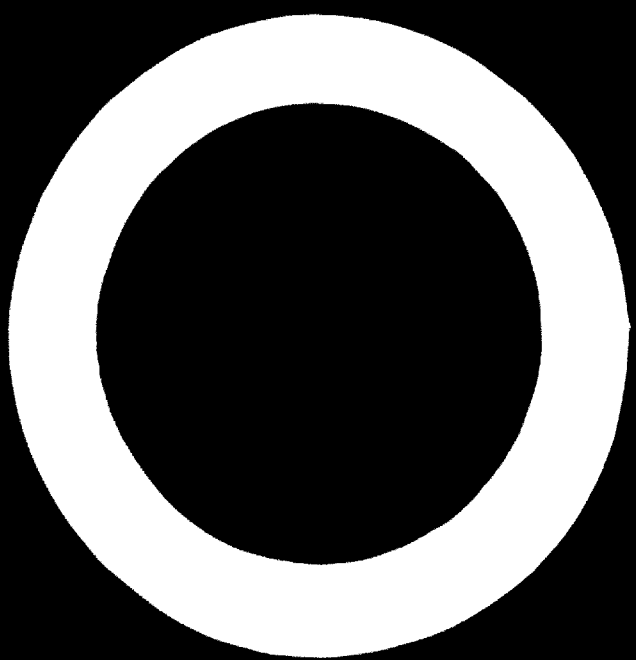

2. THE NUTRITIONAL EFFECTIVENESS AND ACCEPTABILITY OF FISH-PROTEIN CONCENTRATE*

The production of protein-rich foods from the sea has centred about the development of products that are not only low in cost, but stable without requiring normal preservation techniques. In order to maximize the use of marine proteins, it is obvious that fish stocks that are available in abundance and easily harvestable should be used. The tremendous yields of fish meal from the anchovetta in Peru illustrate how much protein may be taken from the sea at low cost. By avoiding the interconversion stage—that is the food chain that starts with feeding marine proteins to animals such as chickens or hogs destined for human consumption—the efficiency of adding a high quality protein to human diet is increased.

Most marine fish used for the production of fish meal are fatty, and the resultant products are moderately unstable owing to the ready oxidation of the unsaturated fats in the meal. The presence of the fats and phospholipids contributes to a characteristic fish odour and flavour, and in populations unaccustomed to fish-flavoured food, such products are unacceptable. Reduction techniques in the manufacture of fish meal also leave much to be desired in the way of sanitary conditions. The direct use of commercially produced fish meal for human consumption presents serious problems, for example, if the meal is to be fed to infants.

There is mounting evidence that proper nutrition is most important for children between birth and two years of age.[1] However, this age group is also very susceptible to infection and disease and the addition of a supplementary protein product to the diet entails risks. While the inclusion of fat in infant nutrition is desirable, since food of high caloric density is highly beneficial to growing infants, it is not recommended that they be fed fish meal as it is normally produced.

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Types and composition of FPC produced for human consumption

Initial attempts to produce an adequate grade of fish meal for human consumption involved the production of a fish meal under sanitary conditions which was subsequently deodorized and defatted. Solvent extraction techniques were employed to remove the fat and at least part of the flavour. By using semi-polar solvents it was also possible to remove the phospholipids, which apparently contribute substantially to the flavour. Since solvent extraction must be used in order to produce a relatively odourless and tasteless product from fish, it is preferable to use fish with relatively little fat.

The solvents must be recovered and purified in order to make any extraction system economically feasible. The use of high solvent-to-product ratios is not desirable, because of the mechanics of manipulating the solvent and its subsequent recovery. The use of comparatively low-fat fish minimizes the need for solvent and involves a simpler technique for separating the extracted fat and for recovering the solvent. Hence, fish of low fat content is frequently used in the production of fish-protein concentrate from whole fish suitable for human consumption.[2]

Table 1. Amino acid composition of FPC from solvent-extracted fish
(Per cent of protein)

Amino acid	Herring[a] (Sweden)	Mako[b] (US)	Sardine (Morocco)[c]
Alanine	7.31	6.81	6.49
Arginine	7.59	7.13	8.09
Aspartic acid	11.20	10.35	10.37
Cystine	—	0.77	0.36
Glutamic acid	15.30	15.39	16.47
Glycine	6.83	8.09	5.12
Histidine	2.38	2.08	2.04
Isoleucine	4.47	4.56	4.26
Leucine	8.70	7.78	7.75
Lysine	9.14	8.41	9.82
Methionine	2.94	3.30	2.91
Phenylalanine	4.48	4.24	4.42
Proline	5.21	5.21	4.84
Serine	5.30	4.65	4.45
Threonine	5.24	4.47	4.68
Tryptophane	1.40	1.03	...
Tyrosine	3.17	3.35	3.05
Valine	5.18	5.26	5.09

Sources: *a* Astra Nutrition, Malmö, Sweden.
b United States Bureau of Commercial Fisheries, College Park, Maryland.
c R. Wetherell and C. O. Chichester, Department of Food Science and Technology, University of California, Davis, California (unpublished data).

A typical product made from low fat fish is produced by the isopropanol extraction process developed by the Bureau of Commercial Fisheries, United States Department of the Interior, College Park, Maryland. The composition of the final product extracted from red hake is: protein, 81.4 per cent; lipids, 0.2 per cent; ash, 13.5 per cent; and moisture, 4.7 per cent.[3] Even at this low level of fats, there is the possibility of some flavour reversion.

A typical amino acid profile of fish protein concentrate is shown in table 1. Although the figures may vary among amino acids, the compositions of most fish protein concentrates are essentially similar. The comparatively high concentration of lysine compared to plant protein obviously provides a more balanced protein for human consumption than do many other sources. The amino acid composition would indicate that lysine is not the limiting amino acid, but rather that other amino acids assume this role in the utilization of protein. This has been demonstrated by experiments with the supplementation of FPC produced from hake (*Merluccius gayi*) in Chile.

Stability for storage

A major advantage of fish protein concentrate is its stability in storage. As the material is low in moisture, carbohydrates and fat, these constituents do not interact to reduce its biological value to the extent that normally occurs in other products. An example of the stability of FPC made from non-oily fish is shown in table 2, which indicates that the quality of the protein does not seem to vary significantly with age. Batch 5 in table 2 represents material that has been stored in a warehouse over two years in paper bags at room temperature. Batches 1, 2, 3 and 4 were stored between three months and one year under similar conditions.[4] Recent experiments with batches of FPC produced and stored under similar conditions for over five years show approximately the same net protein utilization (NPU) values.[5] Thus the product is stable from a nutritional standpoint over long periods of time. Similar results have been reported by Rahi *et al.*[6]

Table 2 Net protein utilization of FPC after storage

Batch	Net protein utilization[a] (per cent)
1	66.9
2	67.9
3	64.3
4	70.7
5	63.5

[a] Net protein utilization (NPU) at level of 10 per cent protein calories.

Effect of heat on chemical composition of FPC

Although a fish-protein concentrate made from low-fat fish appears to be quite stable for storage, its use in food materials submitted to heat may present difficulties. Heating proteins or animo acids in the presence of carbohydrates decreases the availability of many amino acids. The loss of lysine or methionine is especially significant. Losses in the protein quality of bread have beed noted when the bread is enriched with milk or other proteins high in lysine. In the preparation of cereal products fortified with milk solids under high temperature, significant losses in the protein efficiency ratio (PER) were evidenced.[7] Heating amino acids with casein, or heating mixtures of various plant proteins in the presence of lysine and carbohydrates also causes a considerable reduction of the nutritional quality.[8] In experiments in which FPC was used to enrich bread, the increase in the nutritional quality of the bread was smaller than had been expected, and it was demonstrated that the addition of lysine to the FPC-enriched bread increased its protein quality to that predicted, indicating further that treatment under high temperature in the presence of carbohydrates may damage the protein of FPC. This effect has also been noted in milk-enriched bread.[4, 9] When lime-treated corn was enriched with FPC and used in the preparation of tortillas, the protein efficiency ratio was substantially reduced by cooking. Steaming the dough reduced the protein efficiency ratio by approximately 10 per cent, while heating at 350° F, such as in deep-fat frying, caused a further reduction in the PER. These experiments demonstrated, however, that the FPC retained its biological value better than mixtures enriched with soybean.[10]

Use as a nutritional supplement

There have been few proposals that fish-protein concentrate be utilized directly. It has been recommended primarily as a nutritious ingredient of existing foodstuffs, or as a physically inert but nutritionally enriching component of new food materials. Its nature, that of a rather tasteless and odourless powder, suggests its usefulness in products that will tolerate the addition of a filler. Physically, the extracted materials possess a slightly gritty character, and since the protein is inert, it does not suspend well in water without the addition of emulsifiers and stabilizers. These characteristics mitigate against its use in many products. The availability of a non-denatured or modified marine protein could extend considerably the usefulness of FPC. The possibility of producing a non-denatured protein from fish by hexametaphosphate extraction or water extraction with the addition of fat is especially promising in this regard.

Since it is primarily a nutritional supplement with high available lysine, the obvious use of solvent-produced FPC would seem to be in plant-protein mixes that are consumed as food products. Bread, pasta and tortillas are obvious vehicles for FPC. It can be incorporated, however, into many other products in which its physical characteristics do not interfere with the organoleptic properties of the product. Baked in yeast-leavened bread it

tends to degrade the quality somewhat, producing a smaller loaf with an atypical texture and colour.

Acceptability tests

In a series of tests on the enrichment of bread with different levels of FPC, individuals employed in a university hospital were asked to rate these breads as to whether they found them as good as conventional bread, whether there was no difference or whether they were bad. It is obvious from the results of this experiment, shown in table 3, that at the level of 3 per cent there is no significant difference between the non-enriched and the enriched bread. At 6 per cent, differentiation begins to become clear, and at 9 per cent and 12 per cent the colour is sufficiently differentiated to be clearly detectable. In a series of experiments with 300 school children, for whom colour was of no importance, bread enriched with 9 per cent FPC did not increase the rejection rate.[11] The acceptability of enriched spaghetti was measured by 150 adults of a hospital staff and 150 patients. The spaghetti was enriched to a 10 per cent level using FPC produced in Chile from hexane-alcohol extracted hake. The analysis of plate wastes showed that the enriched spaghetti was not rejected more than conventional pasta. A similar experiment was carried out in a children's day school where spaghetti was a principal dish (served three times a week). The rejection in this case was identical to that of the non-enriched product—that is, there was no difference. In a test conducted in Brazil, FPC produced by the isopropanol extraction method was incorporated into macaroni, which was served as a portion of the diet in a school lunch programme. A similar analysis of acceptance or rejection indicated that from the pupils' standpoint the enriched product was no different from the non-enriched product.[12] It thus appears that in most populations bread can be enriched with FPC at moderate levels and pasta up to 10 per cent without a significant rejection rate by consumers. It should be noted, however, that most of the tests with bread and macaroni used FPC produced from non-oily fish.

Table 3. Acceptability test of bread enriched with FPC at various levels

Level of enrichment (per cent)	Good			No difference			Bad		
	W	M	U	W	M	U	W	M	U
0	27	27	20	3	3	8	0	0	2
3	22	25	16	7	5	13	1	0	1
6	20	26	15	8	3	11	2	1	4
9	14	24	16	12	5	14	4	1	0
12	18	22	16	5	8	6	7	0	8

a Ninety tasters were employed: 30 workmen (W), 30 mothers (M), 30 university students (U).

In India, puree or chapati, native Indian cereal based bread, appears to be acceptable when fortified with 5 per cent fish protein concentrate. The FPC in these trials was made from a lean fish, Bombay duck *Harpodon nehereus*. It appears in this case that the method of preparing the FPC influenced its acceptability. In bread fortified at a 5 per cent level, some of the subjects noted a fish odour or flavour [13].

In the study of the addition of FPC to different types of foods such as soup, meat, beans and cornmeal tortillas to a level of 15 g total intake of protein, there was no noticeable rejection of the food materials over the period of study (60 days). The conclusion was that at this level, in a test with children, there appeared to be no significant rejection of the FPC [14].

The obvious conclusion one could make from these experiments, which were conducted almost entirely with FPC made from low fat fish, is that FPC produced by the conventional methods that have so far been proposed is acceptable to large proportions of the population when mixed as an ingredient with other foods. This is particularly so for children.

There have been relatively few studies of the acceptability of FPC produced from high fat fish. Four formulae using FPC produced from Moroccan sardines by the isopropanol process were evaluated as to acceptability by an untrained test panel in the United States. Brown sugar cookies were enriched at the level of 0, 3, 5, and 10 per cent and served to 25 staff members and students from the Department of Food Science and Technology, University of California, Davis, at 10.00 a.m. and 3.00 p.m. The four types of cookies were placed in separate dishes on a central table. Panelists were not informed about the composition of the cookies. Participants were observed in order to determine whether they would comment about the quality of the various samples, and whether some of the cookies would be left uneaten or partially eaten and others consumed more rapidly.

In this series of tests all of the samples were consumed with no adverse comments, however, the cookies with a 10 per cent enrichment appeared to have been slightly less well received than the others. In a more formal presentation, 25 different staff members of the same department were asked to sample the four types of cookies. They were not told that they had been baked with FPC, but were instructed simply to sample the cookies and comment on their impression. The judges found the 10 per cent formula less palatable than the recipes using a lower FPC content. They commented principally on the heavier, chewier texture of these cookies, rather than on the off flavour. They observed no substantial differences between the 0, 3 and 5 per cent formulae [15].

In another experiment bread was prepared using 3, 5 and 10 per cent levels of the Moroccan sardine fish protein concentrate, and presented to two panels of 25 people. The panels were asked to taste the bread samples and to comment on their flavour. They were not told that the bread contained FPC. A non enriched bread was available to the panels for the purpose of comparison. As with the cookies, the panels found the 10 per cent formula less palatable in terms both of flavour and texture than the other three samples.

Comments were confined largely to the colour and the smallness of the loaf. In four instances the judges identified the oil flavour at the 10 per cent level as fishy. Surprisingly enough, however, the formula containing 1 per cent FPC was preferred by 50 per cent of the panelists over the non-fortified bread on the basis that it seemed to be "richer" and "more bakery like" than the non-enriched bread. The 50 per cent who preferred the enriched formula were queried as to their bread buying habits, and it was found that they normally purchased special breads—either whole wheat, French type, sour dough, or breads that differ markedly from the very white breads that are produced commercially in the United States [15]

By comparison with the FPC produced from non-oily fish, the sardine FPC seemed to be slightly less well received, but not sufficiently to militate against its use in the formulas

Experiments with animals

The nutritional efficiency of fish protein concentrates—those made both from oily fish or non-oily fish—has been measured extensively in animals. A large number of studies were conducted using the fish-protein concentrate to enrich a diet representative of the staple food of the country. In almost every case the FPC, whether made from oily or non-oily fish, demonstrated that it was equivalent to casein as a source of protein. In some cases the fish-protein concentrate appeared to induce slightly better growth than skim-milk powder when added to the mixed diet. [16—20]

When FPC was fed as the sole source of protein in a diet given to rats, it had in most cases as high a protein efficiency ratio as casein, and sometimes higher. In a study by Schendel, four generations of rats were fed a diet in which 19 per cent of the total protein was supplied by FPC. The effects were examined and compared with those produced in rats fed with casein. It was noted that the females on the casein diet appeared to suffer from greater nutritional deficiency than they did on the fish-protein concentrate diet. Histological examination of the organs, however, showed no abnormality and no difference between the two groups. [21]

In a similar experiment, three different groups of weanling rats were fed for six months on FPC at a ratio of 20 per cent protein calories. At the end of the six months' period, weights were determined for a large number of organs and histological examinations were made on an even larger number. A significant difference in weight was noted in the organs of some rats that had been fed FPC, but since the histological studies revealed no alteration in the organs, the weight changes appear to be of no particular significance. [11]

In a series of studies made with rats on the protein efficiency ratio of different fish-protein concentrates, Morrison discovered considerable variation in the PER of different fish-protein concentrates. In one that had been severely heat-damaged the difference appeared to lie in the destruction of histidine

or methionine, since weight gains increased significantly when these were added to the heat-damaged mixture. [22, 23] The conclusion from these studies is that the loss of the limiting amino acid (which was shown in other studies to be methionine) must be guarded against in the process of manufacturing.

A study of the isopropanol-extracted Moroccan sardine FPC in the diet of rats revealed that the product has protein efficiency ratios of 2.98 and 3.04 per cent as compared with a casein control of 2.50 per cent. These experiments were performed using 10 per cent protein in the diet. The fish-protein concentrate had a concentration of 82.9 per cent protein. Weight gain and acceptability in the animal-feeding studies were excellent. No rejection of the feedstuff was observed, and the animals had normal growth patterns. [24]

Nutritive value of FPC as a supplement to diets

Experiments with children and adults

In experiments with children and adults, fish-protein concentrate was used to determine the effect of supplementation on the nutritive value of diets. In a study of children nine to ten years of age, fish-protein concentrate derived from oil-sardines was used to supplement a rice diet. Better nitrogen retention was demonstrated on the rice-protein diet than on the normal or control diet. All subjects retained a nitrogen balance and the diet was apparently accepted. [25] Similarly, Korean diets supplemented with 10 per cent fish-protein concentrate were found to be better digested and to effect a better retention of nitrogen than an identical diet in which the fish-protein concentrate was replaced by other protein sources. [26] In a study involving a large number of premature infants the effect of FPC appeared to be equivalent to that of casein or amino acid mixtures. [27]

Graham has reported from a study of convalescing malnourished infants that a mixture of 10 per cent fish-protein concentrate with 90 per cent wheat flour produced weight gains and nitrogen retention indistinguishable from milk. Fish-protein concentrate fed to these convalescent children as the sole source of protein also elicited responses similar to reactions to milk. [28] In another study, fish-protein concentrate was fed as the sole source of protein to normal infants in Chile. The formula consisted of FPC, sugars, carbohydrates, water, salts and vitamins. The preparation was suspended at a level of 22.5 per cent in water, and supplied 90 kcal and 2.4 g of protein per 100 ml. Twelve normal infants two and one half to five months old received this formula for a period of from 30 to 90 days, with an average protein intake of 3.6 g of FPC/kg of body weight per day. Figure 1 shows the weight gain of such infants receiving FPC as the sole source of protein. Haematological tests of the same infants indicated normal values. Lowering the total intake of protein stepwise demonstrated that 2.5 g of FPC/kg of body weight can support normal growth, but at 2.0 g/kg the growth reduced. This is the same order of magnitude as might be expected from a milk formula.[11]

In a study of the nutritive qualities of fish-protein concentrate in the

convalescent diet of kwashiorkor[1] patients, it was demonstrated that cornmeal diets supplemented with dried skim milk produced no statistical differences in weight gain, nor in the protein and amino acid levels in the serum. The conclusion from the results obtained was that fish-protein concentrate may be of considerable value in the prevention of protein malnutrition. [29]

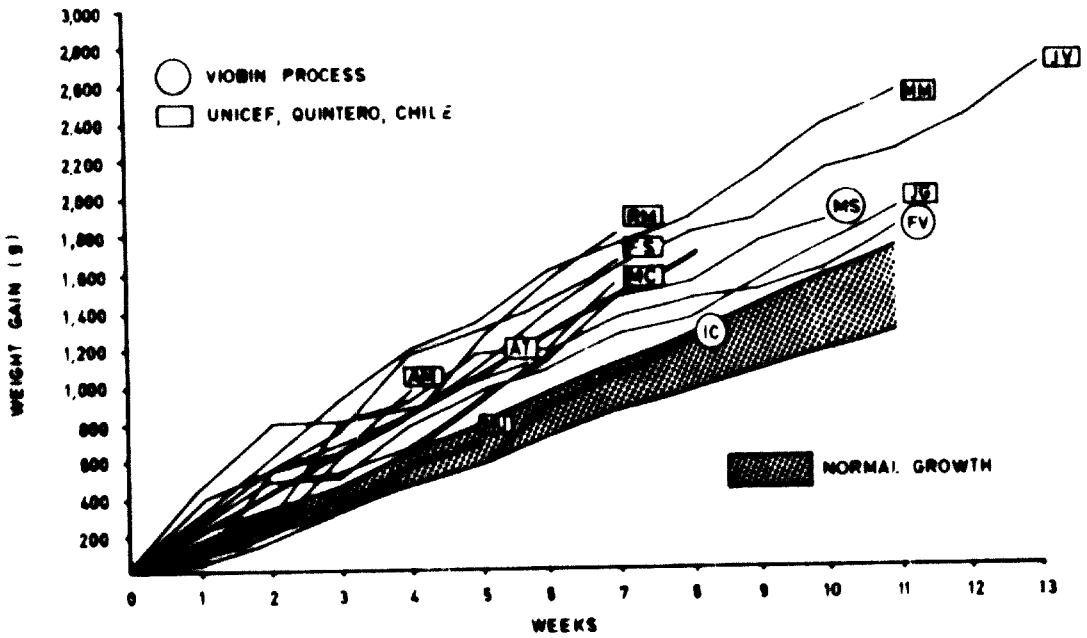

Figure 1. Weight gain in twelve infants fed FPC as sole source of protein

By contrast, other experiments appeared to indicate that for children suffering from kwashiorkor, whose major source of protein was FPC, there was a problem in acceptability. The clinical and biochemical responses were similar to those receiving the diet containing skim milk, except that the weight gain was lower on the FPC diet. It was thought that there might be a shortage of available lysine in these diets. The addition of lysine to the diet, however, did not cause any significant increase in weight gains. [30] It has been noted earlier that the limiting amino acid in most FPC is methionine, and that its availability is decreased considerably upon heating.

It should be noted that diets reported by Dr. Gopalan [30] were cooked in the presence of sugar, and that it was assumed that lysine was the limiting amino acid. It is thus possible under the conditions of the above experiment with children having kwashiorkor that the limiting amino acid, methionine, was further reduced by cooking and its deficiency led to the lower weight gains evidenced.

In a similar set of experiments Graham found that in marasmic infants aged 5 to 54 months who were fed wheat enriched with fish-protein

[1] "Kwashiorkor" is defined in *Webster's Third New International Dictionary* (unabridged) as "severe malnutrition in infants and children that is characterized by failure to grow and develop . . . and is caused by a diet excessively high in carbohydrate and extremely low in protein".

concentrate as the only source of protein the weight gains observed were closely similar to those produced by milk. A significant difference, however, was noted in the ability of the FPC diets to correct hypoalbuminaemia. [28] The exact reasons for this difference have not been determined. In the convalescing subjects the fish-protein concentrate did support nitrogen retentions and growth equivalent to that of milk-based diets.

The data thus far reviewed indicates that there is no question as to the nutritive value of fish-protein concentrate in normal animals and humans from infancy onward. From a nutritional standpoint, however, there are some data that at the present time are not entirely explained.

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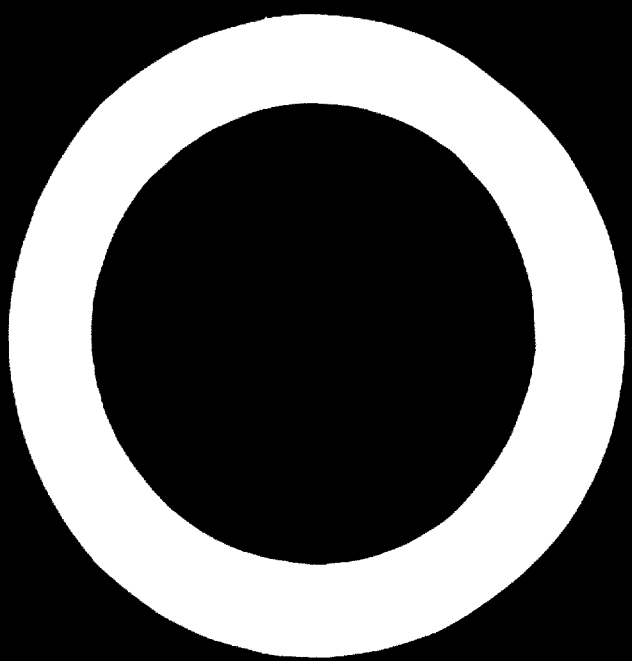

3. UTILIZATION AND QUALITY CONTROL OF FISH-PROTEIN CONCENTRATE*

It is paradoxical but nonetheless true that in countries where malnutrition and in particular protein deficiencies are prevalent, huge fish catches are processed into fish meal and exported to the developed countries for animal feeding. Equally discouraging is the fact that the ample supply of fresh fish from the sea does not enter the diets of people who live just a few kilometres away from the seashore. The lack of adequate handling, of storage and transport facilities for fresh fish account for this distressing situation. Food habits, taboos and low purchasing power also play a role. Finally, the lack of fishing fleets and landing facilities, owing to a scarcity of investment funds, limit the exploitation of fish resources for human feeding.

Measurement of nutritive value

The nutritional effectiveness of FPC is determined by animal feeding studies as well as by clinical studies with humans. In studies with animals, values such as the protein efficiency ratio (PER), net protein utilization (NPU) and biological value (BV) are the main indices for assessing the nutritional effectiveness of the protein. In human feeding, in particular with growing children, nitrogen balance studies and body-height determinations are the standard methods accepted; and serum albumin, plasma amino acid and enzyme levels have been proposed as useful criteria.

When FAO, as early as 1953, started exploring the nutritive value of fish meal (the term FPC had not yet been introduced) through animal feeding studies, wide variations in net protein utilization and biological value were observed, as shown in table 1. These discrepancies resulted partly from the different sources of raw material, but mostly from the different processing methods which were still undergoing development and gradually being perfected. The studies were conducted for FAO at the Bovril Ltd Laboratories by Dr. A. E. Bender. By 1958 the samples of FPC from the same sources displayed digestibility at about 95 per cent, NPU ranges between 64 to 78 per cent, and BV between 67 to 80 per cent. [1]

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* Paper presented to the meeting by George D. Kapsiotis, Chief, Food Science Branch, Nutrition Division, Food and Agriculture Organization of the United Nations, Rome, Italy.

TABLE 1 NUTRITIVE VALUE OF FISH MEALS MADE FROM VARIOUS RAW MATERIALS [1]
(*Per cent*)

Raw material	Chemical compositions			Nutritive value		
	Crude protein	Minerals	Lipids	NPU	Digestibility	BV
Lean fish	75 2	13 5	0 3	73	93	78
Lean fish	71 3	24 8	1 2	77	96	80
Lean fish	70 2	24 8	0 3	49	93	53
Lean fish	64 7	24 8	1 2	77	94	82
Semi lean fish	79 4	19 4	0 1	67	94	71
Semi lean fish	74 7	19 4	0 2	55	96	58
Fatty fish	73 4	20 5	0 1	31	68	46
Fatty fish	72 7	21 2	0 1	29	81	36
Fatty fish	66 6	20 0	0 1	42	71	59
Whole cod	78 7	14 9	0 3	64	95	67
Whole cod	75 7	21 6	0 2	67	95	71
Whole cod	74 0	22 6	0 1	65	95	69
Cod fillets	89 1	4 4	0 2	64	95	67
Gutted haddock	73 6	19 0	0 2	69	95	73
Herring	87 0	3 1	0 3	74	93	79
Herring	83 0	10 4	0 6	56	94	60
Sardines	81 8	9 6	0 5	70	95	74

The available lysine, because of its importance in supplementing the proteins of the lysine-deficient cereals, such as wheat and maize, and the relative ease of its determination by chemical procedures, is in practice a very suitable index for assessing the nutritive value of FPC. Actually, it correlates quite satisfactorily with the PER and NPU values. The available lysine of carefully processed FPC is, as a rule, very high. The values obtained from sardine FPC [2] appear to be higher than those obtained from hake FPC, but both are well above the value 6 5 g 16 g N set as a minimum by the FAO/WHO/UNICEF Protein Advisory Group (PAG) in 1957 and amended in 1961.

The supplementary value of FPC to the protein of lysine-deficient diets has been demonstrated by many investigators. Metta [3] reported that the PER values of most of the East Indian type of cereal diets were significantly improved by adding 3 per cent fish flour. The Central Food Technological Research Institute (CFTRI) of Mysore, India, [4] compared the value of fish flour, fortified with calcium and vitamins and added at the level of 3 per cent to poor Indian diets based on different cereals and millets, with the value of these milk powder as a dietary supplement at the level of 7 5 per cent and providing the same amount of protein. The results showed that as a supplement to diets based on rice, wheat, *jowar* (*sorghum vulgare*) and *ragi* (*eleusine coracana*) fish flour fostered slightly better growth than skim milk powder. Seshadrinathan [5] found high values in cereal diets supplemented with fish flours produced from oil-sardines at a level of 2 to 3 per cent. Rish [6] has indicated that FPC added to milled wheat rice at the 3 per cent level increases its NPU

from 64.1 to 85.9 per cent. Bressani made similar findings in an experiment with rats [7] using lime-treated corn. The maximum PER was reached at the 3 per cent level. Although the higher levels of FPC did not significantly improve the quality of the protein, the rats gained more weight as a result of the higher protein level of the diet.

In 1957 UNICEF in consultation with FAO arranged and financed a study undertaken by the food technology department of the Massachusetts Institute of Technology (MIT). Its purpose was to assess the effects of processing variables upon the composition and quality of protein and the organoleptic characteristics of the final FPC. This investigation covered the processing methods available at that time. It was the precursor of the work undertaken later by the United States Bureau of Commercial Fisheries which resulted in their use of the isopropanol extraction process.

At the present time the available processes, for example, the isopropanol process of the Bureau of Commercial Fisheries, the modified VioBin process adopted by the Alpine Marine Industries, the Astra process, the SONAFAP process and the Halifax process, while utilizing varying sources of fish, are able to produce products displaying high nutritional values, although with differing organoleptic characteristics.

FPC has been evaluated in the treatment of infant malnutrition by various investigators. Graham *et al.* [8] directed an experiment in which a group of malnourished infants with and without kwashiorkor[2] were bottle fed with a liquid preparation of wheat flour enriched with 10 per cent deodorized fish flour (VioBin). This test was compared with bottle feedings with a modified cow's milk preparation and with a vegetable mixture of high biological value. Similar weight gains and nitrogen retentions indicated that the FPC-enriched preparation might well be a good substitute for milk in the diet of infants and children. By contrast, Srikantia and Gopalan [9] found that the same fish flour (VioBin) administered to children suffering from kwashiorkor met with poor acceptability, and the intake of the FPC was unsatisfactory in 15 out of 33 children. The reason for the difference might be that Graham used modified cow's milk to initiate recovery, to stabilize body composition and to obtain a steady gain in weight, whereas Srikantia and Gopalan put the children on the FPC diet immediately without any preparation.

The SONAFAP FPC was tested in infant diets through a series of feeding trials carried out by F. Tavill and A. Gonik at the Casablanca maternal and child health centre (MCH) ("Oeuvre de secours aux enfants") [10]. The trials were conducted over a period of six months (August 1966—January 1967) with a test group of 50 weaning infants, five to seven months of age, to determine to what extent FPC could contribute to basic cereal and vegetable diets in meeting the total protein requirements of this age group. A total daily quantity of just over 10 g of FPC (see table 2, SONAFAP, note *d*) divided into two meals served daily at the centre was the maximum amount

[2] See note at bottom of p. 27

permissible to the mothers—a limiting factor in determining acceptance. (This earlier SONAFAP product did have some odour and taste of fish.) The daily protein intake of the group not under control was brought in line with that of the control group by a daily quantity of 10 g of skim milk. This quantity was based on the allowance established by the United States National Research Council. No statistically significant differences were found between the two groups with respect to length and weight growth, blood urea levels and morbidity pattern. This experience indicated that FPC can make a significant contribution to the prevention of protein deficiency in weaning infants.

FPC made of oil-sardines, processed in a pilot plant at the Central Food Technological Research Institute, Mysore, India, was tested in vegetable mixtures (25 per cent FPC) on boys of six to twelve years of age belonging to low-income population groups for a period of six months. [11] A highly significant increase in height, weight, red blood cell count and haemoglobin level was observed as compared with the control group.

Hygiene

The nutritive value of FPC, as of any other food, depends to a great extent on the hygienic conditions of its production. The raw material used, the handling practices before, during and after processing, the residues of solvents and other processing aids used, the possible interaction of the fish flesh with the solvents are factors that can influence adversely the nutritive value of FPC or jeopardize its safety in use.

By definition FPC must be produced from edible fish or edible parts of fish. While there are several large groups of fish whose flesh is poisonous, [12] it is quite unlikely that industrial producers of FPC could have recourse to poisonous fish. For economic reasons fish catches destined for FPC must come from an abundant supply of schooling fish, which would not be mixed with poisonous fish since the latter live and thrive in entirely different ecological environments.

An inconvenience that might at least affect the colour of FPC produced from whole sardines—as in Morocco—involves the contents of the intestinal tract. The sardine canneries, for example, refuse to accept sardines caught during the day when their intestines are heavily loaded with dark green plankton. These sardines are routed to the fish-meal plants. The difference in colour observed in the FPC of SONAFAP extracted by ethanol and isopropanol might well be attributed to the difference of the raw material as well as to the different extracting characteristics of the two solvents.

The handling practices before extraction can definitely influence the quality of the final product. Obviously, refrigeration is indicated from the time of the catch until delivery to the FPC plant. Long delays at the landing and in the plant would favour bacterial action on the proteins as well as enzymatic oxidation of the unsaturated fatty acids. Samples of oil from sardine FPC examined on thin-layer chromatography were found to be in a

state comparable to that of frying oil heated for several hours [13]. This indicates that the oil had been severely oxidized at some stage, either before, during or after the extraction. Furthermore, samples of the same FPC on gas-liquid chromatography produced several peaks attributed to amines or mercaptans. This clearly suggested that the raw fish—before extraction—had been subjected to bacterial action. Apparently, flavour reversion is apt to appear and, in fact, did. Perhaps the best method to prevent this type of trouble is to immerse the fresh fish upon landing or upon arrival at the plant in the solvent used for extraction.

The type and origin of the solvent might affect the wholesomeness of FPC. As a rule, the use of chlorinated hydrocarbons is avoided in the extraction of food or feed products. Ethylene dichloride (1,2 dichloroethane) is an exception that appears not to react substantially with the components of fish flesh. Actually, the United States Food and Drug Administration permits the use of ethylene dichloride as a solvent for FPC, provided that the extraction is completed with supplementary washings of the FPC with isopropanol. However, the MIT investigation mentioned earlier detected that methionine was heavily reduced by this process, and Morrison [14] found that both methionine and histidine were probably affected by ethylene dichloride. Later Munro and Morrison [15] reported that they had isolated chlorocholine chloride, a fairly toxic substance (LD_{50} of 500 mg/kg) from FPC treated with ethylene dichloride. The subsequent washings with isopropanol apparently removed the chlorocholine chloride from the FPC.

The residues of solvents are of particular importance for the wholesomeness of FPC. So far, tolerances have been established for ethylene dichloride and for isopropanol. However, other solvents such as n-hexane are also used for the extraction of lipids from foodstuffs, including FPC, for which no tolerances are as yet established.

Another feature to watch for in solvents is their purity. Impurities that are non-volatile or that have boiling points high above that of the solvents could constitute a potential hazard. FAO and WHO are now looking into this problem. The Joint FAO/WHO Expert Committee on Food Additives considered the problem during its session in June 1970. The Committee plans to elaborate specifications for identity and purity and to examine the toxicological evaluation of the solvents used in the extraction of lipids from foods. Ultimately, a determination is expected to be made of acceptable daily intakes that carry permissible amounts of residues.

The flavour reversion, often experienced with FPC, is a deterrent to its ultimate utilization in human feeding. It is claimed that FPC from isopropanol-extracted red hake (lean fish) does not undergo a flavour reversion, but FPC made from menhaden (fatty fish) reverts in taste over a period of time, despite the fact that the level of the residual lipids is the same in both FPCs. [16] Preliminary investigations suggest that this effect may be due to the oxidation of lipids whose composition might differ in the two species, and not necessarily to residual amines.

The use of hot solvents such as isopropanol and even n-hexane, combined

Table 2. [illegible]

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Moisture (%)	7.9	9.0	6.56	6.63	6.5	6.6	6.5
Crude protein (%) (N × 6.25)	80.9	80.9	87.98	4.91	86.0	77.7	85.0
Lipids (%)	1.7	1.8	0.54	0.42	0.5	0.22	0.15
Ash (%)	11.0	13.0	7.64	12.52	9.0	17.4	10.97
Calcium (%)						4.8	2.95
Phosphorus (%)						2.9	1.79
Lysine available (g/16 g N) (%)	9.41	9.03	9.29	8.71	9.3	7.95	8.18
PER (Casein 2.50)					2.53	2.67	2.74
NPU (%)	73	72					
Fluorine (ppm)	200	200				70.2	

a FPC from beheaded and eviscerated sardines, Safi, Morocco (INP). See reference [7].
b Beheaded and eviscerated sardines, Agadir, Morocco (BCP).
c Whole sardines, Agadir, Morocco (BCP).
d FPC from beheaded and eviscerated sardines, Agadir, Morocco (BCP). See reference [11].
e Whole sardines from Morocco, processed to FPC by the BCP. See reference [20].
f FPC from baits, average value for 10 samples processed by the BCP. See reference [20].

with stripping with super-heated steam, yields a product practically free of micro-biological load. Samples of FPC withdrawn aseptically from the extraction vessel of the Agadir FPC plant during its early trial runs displayed a total plate count of less than 10 per gram. It is after this point—during the transportation, grinding, sieving and packing stages—that microbial contamination might occur. Sanitary conveyors, milling, sieving and packing equipment and materials as well as sanitary maintenance are essential in preventing microbial contamination and assuring the wholesomeness of the FPC.

Particular attention has been given during recent years to the fluoride content of FPC. Fluoride is a physiologically active element and in small quantities—1 ppm in drinking water— has been universally applied in the prevention of dental caries in children. However, in regions where the drinking water contained a high fluoride content, at the level of 8 ppm, persons between fifteen and sixty years of age showed high incidence of mottled enamel of the teeth and of osteosclerosis. [17] The Twenty-Second World Health Assembly, on the basis of the report of the Director-General of WHO, [18] requested that "continuing research be encouraged into the etiology of dental caries, the fluoride content of diets, the mechanism of action of fluoride at optimal concentrations in drinking water and into the effects of greatly excessive intake of fluoride from natural sources . . ."

Fish-protein concentrates show differing degrees of fluoride content. Table 2, which compares the chemical composition and nutritive value of

selected FPC, indicates that sardine FPC from Morocco had a fluoride content that varied from 200 ppm to one case of 70.2 ppm. If the tolerance must be accepted, the FPC of SONAFAP presents great problems. If the bones are efficiently separated, however, the fluoride content could be considerably reduced [19].

Use in human diet

Texture, organoleptic characteristics and cost are the most important factors that influence the use of FPC. In general, the various solvent-extracted FPC have a gritty texture that is detectable in the mouth even after fine grinding. In terms of its functional characteristics, FPC is quite neutral with no binding and very low dispersibility qualities. Increased pH improves its dispersibility and solubility; it becomes almost completely soluble at pH 12.

Work conducted at MIT on behalf of the Bureau of Commercial Fisheries demonstrated the improved characteristics of such a modified FPC. A textured product in a mixture with soy protein isolate was produced with a smooth consistency and good tensile strength. Such a modification could, however, increase the cost of FPC considerably above the cost of normal FPC. However, it could be used in milk-type products for large consumer groups, probably at comparable or even lower cost than similar products now being introduced in the western world as well as in the markets of Hongkong, Brazil and Singapore.

The lack of binding qualities, unless some binding additive is used, limits the usefulness of introducing FPC in pasta products. FAO has conducted some work with the Morocco FPC at the Braibanti Technical Laboratory in Parma, Italy. Spaghetti and other pasta products lost some 20 to 30 per cent of the FPC added to the wheat flour in the process of boiling. By modifying the cooking method this loss was lowered to 5 per cent, but it is difficult to persuade consumers to change their habits of preparing food.

Holme [21] reported that with the addition of "5 per cent and more FPC, the quality of bread, as we know it, is decreased. Colour, taste, volume and structure are detrimentally affected". This observation may be true of bread "as we know it". However, the bread of North American countries has little in common with the bread made in countries where it is the staple food, for example, flat breads such as *baladi* in the United Arab Republic, *samoon* in Iraq, *chapatis* in India and other thin flat breads that consist essentially of wheat flour, salt and water with little or no yeast. Texture, colour and volume in these breads are hardly affected. Here, FPC might find ready acceptance if flavour and cost do not present insuperable hurdles. From the experience encountered in Morocco with the leavened local bread, the addition of 3 per cent of partly deodorized and partly defatted (1.5 per cent lipids) FPC was largely acceptable to the consumers since the fish flavour was hardly noticeable. The drawback of added cost remained, however. In most developing countries and even in countries in advanced stages of development where bread is an essential part of the diet, the price of bread is a matter of serious economic, social and also political concern. Many governments absorb

the added costs by subsidies or other means, rather than increase the price of bread. Even at 3 per cent of FPC in bread, at a cost of 42¢ per lb of FPC, the cost of bread might increase as much as 15 to 25 per cent and could have serious social and political repercussions. On the other hand, governments are often reluctant to increase the burden of their subsidies.

Disregarding the cost factor, FPC can find its way into staple foods and national diets in developing countries with spectacular nutritional benefits. Odour and taste can easily be masked either by synthetic or natural flavourings and spices that form part of the customary diet in developing or developed countries. However, introduction of FPC into family foods or in protein food mixtures for infants and young children poses a number of problems [22] The ideal method is for the housewife or mother to mix the FPC with the traditional constituent of the family diet and add to the infant food preparation. This might be feasible in sophisticated societies, but the experience with FPC in the United States where it can be sold only in one-pound packages makes this method impracticable. In developing countries a long and difficult educational campaign is necessary to teach mothers in low-income population groups to adopt the method. Instruction is necessary in both the nutritional value of FPC and its preparation according to a formula. The use of too much or too little FPC will nullify the effect of the supplementation.

The preparation of baby food in maternal and child health (MCH) centres or in hospitals does not pose problems if those who are responsible understand the value of FPC. As a matter of fact, the centres offer useful opportunities for teaching mothers the importance of protein supplementation of the traditional staple weaning food.

Experience to date has shown that ready-mixed infant food, in small packages containing enough for one to three days, will be readily accepted by mothers. Price is, of course, a critical factor. The success of a campaign to introduce FPC will depend primarily on adjusting the price as closely as possible to the purchasing power of the sector of the population in need of this food. Hospitals and MCH centres can afford infant food mixtures packaged in large containers, which are sold at a substantially reduced price.

The introduction of FPC into institutional feeding programmes (i.e., organized feeding of groups such as in schools, industrial canteens, MCH centres, hospitals, orphanages, prisons, public works programmes, the army) presents the problem of convincing authorities of the nutritive value of FPC and of the economic importance of its use. The development of recipes is a minor problem that can be easily solved with some imagination on the part of the nutritionist responsible for menus.

Quality control of FPC

The necessity for establishing carefully prepared guidelines for the selection of raw materials, for processing techniques, chemical composition, safety in use, nutritive value and wholesomeness of various protein concen-

trates was obvious from the initiation of the protein food programme of FAO, WHO and UNICEF and the creation of the Protein Advisory Group (PAG). The first "Tentative Specifications for Solvent Extracted Fish Flour—Defatted and Deodorized" were prepared by FAO and reviewed by PAG in 1957. These were revised by a working group during the FAO International Conference on Fish in Nutrition, held in Washington, D. C. in 1961; and they appeared in a report entitled "Tentative Specifications for Fish Protein Concentrate". At its 1962 meeting in Rome PAG agreed that these specifications could be applied tentatively with the stipulation that the fat content of defatted, deodorized products be revised to 2.5 per cent. At that time the solvent extraction could not be reduced below 2.5 per cent by the available processes, and consequently no completely deodorized and defatted FPC was available.

With the development of FPC from hake by the Bureau of Commercial Fisheries the United States Food and Drug Administration issued a "food additive regulation to prescribe the safe use of fish-protein concentrate". [19] This regulation, however, is restricted to FPC extracted from hake and hake-like species. Nevertheless, it covers adequately the stipulations for quality control, and it introduces elements not covered by the PAG tentative specifications, such as residues of solvents, fluoride content and minimum radiation for heat treatment.

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4 POTENTIAL RESOURCES FOR THE INDUSTRIAL PRODUCTION OF FISH PROTEIN CONCENTRATE*

Selection of species for production of food-grade FPC

While the United States Food and Drug Administration allows the use, within United States territory, only of red hake (*Urophycis chuss*) as raw material for the production of a refined (solvent-extracted) FPC for direct human consumption, the protein of the flesh of all fish has approximately the same amino acid composition and a similar nutritive value (not considering fish oil). If food grade FPC is to become a widely used commodity, the selection of fish species as raw material must be broad and flexible. The same processing method can be applied to every kind of fish, and in the industrial production of food-grade FPC the price of the raw material is one of the most important considerations. As in the production of fish meal for animal feedstuff, only those species that are in great abundance and readily accessible to highly productive types of gear can be considered suitable raw material on which to base an FPC industry. Each fishery must ascertain which species of fish can be landed at a feasibly low cost. Another reason for the need for flexibility in the choice of raw material is that many fisheries can have an adequate supply of raw material only if a mixed catch is used. In tropical countries, in particular, the landings that are likely to be used for the production of FPC will often consist of various species (including fish that are usually discarded from shrimp trawlers or other fishing vessels).

Some of the fishery resources referred to in the following description of supplies for fish-meal production may be used for the industrial production of solvent-extracted FPC for direct human consumption if, in future years, there is a market for such products.

World fish production [1]

During the last seven to nine years the world catch has increased at an annual rate of 7.0 per cent per year while the rate of increase in human population has been in the order of 2.0 per cent per year. The increase in the

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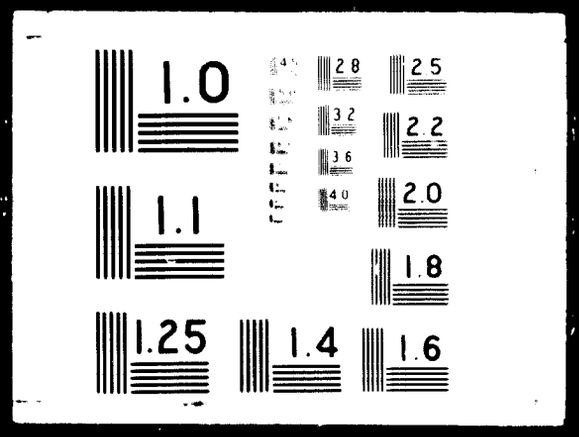

fish catch has been uneven both in terms of the types of species and with respect to their geographical distribution. A substantial part of this increase has been used for reduction to meal and oil.

A high rate of increase in fish landings has been recorded in northwest Europe, mainly due to technological improvements in locating fish which have enabled a more economic exploitation of certain pelagic fish stocks, primarily for fish-meal production. For a modern trawler the actual finding of the fish occupies about half of its total time at sea, and for a purse seiner the proportion is even higher. Thus, the value of innovations in locating fish is obvious. The application of modern fishing techniques is one of the factors responsible for sustaining the extraordinarily high rate of expansion in the Peruvian anchovetta fishery which, in turn, has been mainly responsible for an annual average increase of fish catch in Latin America of 25.9 per cent from 1958 to 1965, the highest increase over a period of seven years recorded in the history of modern fishing.

The application of modern fish location and fish-catching methods was an important factor in stimulating the rapid expansion of fisheries in western South America. A more important factor, however, was the market offered by a rapidly increasing demand for fish meal, due to the growth in the developed countries of pig and poultry breeding on an industrial scale.

Other important considerations have been the recent development of distant water fishing operations and advances in the freezing methods at sea and in producing fish meal on board fishing vessels. These improvements are responsible for the sharp increase in fish landings in some Mediterranean countries, in Japan and in the USSR.

The rate of increase of fish landings in developing countries, in general higher than that in developed countries, varies widely. In the case of Peru and Angola, a high rate of increase has resulted from the rapid development of reduction industries; in other countries, it has been affected by the motorization of traditional vessels and other technical achievements, improved training of fishermen and the expansion of fish marketing. In a few countries industrial high-seas operations have been introduced. It seems that while in the future the growth rate of fisheries in developed countries will decrease, the growth rate in developing countries will continue to increase.

Figure 1 gives the world catch in 1968 of marine fish, crustaceans and molluscs for the various ocean areas.

The potential of the presently important groups of species are approximately as follows:

	Millions of tons
Large pelagic fish (mainly tuna)	3
Demersal fish (cod, bream etc.)	43
Shoaling fish (herring, anchovy, mackerel etc.)	61
Crustaceans (shrimp etc.), excluding Antarctic krill	2
Cephalopods	9

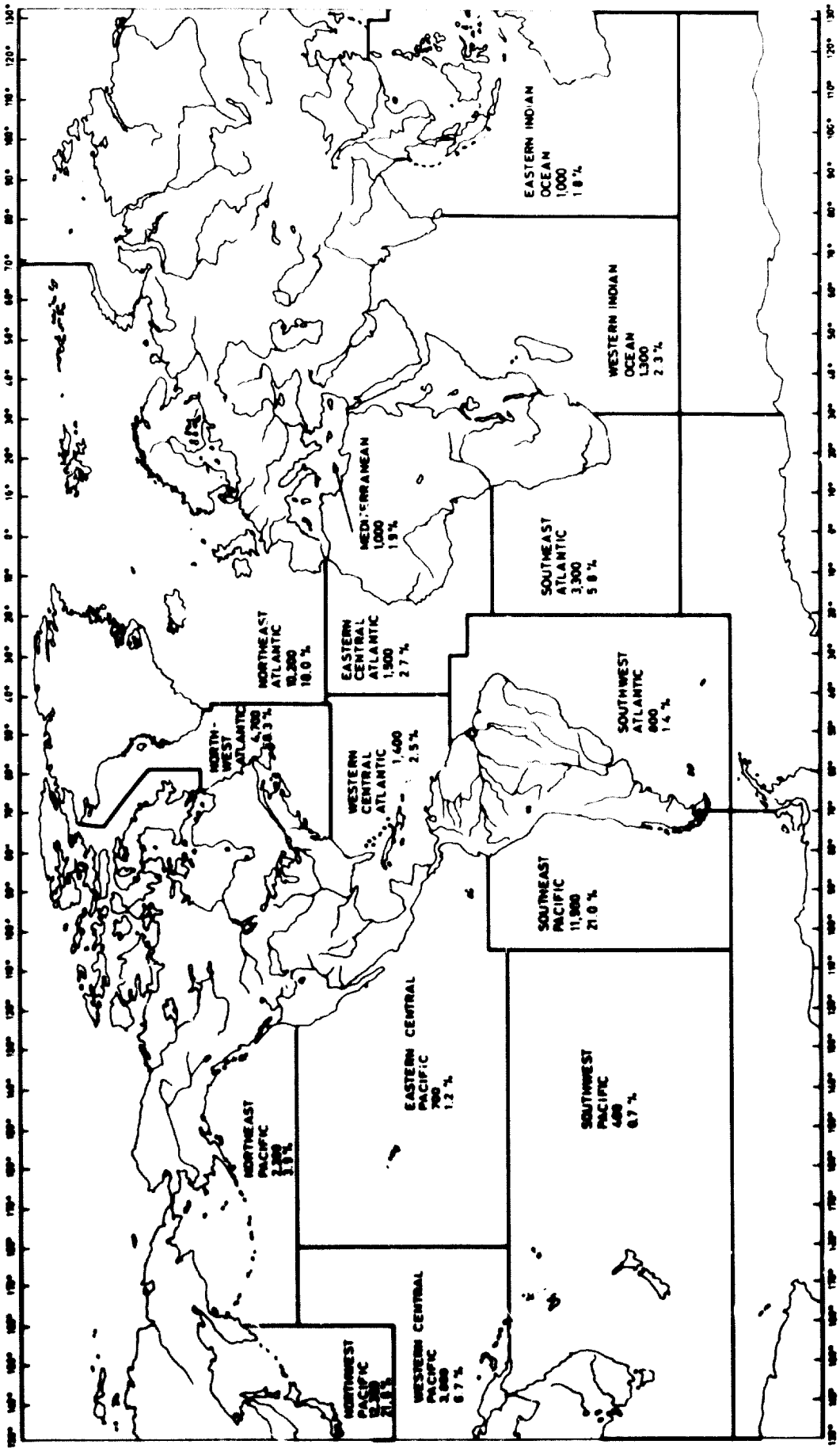

Figure 1. World fish catch in 1968 by major ocean areas (in thousand tons and as per cent of world catch)

The estimated demand for fish for reduction to fish meal in 1985 may be 38 million tons and that for food fish 70 million tons. To satisfy this demand it will be necessary to develop unconventional resources such as small pelagic fish and Antarctic krill. The potential catch of the latter has been estimated at 50 million tons and upward.

Resources for possible industrial utilization

The northeast Atlantic area [2]

This includes some of the fishing grounds with the oldest tradition in the world, such as those off Iceland and Norway and in the North Sea and the Baltic Sea. An important development within the last ten years has been the establishment of fisheries whose catch is specifically earmarked for the production of fish meal. The catches include herring, sprat, capelin and mackerel. In addition, hitherto non-fished stocks of sand-eel (*Ammodytes* spp.) and Norway pout (*Trisopterus esmarkii*) are now being exploited.

In the countries adjoining the northeast Atlantic Ocean herring are mainly used for reduction to fish meal, although appreciable quantities are also used in some countries for direct human consumption. Stocks seem rather heavily fished with the exception of those in the waters west of the British Isles, which have a potential of about 200,000 tons.

Sprat fishing in the North Sea is a coastal industry. A great part of the catch is used in fish-meal production. In some areas an increase in the catch may be possible. In 1965, 75,000 tons were caught, but the total potential yield may be at least 150,000 tons.

Mackerel stocks are commercially exploited in the Kattegat, the Skagerrak and the southern waters of the North Sea. As a result of the expansion of the Norwegian purse seine fishery in 1963 and subsequent years, there has been a very large increase in mackerel catches (1964, 40,000 tons; 1966, 500,000 tons; 1967, 870,000 tons; 1968, 780,000 tons). The mackerel are used mainly for reduction to fish meal. The decline in catches in 1968 suggests that the stocks off Norway are fully exploited, and the sustainable annual yield may be in the range of 500,000 to 700,000 tons. Little is known about mackerel stocks in other parts of the northeast Atlantic area, e.g. in the southern waters (ca. 30,000 tons, according to the International Council for the Exploration of the Sea).

Horse mackerel landings in the North Sea amount to 5,000 tons a year. This seems to be well below the sustainable yield. In the southern waters this species is of greater importance and in 1966, 100,000 tons were caught in the Bay of Biscay off the coast of Portugal. It is believed that catches could be moderately increased.

Increased production of fish meal will require the development of fisheries to catch less exploited and commercially unattractive species, such as capelin (*Mallotus* spp.), sand-eel (*Ammodytes* spp.), Norway pout (*Trisopterus esmarkii*), argentines (*Argentina* spp.), blue whiting (*Gadus poutassou*) and macruridae.

Capelin, a species of the northern part of the North Atlantic area, has been exploited in recent years for industrial purposes. In 1967, 50,000 tons were caught off Iceland, 500,000 tons off north Norway and 500,000 tons off the USSR. In 1962 the total catch in the area amounted to only 3,500 tons.

Recently, new fisheries, especially in the North Sea, have started to exploit stocks of sand-eel and Norway pout for industrial purposes. The size of catches has fluctuated, with a peak in 1967 of 210,000 tons and a low in 1965 of under 70,000 tons. There seem to be other promising stocks of sand-eel west of the British Isles and off the north coast of Scotland. Catches of Norway pout (possibly including some haddock) amounted to a little under 500,000 tons in 1968.

One of the commercially unattractive species at the present time is the blue whiting, with an estimated potential of about 300,000 tons in the areas northwest of Ireland and northeast of Scotland. Argentines (*A. silus* and *A. sphyraena*) are another unexploited species in the North Sea. Argentines and macrurids have been found in depths of between 200 and 1,000 m in the waters west of the British Isles, but probable catch rates do not seem high enough to support a fishery for the production of fish meal.

The eastern central Atlantic area [3]

This includes the Moroccan coast in the north and the waters around the Cape Verde Islands and the Gulf of Guinea in the south.

In 1968, the catches of pelagic fish in the northern area, from the Strait of Gibraltar to Dakar, were as follows:

Small pelagic fish:	280,000 tons—principally sardine landed in Morocco but also small quantities of *Sardinella* spp. landed in Senegal.
Medium pelagic fish:	100,000 tons—principally horse mackerel (*Trachurus* spp.), bluefish (*Temnodon salator*) and mackerel (*Scomber* spp.), caught mainly by trawlers from the USSR and other East European countries.
Cephalopods:	150,000 tons—these are taken mainly by Spanish and Japanese vessels and include squid, cuttlefish and octopus.

In the southern area (Dakar to the Congo river) the pelagic inshore fisheries are based mainly on *Ethmolosa fimbriata* and *Sardinella*. *Sardinella* species are present where there is an upwelling. They are therefore abundant mainly off Senegal, the Ivory Coast, Ghana, Gabon, the People's Republic of the Congo, and in northern Angola. Increased fishing of *Sardinella* seems possible. Studies on pelagic species, especially *Sardinella*, are now being carried out under FAO/UNDP Special Fund Projects in several West African countries.

Quantitative estimates of the potential of pelagic resources are difficult to make, although it seems that none of these have been fully exploited. Catches of sardine (pilchard) off Morocco increased in 1966 to 280,000 tons (from 100,000 tons in previous years), but it is too early to say what effect this increase is having on the stock. The potential of the sardine stocks south of Gibraltar is estimated at 400,000 tons. The other pelagic stocks of the eastern central Atlantic may have a similar potential of some hundreds of thousands (but probably not millions) of tons. Estimates of the potential of pelagic fish species are summarized in table 1.

TABLE 1. ESTIMATES OF POTENTIAL PELAGIC FISH CATCHES IN THE EASTERN CENTRAL ATLANTIC AREA
(Thousands of tons)

	North of 10° N		South of 10° N	
	1968	Potential	1968	Potential
Sardines	280	400	—	—
Anchovy	—	400	—	(×100)
Sardinella	30	100 (?)	70	(×100)
Mackerel, horse mackerel etc.	100	200—500	—	—

Increased catches would probably be possible from the stocks of mackerel, horse mackerel and other larger pelagic fish. These fisheries, however, have recently been expanding rapidly and more data are required for a better estimation of what effect the present catches have on the stocks. The present catches of mackerel, horse mackerel etc. can most likely be increased two to five times, that is, to a total of 200,000 to 500,000 tons.

Anchovy stocks off Ghana and the Ivory Coast (*Anchoviella guineensis*) and others are untouched. Detailed exploratory fishing is required to determine whether the fish can be landed at a sufficiently low cost to support a fish-meal industry.

Among the demersal stocks are many of low economic value, such as elasmobranchs, some croakers in the north and *Brachydenterus auritus* in the south, which could provide the main raw material for a fish-meal industry if they could be fished economically. Cephalopods and small fish such as myctophids are important and still unexploited resources of the open ocean.

The southeast Atlantic area [4]

This extends from the mouth of the Congo river (6° S) around the Cape of Good Hope to south-west of Durban (30° E). The Antarctic waters south of 50° S are outside the area. In this area there are the large sardine and maasbanker (*Trachurus*) fisheries of South Africa, South-West Africa and Angola, and, in addition, Soviet vessels are catching pelagic fish. Pelagic fish support large-scale fish-meal industries.

The pilchard (*Sardinops ocellata*) is the most important coastal pelagic species of the area. The potential of pelagic fish is given in table 2.

TABLE 2. ESTIMATES OF POTENTIAL PELAGIC FISH AND SAND EEL CATCHES IN THE SOUTHEAST ATLANTIC
(Thousands of tons)

Species	1967	Potential			
		Angola	South west Africa	South Africa	Total
Snoek	15	—	20	20	40
Pilchard	1,106	200	2,000	150—300	2,500
Anchovy	300	200	(×10)	200—750	700
Maasbanker	195	600	200	150—400	1,000
Mackerel	140	—	(×10)	50—150	150
Sardinella	—	1,000	(×10)	(×1)	1,000
Round herring	—	—	—	(×100)	300
Sand-eel	—	—	—	(×10)	50
	1,740	2,000	2,300	1,300	5,600

There are signs of the presence of other species that are not yet exploited commercially, such as saury (*Scombresox saurus*), myctophids and squid (*Loligo regnandi*). Saury and squid are obviously not confined to waters relatively close to the coast, as are the species discussed above. The extent to which these stocks can be exploited depends on the possibilities of extended fishing. The supply of myctophids is large but its commercial exploitation would require some technological advances to make it economically feasible.

The total potential of the southeast Atlantic area may be estimated at 8 million tons, that of the northeast Atlantic at 15 millions tons and that of the northwest Atlantic at 6 million tons.

The Indian Ocean coastal waters [5]

These include areas of shallow waters in the Indian Ocean from Madagascar to Australia, taking in the Arabian Sea, the Red Sea, the Persian Gulf, the Bay of Bengal and the Oceanian islands and banks (see figure 2).

The marine catch from the Indian Ocean was estimated to be about two million tons in 1967. [6] There are relatively large unexploited resources, probably in the order of at least one million tons, of sardines or anchovy in the Arabian Sea and the Gulf of Aden. The coastal fisheries of most of the countries bordering the Indian Ocean are in general of an undeveloped subsistence level using primitive gear. In many parts, especially along the coast of East Africa, fishing is done in non-motorized boats and is often very short-range and confined to shallow waters. Other factors that keep production in this area low are lack of storage and distribution facilities for fish at landing areas, fluctuations in supplies, the price of ice and the lack of suitable markets owing to the low purchasing power of a large part of the population in most of these countries.

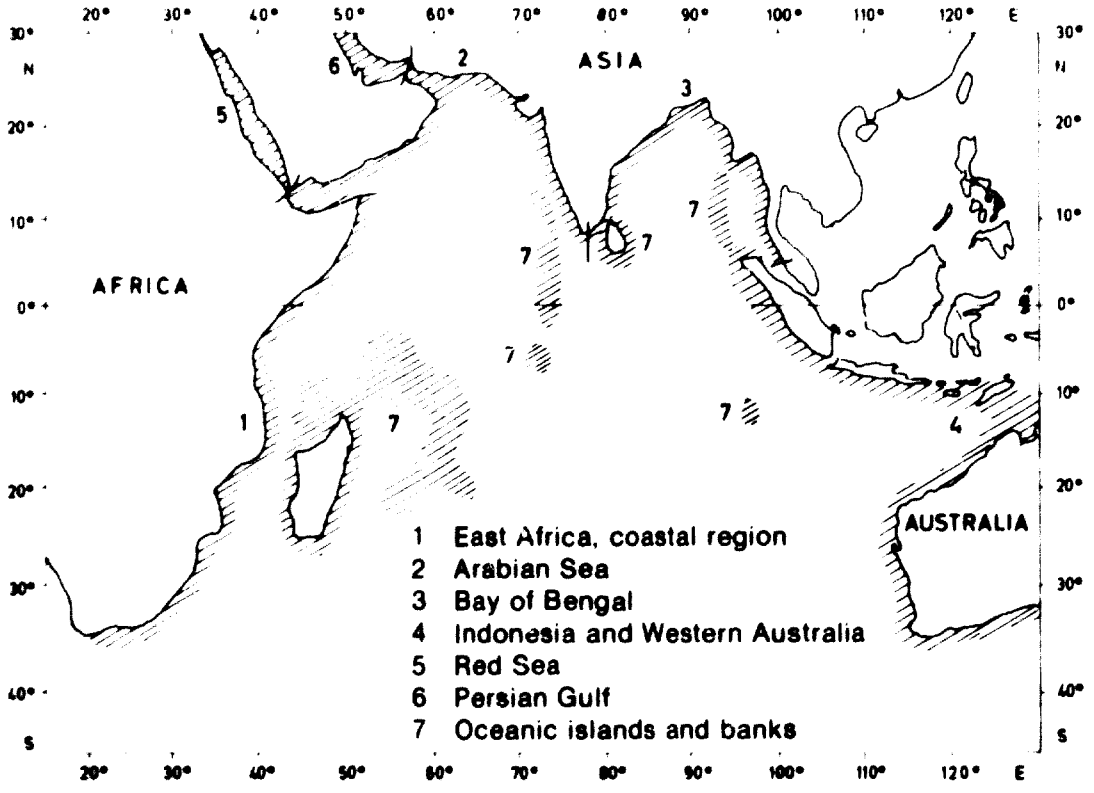

Figure 2. The Indian Ocean coastal waters

Some of the fish species used commercially at present, such as the larger tunas (yellowfin, albacore etc.) in the open ocean, and some demersal species and shrimp close inshore, are fairly well exploited. The greatest opportunity for the increase of fish catches in the Indian Ocean is most likely to be the exploitation of less familiar or less accessible stocks. Such stocks are pelagic fish (sardines or anchovy) in the northwest Indian Ocean, saury and small lantern fish in the open ocean and others. Harvesting these resources will require improved methods in many areas including fishing technology, fish preservation, processing and marketing.

The western central Pacific area [7]

This includes the following bodies of shallow waters (under 200 m): Yellow Sea and East China Sea, Formosa Strait and Chinese south coast, Gulf of Tonkin (to 15° N), Gulf of Thailand (from Cape Cambodia to the Malaysia-Thailand border), South China Sea (from 15° N to the equator), Java Sea (from the equator south and west to Bali), Gulf of Carpentaria and the eastern Arafura Sea. Other shallow waters are along the southwest coast of Java, around the Ryukyu Islands and the Philippines, and around eastern New Guinea and the Solomon Islands.

The most important commercial species of pelagic fish in the Yellow Sea and the East China Sea are mackerel and jack mackerel. Estimates of the

present yield of pelagic fish from the southern waters of the western central Pacific area are only approximate owing to a lack of data from many localities. The best studied area is the Gulf of Thailand, where fishing is moderately important and the catch could probably be doubled. The potential catch of pelagic resources in the shallow water zone of the area down to 50 m is estimated as between one million and five million tons.

At a depth of between 50 and 200 m the pelagic fish are probably more abundant. In addition, demersal fish may have a similar potential catch which would yield a total potential of about one million tons. However, it is not known whether commercial exploitation is possible.

Fishing carried out in the island areas is of a subsistence type except in the Ryukyu Islands and in the Philippines where there are fair-sized commercial fisheries. In the island area as a whole the fishery resources in deeper waters have not been fully harvested, mainly because of inadequate boats and gear and marketing problems. These waters contain pelagic species such as scad and mackerel.

The northwest Pacific area [8]

Studies of this area, which includes Japan, indicate that only a few of the resources of pelagic fish, such as anchovy, could support substantially increased exploitation. Off-shore fishing for greater catches of saury and mackerel may be uneconomical without further technological improvements.

Sand-eel *(Ammodytes personatus)*, on the other hand, is an abundant species in the vicinity of Japan that could be further exploited. In recent years the demand for this species as food for humans has been decreasing, and it has been used increasingly for reduction to fish meal, mainly in connexion with the development of fish culture.

The northeast Pacific [9] *and eastern central Pacific* [10]

These extend from the Bering Sea to northern Peru. Pelagic fish is the most important potential resource. Of particular interest is the unexploited anchovy source off the coasts of California and Mexico. When the California sardine stock declined the reserves of anchovy increased to the point where they could support a fish-meal industry with annual catches of about two million tons. However, for various reasons, for example, to protect the supply for sports fishing, no major anchovy fishery has been developed.

A small fishery in the Gulf of Panama is supplying fish-meal factories, mainly in Panama. The fish-meal industry is using some 60,000 tons of raw material, about three quarters of which are anchovetta and the rest, thread-herring *(Opistonema libertate)*. The thread-herring resources are believed to be larger than those of anchovetta. In the Gulf of Panama the catch of pelagic fish could possibly be increased to about 150,000 to 250,000 tons. The total potential catch of pelagic fish in the tropical area extending from central Mexico to northern Peru is likely to be in the range of one half to one million tons.

Demersal fish are caught and discarded by shrimp trawlers operating along the Pacific coast from Mexico to Colombia. The quantity of this unused, so-called trash fish is estimated at 200,000 to 500,000 tons off the coast of Mexico and 100,000 to 250,000 tons off the coast of Central America. Several attempts have been made over the last ten years to use this trash fish for fish meal or other purposes but they proved to be uneconomical.

Greater quantities of demersal fish could be caught with the use of appropriate fishing techniques. The potential annual catch of demersal fish in the southern part of the area is estimated to be one million tons.

The northwest Atlantic area [11, 12]

This includes the eastern seabord of Canada where a plant is scheduled to be built for the production of food-grade FPC with a capacity of 200 tons of raw material a day, using fillet trimmings from cod as its main resource. Other possible fish stocks for FPC production are inshore species now landed for reduction to fish meal, mainly herring, sand-eel and trash fish caught in the trawl fisheries for cod and the like. At present trawlers discard commercial species that are under size as well as many unmarketable species such as skate, dogfish, red hake, eelpout, grenadier, sea ravens, sculpin and others. In addition, resources of sand-eel and argentines, and in deep water further exploitation of grenadier, lantern fish, barracudina and other species is possible, although at the moment uneconomical.

The western central Atlantic area [13]

This includes the Gulf of Mexico, the Caribbean and the Atlantic coasts of South America. Here again, trash fish caught by shrimp trawlers could be utilized. The amount caught and discarded by United States shrimp trawlers may be as much as 600,000 tons. A similar quantity may be caught by shrimp vessels of other nations.

The entire catch of the United States menhaden fishery in the Gulf of Mexico is used for the production of fish meal. While peak landings are over one million tons, the stocks are declining. Anchovy and thread-herring stocks seem to be large but are unexploited. The total potential annual catch of pelagic fish is estimated at one million tons in the Gulf and 750,000 tons off the United States Atlantic coast.

The Caribbean appears less productive than the Gulf of Mexico, except for the eastern part of the South American coast.

The main fishery for pelagic fish (excluding tuna) is along the coast of Venezuela where some 40,000 tons of sardine *(Sardinella anchovia)* and smaller quantities of anchovy *(Cetengraulis edentulus)* and round herring *(Opistonema oglinum)* are caught annually. There is no apparent reason why the sardine supply cannot be further exploited, but it is probable that other pelagic species offer better possibilities for major increases in the size of catches.

In the area off the United States coast, sand-eel *(Ammodytes americanus)* could be more widely exploited.

Processed fishery products and FPC

The problem of supplies is central to the expansion of fish processing industries in various parts of the world, including developing countries. Information about resources must be supplemented by knowledge of the facilities available for catching and landing and the cost of the raw material. The level of the technological development and education in a country must also be considered.

Another most important and complex problem connected with the production of fish-protein concentrate is marketing. FPC encompasses a broad range of products with correspondingly diverse markets. For this reason, the establishment of appropriate product specifications is essential from the outset.

Fish meal is the most common feed-grade FPC product with a world production of almost five million tons in 1968. Its market is increasing, due mainly to its use in formulated feed mixtures. In Japan compound feed mixtures for animals utilized 382,039 tons of fish meal in 1967 and 466,655 tons in 1968. In addition, an estimated quantity of 55,000 tons of fish meal was used in compound feeds for fish. Only about 60,000 tons of fish meal were used for direct feeding of animals in 1968.

According to the FAO circular "Prospects for world fishery development in 1975 and 1985", the demand for fish meal will gradually outstrip the supply, particularly if the price in relation to competitive products remains fairly stable. The projected total world demand for fish meal for 1985 amounts to 8.5 million tons. The consumption in developing countries was 326,000 tons in 1965 and their estimated demand for 1985 is 1.56 million tons.

Recent products with a limited but obviously growing market are solvent-extracted feed-grade FPC products made from fish meal or raw fish. This feed-grade FPC need not be completely tasteless.

So far as food-grade FPC is concerned, there is as yet no market in the food sector and there is no information available that would point to the market possibilities for a refined FPC product for direct human consumption. Large-scale market research is necessary. So far, no attempt has been made to assess markets on a commercial basis. In the United States, where intensive technological research has been carried out, no positive attempts have been made to create a market for food-grade FPC. Other countries have not had the means to engage in market research and acceptability tests. In most developing countries the food industry is not large enough or sufficiently developed to use considerable quantities of FPC, which is costly to extract, as protein supplements. The United Republic of Tanzania is planning to use FPC to fortify corn-flour, but because of a number of difficulties progress has been delayed.

A breakthrough might be achieved if food-grade FPC were used in developed countries where it could be incorporated into certain food formulas. However, it would have to face competition from other commodities such as soya products and dried skim milk. In this connexion, it is well known that

the functional properties of FPC need to be improved, although no serious research has been carried out in this respect.

FPC production has been evaluated as to its economic feasibility, but in the absence of large-scale industrial production it is not possible to obtain realistic cost calculations. With the exception of a small production of food-grade FPC for aid programmes, all FPC plants originally set up for the production of refined food-grade FPC are producing solvent-extracted feed-grade FPC, or have closed down. Production solely for aid programmes may support some individual plants but it cannot be considered a sound basis for an industry. Unless commercial markets can be developed, industrial production of solvent-extracted food-grade FPC will not be feasible.

In several countries there may be a market for relatively small quantities of low-cost food-grade FPC as a food supplement or for use as a condiment. At present different methods of producing FPC of various types and for various purposes are being explored in several research institutes. It seems likely that in the near future products for human consumption will be developed that are cheap, that do not require large centralized fish supplies and that can be adapted to the food pattern of certain countries.

A great advantage of FPC is that it is an animal protein of high biological value that does not require the addition of amino acids. A further advantage is that unutilized and underutilized fish stocks could be used as raw material, thus employing presently wasted fishery resources. In this respect, it would be desirable to use fishery resources that are too small or otherwise not suitable for the production of fish meal.

The extent to which developing countries will, in the near future, be in a position to engage in the commercial manufacture of food-grade FPC will depend on the process used, the availability of raw material at low cost and the development of an outlet for the product. In view of the low purchasing power of consumers in developing countries, it would be necessary to reduce the costs of raw material, processing and distribution in order to produce low-cost products. Sufficient attention must also be given to the marketing and promotion of the products and to close collaboration between technologists and marketing experts at the time FPC products and foods supplemented with FPC are introduced. Finally, FPC is only one of many fish products and its development should be considered within the general framework of the development of fish products.

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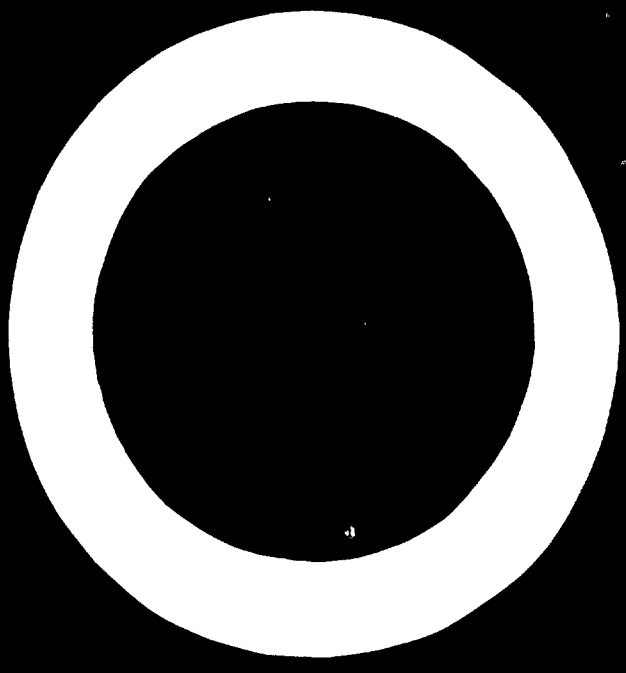

5. PRODUCTION OF FISH-PROTEIN CONCENTRATE FROM MOROCCAN SARDINES*

Between one half and one third of the world's population suffers from protein malnutrition, and strong evidence indicates that such protein starvation in early childhood permanently stunts mental development.

The potential contribution of fish-protein concentrate is indicated by the fact that one ton of high grade protein is a sufficient amount to significantly supplement the diets of 100,000 people for one day. Moreover, large-scale production of FPC is quite possible since the technology involved is not elaborate. A sufficient quantity of small fish are being caught for industrial use. These comprise more than 40 per cent of the world's fish catch and if converted to FPC they could provide a useful direct protein supplement to 750 million people.

Thus, the need, the resources and the know-how for a large-scale FPC industry all exist, and it is reasonable to assume that the logic of its use will ultimately lead to the widespread production of FPC.

Unfortunately, people who need additional protein in their diets usually are not aware of it and therefore are naturally not disposed to pay more for enriched bread that tastes and looks no different than ordinary bread. Furthermore, suspicions and rumours, as well as a general reluctance to modify traditional food habits, inhibit the adoption of new foods. Hence, because of the problems of marketing FPC, capable manufacturers and distributors are unwilling to invest in the product. Time, persistence, skill and money will be needed in generous amounts to promote this worthwhile industry commerically.

However, the political, social and economic obstacles that deny FPC to those who need it are not considered here but rather the far simpler problems of production and, more specifically, the technology of producing a low-fat, bland and inconspicuous FPC by extracting fish with alcohol.

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* Paper presented to the meeting by John H. Blake, formerly an independent consultant, Portola Valley, Calif., USA. At present, Mr. Blake is Program Supervisor, Bechtel Corporation, San Francisco, Calif., USA.

History of the FPC production effort in Morocco

The project to produce an edible FPC in Morocco began about ten years ago. The Société de l'Union d'Azote at Safi untertook the development of a process and constructed a pilot plant capable of making about 500 kg per day of products from Moroccan sardines (*Sardina pilchardus*).

Since the material produced by the pilot plant was considered quite acceptable, safe and highly nutritious, in 1964 the Government of Morocco in partnership with Azote Union financed the construction of the commercially sized plant located at Agadir. The SONAFAP (Société nationale de farine de poisson) organization was created to manage the enterprise.

This plant was modelled after the small one at Safi, which had proved so successful, and employed a process consisting of the following principal steps:

(*a*) Fish were reduced to meal in a small reduction plant by cooking, pressing and drying;
(*b*) the meal was extracted with ethyl alcohol and then with hexane;
(*c*) the extracted meal was dried unter vacuum, then ground, screened and packaged.

Unfortunately, the quality of the product from the larger plant was not as high as that from the pilot plant. Although the flour was safe and nutritious, it imparted an undesirable odour, taste and colour to foods in which it was incorporated. As a result, the extraction plant made only two campaigns to launch the product, putting out 32 tons in 1965 and 143 tons in 1966.

At the request of the Government of Morocco, the United Nations sent a mission to Agadir early in 1967 to assess the plant and to recommend a course of action.

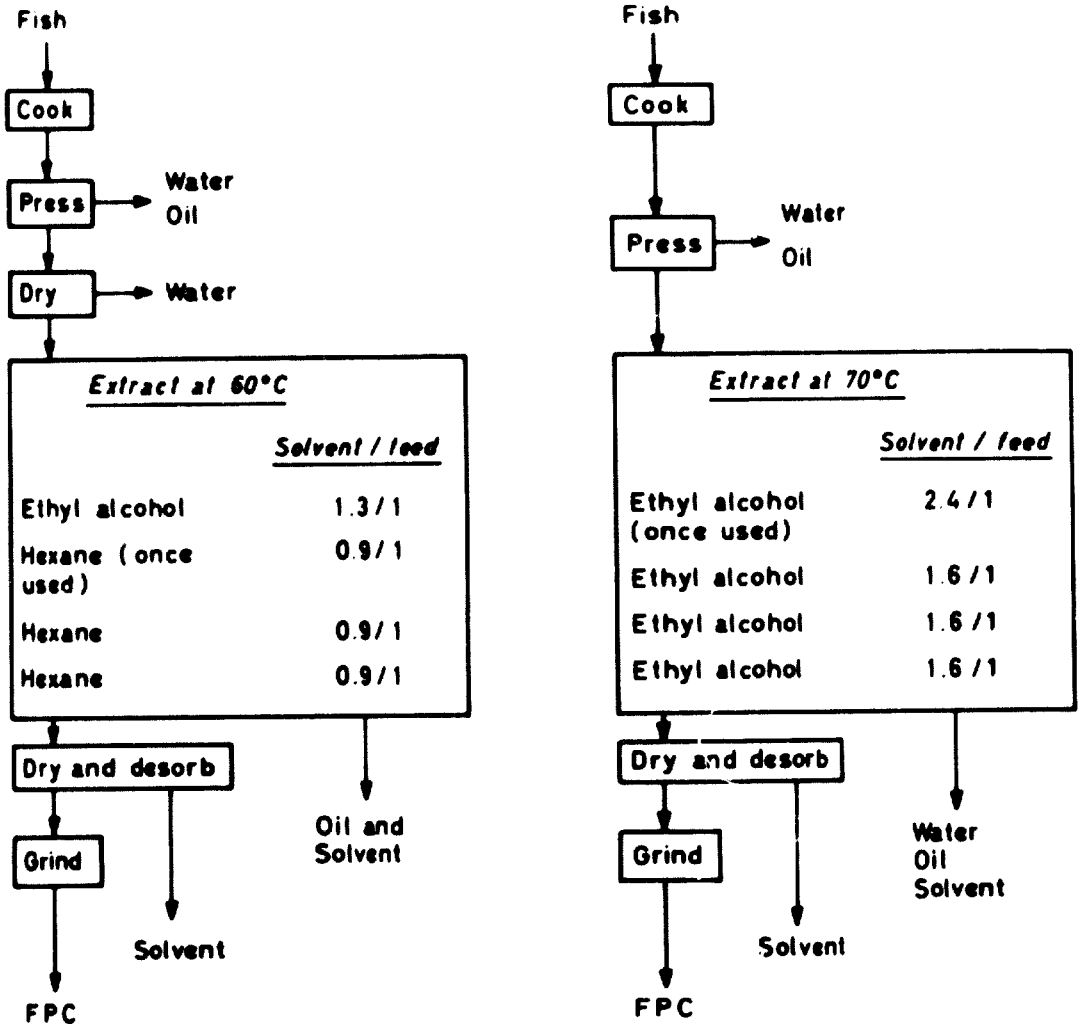
The mission recommended a four-phase programme to do research into the viability of producing FPC commercially based on the work up until then. The first phase of the experiment demonstrated that raw sardines extracted with isopropyl alcohol could make an acceptable FPC. In the second stage of the operation the existing plant is being used as a pilot plant to produce 20 to 40 tons of high quality FPC, and to gather sufficient engineering data to aid in designing an economical plant and in predicting the necessary investment and costs of production.

Phase three envisages a survey of the market for and uses of FPC in Morocco, and phase four, detailed plans for the revision of the present plant. These final phases were scheduled to be initiated in 1970.

Earlier results

As mentioned, the SONAFAP plant was originally designed to extract fish meal (cooked, pressed and dried) with ethyl alcohol followed by hexane. A batch of about two and one half tons was extracted and dried in 14 hours, giving a production rate of roughly 4 tons of FPC per 24 hours. The first column of table 1 shows the sequence of operations, the solvents and conditions of use.

TABLE 1. SONAFAP PLANT FPC PROCESSES



[a] Ethyl alcohol was later replaced by isopropyl alcohol.

Despite the fact that the FPC was considered to have too much odour and taste, the product did have good properties. It was definitely safe, wholesome and nutritious with a protein efficiency rating (PER) better than casein and equal to other high quality FPC products. (Table 2 gives some of the data.) In 1965 a few batches were made with headed and gutted sardines, but the high cost of this operation obliged SONAFAP to use whole fish for most of the production. The product from whole fish was darker in colour and contained a somewhat lower protein content, but the protein quality was excellent. The lower lipid content for the FPC from headed and gutted fish may have been caused by extraction with a larger quantity of solvent. Tests of the presence of various types of bacteria, including enterococcus, *Salmonella*, *Shigella*, *Staphylococcus*, *Clostridium*, and pathogens, were completely negative.

TABLE 2. COMPOSITION OF FPC FROM SONAFAP CAMPAIGNS OF 1965 AND 1966
(Per cent)

Sample number	*Headed and gutted fish*			*Whole fish*
	FAO 260 E (7) (1965)	FAO 261 E (8) (1965)	FAO 262 E (6) (1965)	
Protein (N × 6.25)	88.5	88.0	84.5	79—80
Lysine—available (% of protein)	8.8	9.3	8.7	7.4
H_2O	5.1	6.5	4.6	2—4
Lipid	0.52	0.54	0.42	0.8
Ash	8.7	7.6	12.5	13.0

The odour and taste were most likely caused by the product's high lipid content, about 0.8 per cent; in particular, the slight but unpleasant and persistent aftertaste suggestive of varnish is characteristic of oxidized lipids.

When this FPC was incorporated in baked goods at the level of 4 to 5 per cent dry basis, some users noticed this aftertaste and some did not. The product may well have been criticized too severely, however. It should have been possible to sell it as a concentrated fish to people who accept the taste of fish, and also to those who do not if it is incorporated in soups, gravy, cookies and coarse cereal products at a low level—say 3 per cent.

THE PRESENT PROJECT

The objectives of the experiment at the SONAFAP plant were to verify that a bland FPC having very little odour or taste could be made; to produce about 30 tons of a high quality product for market development and acceptance studies; and to acquire the engineering data needed in order to improve the existing plant.

Since the undesirable taste of the earlier product was probably imparted by oxidation of lipids when the fish was first dried, the logical modification of the process was to omit the drying step and to feed press cake (cooked and pressed fish) directly to the extraction system. Also since hot alcohol—either ethyl or isopropyl—is an excellent solvent for these lipids, and since alcohol liquifies the press cake readily, the use of hexane was abandoned. Table 1 compares this scheme with the former procedure.

Extraction of press cake requires more solvent than dry meal, but since the unoxidized lipids are more soluble, a better product results. Press cake, however, requires much less solvent than raw fish for a given production of FPC. When the quantities of solvent required to make FPC from dry meal, press cake and raw fish are compared, as shown in table 3, it becomes apparent that the same extraction and solvent recovery system can make nearly twice as much FPC from press cake as from raw fish.

TABLE 3. SOLVENT REQUIREMENTS FOR PRODUCTION OF 15 KG OF FPC FROM VARIOUS MATERIALS

(Basis: 100 kg of raw fish)

	Fish meal	*Press cake*	*Raw fish*
Quantity extracted (kg)	18.4	34.0	100.0
Oil content (kg)	1.7	1.7	10.0
Water content (kg)	1.5	17.1	72.0
Clean solvent needed (kg)	74.0	102.0	200.0
Solvent/feed ratio	4/1	3/1	2/1
FPC production expressed in index numbers	2.7	2.0	1.0

Another way to state the case is that cooking and pressing is probably a cheaper way to remove most of the water and oil from fatty fish than is solvent extraction. And it bears repeating that most of the low-cost fish resources particularly suitable for FPC have high fat contents.

Detailed description of the SONAFAP plant

Figure 1 shows the principal items of equipment and the flow of material. The fish, after cooking and removal of most of the water and oil in the screw press, pass through a disintegrator where the large lumps of moist cake are

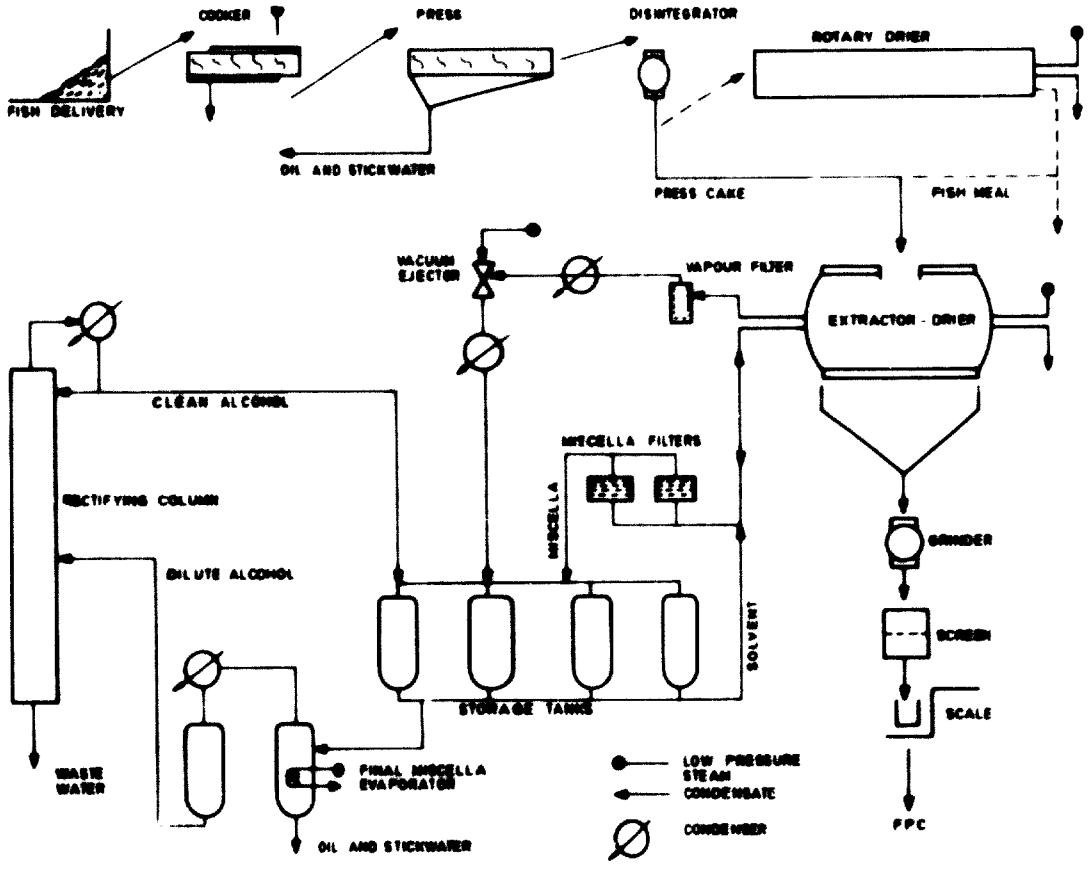


Figure 1. Equipment and flow diagram of SONAFAP plant

shredded into pieces of 0.5 to 1 cm. This part of the process in the present plant uses conventional equipment for producing fish meal, and the conditions are not sufficiently sanitary for other than limited experimental production. The use of this particular equipment cannot be recommended as good practice generally.

A one- or two-ton batch of press cake is next weighed out and charged to the extractor. The extractor is a horizontal mixing cylinder which rotates (see figure 2). It has a steam jacket for heating the mixture, filter sleeves to drain the liquid miscella and to hold back solids, and rotating seals on the axis to permit solvent and steam to enter and vapours and condensate to leave. To filter off miscella, rotation is stopped and a suction hose is attached to a fitting in the bottom. The extractor also serves as a vacuum dryer when the extraction cycle is finished.

A typical extraction and drying sequence is:

(*a*) Wash with 2.5 times by weight of once-used solvent, mixing at 70° C for 15 minutes before filtering off the miscella;

(*b*) wash three times more with 1.6 times by weight of clean solvent. Mix 15 minutes at 70° C before each filtration;

(*c*) dry under atmospheric pressure at temperature up to 90° C, then continue under 500 mm of vacuum to 105° C. Sparge dryer with steam while temperature is above 95° C. Sparging time varies from 30 to 90 minutes.

The above treatment will make FPC containing 0.3 per cent or less of lipids and 3 per cent moisture from press cake of 50 per cent moisture and 5 to 6 per cent lipids. Tables 4 and 5 describe the results in more detail.

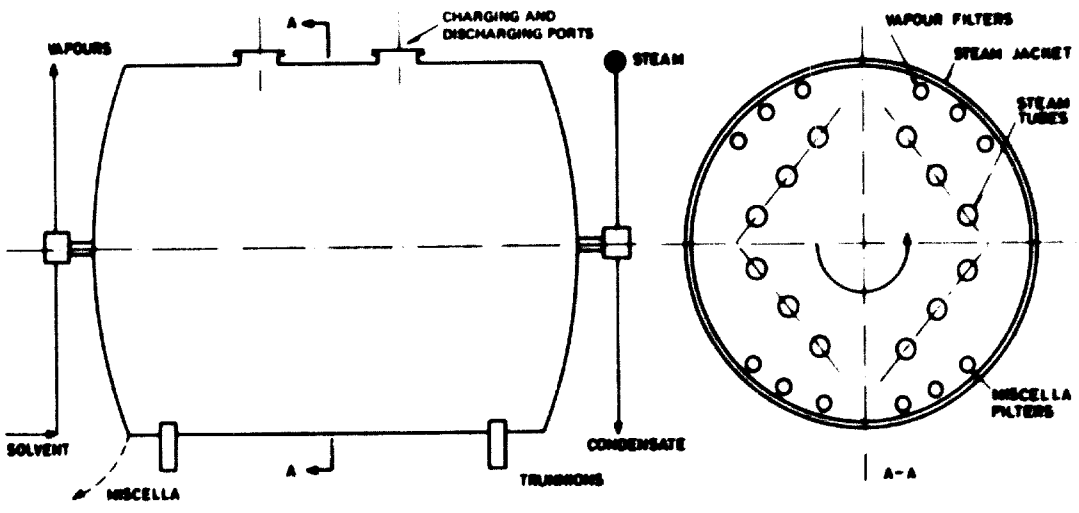


Figure 2. Ten-cubic-metre extractor-dryer used in production of FPC

TABLE 4. FPC PRODUCTION WITH ETHYL ALCOHOL (E)

Batch number:	*E-7*[a]	*E-8*[b]	*E-9*[c]	*E-10*[d]	*E-13*[e]	*E-14*[f]	*E-15*[g]	*E-16*[h]	*E-21*[i]	*E-22*[j]
Date (Day/month):	*17/9*	*20/9*	*23/9*	*1/10*	*6/10*	*7/10*	*8/10*	*9/10*	*17/10*	*18/10*
Press cake (kg)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Lipids (%)	6.6	7.0		6.0	7.1	7.2	6.9		7.3	7.0
H_2O (%)	46.2	44.8		50.5	47.0	45.9	45.5		48.5	48.6
Extraction										
Stage 1	3,000 M-3	3,000 M-3	Same	Same	Same	Same	Same	Same	Same	Same
Stage 2	2,000 M-0	2,000 M-3	as for	as for	as for	as for	as for	as for	as for	as for
Stage 3	2,000 M-0	2,000 M-0	E-8	E-8	E-8	E-8	E-8	E-8	E-8	E-8
Stage 4	2,000 M-0	2,000 M-0								
Stage 5	2,000 M-0									
FPC (kg)	485	450	442	450	435	456	456	431	445	483
Lipids (%)	0.18	0.25	0.28	0.29	0.28	0.33	0.30	0.32	0.36	0.36
H_2O (%)	2.6	2.9	3.8	3.4	3.1	3.1	2.9	4.3	3.7	4.5

Note: M-3 = litres of once-used solvent; M-0 = litres of clear solvent.

a Washed fish. 2 kg of citric acid added to the last wash.

b Washed fish. 2 kg of citric acid added to the last wash.

c Excellent fish, washed. Fat content—14.4%, water content—64.0%. Steam off at 110° C.

d Excellent fish, average weight—20.3 g, not washed. Centrifuge fines included in press cake. Steam off at 105° C.

e Steam off at 105° C.

f Steam off at 105° C.

g Steam off at 100° C.

h Excellent fish, average weight—31 g. Steam off at 100° C.

i Small sardines, fair to poor quality. Steam off at 100° C.

j Very good sardines, average weight—20 g. Steam off at 100° C.

TABLE 5. FPC PRODUCTION WITH ISOPROPYL ALCOHOL (IPA)

Batch number	*IP-1*[a]	*IP-2*[b]	*IP-3*[c]	*IP-4*[d]	*IP-5*[e]	*IP-10*[f]	*IP-11*[g]	*IP-15*[b]	*IP-16*[b]	*IP-17*[i]
Date (Day/month)	*22/10*	*23/10*	*24/10*	*25/10*	*27/10*	*4/11*	*7/11*	*16/11*	*17/11*	*29/11*
Press cake (kg)	1,000	1,000	1,000	1,000	1,000	1,520	2,000	2,000	1,800	2,000
Lipids (%)	6.47	7.2	7.2	6.2	6.3	6.9	7.2	6.4	6.0	6.6
H_2O (%)	48.1	47.3	48.5	51.5	48.7	49.0	47.5	50.0	52.6	51.5
Extraction										
Stage 1	3,000 M-3	Same	Same	Same	Same	4,500 M-3	6,000 M-3	Same	Same	Same
Stage 2	2,000 M-0	as for	as for	as for	as for	3,000 M-0	4,000 M-0	as for	as for	as for
Stage 3	2,000 M-0	IP-1	IP-1	IP-1	IP-1	3,000 M-0	4,000 M-0	IP-11	IP-11	IP-11
Stage 4	2,000 M-0					3,000 M-0	4,000 M-0			
FPC (kg)	465	440	447	405	437	664	888	875	800	850
Lipids (%)	0.16	0.15	0.29	0.18	0.18	0.18	0.10	0.12	0.12	0.12
H_2O (%)	2.8	3.0	3.5	3.7	3.3	2.1	2.2	1.6	1.3	1.9

Note: M-3 = litres of once-used solvent; M-0 = litres of clean solvent.

a Excellent sardines, average weight—30 g. 100% IPA in each stage. Sparge 1 hour. FPC colour lighter. Fish odour when FPC stored.

b Sparge 1 hour. New filters, changed for the first time since batch E-1.

c Excellent sardines and some anchovies. Approximately 1 kg of citric and ascorbic acid added to stage 4. Sparge 1 hour. Six filters exchanged because they were too tight.

d Fresh saurel, average weight—50 g. Approximately 1 kg of citric and ascorbic acid added to stage 4. Sparge 1 hour.

e Varied sardines and 10% anchovies; 0.5 kg of ascorbic acid added to stage 4. Sparge 1 hour. New filters freshly cleaned.

f Excellent sardines. Sparge 1 hour. IP-6 to IP-10 packed in 4 kg plastic bags.

g Sparge 1½ hours.

h 2 kg of citric acid and 0.66 kg of BHT added to stage 4. Sparge 1½ hours. 3 vacuum breaks. Steam off at 105° C.

i 2 kg of citric acid and 0.66 kg of BHT added to stage 4. Sparge 2 hours. 3 vacuum braks.

Two of the most important criteria of quality are subjective: odour and taste. Besides simple tests for smell and taste the product was combined in various recipes to evaluate these properties under conditions of use. In butter cookies (200 g butter, 200 g sugar, and 500 g flour) 5 per cent of the poorest quality of FPC in the flour was barely discernible to the taste. The colour of the cookies was noticeably darker, however.

In unleavened crackers (flour, water and a trace of oil and salt) up to 7 per cent FPC produced no fishy taste or odour, but the crackers were somewhat tougher and their colour was quite a bit grayer than those without FPC.

In coarse or coloured baked goods, 3 to 5 per cent of this FPC can be hidden very effectively.

With regard to the possibility of contamination of the product, total counts of bacteria were less than 10,000/g, and tests for *E. Coli*, enterococcus, *Salmonella* and staphylococci were negative. The first sample, taken before the system was cleaned, did show 70 coliformes/g, however. The product is clean despite the unaesthetic nature of the cooking and pressing operations, because of the contact with hot alcohol and also because of the temperature used in drying and desorbing alcohol. (See table 6.)

If fresh fish are used and if the solids are not overheated in the drying step, the major controllable indicator of product quality is the lipid content. FPCs made from fresh fish and with lipid contents below 0.3 per cent have very little odour or taste. Lipid content can readily be varied from over 1 per cent to as low as 0.1 per cent by the number of extraction stages and the ratio of solvent to fish.

Oxidation of small, fatty fish such as sardines occurs with surprising speed. Even prolonged extraction will fail to remove a noticeable oxidized lipid aftertaste from the FPC if these fish have been kept in frozen storage, have been held in the sun or have been processed too long after capture.

The protein content of the FPC depends on the fish themselves and on the soluble material removed with the press liquor. For these samples it varied between 78 per cent and 82 per cent. To minimize the loss of protein in the press liquor, as little direct steam as possible should be used in the cooker.

The cooking does not seem to hurt the quality of the protein; even the 1966 production had a high PER value (3.14 with casein at 3.00). Results of the process in operation showed that if the drying temperature stays below 120° C, the nutritive value of fish-protein is little affected by extraction and drying.[1]

The colour of the FPC produced in this way from sardines is a light tan. While a lighter colour would be more desirable, it could not be obtained even by varying process conditions or by using additives such as ascorbic or citric acids.

Sardines contain many dark-coloured components and after cooking these appear to be mostly insoluble in the alcohol. It is also possible that contact with mild steel in the plant affected the product's colour. The present plant is composed almost entirely of mild steel.

TABLE 6. BACTERIOLOGICAL ANALYSIS OF FPC[a]

Sample number:	*E-6*	*E-7*	*E-10*	*IP-1*	*IP-2*	*IP-3*	*IP-6*	*IP-7*	*IP-8*	*WHO/TNO tentative requirements*
Total aerobic/g	1,000	1,000	300	800	500	100	500	100	300	<100,000
Aerobic spores/g	70	60	30	20	10	10	<10	<10	<10	Same as aerobic count
Total anaerobic/g	1,000	80	40	20	10	10	<10	<10	<10	<10,000
Mold spores/g	40	10	20	<10	10	<10	<10	10	<10	<10
Salmonella spp./25 g	—	—	—	—	—	—	—	—	—	—
Shigella spp./25 g		—	—	—	—	—	—	—	—	—
E. Coli/10 g	Pos.	—	—	—	—	—	—	—	—	—
Enterobacteriaceal/0.1 g	Pos.	Pos.	Pos.	—	—	—	—	—	—	—
Sulfite reducing bact./g	30	20	<10	<10	<10	<10	<10	<10	<10	100
Streptococci/g	<100	<100	<100	<100	<100	<100	<100	<100	<100	100
Staphyloccus aureus/g	—	—	—	—	—	—	—	—	—	—

a Analyses by TNO Laboratories, Zeist, Netherlands.

Besides the lipid content, the other vital product characteristic that is directly controllable in plant operation is the bacteria content. Cleanliness and sanitary practices are essential not only in handling the product but also in the rest of the plant to avoid contamination of the product area. The treatment with hot alcohol effectively sterilizes the fish protein, and it is essential to keep the product clean after it is discharged from the drier.

Packaging in watertight bags of heavy polyethylene keeps the product dry; contact with moisture induces rapid spoilage and generates foul odours.

No difference in quality could be discerned between FPC prepared with ethyl alcohol and that with isopropyl alcohol. It is of course essential to desorb the solvent from the dried solids very thoroughly after extraction with isopropyl alcohol. This is accomplished by sparging with steam, and it is particularly effective if the steam pressure rises and falls during the sparge. Table 7 gives a quality analysis of SONAFAP FPC.

During the initial stages of production with ethyl alcohol, the quantity of solvent on hand was quite limited. The extraction scheme outlined in tables 4 and 5 was devised to yield a reasonable quantity under this constraint.

Although a counter-current stage-wise extraction makes the most efficient use of solvent, in a batch system such as this it is necessary to store once- and twice-used solvent for re-use, and, unfortunately, insufficient solvent was available to do this. When the isopropyl alcohol arrived, later in the experimental programme, trials of counter-current extraction were deferred in favour of producing as much FPC as possible in the short time then available.

The degree to which miscella and solids are separated between extraction stages has considerable effect on the lipid content of the final FPC. Miscella adhering to the solids after one stage contributes its dissolved lipids to those that the following stages must remove.

Miscella drains out from this extractor through cloth-covered filter sleeves in the bottom. Since these sleeves are mounted a little above the bottom of the vessel, and since there is no way to wring out or press the solids, much liquid remains behind. After the first extraction stage, the solids retain 1.6 times their weight of miscella and after the last stage they hold 1.3 times their weight. If separation were by centrifuge, the solids would retain only about 0.6 to 0.7 times their weight of miscella. It is pertinent to note also that the solids in press cake appear to drain more readily than is the case when raw fish is extracted.

The rise in lipid concentration of the FPC between batches E-16 and E-22, tabulated in table 4, is believed to be caused by less effective filtration from stage to stage. The filter cloth, which had not been changed since batch E-1, was becoming clogged, and insufficient time was allowed in processing these batches for all the miscella to drain from the extractor. With batch IP-1 (table 5) particular care was taken to complete each filtration, and before IP-2 and IP-3 the filters were replaced and the extraction became more thorough.

TABLE 7. QUALITY ANALYSIS OF SONAFAP FPC[a]

Sample number:	*E-6*	*E-7*	*E-10*	*IP-1*	*IP-2*	*IP-3*	*IP-6*	*IP-7*	*IP-8*
Moisture (%)	3.6	4.1	3.9	4.5	5.0	5.4	3.2	4.0	3.9
Crude protein (%)	79.1	80.1	82.7	81.4	82.3	81.9	83.1	81.2	81.4
Crude fat (%)									
(Weibull)	0.1	0.15	0.2	0.12	0.06	0.08	0.10	0.04	0.04
Ash (%)	19.0	18.3	17.2	16.9	15.9	15.9	17.0	16.5	15.7
PER actual	2.39	2.54	2.53					2.76	
(sample casein)	2.36	2.36	2.36					2.50	
PER, casein at 3.0	3.04	3.23	3.21					3.31	
Steam to jacket of extractor cut off at:	100° C	100° C	105° C						
IPA residue (ppm)[b]				3,000					
F (ppm)				110	111		94	92	
Cl (%)				0.20	0.20		0.12	0.12	
Available lysine (g/100 g)			6.3					6.9	
Methiorine (g/100 g)			2.7					2.7	

a Analyses by TNO, Zeist, Netherlands.
b Analysis by BCF, United States.

Large batches caused the pool of miscella remaining behind in the bottom of the extractor after each filtration to be proportionately smaller, which in turn caused the final lipid concentrations to decrease after batch IP-5. The amount of press cake extracted increased from 1,000 to 2,000 kg at this point.

The decrease in lipid content of the FPC, beginning with batch IP-1, was also due in part to a greater effectiveness of isopropyl alcohol (IPA) as a solvent. IP-1 was extracted entirely with 100 per cent alcohol, and smaller amounts of alcohol, more concentrated than the azeotrope, were used in succeeding batches up to about IP-8.

Higher concentrations of total non-volatile solutes (nearly all oil) in the first miscella of the extractions with IPA prove that it is a more powerful solvent, and after batch IP-3 the first miscella always contained more water than the azeotrope. (See table 8.) Unfortunately the effect of the IPA is partly obscured by the improved filtering procedure that was initiated at the same time.

TABLE 8. CONCENTRATIONS OF TOTAL NON-VOLATILE SOLUTES IN MISCELLA FROM VARIOUS EXTRACTION STAGES AND LIPID CONTENT OF FPC

(Per cent)

Batch No.[a]	Extraction stage				Lipid content of FPC
	1	2	3	4	
E-9	1.26	0.66	0.44	0.20	0.28
E-13	1.77	0.90	0.60	0.30	0.28
E-17	2.61	1.38	0.54	0.29	0.36
E-19	1.83	1.14			0.39
E-21	1.95	1.26	0.75		0.36
IP-1	2.28	0.77	0.24	0.08	0.16[b]
IP-3	2.34	0.72	0.31	0.19	0.29
IP-4	2.20	0.88	0.44	0.15	0.18
IP-5	2.33	0.79	0.35	0.16	0.18
IP-6	2.75	0.93	0.82	0.14	0.12
IP-7	2.34	0.86	0.33	0.09	0.16

a E = batches extracted with ethyl alcohol.
IP = batches extracted with IPA.
b Extracted 36 hours in BBS apparatus, compared to 8 hours for others.

No improvement in the extraction was noticed when the solids were washed for 30 minutes during each stage instead of 15 minutes. Thus, the distribution of lipids between solids and solvent apparently reaches equilibrium in less than 15 minutes.

As noted earlier, the extractor also serves as a batch dryer with heat supplied through a steam jacket and tubes filled with steam. There are 12 tubes, 100 mm in diameter, running the length of the extractor. Rotation of the extractor brings the solids into contact with the heated surfaces.

Drying was carried out under atmospheric pressure at temperatures up to 90° C during which period most of the solvent evaporated. Heating continued under 500 mm of vacuum to 105° C, or to 110° or to 115° C in a few cases. After reaching 95° C the drier was sparged with steam for at least 30 minutes. Drying ordinarily took two to four hours, depending on the size of the batch.

At this writing only a few analyses of the residue of isopropyl alcohol remaining in the samples are available: 3,000 ppm for IP-1 and 2,000 ppm for IP-10. These residues are too high, so that longer sparging with better contact between steam and FPC is indicated. Higher temperature, up to perhaps 130° C, would probably be beneficial also.

With regard to yield, 1,000 kg of press cake gave on the average 446 kg of FPC, while about 2.8 tons of fish were required to make one ton of press cake. This gives an over-all yield of 16 per cent FPC from the raw fish.

Typical analyses of raw fish are: lipids 14 per cent; volatiles (moisture) 66 per cent; solids (by difference) 20 per cent. The yield of "solids" as FPC is thus about 80 per cent.

Proximate analyses of sardines from the Agadir region averaged fat 11 per cent, protein 15.7 per cent, other organic material 0.8 per cent and inorganic material 3.5 per cent. [2] The fat content varies with the season, and moisture-plus-fat percentages together are usually constant.

The final or most concentrated miscella is first evaporated at atmospheric pressure to separate the alcohol and most of the water from the oil, solids and dissolved material. Water and alcohol are then separated by rectification, with the overhead stream of clean alcohol having a concentration close to the azeotrope.

The evaporator is simply a 5,000-litre vertical cylinder with a coil of 50-mm tubing at the bottom for steam. After each two batches of FPC were processed, the bottom liquor (oil and water) was stripped with steam and drained into barrels.

The rectifying column is designed for ethyl alcohol and has 24 bubble cap trays in the rectifying section and 15 in the stripping section. Heat is supplied by direct injection of steam into the bottom. The column is 1,100 mm in diameter and 8.7 m high.

The separation of IPA from water by rectification is easier than the separation of ethyl alcohol. To illustrate this point, the vaporization equilibrium constants, y/x (y is concentration of alcohol in vapour phase in equilibrium with x, its concentration in the liquid phase) are plotted in figure 3 for both alcohols at low concentrations and at concentrations close to the azeotrope. It is apparent that IPA is considerably more volatile than ethyl alcohol in each case and thus fewer theoretical stages are needed to make a given separation. While no attempt was made to analyse the performance of SONAFAP's rectifying column in any detail, a convenient operating rate for ethyl alcohol was 1,000 litres per hour of overhead distillate containing 92 to 93 per cent ethyl alcohol (azeotrope 95.6 per cent) and bottoms with 0.11 to 0.12 per cent ethyl alcohol. With IPA the rectifying column worked

well with 1,000 to 1,100 litres per hour of overhead distillate at 86 to 87 per cent IPA (azeotrope 87.7 per cent) and bottoms with about 0.05 per cent IPA.

As an extraction proceeded, the pH of the miscella rose from stage to stage from about 6.5 to 8.0, and the solvent condensed from drying and steam stripping had a still higher pH, of 8.0 to 8.5. Also the pH of the dilute alcohol distilled from the evaporator was higher than the pH of feed: 7.5 to 8.0 vs. 6.5 to 7.0.

Others have observed that "fishy" odours often develop in FPC made

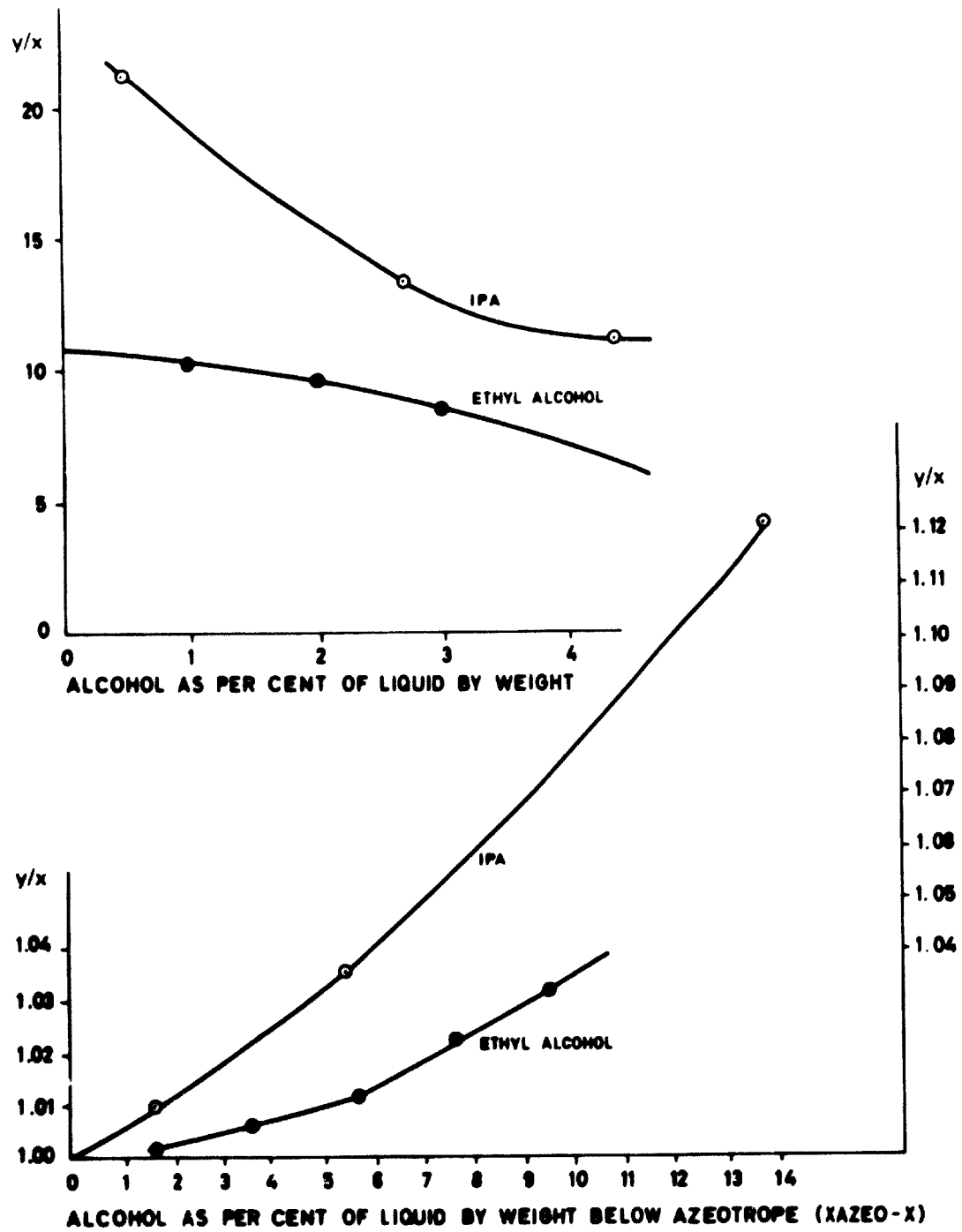


Figure 3. Relative volatility of alcohol and water

with re-used solvent. [1] These odours are mainly volatile amines and they account for much of the increase in pH observed here.

Phosphoric acid was added to the dilute alcohol from the evaporator before it was rectified, and an attempt was made to keep its pH at 6.0 to 6.5 as it was fed to the column. As much as 10 milliequivalents of phosphoric acid (assuming two equivalents per mole) per litre of dilute alcohol were needed to keep the pH at this low level. The phosphoric acid converts volatile amines to their non-volatile phosphate salts and thus causes them to leave the system along with the bottom liquor from the column. There was no measurable loss of solvent, and it did not appear to deteriorate in quality with repeated re-use.

No significant problems were encountered in the recovery of solvent, although there was considerable foam in the evaporator in the previous campaigns in 1965 and 1966. Except for a minor amount of foaming, no trouble from this source was encountered in the later phases. Perhaps the more viscous oil extracted from the dried meal caused the foam in the previous operations.

The foaming occurred when the evaporator was fed with solutions containing very low concentrations of alcohol after the tanks were washed with water. It was readily controlled by adding a little lubricating oil, which contains an anti-foam compound (Esso Estor HD 40).

An effort was made to treat the product with antioxidants to avoid development of off-flavours by oxidation of the small content of residual lipids in the FPC. Ascorbic acid or BHT (an antioxidant for oils and fats) at the level of 0.05 per cent was added to the clean solvent entering the last extraction stage. In this way the solids tended to "extract" the antioxidant from the solvent as it progressed through the counter-current extraction. Since to get effective contact with lipids contained in solids is very difficult through the use of antioxidants, this method should be very effective, for it enables the agent to permeate the solids. However, too little time has elapsed to judge the results.

The use of BHT in this manner to prevent development of rancid tastes in fish flours containing 1 per cent or so of lipids should be explored, since such a concentrate can be produced by solvent extraction more cheaply than can the low-fat FPC.

Proper sanitation in the first part of the process—the cooking, pressing and disintegration stage—presented a problem. For producing fish meal the equipment at the SONAFAP plant is excellent, but for the production of foodstuff, better sanitation is needed.

Ideally the cooker, press, disintegrator and associated conveyors should be made of stainless steel, and it should be possible to clean them of fish solids at the end of each day's operations. Also the equipment should be so arranged that everything drains well, and all points where fish solids might accumulate should be eliminated.

Despite the fact that the plant's sanitary conditions for the initial stages of production are not as satisfactory as they should be, the product was nearly free of harmful bacteria, thus demonstrating the efficiency of extracting with

hot alcohol to produce a safe product. In addition, it should be noted that the first part of the plant was always operated long enough to be thoroughly purged and to reach operating temperature before press cake was taken for extraction.

From samples of miscella it appeared that the solubility of the lipids in alcohol decreases greatly as the temperature falls. On cooling a sample of final ethyl alcohol miscella, which had contacted the press cake at 70° C, it began to become turbid at 65° to 60° and was almost completely turbid at 45° to 50°. This observation indicates that the solubility of some of the lipid components is low at temperatures as high as 65° C. This final miscella contained about 77 per cent ethyl alcohol; the lipids were somewhat more soluble in more concentrated alcohol.

It is important for efficiency to extract close to the solvent's boiling point and this temperature must be maintained while the solids and miscella are filtered (or separated by other means) between extraction stages.

The oil and water drained from the evaporator were slightly acid, pH 6.5. The oil, while darker than that from the press, appeared to be of usable quality. The oil recovered from the extraction of fish meal was black and viscous—almost a tar—which is further evidence of oxidation-induced polymerization in the fish-meal drier.

In the course of this work FPC was made from fish other than sardines. Batch IP-4 was composed of saurel, and E-19 was a mixture estimated to be 50 per cent anchovies, 20 per cent mackerel and 30 per cent sardines. In addition, several batches were made from sardines containing about 10 per cent anchovies. These other fish caused no processing problems, and the FPC appeared equivalent to that made from sardines. FPC made from saurel was slightly lighter in colour because of its lighter coloured flesh. Good FPC can probably be made from any edible fish.

Recommendations for design of FPC plants using solvent extraction

The experience in operating the SONAFAP plant has generated certain ideas for the design of plants to extract press cake. First, the extractor and probably also the drier should be fed continuously. The equipment can be smaller and the operation simpler and more economical than for a batch-wise system. The extraction should be counter-current, with three or possibly four stages of contact. Figure 4 indicates a conservative number of process steps and gives some of the flows for making five tons per day of FPC.

Since the fish are highly perishable, they should be processed within a few hours after their arrival at the plant. For this reason the cooker and press should have capacities several times greater than the solvent extraction line—perhaps 5 to 7 tons of raw fish per hour in this case. To use these appliances economically, a drier is supplied to make fish meal at times when press cake is not needed for extraction.

For storing press cake, a tank is provided in which it is mixed with alcohol (actually with miscella from the second extraction stage). Capacity

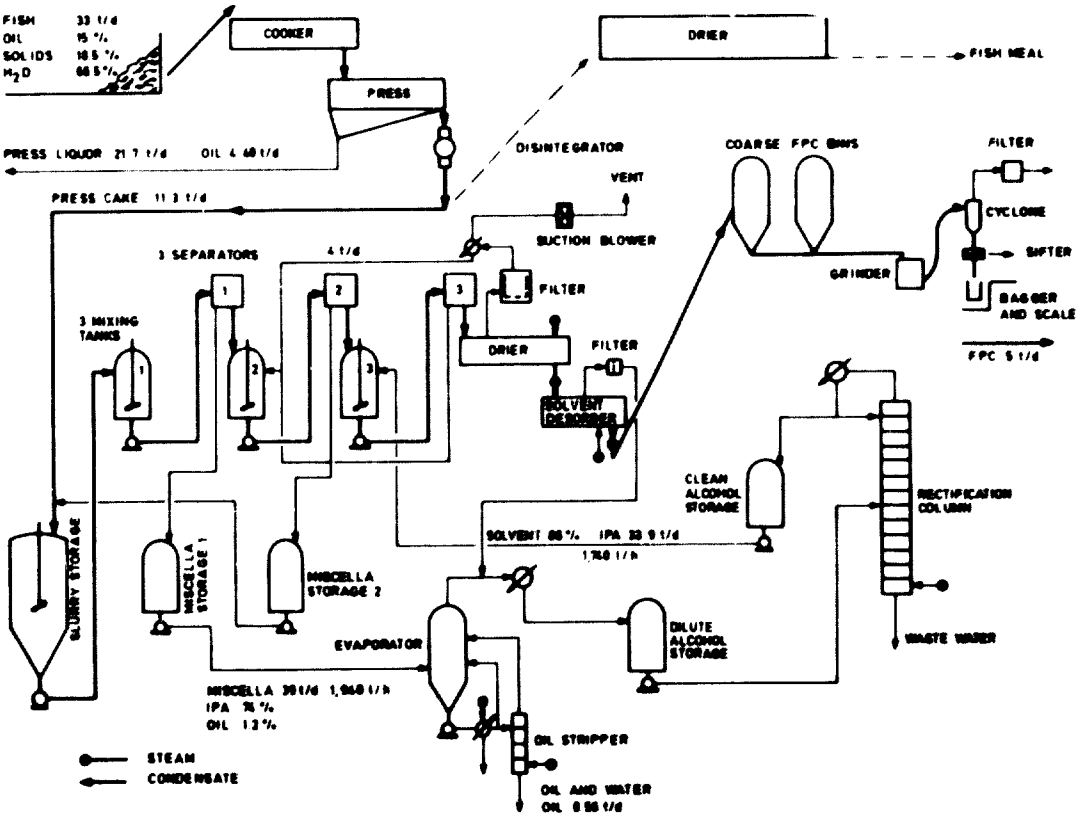


Figure 4. Process of manufacturing five tons per day of FPC from press cake

to store press cake for one to two days would allow the extractor to operate continuously.

Figure 4 points out the effectiveness of the cooker and press in removing water and oil—nearly 90 per cent of the oil can be removed ahead of the extractor.

Three extraction stages and a solvent-to-press cake ratio of 3 to 1 are presumed. If separation of miscella from solids between stages is thorough, so that the wet solids contain less than 50 per cent solvent, the solvent ratio can be somewhat less to yield FPC with 0.3 per cent lipids. Also use of a fourth extraction stage would reduce the solvent requirements to perhaps 2.5 to 1 or less.

The separation between extraction stages can be accomplished in several ways: by centrifuges, screw presses, screens, filters or possibly even by settling.

After leaving the drier and desorber the FPC must be handled very carefully to prevent contamination. Storage in several well protected bins is recommended so that grinding and packaging can be carried out in one shift. This would permit better supervision of these critical operations, even though a larger grinder would be required.

Figure 4 shows an evaporator to seperate alcohol and water from oil and fish solids in the miscella, as was used in this operation. It is likely, however, that the miscella could be fed directly to a column, in the bottom of which

alcohol could be stripped from the oil and water. Such a scheme would simplify the process and considerably lessen the requirement for steam; it should be tried experimentally.

Recommendations for efficient FPC production

In considering the possible manufacture of FPC it is necessary to study the effects of many factors on the cost of the final product. Past efforts have tended to neglect a number of important considerations. These are the following, in their approximate order of importance:

(1) Sufficient fish must be available at low cost. This obvious need has often received too little consideration. The least expensive fish are small clupeoids—sardines, anchovy, herring and the like—that gather in dense shoals and can be caught efficiently by purse seining. Because of their low cost they provide most of the raw material for fish meal.

While the high oil or lipid content of clupeoid fish may complicate processing them into FPC and cause the resulting FPC to be darker in colour than that made from white fish, the by-product, oil, can reduce the cost of the FPC significantly.

(2) The quality of the fish must be good. In warm weather clupeoid fish deteriorate badly within 12 hours after being caught. Most of them are small fish with delicate flesh and tissues and hence the destructive enzymes in their entrails are dispersed more readily than is the case for larger fish. Moreover, economy requires bulk handling which breaks up many fish and so speeds spoilage.

These factors argue strongly for a plant location where fish can be caught near shore and landed and processed within a few hours of capture. Refrigeration does permit the use of longer range fishing vessels, but the abrasion caused by cooling with refrigerated sea water is hard on these small fish. Also storage on ice or by freezing is usually too costly for economical FPC production.

Fish kept in frozen storage are subject to oxidation of their lipids or "freezer burn". This creates bad flavours which cannot be removed by extraction with alcohol.

"Close-in" fish are generally available off the coasts of developing countries, and Morocco is particularly favoured in this respect with a large resource of sardines in its coastal waters.

(3) Close proximity to a fish-meal operation is vital. For a long time to come the production of fish meal will greatly exceed that of FPC. Therefore, in order to have a sufficient fishing effort to support an FPC operation when fish are scarce and to use the excess fish when gluts occur, a fish-meal plant is needed. Furthermore, off-quality fish can go into fish meal and the ready market for meal can sustain a large enough fishing effort to be efficient.

Most fish-meal plants are equipped to use the by-products (oil and

stickwater) from an FPC plant; this capability could save capital and reduce waste for an FPC enterprise. Savings are possible by sharing utilities of an FPC plant and a larger fish-meal operation. Systems for steam, fresh water, electric power and waste disposal could readily serve the needs of both operations.

(4) A dock and efficient fish unloading facilities at the plant site are a big advantage. Trucking fish from dockside to a plant site is expensive, and it degrades the quality of the fish by exposing them to additional time, heat and handling.

(5) Finally, a location near other industrial activity is advantageous. Availability of skilled labour, fuel, supplies, electric power and transportation are important to the economic operation of a plant. While many smaller port cities are probably well situated in this regard, an FPC plant cannot be regarded as a suitable enterprise for a village, or for a region with no industrial base.

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6. OBSERVATIONS ON FISH PROCESSING*

PROCESSING AT SEA [1—5]

Simple forms of processing at sea have been employed for many years. As early as the sixteenth century Portugese fishermen were engaged in the production of salt fish at sea in long-range operations [6], and whale processing, canning and even freezing at sea have quite extensive histories. The enormous growth of processing and preservation at sea, however, can be considered primarily a development of the post Second World War years. It results from an increasing shortage of fish species traditionally consumed by sophisticated catcher-consumer countries, and available to trawlers using icing, together with the drive towards increased fish production by countries not traditionally associated with "distant-water" fishing.

The depletion of stocks has been a major factor in the development of processing at sea;[7] but there are other economic considerations. For instance, some fisheries are seasonal, or so short-lived that shore-based operation becomes unprofitable. In such situations, however, it is necessary to examine the fishing industry against the background of the local food industry as a whole. Other crops may have complementary seasonal demands: the canning or freezing of fruits and vegetables, using common facilities with fisheries can tilt the economic balance away from processing at sea to a shore-based operation.

Another factor that has contributed to the development of processing at sea is the unavailability of shore bases, as in some parts of the North Pacific and the Atlantic Oceans, where problems of communication and climate are considerable. The extent of processing required depends on the nature of the over-all operation, but in general processing costs ashore are considerably lower. Almost any fishing operation on the high seas involves a degree of processing such as gutting prior to chilling.

An encouragement to processing at sea has been that in a factory at sea the catcher is free of, or less susceptible to, local conditions ashore, such as labour problems. The catcher realizes perhaps more readily that his side of the operation must co-ordinate with the processor's and the processor is less susceptible to what might be considered the unreasonable attitudes of local

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* Paper presented to the meeting by Noel R. Jones, Head of the Food Science and Technology Department, Tropical Products Institute, London, United Kingdom.

catchers. Finally, mobility—the possibility of moving on to other grounds—is an important asset for a catcher. However, the operation of a highly mobile factory or freezing fleet can present problems of control by or conflicts with local fishing interests.

Various processing operations can be carried out at sea. The nature of the species of course determines the approach. Some species are adapted to different methods of processing; for instance, clupeoids may be salted, frozen or canned at sea. Requirements for processing prior to final preservation differ, however, even for single species, and more considerably among species, as, for instance, between the freezing of white fish fillets and the canning of king crab. Consequently only methods of general interest or of increasing economic importance are considered here, such as primary processing and freezing at sea for secondary processing or direct sale ashore. [2, 8]

Preliminary processing: washing, scaling, heading and gutting [3]

In general, heading and gutting are indicated for large species of fish destined for secondary processing or consumption by populations that readily accept such products. However, some populations demand the fish intact, and gutting does not necessarily improve the keeping quality of all species in a chilled or frozen condition.

Technically acceptable washing and de-scaling equipment (the latter often of revolving mesh-drum type) have been available for many species for some years. Heading machines are also commercially acceptable for many species, as well as, more recently, gutting machines. Machines that combine these functions with adequate filleting performance when required are also available for some species.

Fish-processing equipment of this general type vary in efficiency as compared with manual operation, according to the condition of the fish. Price premiums deriving from the superior quality achieved with manual operation must sometimes be weighed against the lower costs in crewing when machines are used. And both factors must be weighed against space demands for processing as compared with those for storage, which can determine the length of voyage in the absence of trans-shipment facilities.

Buffer storage prior to secondary processing aboard [2, 3, 9—11]

Questions of short-term, or occasionally longer-term buffer storage are among the primary calculations of the designers of factory vessels. Initially, the problem was considered to be essentially one of spacing out supplying material to the processor while limiting spoilage. But it has been realized increasingly that the production, for instance, of frozen fillets of the highest quality requires specific periods under specified conditions of chilling to control bleeding and *rigor mortis*. [2, 12] No one method of chilling is preferable to others. It is becoming increasingly apparent, however, that refrigerated sea water offers many economic advantages for short-term chilling without incurring significant loss in quality that occurs with the

migration of salts. For longer-term storage (one day approximately) the traditional fresh water ice has advantages for quality; but the use of refrigerated sea water is more typical of integrated processing operations at sea.

Perhaps buffer storage of this type applies most to processes involving freezing at sea, [2] although it is relevant to other processes. For instance, in drying at sea, the control of *rigor* contractions is necessary, since these alter the size of the tissues and hence can affect adversely the economics of drying. It appears that more than usual attention should be given to such considerations in canning operations, especially under tropical conditions where a number of projects have run into difficulty with break-up problems.

Filleting [2, 12]

Filleting is a basic operation in a number of methods of fish processing. Machines with a high degree of efficiency in seagoing operation are in common use, some of them combining capabilities for gutting, skinning and the like.

While the economic savings in crewing for such operations can be considerable, some machines have encountered difficulties in filleting fish in *rigor*, and the handling of *pre-rigor* filleted fish as wet fillet has presented problems. For instance, fillets subjected to high temperatures, or roughly handled, frequently lose weight in "drip" due to contraction, and this can result, of course, in considerable economic loss. Furthermore, badly contracted fillets are poorly received by some (although not all) consumer populations.

Consequently, the control of *rigor* in *pre-rigor* filleted fish at sea can be crucial to the economics of operation. Buffer storage of the type indicated above is generally unsuitable for whole fish. Short-term chilling in water may be an acceptable treatment for some fillets, although it might present certain microbiological hazards which may be of concern to public health authorities (and certain other technical difficulties in all but the shortest immersions). Chilled air appears to be preferred for handling *pre-rigor* fillets.

Freezing

The freezing of fish at sea was the subject of detailed discussion at an FAO Technical Conference in 1967. [13] It was also considered in the broad context of the problems of food refrigeration in developing countries at a UNIDO expert group meeting in Vienna in 1969. [14] A detailed account is hence unnecessary here. However, the rapid developments in this area within the last decade have been among the more significant in the fishing industry. Not only have they established the basis of new patterns of distribution and of tertiary processing ashore; they promise to provide greatly extended buffer storage for factory operation afloat (although it is doubtful that the latter will replace to any major extent the production of frozen fish at sea for direct distribution or further processing ashore).

In an evaluation of modern techniques for freezing whole fish at sea, Ranken [3] points out that while the original premise was to reduce to a mini-

mum the changes required in conventional trawlers compared with traditional icing methods, ". . . latterly it has been concentrated on limiting the capital, running costs and crew problems, associated with freezer vessels, by leaving as much as possible of the processing operations involved to be done ashore, where they can be conducted much more economically, on a large scale, with cheaper and more suitable labour, including women, and under better discipline and control". In practice, the situation varies considerably from one country or company to another and equally urgent arguments in terms of lower storage/shipping costs can be made for complete fillet-freezing operations at sea in some circumstances, [15] especially for far distant water fisheries where local shore-based processing facilities are not available.

Optimal methods of freezing at sea are determined in large part by the desired nature of the product.

Brine freezing [4] has advantages in economy when the product can withstand the treatment, as with tuna destined for canning. However, salt is of limited acceptability in many frozen products: contamination can give rise (particularly under poor conditions of frozen storage) to undesirable "salt-fish" flavours; and oxidative rancidity generally is accelerated.

Fish is commonly frozen at sea in plate- or blast-freezers. [4] In some freezer trawlers—particularly Japanese vessels—a "semi-air blast" system, embracing elements of both methods, is employed.

Blast freezers are more versatile but in some respects less economical than plate freezers in seaborne operations, particularly in terms of space requirements in relation to through-put. Ranken [3] discusses the basic approaches to freezing at sea in relation to the type of vessel and to the structure of the fishery as a whole. The vertical plate freezer has proved effective in whole-fish freezing, lending itself readily to an integrated vertical organization of the vessel's processing operation. Horizontal plate freezers have advantages in "pack" freezing, for instance, of fillets. In some situations they have definite advantages (together with semi-air blast systems) over "vertical" systems. A number of European vessels combine capability for fillet and whole-fish freezing, for instance; and certain Japanese vessels extend this versatility to the freezing of muscle minces destined for secondary processing for fish sausage or "kamaboko" production ashore (see below).

The basic requirements for storage subsequent to freezing are now well understood in terms of time-temperature tolerances and the desirability of temperatures in the order of — 30° C or below for anything in the nature of longer-term storage. Temperatures of this order are commonly employed in current freezer-trawler design.

At present there is considerable interest in the potential use of liquid nitrogen as a refrigerant for freezing fish both at sea and ashore. [16, 17] It has been suggested that for freezing fish at sea such operations may be particularly applicable, for instance, to the preparation of individual quick-frozen fillets for the export market; and it has been pointed out that, by comparison with alternative freezing systems, the initial capital costs of equipment for freezing are low. Further developments are awaited with

interest, especially information on "cross-over" points between running and capital costs in practical application at sea.

Thawing [18—20]

In recent years attention has been devoted increasingly to the problems of the economics of thawing in relation to considerations of quality control and of speed and flexibility. Such calculations have been based predominantly on the experience of shore-based thawing operations for reprocessing and the transport and sale of "wet" fillet to the consumer. Somewhat similar considerations apply, however, to proposed uses of frozen buffer storage, longer in term than the chill storage referred to above, for "evening out" catches for canning on factory vessels. It would appear at present that refinements of buffer storage of this nature, as compared with chill storage, are likely to be economic only for fishery products of the highest value, such as canned shellfish.

Merritt has compared the economic performances of blast—water, dielectric and electrical resistance —thawers of comparable through-puts. For many purposes, it would appear that a single blast-type thawer of the Torry kiln design has advantages, especially under conditions of high ambient air temperature; the continuous dielectric systems may well have critical advantages in space-saving in shipboard operation.

Potentially, the use of such equipment on *pre-rigor* frozen fish can give rise to difficulties of thaw *rigor* with attendant economic loss as "drip". The technology of avoiding such losses is now well understood, however; [2] and the use of such buffers in shipboard factory operations should not be troublesome if directed by competent quality-control staff.

Canning [1]

Floating canneries are presently being used primarily by the Japanese, Russian and United States operating vessels, mainly in the Northern Pacific Ocean for high-value salmon and crustacean fisheries. In certain situations the canning of cheaper species such as brisling may also be economic. As is the case with modern freezer-trawlers, such vessels carry a variety of specialized equipment and machinery. Most canning operations at sea are carried out on large-size mother ships.

Whereas provision for quality adjustment by the economic use of additives is still in its infancy in the freezer-trawler industry, considerable possibilities exist for the improvement of consumer acceptability at the packing stage in canning. Flavour, texture and appearance can all be manipulated.

Present canning operations are capable of a high degree of automation to cut costs of crewing. Apart from the high costs of crewing and the space requirements for crew and equipment, a major factor in canning is the availability of fresh water. In the past barges were employed to carry water to some off-shore United States canneries; modern factory ships on the high seas employ large-scale distillation equipment.

Salting and drying [2, 6, 21]

Salting was the first of the preservation processes to put to sea and it continues to play an important role in some fisheries.

In the traditional Portuguese dory fishing on the Grand Banks, the fish is taken during the day with bait by men fishing singly in small boats from mother schooners. The fish are split, washed and salted down in barrels on the mother vessel in the evening. While some fishermen from other countries are also involved in this highly hazardous type of operation, there has been a pronounced trend away from it towards salter-trawlers, insofar as salting continues in competition with the rapid development of the freezer-trawler industry and its offshoots.

Salting clupeoid species (rather than "white" fish) at sea is done both by processor-catchers directly and by mother ships escorted by catchers.

Traditional salt fish cures continue to be well received by many populations, although consumption has declined rapidly in others with the competition of newer fish products and other cheap foods.

Other dried fish products, of the "stockfish" type, also continue in demand in some countries, but traditionally these have been prepared ashore. In recent years, efforts have been made to develop tunnel dryers, suitably programmed for production of dried fish of this type at sea. Rates of heating and drying are controlled carefully within predetermined limits. Further developments in this field are awaited with interest, especially with respect to proven economics of the operation.

Concluding observations on processing at sea

While canning and salting continue to be important processing operations at sea, freezing has rapidly caught up with them during the last decade and promises to supplant even conventional icer-trawler operations in many countries.

A high degree of automation is now available for both the preliminary primary processing and the preservation phases of shipboard operation. Equally, biochemical research, in conjunction with that of refrigeration and drying engineers, has established satisfactory operating regimes for a number of species of economic importance. This information is available primarily for cold- and temperate-water species. For many warmer water species, especially some of those of interest to developing countries in the tropics, appropriate guidelines are lacking. [2]

The operation of factory vessels (particularly factory trawlers) requires the closest co-operation between the catching and processing ends of the operation. If necessary, catching rates should be reduced to allow the demands of quality requirements in processing to be met. Detailed evaluations of quality/price relationships enter into such considerations.

Planners concerned with the development of programmes for processing and preservation at sea should consider in detail the patterns of acceptability

of fish products within proposed consumer populations, together with the availability of adequate technical expertise, in their general assessments of economic feasibility. Reference may be made in this context to recent West African experience with the developing freezing-at-sea industry.

Populations vary considerably in their acceptance of different types of fishery products. Many in developing countries require whole fish rather than filleted or gutted fish. "Fresh" flavours are not always appreciated. Among the developed countries, requirements in appearance also vary and cognizance should be taken of these variations in attempts to build up export industries, particularly with unfamiliar species.

Perhaps even more than with a land-based fish-processing industry, the closest co-operation is desirable between the industrial planning and designing staff, the technologist in the vessel and the fishery biologist. Calculations of the relative profitabilities of shore-based and shipboard operation in the longer term are dependent ultimately on reliable estimates of the potential productivity of the fishery; and the solution of day-to-day quality production problems is greatly facilitated by accurate forecasts of the nutritional and general physiological status of the resource.

Fermented fish products: autolysates and hydrolysates

The increasing emphasis on protein lack in considerations of the world's food resources has prompted a number of studies of the possibilities of improved utilization of fishery resources. Among these have been scientific and technological evaluations of traditional South-East Asian approaches to fish preservation with a view to their transplantation elsewhere largely unchanged, or to their incorporation in more sophisticated methods of modifying flavour by microbial agencies. A number of groups have been involved in this work in the United States, France, the United Kingdom and elsewhere.

Reference was made earlier to varying comsumer preferences. In many developing countries strongly flavoured products are preferred to the relatively bland or moderately sweet, meaty taste of "fresh" fish commonly appreciated in North America, most European countries and Japan. [22] In South-East Asia, techniques of fermentative preservation frequently produce fish pastes and sauces with a strong cheese taste, combined with other characteristics. These add interest and valuable nutritional supplementation to an otherwise monotonous diet based largely on rice, [23, 24] and the low cost of the preservative procedures are a major factor in fish utilization among low-income populations which may not be able to support the costs of canning, freezing or even chilling.

Similarly prepared but milder products, which are not fermented to the extent commonly practised in South-East Asia, are prevalent elsewhere. For instance, bacterially fermented herring and trout are produced commercially in Scandinavia. These retain their basic structure and are not sold as pastes or sauces.

Fermented fish pastes [24—28]

Normally, fish (often clupeoids) are cleaned and mixed with salt in the proportions 1 of salt to 3 of fish. Van Veen [24] refers to the use in the Philippines of clay vats and sealed cans for maturation. This writer has seen wooden barrels and vats employed elsewhere in South-East Asia.

Often fermentation appears to result mainly from the activities of the tissue enzymes rather than from microflora. In practice this depends on the extent of evisceration.

Precise methods of preparation vary considerably from country to country according to the nature of the raw materials and local custom. The basic procedure above refers to the *bagoong* of the Philippines, where, as in Thailand, small shrimp are also used as raw material.

The *prahoc* of the Khmer Republic is prepared from eviscerated, beheaded, scaled fish after trampling. The material is fermented with salt under pressure, in contact with banana leaves, and then partially dried and fermented in the sun for a day. After further maceration more salt is added and the mass is maintained for up to a month in sealed jars.

While such a pattern of anaerobic fermentation is common in the production of many fish pastes, it can be varied. Some Indonesian shrimp or planktonic pastes, for instance *trassi*, are fermented in thin, lightly salted layers, aerobically, under the sun.

Often such products are mixed for sale with dyes and spices. In many instances also the fish is mixed with vegetable materials either before or during fermentation, as in the preparation of *padec* in Laos (containing rice bran) and *phaak* (containing rice fermented with yeasts) in the Khmer Republic.

Plant enzymes are also employed in some types of fermentation. For instance, *mam-cu-sak* contains small fish, which are fermented anaerobically in the presence of added carbohydrate in the form of roasted rice and mixed frequently with papaya or pineapple to facilitate proteolysis. Undoubtedly the recent development of suitable fungal enzyme preparations in the Philippines for use in fish fermentation has considerable potential for use in such material.

Fermented fish sauces [23, 24, 29—33]

Fish sauces are commonly prepared in areas that produce pastes and are also found in parts of China. While their salt content limits their intake and hence their over-all contribution to the diet, they are widely used as condiments for rice dishes throughout South-East Asia.

In fish sauces the partial lysis of the pastes is extended: the products are salty liquids with a cheesy aroma and a high free amino acid content. While much of the production is consumed domestically, there is some exportation of fish sauces to the West from Hong Kong.

Probably the most widely known and examined of these fish sauces is the *nuoc-mam* of the Khmer Republic, Laos and Viet-Nam. Other sauces

such as the *nuoc-mam mioc* of Thailand are made somewhat similarly, but the *patis* of the Philippines consists of the drained liquor from *bagoong* paste prepared from shrimp. Similarly, concentrated liquors from salt fish production (for example, the *tak-tray* of the Khmer Republic) are not strictly comparable with fermented fish sauces.

The scale of fish sauce production in individual operations varies considerably. At its simplest, small fish are mashed by hand or foot, salted and packed in pots which are then sealed and buried in the earth for months or years. After maturation, the liquors are decanted or strained.

In larger-scale operations large vats are used. The proportion of salt is higher than that used in paste production (5 parts salt to 6 parts fish). In the operation described by Van Veen [24] the fish are piled above the top of the vat with a final layer of salt on top. All or a proportion of the bloody liquors that accumulate during the first three days or so is removed. It clarifies somewhat after standing open to the air. The fish pack down and are covered with the remaining liquor to a depth of 10 cm and pressed under "weighted wicker work". In the process, as observed by this author, heavily weighted sacking was used to assimilate conditions of anaerobiosis.

Fermentation then proceeds for months or years according to the species and size of fish and the salt content. In the production of *nuoc-mam* of the highest quality, the liquor is tapped directly. Usually the residue is extracted with boiling sea water. The extract is minced with the liquor and with carbohydrate containing materials (for example, caramel, molasses etc.) to cause browning and to improve keeping quality by lowering pH in secondary fermentation.

While some progress has been made in the chemistry, microbiology and biochemistry of fish fermentation and in the rationalization of basic production procedures and their adaption to the development of new fisheries products, there remain large gaps in our knowledge of the bases of control of lysis in fish tissues, especially for tropical species. Nevertheless, considerable advances may be expected in commercial exploitation within the next ten years on the basis of continuing work in the Philippines and elsewhere. The Tropical Products Institute in collaboration with others in West Africa and South-East Asia is making an examination of the bases of acceptance and quality.

Other hydrolysates [34]

The use of acid and the controlled use of autolysis in the production of fish ensilages and amino acid concentrates have been established for some time. Obviously these processes have further potential, possibly in combination with fermentation methods, for use in the yeast/meat extract filed.

Fish sausage [35—41]

While a considerable volume of work has been carried out in a number of countries on the development and test marketing of meat substitutes and

sausages from fish, large-scale commercial exploitation of these products has occurred only recently and primarily in Japan. The industry was established in Japan in 1953; its rapid development has resulted from the absorption of the smaller by the large catching companies, thus ensuring a fully integrated operation.

Kamaboko

The production of *kamaboko* provided the basis of the present sausage industry in Japan. It is described as a type of "meat loaf", but to a Westerner it resembles more closely a moulded white or translucent jelly. In essence, it is a gel of myosin extracted from fish muscle. Its manufacture was made technically possible by the work of Japanese fish-muscle biochemists, and especially of W. Shimizu. The principles of manufacture are essentially the same as those described below for sausage, except that certain additives, particularly pork fat, are omitted.

Fish sausage and hams

While certain species are preferred such as tuna for sausages and croaker for the preparation of *kamaboko*, because of colour or myosin stability, most fish species and also whale meat can be used. The raw fish is filleted (if suitable sea-frozen mince is not used). Fillets are then minced and ground under conditions of refrigeration, with the addition of about three per cent sodium chloride, together with other additives as indicated (polyphosphate, starch, chemical preservatives such as sorbic acid, monosodium glutamate, colouring, spices and so forth). Pork fat is added late in the grinding process. In the production of fish hams, pre-cured dried tuna meat is also added at this stage.

The ground mixture is then transferred to a semi-automatic or fully automatic casing stuffer and sealer. The introduction of vinylidene chloride and satisfactory rubber hydrochloride casings marked a crucial stage in the development of the industry. After sealing with aluminium wire, the sausages are conveyed automatically to a heat pasteurizer. Amano describes a heating regime of 85° C for 20 minutes for sausages 3 cm in diameter, followed by water heating at 90° C for 50 minutes. The sausages then pass to a cooling tank.

Undoubtedly, the high fish consumption in Japan has played a large part in the successful development of the fish sausage industry, together with the production of casings that can endure pasteurizing treatment and the broad-minded attitude of public health authorities concerning chemical additives.

Nonetheless, a number of microbiological problems have been encountered in the industry and it could be argued that refrigeration of the sausage for marketing is more desirable than the use of chemical preservatives that may become unacceptable as health legislation changes. However, in practice, the problem of starch stability arises in the product under these conditions.

Obviously, countries considering the establishment of a fish sausage industry must follow closely current developments in film stabilities and sealing efficiency. In Japan, the use of additives extends shelf life to upwards of three weeks, allowing the products to be transported to remote rural markets. Untreated sausage keeps only three days at room temperature, but two weeks under refrigeration.

Even within Japan, the use of some additives has been questioned as ineffective. Amano and Ukiyama, [42] for instance, examined the effect of legally permitted concentrations of nitrofuran compounds on the germination of *B. panthothenticus* spores, which produce softening spoilage, and found they did not inhibit germination. Spoilage due to other bacilli has also been observed in fish sausage.

Salting [22, 43—50]

Salting as a means of preservation takes different forms. In an earlier section it was noted that the addition of salt is an integral part of the fermentation process. In medieval Russia a similar treatment was given herring, which were packed tightly in barrels and then buried in the ground (at 0° C temperature). Dry salting may be considered as a development of simple drying. Another approach to salting is practised in South-East Asia with mackerel-type fish, which are preserved by boiling in brine. Cold brining and the salting of minces for drying are other methods.

With the exception of the hot brining process, and that employing external drying, the basic requirements for salt preservation are much the same whether granular salt or brines are used in the treatment. The aim is to introduce salt in the concentration required to suppress the development of the spoilage microflora and, at the same time, to allow maturation of flavour while preventing undesirable oxidative effects. With fatty species such as herring this entails, for instance, the tightest possible packing of barrels, when these are used. With larger non-fatty species, treatment in heaps is still commonly practised.

Salting of fatty species such as herring

Murata and Ohoishi [47] have developed the formula

$$\frac{\text{Salt content (\%)}}{\text{Water content (\%)} - 35} \times 100 = 50$$

at the acceptable condition, where concentration of salt and lowered water content combine to produce an organoleptically acceptable, unspoiled product.

Fish may be preserved by salting in such containers as vats, bins or barrels. While large containers have obvious advantages in the handling of high-volume catches, such as are common in clupeoid fisheries, their use does present a difficulty in that the high pressures can be harmful to soft-fleshed species. Nevertheless, the advantage in the ease of chilling, for instance by flake ice, may outweigh the disadvantages in their use; such large-volume

operations also facilitate the use of pumped brine systems to improve the efficiency of wet salting.

Barrels have been used increasingly as more adaptable to shipboard operations throughout the world. Voskresensky [21] distinguishes two basic methods of barrel salting: first, dense packing without opening the sealed barrel after preservation in salt; and second, less dense packing, particularly under the pressures of shipboard operation, followed by repacking, or "topping up", using the same day's catch.

Methods of treating herring and other species vary widely according to the size and physiological condition of the catch, as well as the pressures of the operation, which are considerably greater on a vessel in a high-density fishery than in a salting house ashore. Dutch fishermen partially eviscerate the fish, and pack them densely in a high-grade salt concentration of from 16 to 20 per cent, whereas the Icelandic shore-based operation employs 22 per cent salt on beheaded fish. In the Scottish operation ashore, the herring are packed fairly loosely at first and then repacked. When young fish are being salted, relatively low concentrations of salt are employed, with excellent results. The Russian high seas fleet uses whole herring, loosely packed in a mixed brining/dry salting system. The Norwegians re-salt ashore fish that have been handled at sea similarly to the Dutch method. As with other forms of processing, a flexible approach rather than the dogmatic adoption of standard methods is indicated for the preservation of new species.

Salting of white fish

Salted cod and other gadoid species are major commercial items still commanding considerable world markets, and this basic approach to the preservation of white fish could undoubtedly be applied considerably in other fisheries.

Commonly, fish in rather poor condition are salted to prevent total loss. However, the evidence indicates that for the production of good salt fish it is essential to use raw material of good quality.

As with fatty species, methods of salting vary. In "kench" salting, the fish are split and stacked in layers between layers of salt which is in contact with flesh rather than skin. The liquor or "pickle" is allowed to drain away and the fish is then dried after the removal of the adhering salt layer. In "pickle" salting, a similar process is used, but the fish is placed in barrels or tanks and remains in a strong brine while the water is removed from the flesh by osmosis.

Often, salting is followed by drying; and the degree of salting will depend in part on the subsequent conditions of drying. Dry salting under tropical conditions reduces the moisture content of fish by varying degrees. For instance, water content in the order of 36 to 65 per cent has been measured in Singapore markets, and in Aden the water content ranges from 33 to 69 per cent, the fish being dried in the dry atmosphere of the Gulf or the Red Sea. [45]

Where the moisture is higher, in Singapore, the fish keeps only a few weeks, whereas fish sold through Aden is commonly marketed in Ceylon and East Africa three months after processing. It will be noted that the main preservative action is the removal of water by osmosis. The direct destruction of the microflora by salt is secondary. Heavily salted material is difficult to dry in the humid tropics; it tends rather to absorb moisture.

In this regard, Van Klaveren and Legendre [43] comment on the effects of high temperature in determining the concentration of salt necessary to control bacterial attack under Canadian climatic conditions. Obviously, a balance of factors is involved to achieve optimal results. Van Klaveren and Legendre also observe that Mediterranean importers of Canadian salt fish insist on first-rate products and are prepared to pay for them. Quality in salt fish is affected by a number of factors, such as the raw material and the purity of the salt. Cole and Greenwood-Barton [45] point out that salting fish in pure sodium chloride tends to produce a "flabby pale yellow" product without the characteristic flavour of salt fish. They note that small quantities of calcium and magnesium salts are always present in commercial salt, and that these whiten and stiffen the fish, imparting a bitter taste that is appreciated by many consumers of salt fish. This author has noted, however, that the use of some crude solar salts of commercial origin can produce fish with a very bad colour. I have also seen commercial samples of purified brine that contained unacceptable levels of copper. The presence of traces of copper [49] and iron salts catalyses carbonyl-amino reactions, producing discolourations and off-flavours. In this respect it may well be that Cole's views represent an over-simplification of the situation; on balance it would appear that for many consumers preferring fish that approach the original state on reconstitution, the purer the salt the better.

Drying and dehydration [43, 51—53]

Much fish is dried further after salting. There follows a discussion of simpler drying procedures, particularly those relevant to salting and smoking, as well as a brief reference to certain aspects of vacuum dehydration and meal production. For convenience, the term dehydration, as distinct from drying, is restricted to its technical connotation of a process of drying by controlled artificial means. [52]

In developing mathematical formulae for the drying process, Jason [52] and others have considered the factors controlling the outward movement of water from the fish, together with those controlling the inward transfer of heat. In practice (although this may represent a theoretical over-simplification) the early stages of drying are characterized by a constant rate phase. This is followed by a period of falling rate, during which internal diffusion is the limiting factor. The lack of basic physical data on fish muscle appears to be a limiting factor in theoretical analyses of some drying processes. Briefly, the rate of outward movement of water can be considered as relating to its removal from the medium surrounding the surface, to its mixing with the

medium or atmosphere at the surface and its migration from the centre to the surface within the material. In the more conventional methods of drying, heat transference into the fish is, in turn, dependent on a number of factors such as conduction within the system, partial enthalpy of solution, and emission from source together with transmission to the surface. It must be recognized, however, that the relative importance of different factors varies widely in practice, according to species and the nature of the drying operation. For instance, the drying characteristics of frozen and unfrozen muscle are quite different; the unfrozen muscle remains a gel through much of the drying operation, behaving largely as an isotropic medium, whereas frozen muscle behaves anisotropically. Jason's review [52] is excellent for a detailed discussion of diffusion coefficients together with considerations of density and thermal conductivity as determinants of the drying rate.

Natural drying [46, 54]

Air drying under the prevailing atmospheric conditions is prevalent in many countries. Normally, the fish are gutted and split; they are then sometimes beheaded and hung on a drying rack. In Scandinavia the fish are hung in pairs over poles and drying frequently takes from two to six weeks. In the tropics fish are often set to dry in the open sun, sometimes on mats or racks, often on the sand. [45]

While high temperatures are desirable in some respects, they can lead to an unacceptable degree of spoilage and fly damage. Thus, for instance, stockfish is produced in Norway mainly in the spring before the season for flies.

In the past, the final drying of salt fish was by natural drying. However, salt cod is now mainly dried artificially. In the former process, the moisture content was reduced progressively from 55 to 60 per cent after salting to 20 to 45 per cent.

There is still a very considerable market for such stockfish and salt fish in the Mediterranean areas and many tropical countries. In the tropics, infestation by insects can present a very considerable problem, particularly with locally produced dried fish.

Adequate drying and handling techniques can eliminate a number of quality defects commonly encountered in dry, salted fish prepared or stored under tropical conditions. [45] For instance, "pinking" due to halophylic micro-organisms can be eliminated by reducing the moisture content rapidly and by the use of a deep "pickle" technique at the salting stage.

At the same time, it should be noted that the acceptability of dried and dry, salted fish follows quite different patterns in different countries. [8] As indicated in the section on fermented products, the populations of many developing countries prefer strongly flavoured fish. What a European or North American population would consider to be of excellent quality may well be rejected for fish with the flavours of rancidity, "pink" or bacterial decomposition. Indeed, partial fermentation is an integral stage in some West African drying operations.

In practice in such situations, natural drying is often complemented by the use of open fires, together with simple kilns made of oil drums. Such approaches to drying are quite common in the humid tropics. Recently there have been indications, however, that such processing may possibly contribute to the high incidence of primary carcinoma of the liver in some countries, as a result of contamination of the fish by polycyclic hydrocarbons and the formation of nitrosamines. [8]

Tunnel drying

The essential factor in satisfactory tunnel drying is the control of temperature, humidity and air velocity. Control of temperature is necessary in that the rate of drying must be measured against the ill effects of over-high temperatures, particularly in the early stages, in terms of "break-up" and irreversible damage to proteins, affecting reconstitution. Humidity affects both the drying rate and final appearance Linton and Wood [55] found that drying rates increased with air velocity up to 200 to 300 feet per second. Above this rate power costs increased without further significant improvement in the drying rate.

As indicated earlier in this article, development work has been carried out on programmed tunnels for the production of material of "stockfish" type at sea. However, at the present time such dryers are employed mainly ashore, often for the final stages of salt-fish production.

In general lightly salted fish present considerably greater difficulties for dehydration than heavily salted material.

A number of designs have been described, usually employing trucks or racks to mount the fish laid on trays. Linton and Wood's design provides for recirculating part of the drying air, which can be heated indirectly by steam where this is available. Under conditions of high external relative humidity, drying will not be possible unless some form of dehumidifying system is used. Lithium chloride has been employed in Canada, but it is expensive. More usually, a system is used of pre-cooling below the dew-point before drawing air into the heater, or of utilizing activated alumina or silica gel. An early European system employed sulphuric acid as a desiccant. [56]

Conversely, there may be need to humidify incoming air in some situations since the appearance of the product suffers if the humidity of the drying air is too low.

Proper conditions of temperature and humidity vary continuously through the drying process, according to the species of fish and the preferred product. Obviously, as in other forms of fish processing and preservation, considerations of quality must be balanced economically against possible variations in the drying regime.

Most development work has been carried out on temperate-water or cold-water species. Drying temperatures are often in the order of 25° C, although they vary according to the required conditions of drying, as indicated above. Many tropical species can withstand considerably higher temperatures of operation.

Certain ancillary practices are employed in the drying of salt fish. In the production of salt cod, for instance, an undesirably rough surface results from drying freshly salted material. Consequently, after salting, the fish is washed and placed in piles. The weight flattens and smooths the product, pressing out brine and increasing the surface area presented to the air; and drying time is reduced. This process is known in Canada as "water horsing". A somewhat similar procedure can be introduced later into the drying operation. Rates of water evaporation fall when the surface of the fish has dried. Removal of the remaining water can take considerable time, especially with large fish. Consequently, fish is removed from the dryer periodically and placed in piles (but unwashed). Water then is equally distributed throughout the fish from the inner layers to the surface. This process is known as "press piling" and it considerably reduces time in the drier.

Thus it is apparent that a wide range of operating conditions exist, and at least in theory continuously variable automatic control should have considerable advantages over manual manipulation of the dryer and fish. In practice, however, the commercial salt-fish dryers have commonly adopted a compromise regime with fixed-temperature and fixed-humidity, without the control of air conditioning since costs can be prohibitive. However, fully automatic systems have been developed for commercial use. For instance, Legendre [51] has elaborated a process for the artificial drying of salt fish by thermo-couple control and Jason, at the Torry Research Station, Aberdeen, has helped to develop a programmed tunnel dryer in collaboration with a major British shipbuilding company. Undoubtedly, under conditions of strict control, such as the Canadian thermo-couple system employs, it is possible to dry fish well at higher external dew points than would normally be possible using a commercial manual operation.

Drying of minces with warm air [57]

During the Second World War a considerable amount of research and development was devoted to drying fish minces for human consumption. In some respects the problems raised were similar to those that arise in commercial fish-meal production, and they are pertinent to some processes used for the production of very high quality meal. However, as in other approaches to dehydration, which is discussed here, problems concerning reconstitution are more important than in the production of fish meal.

Although elasmobranch species develop ammoniacal flavours during storage in both a wet and dried state, almost any type of material can be used, provided that it is fresh and has not been subjected to lipid oxidation before processing. In the basic process, as discussed by Cutting *et al.*, [57] the fish is washed, headed, gutted and filleted; only the fillet is used.

The fillet is then either cooked directly in live steam at a pressure of 2 lb per in^2 for about 30 minutes or it is minced and the mince cooked similarly. Something in the order of 20 to 40 per cent of water escapes, together with some nutrient, as in the case of the "glue water" or "solubles" in meal production.

Cooked fish is cooled and minced (~ ½-inch holes) for loading on to drying trays at a density of 2 lb per ft² to form a rough granular bed. Pressing at this stage is avoided since this results in a product that cannot be well reconstituted. For this reason, also, the drying of flakes is contra-indicated.

Drying is carried out at between 85° and 65° C with relative humidity controlled initially (wet bulb temperature above 50° C) to avoid bacterial spoilage. Quite low air velocities, in the order of 10 to 15 ft per second, can be employed. The dried material is packed in cans under nitrogen. Shelf life varies from several years at 10° C to a few months at 37° C.

Such approaches are not dissimilar to the less mechanized systems for producing fish meal. [34] The differences lie primarily in the extent of initial processing, and the care taken to avoid spoilage and such high temperatures in the drying process as to make for poor reconstitution.

By comparison, commercial meal operations often use offal as raw material. Whitefish can be flame dried directly without precooking, and if inlet temperatures are high, difficulties with glue water are avoided. More commonly, the cooked minced material is pressed to remove some water, and oil which is recovered, and the mass is then heated (to a temperature of about 100° C at the outlet).

The loss of solubles in the warm-air drying processes represents a considerable loss of nutrients. In many variants of meal manufacture this loss is avoided, either by their recirculation into the drying meal or by direct recovery as condensed solubles.

Roller drying and hot press-plate drying

Although a system of roller drying was patented as long ago as 1922, [58] its application appears to be limited. Cutting *et al.* [57] have reported on roller drying minces. The products reconstituted well but difficulties were encountered in obtaining uniform samples. However, the agreeable texture in the mouth, somewhat resembling that of freshly cooked fish, differs with much of the experience obtained with other products; and it may well be that the possibilities should be examined further.

In Japan, a variant of fat drying is employed in which pre-processed squid rings are dried and fried under pressure between hot plates.

Fat oil drying

Sparre [34] has reported that in the production of fish meal a system of dehydration under vacuum in hot oil is excellent for heat transference. He points out that pressing to obtain a pure oil and reasonably fat-free cake presents difficulties, and that success depends on improvements in solvent extraction. A patent [59] for a process in which foodstuffs in general are dried by heating in oil or fat under reduced pressure at 80° C does not appear to have been adopted for commercial use. Removal of the fat by drainage, centrifugation or solvent extraction was proposed. Drying times were reported to be in the order of 2 hours.

Solvent extraction, wet extraction [60]

The basic approach to drying in the wet extraction process is in some respects similar to oil dehydration, but essentially the processes differ in that in the wet extraction process the solvent is added directly to the wet product and the water/solvent mixture evaporates azeotropically.

Freeze drying and accelerated freeze drying

Essentially, the development of freeze drying as a commercial process for the preservation of foods followed upon the earlier introduction of the Danish "pressfish" process. [61] In the latter process fish were placed between heater plates in a vacuum chamber. Since the pressure of water vapour in the system always exceeded that of ice at the highest temperature at which fish will remain frozen ($\sim -1^\circ$ C), the fish did not freeze dry. However, in view of the basic potential of the process, further development work was carried out in the Aberdeen Experimental Factory of the British Ministry of Agriculture, Fisheries and Food, [53] supported by applied research at the Torry Research Station [e.g. 62—65]. Eventually products of excellent quality were obtained.

In the original operation, pressure was brought to bear on the product during drying by the hydraulic manipulation of the heater plates, with the object of increasing bulk density. In practice, this method adversely affected reconstitution properties and was abandoned. To ensure uniform initial heat transference, attention was turned to feeding uniformly thick fillets to the dryer, and appropriate cutting equipment was developed. However, it was quickly realized that the drying of steaks, rather than fillets, had advantages in that water vapour migrated more rapidly along the line of muscle fibres than across them. Frozen fish steaks can be readily sawn to uniform thickness. Drying times were in the order of eleven hours at a thickness of 1.7 cm.

Times were reduced by about 40 per cent when it was observed that the rate of vapour loss from the plate/fish interface was the limiting factor. The reduction in time was achieved by placing expanded aluminium sheets between the plate and the fish. [66] Heat flow was adequate and vapour flow was greatly increased through the mesh graps. At the same time, difficulties that had been encountered with local thawing effects, which had damaged the fish, disappeared. A number of further developments have been made in plate design to improve heat flow, but some of these are of limited commercial value since they present cleaning problems.

The successful commercial application of accelerated freeze-drying techniques has been confined largely tu such high-priced fishery products as shrimp, which is often of excellent quality when reconstituted. The application of these techniques to lower-cost products, such as dehydrated cod steaks, has been less successful.

Considerations of quality in the market of dried and dehydrated fish

While some of the "defects" of products referred to in this section are less important to (or even welcomed by) some consumer populations, as a rule the housewife prefers a dried product of good appearance, which does not have a strange odour, and which reconstitutes well on preparation and cooking.

Discolourations are caused by microbial attack (such as "pink" and "dun" salt fish), which can be controlled, together with sliming, by adequate attention to plant sanitation and the correct drying and packaging to ensure that the amount of moisture remains low. The most common discolourations in dried-fish products result from carbonyl-amino reaction. Frequently, the "carbonyl" in such reactions is contributed by the free or phosphorylated hexoses and pentoses of the muscle. In fatty species the products of lipid oxidation can contribute "carbonyl".

While sugar-amino reactions can be suppressed in their later stages by the addition of sulphite, such additives may well be considered undesirable nutritionally. At the present time it would appear that pre-processing leaching with water is the better form of control. When lipid oxidation occours with cheaper products, little can be done other than to take recourse to solvent extraction or antioxidants, where either is toxicologically and economically permissible. When such reactions take place with more sophisticated products, as in the co-oxidation of carotenoid pigment in freeze-dried shrimp, the problem can be resolved by improved packaging, or by breaking the vacuum in the process with nitrogen.

The packaging of more sophisticated products may represent to some extent a compromise between measures to avoid different types of deteriorative reaction. For instance, a very high degree of dehydration has advantages in preventing sugar-amino reaction, whereas a little water in the product has significant antioxidant properties.

For less sophisticated dehydrated products other factors are considerably more relevant to acceptability and losses. Although in some developing countries, such as parts of East Africa, the problem with insects is not serious, in others, such as in the Lake Chad area, for instance, losses due to insect attack are enormous. It ist known that adequate control of bacterical spoilage during the early stages of drying, and prior to drying, can reduce subsequent attack considerably, but undoubtedly a major contribution to the avoidance of losses of this nature in simpler dried fish products could be made by further improvements in packaging.

Quality on reconstruction is important for many dried products. It is affected in part by carbonyl-amino reactions; hence, control of copper concentration of salt used in processing is indicated. More important in many instances, however, is the control of protein "denaturation" and aggregation reactions during processing and storage, especially by adequate attention paid to temperature at critical moisture content.

While it is commonly accepted that excessively high temperatures can

damage protein during processing in terms of nutritional quality in addition to organoleptic quality, there is currently less agreement on the importance of such reactions at lower temperatures to the production and storage of dried fish. However, nutritional considerations are of considerable importance for the rational exploitation of fishery resources. While nutritive value may not be immediately relevant to marketability for human consumption, fish meal is sold increasingly on the basis of nutritional quality.

Smoking [67—74]

Discussion of fish drying must of necessity include some reference to smoking, since even very mild smoking during drying plays a key part in the process, especially at the surface. As occurs more commonly in the process, the physical removal of water associated with salting or brining, together with the deposition of smoke, each contribute in part to over-all preservation.

During the smoking process, pre-salted material is dried in the presence of a complex system of gases and particles. The degree of salting varies according to the keeping qualities desired. While "hard" cures are less marketable in western countries than formerly, they are still of interest to countries with limited means of transport and refrigeration.

Considerable research has been done on the physical and chemical properties of wood smoke, and this has been combined with some excellent developmental work in the production of improved kilns. However, in many countries the pattern of the operation has changed little over the centuries. In many situations the open fire, or the simplest of stacks, is still found.

It ist commonly recognized in western countries that the production of quality smoked fish, as demanded by their markets, requires fresh fish, handled carefully. However, in many African countries it is a normal practice to smoke spoiling fish to avoid complete loss, and the product is readily marketable. Thus a wide range of flavours are found among dry-smoked products. Methods of preparation also vary widely, but, in general, fish are split prior to salting and smoking. Salting is done either in brine or with dry salt as described above.

Smoking processes *per se* can be divided into two main groups. In the preparation of cold smoked products such as "kippers" temperatures do not exceed 30° C, whereas smoking temperatures run as high as 100° C or above in preparing hot-smoked products such as *Kieler Sprotten*. The flesh of the latter is cooked, whereas the flesh of cold-smoked products remains essentially raw. Moisture loss varies according to the product. Kippers commonly lose 15 to 20 per cent during smoking; but in the production of some hot-smoked products, a preliminary drying at a lower temperature is carried out before smoking in order to reduce moisture by 20 per cent. This prevents over-softening during the subsequent cooking in the kiln.

The fish are hung in a kiln for smoking, either stationary or on a movable trolley. The type of wood used varies according to the species

being processed. In general, however, the flavour of the products depends more on the quantity of smoke than on the wood. A number of automatic or semi-automatic systems for producing smoke have been developed.

Two types of kilns are generally used: "chimney" and "mechanical". The first of these varies widely in design, and operation is an art in that airflow, temperature and humidity are difficult to control. The fish are turned repeatedly in the kiln in order to ensure a measure of uniformity in the product.

Many industrial producers of smoked fish employ mechanical kilns which control key variables such as the amount of smoke, temperature, airflow and humidity. Most operate batchwise, although attempts have been made to develop systems using continuous feeding. Other methods employ smoke concentrates and dips, whereby the fish is first dipped in the concentrate and then dried conventionally.

The marketing of lightly cured smoked products can present difficulties in that the preservative action of smoke and salt have limited value since recontaminatioon can occur rapidly in the presence of a spoilage microflora. Obviously, ice cannot be used as a preservative; the alternative is to use refrigeration. If necessary, smoked fish can be cold stored, but for countries without an adequate refrigeration chain, the continued use of traditional hot-smoking techniques, modified as appropriate, is preferred.

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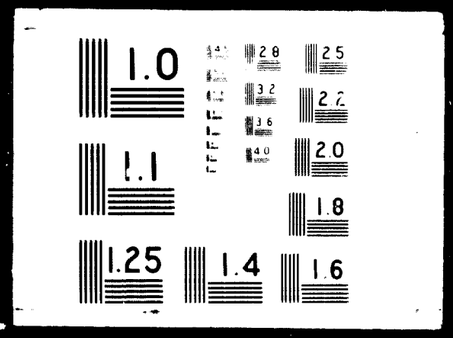

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7. DESCRIPTION OF OPERATIONAL FPC PLANTS*

Two processes for the production of FPC have been approved by the United States Food and Drug Administration, one using a single solvent and one using two solvents. The two operational FPC plants in the United States use the two-solvent VioBin process. They are the Alpine Marine Protein Industries, Inc., New Bedford, Massachusetts, which is capable of processing over 100 tons per day of whole wet fish, and the Cape Flattery Company, Neah Bay, Washington, which can process 200 short tons per day of whole wet fish.

The New Bedford plant is currently producing FPC on a US/AID (United States Agency for International Development) contract. The Cape Flattery plant has a long-term contract to produce an animal food supplement of high biological value. Both of these plants use the process that removes water from the fish by azeotropic distillation in ethylene dichloride. The one drawback to the operation of these two plants is the limited supply of fish (hake) for producing FPC.

The basic process combines solvent extraction and azeotropic distillation for separating water and oil from proteinaceous fish tissues. The solvent is ethylene dichloride (EDC). The extraction and distillation occur at a temperature of 159° F and thus do not destroy the high-quality amino acids of animal protein. Product yield is much higher than conventional methods of fish reduction because there is no loss of water-solube proteins. The biological value is higher when these factors, broadly categorized as "unidentified growth factors", are retained.

A recent comparison was made between a single-solvent process requiring five extraction stages and the VioBin process using ethylene dichloride in the first step, followed by a three-stage extraction using 91 per cent isopropyl alcohol (IPA). The VioBin process has a higher yield which, for an FPC plant of 200 tons per day input (in this instance herring), represents a difference of 3.56 tons per day of FPC. At 30¢ per lb in a 200-day operational year, the difierence amounts to $427,000 in one year. The greater loss in the single-solvent process occurs primarily because of the solubility of certain proteins in the dilute alcohol during stages one and two of that extraction.

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* Paper presented to the meeting by James S. Tolin, President, Marine Protein Inc., Panorama City, Calif., USA.

The extractor is the primary vessel in the VioBin system and it maintains the proper temperature for separating liquids from moist proteins by boiling the ground-up fish in a solvent immersible with water. At this temperature, water vapour from fish tissue boils off as a heterogenous azeotrope with the solvent vapour. (At the boiling point of the azeotrope, the sum of the vapour pressure of water and of solvent equals the total pressure—1 atmosphere.) This separates water from non-volatile fish oil so effectively that no water-oil emulsion is formed. (The removal of fish oil from a water-alcohol-fish-oil emulsion is a costly process.) The remaining liquid, called miscella, is a solvent-oil solution. The solvent is recovered from the miscella and separated from the oil by evaporation, filtering and finally by steam stripping the oil. Losses are less than one per cent of solvent based on the weight of product. The residue of oil is of significant value.

As water and oil are removed in the primary extractor, the density of the fish solids increases. The proteinaceous solids then drop to the bottom as their specific gravity increases above that of the EDC, and they are conveyed to an agitated washer where they contact fresh solvent. After this washing process, the meal, wet with EDC, is conveyed to rotary steam-jacketed vacuum dryers. These dryers remove adhering and absorbed EDC by evaporation and by several applications of purge steam. (The product from this stage contains 300—500 ppm of EDC.) The FPC is then milled and either screened and stored or conveyed to the second stage of the process, an IPA extraction unit, for further deodorizing, which enables it to meet the United States Food and Drug Administration specifications.

Solvent vapours (EDC and water vapours) coming from the extractor in the first step of the process as well as from the evaporators and dryers are condensed and conveyed to a decanter, which discharges the water and recycles the solvent for another use. Vapours vented from the vacuum pump and various process vessels are fed into a solvent recovery system for further recovery of small amounts of solvent which would otherwise be lost.

The second stage of the process, the IPA extraction, is very similar to that which is in use in the plant at Agadir. The alcohol-extracting unit installed at the New Bedford plant operates essentially by combining the FPC from the first part of the plant with a solvent of IPA and water to further extract flavour and aromatic materials. The FPC flows from chamber to chamber in a counter-current to the flow of solvent. Removal of solvent ist conducted in much the same manner as in the first stage. Two solvent removers are used for the drying operation; while one unit is on the line drying, the other accumulates the continuous flow of drained solids from the extraction unit.

As in the first stage of the process, the alcohol and some EDC are recovered through the specially designed solvent recovery system. The cost of extracting the primary meal with IPA is between 3¢ and 4¢ per lb.

The VioBin process, particularly the continuous separation of fat and water from wet tissue, is based on the following premises:

Many substances, especially of animal origin, contain high proportions of water, either in the form of intercellular fluid or in the cell tissue as intracellular fluid. The presence of a moisture content in tissue in excess of 20 per cent greatly impairs, or prevents, the use of a solvent immiscible with water for the removal of fat from the tissue.

An azeotropic mixture has the property of boiling at a lower temperature than the boiling point of either of the liquids that form the azeotrope.

The solvent and water should form an azeotrope which will remove a substantial proportion of water in relation to the amount of solvent distilled at the operating temperature. Among the solvents of this type, ethylene dichloride is preferred. EDC has a boiling point at atmospheric pressure of 83.5° C; a water ethylene-dichloride azeotrope boils at 70.5° C.

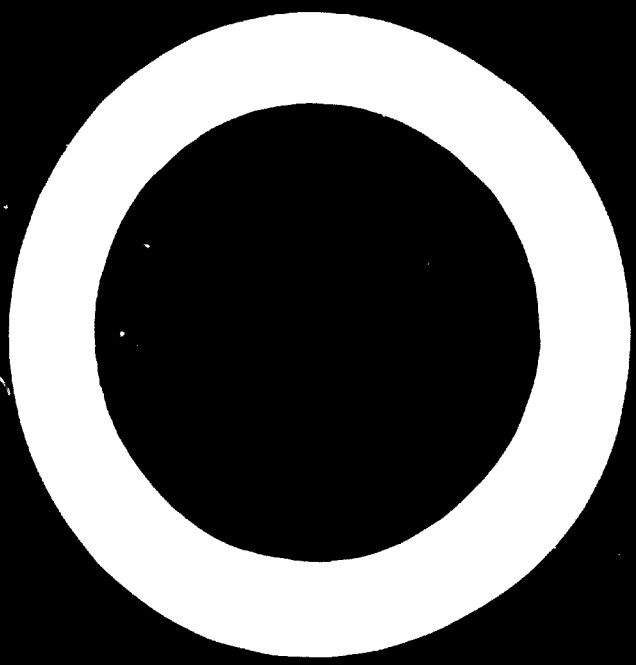
The solvent must not be reactive with the tissue constituents under operating conditions, and it must be capable of being removed by evaporation from the FPC without leaving harmful or toxic residues.

The sale of FPC in the United States and to markets subsidized by the US/AID requires a manufacturing process approved by the Food and Drug Administration. Review of the over-all FPC manufacturing experience available today indicates that the VioBin process is the one best suited for large-scale production.

The VioBin process has been in continuous development since 1958, but only since mid-1967 has the move been made from the laboratory to a plant with a processing capability large enough to make production economic. It has now been demonstrated that fish-protein concentrate may be economically produced on a large scale, by fully utilizing the whole wet fish and making optimal use of various solvents.

Considerable effort has been expended by Marine Protein, Inc. towards establishing design criteria for a shore-based plant and an incremental shipboard plant processing 200 tons per day (of raw fish). These plants are designed for a dual solvent process, but they could have been designed for a single-solvent process if that were well enough developed.

The benefits of a shipboard plant are numerous. The most significant are the increased days of production per year and the reduced cost of landing fish at sea versus the cost at a stationary shore-based plant. However, before comparing the relative merits of shipboard versus shore-based plants a feasibility study should be undertaken which would analyse thoroughly all factors such as location, fish harvesting, process utilization, labour supply and transportation in order to select the optimal conditions for the particular situation.



8. DESCRIPTION OF THE DEMONSTRATION PLANT OF THE UNITED STATES BUREAU OF COMMERCIAL FISHERIES

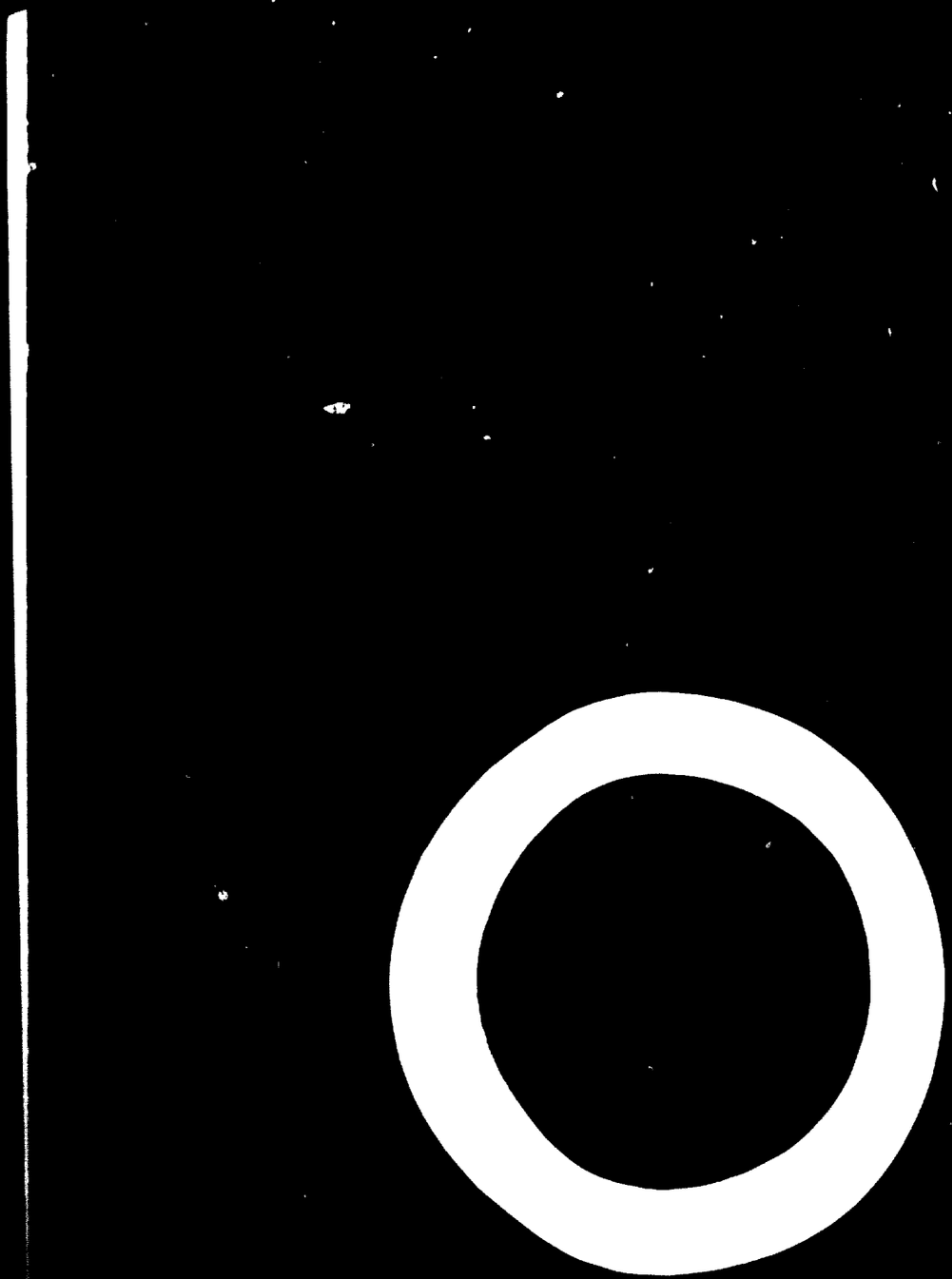
The purpose of the plant to be built in Aberdeen, Washington, is to demonstrate the feasibility of the isopropyl alcohol extraction process for making FPC on a near commercial scale and to provide cost and engineering data. The contractor, Ocean Harvesters of Los Angeles, California, represents two firms: SWECO, whose responsibility is to design and construct the plant, and Star Kist Foods, which will operate it.

The plant is planned with a capacity to handle 50 short tons per day of raw fish on a 24-hour basis, or about 2 short tons of fish per hour. The plant will be able to produce about 7.5 to 8 short tons of FPC per day.

The extraction system will consist of a continuous counter current stage type. The mean contact time per stage will be 15 minutes and between each stage the miscella and solids will be separated by a SWECO vibrating screen. Additional miscella will be squeezed from the solids by a screw press.

The solvent recovery system is a single distillation column, with azeotropic alcohol going overhead, and oil, solubles, and water leaving from the bottom. This system has been thoroughly checked and the solvent is recovered and recycled. The wet FPC is dried, freed of solvent, milled and packaged in a manner similar to that followed by the plant at Agadir. The design of the Aberdeen plant has been completed, the ground was due to be broken 8 December 1969 and the tentative start-up date was 1 August 1970.

Paper presented to the meeting by George M. Knobl, Jr., Acting Research Director, National Center for Fish Protein Concentrate, Bureau of Commercial Fisheries, Fish and Wildlife Service, United States Department of the Interior, College Park, Md., USA.



9. PRODUCTION OF LOW FAT FISH MEAL IN NORWAY*

Following a year in which there was an over-catch of fish in Norway with insufficient facilities for processing the fish, a plan was initiated by fish-meal producers to utilize such excess quantities to make fish meal. They developed the Pescamino process, relying on the expert knowledge of Mr. Eric Hayne and based on the experience of producers in Sweden.

An initial problem involved defatting herring and mackerel, since by cooking and pressing these fish it is difficult to produce a fish meal with a fat content below 7 or 8 per cent. The problem of evolving a homogeneous extraction process was solved by adopting a modification of the Lurgi plant process, combining the soya-bean and rice-bran processes. This system provides for preconditioning the meal, adding moisture again, and making meal pellets of the right consistency to be drawn or carried in a counter-current extraction with hexane. The operation uses a roto-disk, steam-dried system for processing conventional fish meal, and the product consists in part of meal made directly from fresh mackerel or herring and in part of meal stored up to three months.

The Pescamino plant started operating in May 1969. The Soxhlet analysis of the fish meal reveals 80.8 per cent protein, 8 per cent moisture, 10.5 per cent ash and 0.3 per cent fat. It contains 1.3 per cent salt and 0.19 per cent ammonia. Other factors are normal for fish meal. No elements are destroyed in the extraction process, and since the fat is largely removed the taste is acceptable even for human consumption.

In the first months of production the average cost was $18 per ton of extracted product, including the cost of bringing steam from an adjoining fish-meal plant, electric power, packaging, wages, maintenance etc. The initial investment for building and equipping the plant was $350,000.

The plant is run on a strictly business basis, producing 50 tons of fish meal a day, or roughly 1,000 to 2,000 tons a month, to be sold on contract. The product, which is marketed for 3¢ more per lb than the normal price of fish meal, has two main outlets: for pet foods and as a substitute for milk in the diet of calves. In producing for these markets, the firm works in co-operation with a Swedish company (Lactomeen), which owns a size-

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* Paper presented to the meeting by Gerdt Løvold, Manager, Pescamino Ltd. A/S, Oslo, Norway.

able laboratory for mixing and blending. The product has also been sold in considerable quantity in the United Kingdom as feedstuff for young pigs and in Denmark for feeding young salmon.

One problem in the way of further development of fish meal in Norway for human consumption involves the hygienic standards of some processes used to produce fish meal. An additional difficulty is imposed by the scarcity of raw material. One recourse has been to use floating factories. However, the experience of the Astra plant has been that while floating factories are adequate for producing fish meal, they are inadaptable to the extraction process because of the motion of the sea and other factors.

The Pescamino company employs a cargo liner equipped with the most up-to-date machinery for producing fish meal. The fresh meal is brought ashore; part is sold directly and part is used for extraction. The company plans to develop a more sophisticated product—one for human consumption—as a side operation.

10. THE HALIFAX ISOPROPANOL PROCESS FOR THE MANUFACTURE OF FPC*

Work was started in the early 1950s at the Halifax Laboratory to develop a defatted and deodorized fish protein concentrate suitable for human consumption. Two different approaches were explored: enzymatic hydrolysis and solvent extraction. Research on enzymatic hydrolysis will not be discussed here.

Studies on solvent-extracted fish protein concentrate focused on an investigation of the use of isopropanol. Earlier studies had proved the effectiveness of this solvent in the extraction of fish roe. Its characteristics make it a logical choice for use in the extraction of fat, water solubles and water from fish. It is relatively non-toxic to humans, and it does not combine with the components of fish to form toxic compounds. Isopropanol is readily available at relatively low cost, easily handled, non-corrosive to equipment, and there are few government restrictions on its commercial use.

Research involved the extraction of filleted scrap to produce a tasteless and odourless product. Dr. Guttmann describes the procedure, which is essentially the same as that characterized in Progress Report No. 17 in 1957, in the 1955—1956 annual report of the laboratory. The method was then still in the experimental laboratory stage.

The Guttmann-Vandenheuvel-Gunnarsson process was adapted for use on a pilot scale in 1958, and for the next two years it was investigated in detail. Its essential features are listed below:

(1) Wash material, discard heads;
(2) Grind to $\frac{1}{4}$ in or less;
(3) Add 2 parts (weight) water, pH 5.5 H_3PO_4;
(4) Heat to 76° C, stir 30 minutes;
(5) Filter. Hot water wash;
(6) Add isopropanol (IPA) up to 70 per cent;
(7) Wash with 86 per cent IPA;
(8) Repeat (6);
(9) Repeat (7);
(10) Dry cake;
(11) Screen to: FPC, intermediate, bone;
(12) Grind to pass through $\frac{1}{32}$-in screen.

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* Paper presented to the meeting by David R. Idler, Atlantic Regional Director of Research, Fisheries Research Board of Canada, Halifax, Nova Scotia, Canada.

The colour of batches of FPC (figure 1) varied considerably. This characteristic possibly reflected seasonal alterations in the same species (figure 2).

A major difficulty was encountered in filtering or centrifuging the gelatinous mass which formed when water and acid were added to the ground fish. This problem was envisaged by Gunnarsson, but he anticipated that centrifugation would solve it. Although some batches were satisfactory, others had a fish odour, presumably as a result of inadequate washing; and the processing of still other batches had to be discontinued when the centrifuge cake became completely impermeable to water.

Modifications of the process were indicated. Yet, despite the limitations of the process, a fair amount of high-quality FPC was produced and distributed during this period.

Extraction with water was introduced originally to remove water-soluble materials prior to the extraction of lipid with isopropanol. In a separate experiment a study was made of the protein of cod muscle as free as possible of other components, using various mixtures of isopropanol and water for the extraction of fat, water solubles and protein (figure 3). It became apparent that the isopropanol extracted the water soluble materials effectively if it contained 15 to 20 per cent, or more, water. Fat was extracted optimally when the isopropanol contained 20 to 30 per cent water. Practically

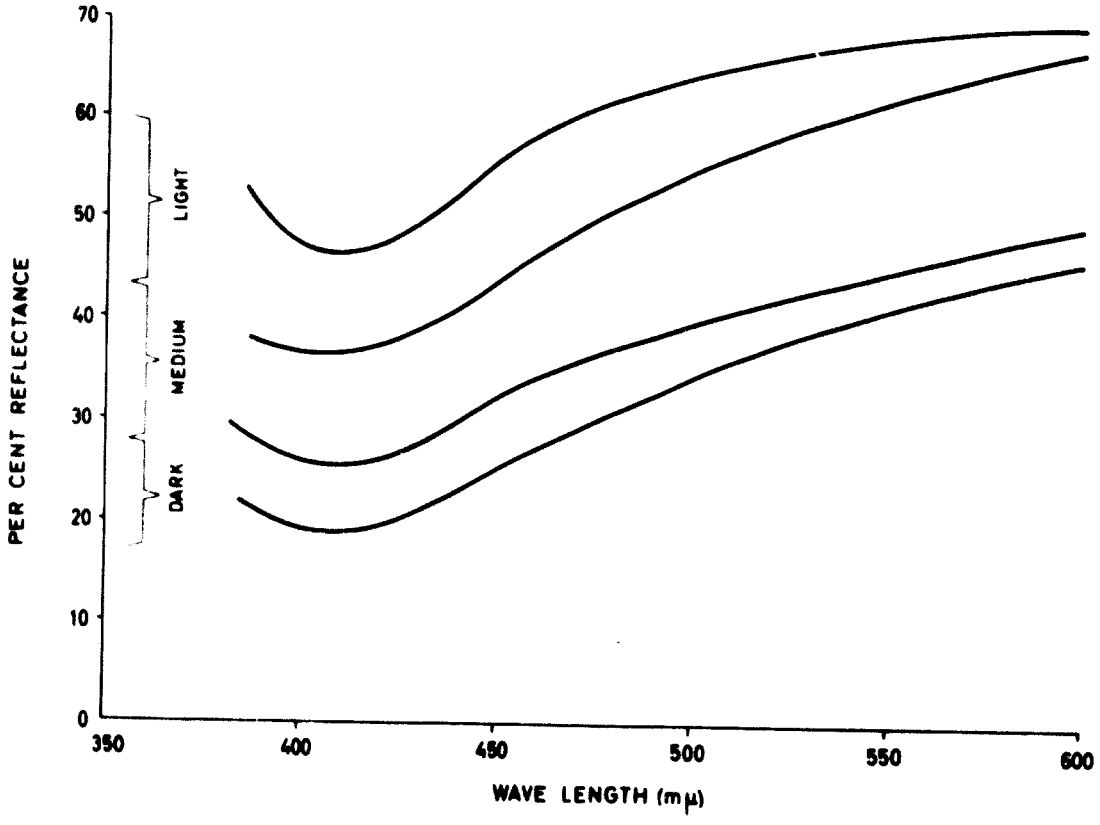


Figure 1. Typical reflectance curves indicating colour for various samples of fish-protein concentrate

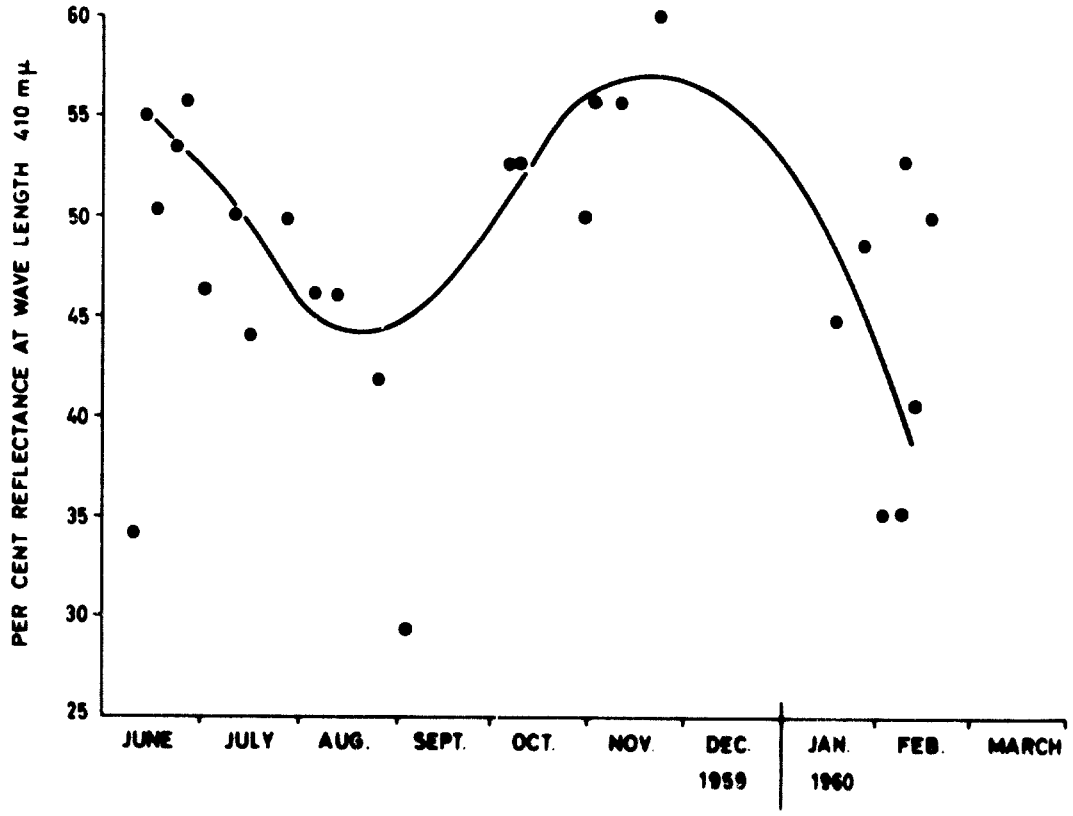


Figure 2. Variation of colour of fish-protein concentrate by month fish were caught

no protein was extracted unless the water content exceeded 20 per cent and very little was extracted with a water content of from 25 to 30 per cent.

The solution of the problems presented by water extraction was now apparent, and from this point on extraction was performed with 70 per cent isopropanol. This procedure produced a porous mass resembling a mixture of fine sawdust and water; it completely eliminated the problems connected with centrifugation and various fish odours. It also provided a means of preserving the raw material, which had been very susceptible to spoilage.

The Power-Dambergs improved method for preparing FPC from cod and related species as described in the *Journal of the Fisheries Research Board of Canada*, Vol. 19: 1039—1045, 1962, is as follows:

Step 1: Fresh, skinned cod fillets (or other material) are ground to ¼-in size in a 1.5 hp meat grinder (see figure 4). A sufficient amount of 99 per cent isopropanol is added to give a 70:30 isopropanol:water ratio in the mixture, making use of the water already contained in the muscle. This requires approximately 19 imperial gallons of 99 per cent isopropanol per 100 lb of fillet. The mixture is stirred for 15 minutes in a stainless steel tank, during which time sufficient 20 per cent phosphoric acid is added to bring the pH to 5.5. This partly hydrolyzes the connective tissue, making the collagen and gelatin more soluble. The flesh of this fillet is dehydrated and slightly denatured by the alcohol. The texture of the flesh changes from a soft paste to granular particles. This makes possible the use of a high-speed

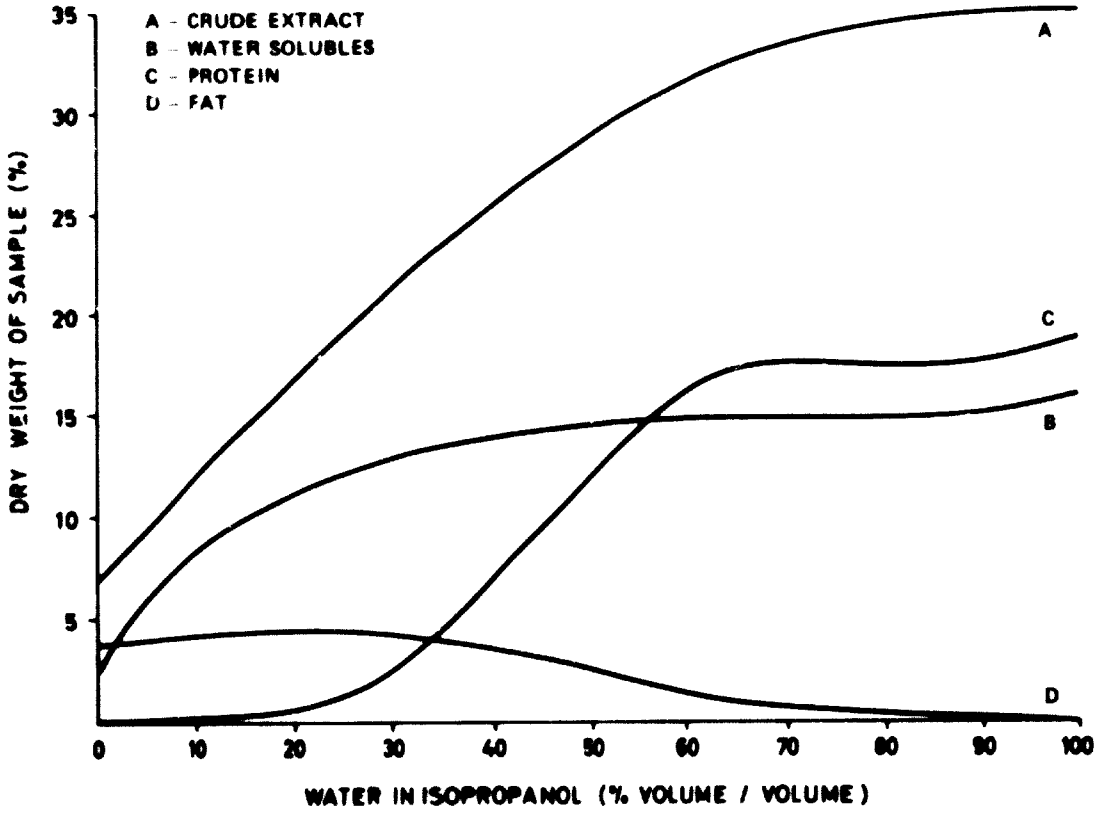


Figure 3. Effect of isopropanol concentration on extraction of water solubles, protein and fat from cod muscle

comminutor to reduce the size further. The alcohol-fillet mixture is then put through a Fitzpatrick comminutor fitted with a screen having holes of $\frac{1}{8}$-in diameter.

Step 2: The material is put into a 30-gallon reaction kettle and maintained at 178° to 180° F with constant agitation for 30 minutes. A glass reflux condenser is used to prevent loss of alcohol. The material is then pumped to the bird-basket centrifuge and the liquid is seperated off. The cake then contains 45 to 50 per cent liquid. At this point approximately 94 per cent of the fat and 72 per cent of the water solubles to be removed have been extracted. The cake is then broken up by passing it through the Fitzpatrick comminutor, this time fitted with a screen having $\frac{1}{2}$-in^2 openings.

Step 3: The shredded cake is replaced in the reaction kettle with 10 gallons of 70:30 isopropanol:distilled water mixture for each 100 lb of starting material. The temperature of the mixture is kept at 178° to 180° F and held there for 15 minutes with constant agitation. It is then pumped to the bird-basket centrifuge and the liquid removed. After this extraction approximately 97.5 per cent of the fat and 98 per cent of the water-soluble material to be removed has been extracted. The cake is again shredded in the Fitzpatrick comminutor, using the screen with $\frac{1}{2}$-in^2 holes.

Step 4: The material is then put into the reaction kettle with 99 per cent isopropanol and again heated to 178° to 180° F for 15 minutes while being

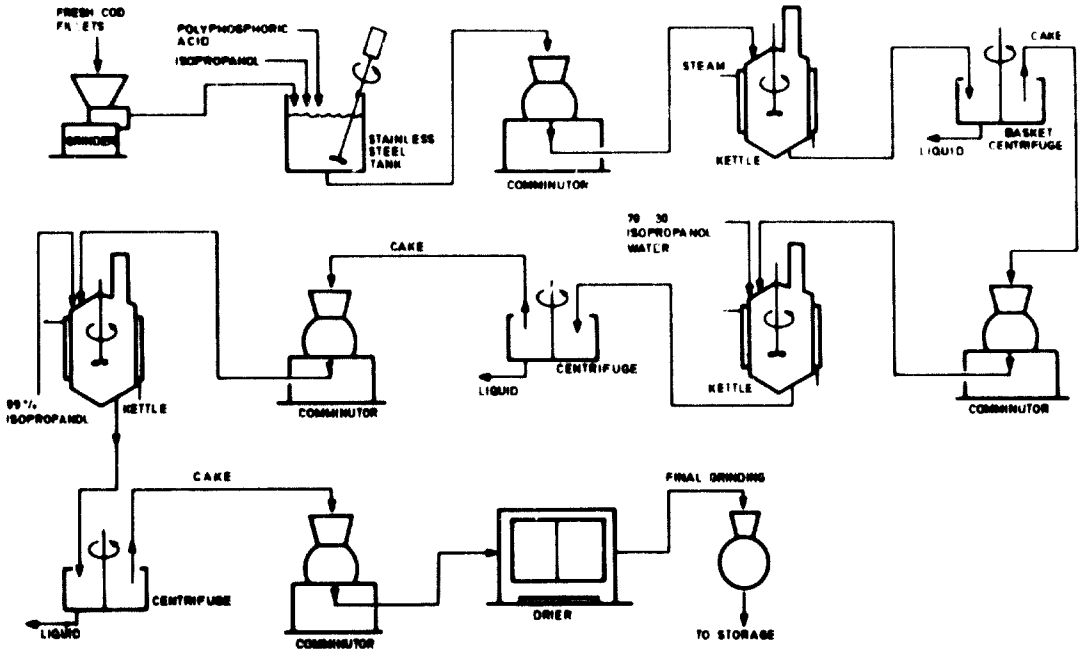


Figure 4. Flow diagram for production of fish-protein concentrate

constantly agitated. In this extraction 10 gallons (imperial) of isopropanol are used per 100 lb of starting material. The slurry is then pumped to the centrifuge and the liquid separated off. An additional 4 gallons (imperial) of 99 per cent isopropanol is then placed in the kettle and heated to 178° to 180° F and then pumped into the centrifuge in order to clean the last of the solids from the kettle, pump and lines and to wash the cake. The cake is then broken up in the Fitzpatrick comminutor.

The fat content after the extraction is less than 0.06 per cent (usually from 0.016 per cent to 0.04 per cent) on a dry basis as measured by extraction with a methanol-chloroform mixture (the Bligh and Dyer method). Extraction by ether in a Soxhlet apparatus produces FPC with a smaller fat content.

Step 5: The ground cake is then dried in trays, using a cabinet-type dryer in which air heated to 100° to 110° F is blown over the trays. Drying takes from 24 to 36 hours depending on local weather conditions. The alcohol is removed and the moisture reduced to 3 to 4 per cent. After drying, the cake is finally ground to flour in a Reitz disintegrator, using a screen with 0.032-inch holes. The final product is then sealed in polyethylene bags.

The use of 99 per cent isopropanol for the final extraction produced a cake that was easier to dry and eliminated the risk of spoilage during an extended period of drying. Acid can be eliminated if very fresh material is used at the outset. However, experience indicates that there is a definite risk that the finished product will have a fish odour or undergo a flavour reversion if acid is not used. When acid has been used, colour and flavour have been consistently satisfactory.

The process has been modified for application to fatty species. In this case, the ispropanol content is raised as high as possible during the second extraction. Two extractions of herring reduced the fat content to 1 per cent, and a third extraction brought this figure down to less than 0.1 per cent, compared with 0.02—0.056 per cent for lean fish. All these values are well below fat contents that have been recommended as satisfactory for the best quality FPC.

FPC has been prepared from cod fillets, filleted line scraps, filleted line-scrap press cake, whole cod, whole eviscerated cod, eviscerated and headed cod, mature and immature herring, capelin, whole skate and whole dogfish. All of these products have satisfactory colour, flavour and odour.

Air drying leaves a residual isopropanol content of approximately 1 to 1.2 per cent; vacuum drying removes very little more of the residual alcohol. Steam stripping and redrying reduces the level of residual solvent to 250 ppm or less.

Removal of all or part of the bone from the raw material before processing makes for higher protein yield and for low levels of fluoride in the final product.

Table 1 gives a proximate analysis of fish-protein concentrate made from various raw materials. The protein content is highest from fillets. Whole cod yields a concentrate containing 84.7 per cent protein, and cod trimmings, 87.2 per cent; whole herring yields 89.7 per cent protein. The residual fat varies between 0.02 per cent and 0.056 per cent for lean fish to a high of only 0.18 per cent for herring.

TABLE 1. PROXIMATE ANALYSIS OF FISH-PROTEIN CONCENTRATE MADE FROM COD AND HERRING

(Per cent)

Raw material	*Protein (dry basis)*	*Moisture*	*Ash*	*Fibre*	*Fat (ether extraction)*	*Fat (chloroform-methanol extraction)*
Cod fillets	92.9	4.64	1.89	0.50	0.02	0.033
Whole cod	84.7	7.62	14.6	0.88	0.02	0.056
Headed, eviscerated cod	90.26	5.25	8.37	0.81	0.02	0.02
Cod trimmings	87.2	3.54	11.42	0.34	0.039	0.04
Whole herring	89.7	8.24	7.13	0.94	0.09	0.18

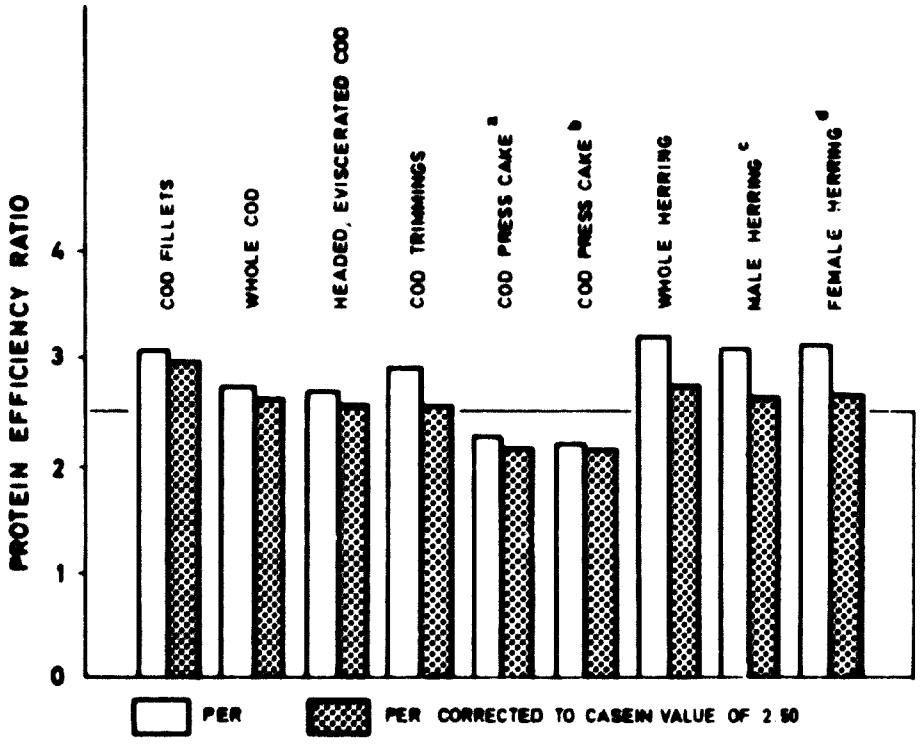
The nutritive value of the protein concentrate is high. The protein efficiency ratios (PER) of all samples (figure 5) are higher than the corresponding values for casein, with the exception of the samples produced from press cake, where the loss of proteinaceous material during pressing most probably causes the decrease in quality of protein. Press cake cooked with live steam injected directly into the material showed the lowest PER as a result of the extractive effect of the steam condensate. The highest PERs were manifest in the concentrates produced from cod fillets, whole herring and whole cod.

The PERs for these concentrates were 2.97, 2.74, and 2.64, respectively. Protein concentrate made from headed, eviscerated cod and cod trimmings had intermediate PER values of 2.58 and 2.57 respectively, compared with a value of 2.50 for casein. The samples of protein concentrate produced from two types of cod-trimming press cake had the lowest PER values: 2.19 and 2.12 respectively, or considerably lower than the values for casein.

The values of available lysine as per cent of protein are also very satisfactory. The range is between 6.14 per cent and 10.1 per cent (see table 2). With the exception of the concentrate prepared from mature female herring just prior to spawning, all values are above the minimum of 6.5 per cent recommended by FAO in their tentative specifications of 1961.

The Fisheries Research Board and the Department of Trade and Industry have been co-operating to obtain approval by the Food and Drug Directorate of FPC for human consumption in Canada. The chemical, nutritional and toxicological tests required by the Canadian Government before approval have been successfully completed.

The request for approval by the Canadian Food and Drug Directorate was based on fish-protein concentrates made from four raw materials: whole herring, whole capelin, and cod and haddock trimmings (that is, the remains



a Cod trimmings cooked with indirect heat and pressed to 60% moisture.
b Cod trimmings cooked with live steam and pressed to 60% moisture.
c Male herring just prior to spawning; gonads 19.5% of total weight.
d Female herring just prior to spawning; gonads 22% of total weight.

Figure 5. Protein efficiency ratios for FPC made from cod and herring

TABLE 2. LYSINE AND AVAILABLE LYSINE VALUES FOR FPC MADE FROM COD AND HERRING
(Per cent)

	Lysine	*Lysine as per cent of protein*	*Available lysine*	*Available lysine as per cent of protein*
Cod fillets	12.6	14.2	8.49	9.58
Whole cod	11.5	14.7	7.87	10.1
Headed, eviscerated cod	11.7	13.3	7.04	8.23
Cod trimmings	7.7	9.1	7.5	8.9
Herring[a]	11.6	14.1	5.82	7.07
Male herring[b]	11.2	15.03	6.28	8.43
Female herring[c]	9.63	11.3	5.13	6.14

a Mixed immature herring.
b Male herring just prior to spawning.
c Female herring just prior to spawning.

of the eviscerated fish after the fillets have been removed). Approval was also requested for species related to the foregoing and for fish-protein concentrate made from hake on the basis of approval of this FPC by the American authorities. It was also planned to obtain approval of fish-protein concentrate made from a wider range of edible species. Those being considered and that are not fully used at the present time as food in Canada are skate, dogfish, sand launce, argentines, flounder and many other underutilized species.

Underutilized marine resources in Canada could be of major importance to the economic production of FPC. Among the large quantities of edible fish caught by trawlers, a sizeable inedible remainder is returned, dead or dying, to the sea. With conversion to FPC these presently unusable species could provide high quality protein that would otherwise be wasted. Species of potentially edible fish that are rarely if ever caught include sand launce, argentines, hake and the elasmobranchs.

The establishment of an FPC-based industry would aid both the fisherman and the consumer. Fishing vessels bringing in edible fish and fish for conversion to FPC could obtain a full load more quickly and make shorter trips with a consequent increase in the freshness and quality of the fish. Species presently landed for meal could also command a higher price if they could be transformed into a product suitable for human consumption.

The Federal Government has appointed an interdepartmental committee on fish-protein concentrate to promote the commercial application of the isopropanol process for making FPC in Canada. Various subcommittees report to the committee on such matters as research and marketing.

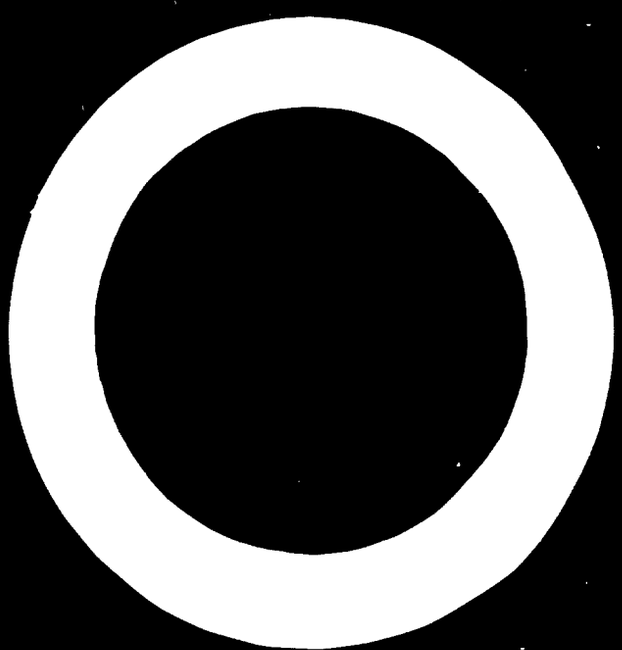
Last year, Cardinal Proteins Ltd, with head offices in Halifax, announced plans to proceed with the construction of a full-scale commercial plant to manufacture fish-protein concentrate at Canso, Nova Scotia. The

Halifax isopropanol process will be used. It is planned that this plant will have the capacity initially to process 200 tons of fresh fish per day; this will result in an output of 30 tons of protein concentrate per day. Raw material will be herring, cod and haddock trimmings, and edible species presently not used for human food. This plant, financed for Canadian $5 million, was expected to go into production near the middle of 1970. The selling price of the product was calculated to be about 35¢ per lb. Scientists of the Fisheries Research Board of Canada have been co-operating closely with company engineers in the design of this plant and are continuing research related to the process. This prototype plant is expected to be modified extensively as experience is gained.

Research is continuing on fish-protein concentrate at the Halifax Laboratory. Methods have been developed for determining the fluoride remaining in FPC, and studies are underway to determine the fluoride content of various parts of fish for a number of species. A gas chromatographic method has been developed to enable the residual alcohol content to be determined rapidly. Work on improving the efficiency of the extraction process is continuing; and it has been demonstrated that the isopropanol-water azeotrope, easily recovered by simple distillation, can be used effectively in the extraction process, even for fatty species such as herring. The possibility of producing fish-protein concentrate with various physical characteristics such as water-binding and heat-coagulating ability is also being studied; such an FPC could be used in meat products. In fact, fish-protein concentrate is not a product, but rather a variety of products, each modified to meet specific requirements. Jack Davis, Federal Minister of Fisheries and Forestry, compared producing FPC with pulping in the forest industry.

A great advantage to properly packaged FPC compared with conventional fish products lies in its almost indefinite shelf life under nearly every environmental condition. This is a very significant consideration in countries where refrigeration is at a premium. The stable nature of the product is also a plus feature when it comes to systematic marketing.

The plant at Canso is expected to be the forerunner of many similar operations in Canada and in other parts of the world. In this way, Canadian marine protein resources will be better able to make an important contribution to solving the problem of a world-wide scarcity of high quality protein.



11. ASPECTS OF PLANNING FPC PRODUCTION FACILITIES*

In planning FPC plants, basic objectives must be clearly defined. These will differ in each case. They should include the provision of raw materials, the specification of the product in relation to market requirements, cost factors and the disposal of by-products.

The isopropanol extraction process can be applied on a commercial scale with a good deal of flexibility to meet the specific requirements of individual projects. Examples of adaptable process features include raw material storage, bone removal, extraction techniques and FPC grinding and deodorization.

An adequate supply of fish resources without danger of depletion represents perhaps the most important key to the success of an FPC plant. Suitable harvesting techniques must also be developed. The project should be supported by a fishing fleet at its disposal to provide the plant with landings of the desired quality, quantity and according to a schedule. The location of the plant, its capacity, the methods of fish handling and storage, the size of storage facilities and, indeed, the process route itself must be established on the basis of what fish supplies can be expected.

Various markets and applications call for different product characteristics in respect of mineral content, particle-size analysis, trace components, solubility, dispersing power, heat-coagulating ability, flavour, colour and the like. For each project, such factors should be considered as where the FPC is to be marketed, and what the major applications and the requirements of purchasers and public health authorities will be. This information will determine the appropriate range of product specifications and the design of the plant. Otherwise a process of manufacture might be adopted that might handicap the utilization of the product. Technology has advanced to the point where even on a commercial scale, variations and control of certain functional properties of FPC may be determined during its manufacture without compromising the quality of the product.

The method of manufacture and the degree of complexity of the equipment can, within limits, be adapted to suit the price that the market can tolerate and that the cost of the raw materials will permit. Many figures

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* Paper presented to the meeting by Arnold Carsten, Specialist, Surveyor, Nenniger and Chénevert Inc., Montreal, Canada.

have been quoted in recent years on the capital cost of FPC plants and on production costs. They differ widely as they depend on factors that relate more to the specific circumstances of a particular project than to the requirements for materials and energy of the process chosen. The largest item in the production cost of FPC is the raw material, but related features such as storage of materials, material handling, solvent requirements, sanitation, pollution control, processing of by-products and cost of construction, to mention only a few, can have far-reaching effects on the overall economics. Too much significance should not be attached to figures that are not adequately substantiated nor should conclusions be drawn from figures until it is determined that they are applicable.

The manufacture of FPC can yield a number of by-products such as fish oil, fish meal, bone meal and solubles. In determining the basic design criteria for an FPC plant, there must be a clear understanding of the effluents involved, and how the facilities to process them profitably can best be integrated with the FPC manufacturing process.

For example, recent interest has been shown in storing raw fish in refrigerated sea water to cope with fluctuations in the supply of raw materials and to take advantage of this method of storage in subsequent process steps. However, the used water would contain organic material. If pollution control regulations prevented the disposal of contaminated water and if treatment facilities were too costly or if there were no outlet for the recovered material, this apparently insignificant obstacle would require a major revision of the proposed process route.

This example illustrates the futility of attempting to develop a single process, let alone a plant design, for universal use. This does not mean, however, that the results of development work in Agadir or elsewhere cannot form the basis for future FPC plants, but rather that the rapidly growing scientific and technological knowledge of FPC already permits the adaption of a plant to specific circumstances. This flexibility will increase over the years as a variety of processes currently being developed come into commercial use. These processes are not necessarily competitive, since they aim at developing products with widely differing properties.

The most advanced processes are based on solvent extraction, and a number of them, such as those developed by the Bureau of Commercial Fisheries in the United States, the Fisheries Research Board of Canada, the VioBin Corporation and others can now be applied on a commercial scale.

This paper deals with the isopropyl alcohol extraction process, which is one of the two approved so far by the Food and Drug Administration of the United States. This process is being referred to in order to illustrate not only that FPC of the highest quality can be produced on a commercial scale, but also that a measure of flexibility to meet varying circumstances has already been achieved. The only plants of this type now in operation are a few pilot plants and a commercial plant for making a feed-grade product from fish meal. However, the process design has been completed for the first commercial facility and it is certain, on the strength of numerous pilot-

plant and equipment tests, that no insurmountable problems will be encountered in using the process.

It is now known how long and under what conditions fish and intermediate materials can be stored without refrigeration in the solvent. This means that plants can be built to cope with specific fish-landing schedules, and consideration can be given to shipment of intermediate materials to a centrally located extraction plant.

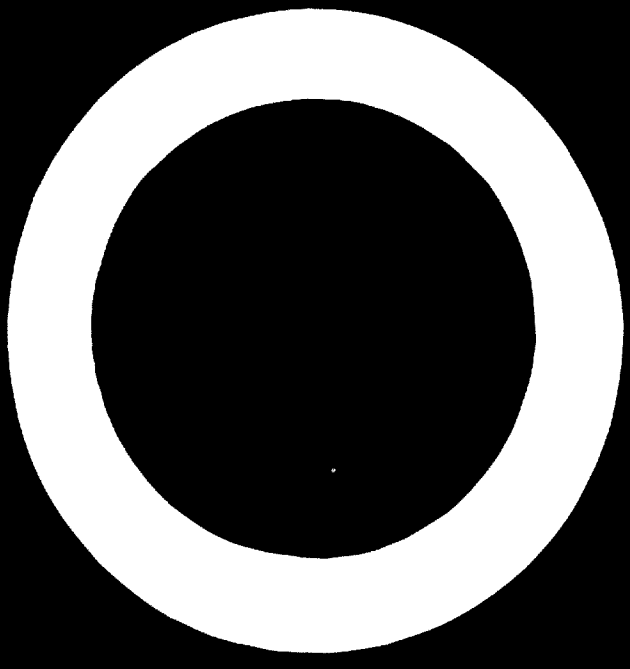
Extraction need not necessarily begin with the ground fish. Depending on the circumstances surrounding the project, extraction may be preceded by mechanical removal of the bone or by cooking and removal of oil and solubles by conventional means.

The extraction procedure itself offers a high degree of flexibility as to the number of extraction stages, process conditions, contacting and separation techniques and the like. The design can thus be adapted to suit different starting materials and to achieve products of the most exacting specifications.

A variety of techniques have been explored for final grinding and classification of the FPC. These differ widely in performance and cost. They may also serve to effect partial removal of bone unless this has already been accomplished earlier in the process. The partial or complete removal of bone not only limits the fluoride content of the product to meet the requirements of public health authorities, but also opens the door to a wider range of applications. Here again there is an opportunity to tailor the process to meet specific requirements.

Deodorization of the solvent before it is recycled can be expensive. The problem is no longer serious, but before further action, the results of a fully continuous operation must be determined. One or a combination of three methods may be employed, namely acid treatment, fractional distillation and adsorption. Odour compounds can also be removed elsewhere in the process, namely by pH control during extraction and by steam-stripping during desolventizing of the FPC. The effects and economics of all these steps are interrelated and also dependent on other process variables. The complexity of the deodorizing system must therefore be related to the process as a whole as well as to the proposed applications of the product.

The above remarks are intended to stimulate discussion, to illustrate how much knowledge is available for commercial application, and to suggest that it is better to remain flexible and not to develop a concept of an FPC plant that is restricted in usefulness by premature detail. The author is not at liberty to disclose work for specific clients. He will be pleased, however, to contribute engineering details to any specific project as and when required.



12. AN EXPERIMENT USING ISOBUTANOL FOR THE PRODUCTION OF FISH-PROTEIN CONCENTRATE IN CHILE*

As has been pointed out by Oswald A. Roels in article 1, Chile is ideally suited to the development of an FPC industry, because of its long coastline, the fish consciousness of the population, and the need to fortify the diet, which consists primarily of carbohydrates and fats, with a source of protein. After an attempt had been abandoned to produce FPC in Chile by an extraction process using ethanol and/or hexane, an experiment was made employing isobutanol as a solvent. The advantage of isobutanol is that it can be produced in Chile, whereas other solvents, such as hexane, isopropanol and ethylene dichloride, must be imported.

The process was developed on a basis similar to the one initiated by Levin. [1, 2] The hake was extracted with solvent, and the water, solvent and volatiles were continuously distilled at a constant temperature. The distillate underwent two immiscible phases: one rich in water, and the other in solvent, the latter being recirculated as reflux.

The raw material used was whole Chilean hake *(Merluccius gayi)* processed no later than twenty hours after being caught. The mean composition of the hake is given in the table below. This composition showed a marked variation during the period of work (March to July). The fat content varied from 4 per cent up to 22 per cent on a dry basis. These figures may appear high for a lean fish, but they agree with those given by Yáñez *et al.* [3]

COMPOSITION OF HAKE
Per cent

Batch	*Protein*[a]	*Ash*	*Fat*
1	66.1	14.4	19.5
2	64.9	14.1	21.0
3—4	67.5	14.3	18.2
7—8	75.7	14.4	9.9

Note: All analyses were made by methods of the Association of Official Agricultural Chemists.

a N × 6.25.

* Paper presented to the meeting by P. Hevia, Fernando Acevedo Bonzi, and S. Kaiser of the Catholic University of Valparaiso, Chile. Mr. Hevia is with the University's Institute for Scientific and Technological Research; Mr. Bonzi is Head of the Research Department of the University's School of Engineering.

When the supply of fresh fish was not constant, the raw material was comminuted and then kept in isobutanol for not more than one week, a perfectly safe period according to the United States Department of the Interior. This preliminary treatment facilitated the extraction, preventing the formation of lumps. The solvent used was Merck isobutanol (2 methyl 1 propanol) technical grade.

Isobutanol is partially miscible with water, which is an advantage in that it eliminates approximately 50 per cent of the water in a continuous process through distillation and decantation, saving energy and progressively improving the contact between solvent and fat. It penetrates cells better than immiscible solvents; and it prevents loss of valuable solubles. A chromatographic analysis of the used solvent showed no trace of amino acids.

In addition to this property of partial miscibility, isobutanol distils azeotropically with water at 89.2° C, a temperature considerably lower than 108° C, the boiling point of the pure solvent. Hence, extraction-distillation takes place at a nearly constant temperature, about 91° C.

Although 91° C may seem to be much too high for preservation of the nutritive value of the fish, studies made by Yáñez *et al.* [4] showed that the nutritive value of hake was retained, even after the material dried at 105° C.

Added to these advantages is the high boiling point of the pure solvent which eliminates the difficulty of handling more volatile solvents. Finally, isobutanol is not very toxic. [5, 6]

The process consists of six basic operations: washing, comminution, extraction, filtration, drying and grinding. Approximately 2 kg of fresh whole hake were washed with fresh water, then comminuted and homogenized in a ¾ hp Hobart comminutor-homogenizer for 5 minutes. The fish, now in the form of a paste, was transferred to the extractor-distiller, which consisted of a 10-litre glass flask with variable speed agitation, a reflux condenser, a distillate receiver externally cooled with water, and a 1,000-W heating mantle with temperature regulator.

The first extraction was done at room temperature for 30 minutes and then at boiling temperature (89.2°—91° C) for hours using a ratio of 3 kg solvent to 1 kg fish. The extracted fish was then washed twice with cold solvent. The final fat content was 0.3 per cent on a wet basis.

The next step, filtration, was done under an absolute pressure of 100 mm Hg through a bed of activated carbon. The solids were dried in an agitated glass reactor, heated externally with hot water at 60°—65° C under an absolut pressure of 25 mm Hg. The drying operation proved inefficient, since 18 hours were required to dry from a moisture content of 45 per cent to one of 3—4 per cent. For the final operation, grinding, a Mikro Sampmill (hammer mill) was used.

The problem of solvent recovery was not studied in depth, but some experiments indicated that this operation is feasible. The solvent-fat solution was distilled in conventional laboratory glass equipment, using a column (35 cm in height, 6 cm in diameter) packed with activated carbon. The

carbon served both as an absorbent for odorous substances and as packing for better rectification.

This method produced a fine light yellow-grey flour with no odour and only a slightly fishy taste. The product showed marked stability; no alterations were observed after several months of storage in glass bottles at room temperature. A sample stored for two months at 60° C in a flat dish placed in a forced circulation oven showed no change.

The process yield was 17 per cent FPC with no significant variations. The FPC obtained had the following composition on a wet basis: protein—80 per cent, ash—16 per cent, fat—0.3 per cent and volatiles—4 per cent. AOAC methods of analysis [7] were used; results shown in the table are mean figures for eight runs.

Biological quality was measured by the protein efficiency ratio (PER); FPC was 2.9; casein was 2.9. The pepsin digestibility was 97.2 per cent, and the available lysine content was 7.5 per cent. PER tests were performed according to Chapman's method, [8] using 10 rats on a standard diet of casein.

On the whole, the result of this experiment was positive. Isobutanol demonstrated valuable properties for defatting and deodorizing, and the final product had good organoleptic and nutritive qualities.

The PER value of the FPC equalled the value of the control test made with casein; in other words, it was very satisfactory. The values of pepsin digestibility and available lysine were also satisfactory. The three values were similar to those given by other processes (Brody; [9] United States Department of the Interior; [10] Power; [11] Yáñez *et al.* [4]) and were higher than the minimum values recommended by the FAO tentative specifications for FPC. [12]

For a definitive evaluation of the method, further study must be made of the toxicological aspects, stability during storage and the economic considerations of optimizing the process, such as production costs on an industrial scale.

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13. PROTEOLYSATE OF SARDINES*

In 1965, the Institut Scientifique Marocain de la Pêche Maritime undertook a study of the production of marine proteolysate using Moroccan sardines. On the basis of highly encouraging laboratory findings, the decision was made to collaborate with private enterprises with the aim of organizing and financing an industry.

A marine proteolysate is produced from raw material (*Sardina pilchardus* or any other seafood or fish waste), which is submitted to a complicated process, using various enzymes in an acid medium.

COMPARATIVE ANALYSIS OF PROTEIN CONCENTRATES FROM SARDINES, MEAT AND MILK

	Sardine proteolysate	*Meat flour*	*Powdered milk*
		Per cent	
Total protein	75—95	69.50	30.00
Ash	5.5—15	5.84	4.00
Moisture	4	11.00	8.00
Lipids	0.50	5.84	18.00
Indispensable amino acids			
Isoleucine	4.00	6.00	8.50
Lysine	8.25	7.50	7.25
Leucine	6.70	7.00	11.00
Methionine	2.10	2.30	3.40
Histidine	2.54	2.90	2.60
Phenylalanine	3.40	1.30	5.70
Threonine	3.50	3.30	4.50
Vitamins		*mg/100 g*	
A	0.80	0.004	0.06
B_1	0.055	0.05	0.05
B_2	0.30	0.20	0.20
B_{12}	0.018	—	—
PP	0.48	Traces	0.40
B_6	0.15	—	—

* Paper presented to the meeting by B. de Gero and O. Skiredj. Mr. de Gero is Chief, Station Océanographique, Institut Scientifique Marocain de la Pêche Maritime, Casablanca, Morocco; Mr. Skiredj is General Director, Société Privée de Développement Economique, Rabat, Morocco.

The product has entirely natural organic, biological and metabolic properties, and can therefore be assimilated by the human body. It resembles human tissue and cell structure since it is produced according to a biological principle. As indicated in the following table it contains all the indispensable amino acids, and all the biocatalysts (vitamins) exept vitamin C.

Sardine proteolysate is a whitish powder with an odour resembling that of powdered milk; its flavour depends on the percentage of free amino acids.

Its price, based on a cost of 0.055 dirhams per kg of sardines, is approximately 1.80 to 2 dirhams per kg. The capital outlay for equipping a plant with a capacity of 1,000 tons per year is 3.5 million to 4 million dirhams.

14. ANALYSIS, TESTING AND USES OF FISH-PROTEIN CONCENTRATE*

In 1961, the United States Bureau of Commercial Fisheries initiated a broadly based research programme to investigate simultaneously three different approaches (physical, biological and chemical) to the manufacture of fish-protein concentrate from whole fish. The use of whole fish was deemed essential since processing operations, such as filleting or eviscerating, would increase the cost of the product and thus limit its use as a protein supplement among people with low incomes.

It became apparent in the initial stages of this research programme that the United States Food and Drug Administration (FDA) would not, without sufficient evidence of its value, approve the distribution and sale in the United States of FPC made from whole fish. Hence, the Secretary of the Interior directed the National Center for Fish Protein Concentrate to devote its major effort to gathering the data necessary for FDA to evaluate the usage of whole fish in making FPC. One method for making FPC was to be selected and developed, and the product was to be exhaustively examined for wholesomeness, stability and nutritive value.

On the basis of earlier work, particularly that of the Canadian researchers, the Center selected a chemical approach (solvent extraction) using isopropanol. Isopropanol was chosen because it was known to be highly effective in the removal of water and fat from raw fish. Since it is prepared by a synthetic process, its purity could be carefully controlled. In addition, isopropanol was known to be reasonably priced, to be an effective bacteriostat and to be safe for use in food processing.

The fish chosen for the manufacture of FPC was red hake *(Urophycis chuss)*. Red hake, an underutilized schooling species of lean fish, was being eaten in small quantities. Thus it appeared that a satisfactory method could be quickly evolved employing this species.

The accelerated FPC project developed one process which can be defined as a three-stage counter-current batch extraction. [1] The work at

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the Bureau of Commercial Fisheries demonstrated that FPC can be produced from whole fish at a relatively low cost by solvent extraction. It also established that the FPC produced was highly nutritious, safe and wholesome and that it would therefore be entirely satisfactory as a dietary supplement for human consumption. A petition incorporating these findings was submitted to the FDA, and on 2 February 1967, the FDA approved the process using hake for the manufacture of FPC.

The National Center for FPC has since been engaged in research to persuade the FDA to extend its approval of FPC from hake and hake-like fish to other fish that are available in large quantities and are edible but that are not widely used for human consumption. The Center has made FPC from the following species: alewife *(Alosa pseudoharengus)*, Atlantic menhaden *(Brevoortia tyrannus)*, Atlantic herring *(Clupea harengus harengus)*, northern anchovy *(Engraulis mordax)* and ocean pout *(Macrozoarces americanus)*. The data obtained from experiments with these additional species have been evaluated and (will shortly be) presented to the FDA with the expectation that they will permit FPC to be made from these and related species.

Chemical composition

The chemical composition of FPC has been studied extensively by the research group at the Center. The analysis has not been limited to the usual macro-components but has also encompassed micro-components, including flavour compounds.

Table 1 shows the proximate composition of ten representative samples of FPC, which were processed from ten different batches of red hake. The

Table 1. Proximate composition of samples of FPC prepared from ten 150-pound batches of red hake

(Per cent)

Sample	*Crude protein (N×6.25)*	*Volatiles*	*Ash*	*Lipids*
1	81.78	7.55	14.35	0.17
2	81.26	7.38	13.72	0.15
3	78.04	10.78	13.06	0.17
4	80.74	7.58	13.80	0.13
5	80.63	7.53	13.22	0.19
6	79.30	8.91	13.42	0.15
7	81.85	6.25	13.48	0.21
8	82.28	7.67	12.92	0.19
9	81.17	6.74	13.47	0.19
10	81.53	6.72	13.56	0.22
Average	80.86	7.71	13.50	0.18
Standard deviation	1.2876	1.2953	0.4055	0.0283
Standard error of mean	0.4072	0.4096	0.1282	0.0090

crude protein averaged 80.86 per cent, volatiles 7.71 per cent, ash 13.50 per cent and lipids 0.18 per cent. In general, the composition of the samples was quite uniform. Table 2 indicates that the proximate composition of six batches of Atlantic menhaden-FPC was also uniform. The percentage of volatiles was about one-half that in red hake-FPC. The average crude protein content of this more bony fish was less, and the ash was approximately 6 per cent higher. The percentage of volatiles was less in the menhaden than in the hake because slightly different desolventizing systems werde used.

TABLE 2. PROXIMATE COMPOSITION OF SAMPLES OF FPC PREPARED FROM SIX BATCHES OF ATLANTIC MENHADEN
(Per cent)

Sample	*Crude protein (N×6.25)*	*Volatiles*	*Ash*	*Lipids*
1	78.44	3.80	19.56	0.16
2	78.01	3.60	20.06	0.29
3	78.14	3.55	19.51	0.26
4	78.75	3.66	19.44	0.13
5	77.77	4.48	19.56	0.15
6	80.01	3.68	18.39	0.10
Average	78.52	3.80	19.42	0.18
Standard deviation	0.81	0.34	0.55	0.08
Standard error of mean	0.33	0.14	0.22	0.03

Table 3 shows the proximate composition of FPC made from seven other species of fish. As would be expected, there was a greater variation in the composition of FPC made from different species of fish than in that made from different batches of the same species. Ocean pout-FPC and alewife-FPC had the highest percentage of crude protein. The amount of residual lipids in all samples was less than 0.30 per cent. Moroccan sardine-FPC was comparable to hake in composition.

TABLE 3. PROXIMATE COMPOSITION OF SAMPLES OF FPC PREPARED FROM VARIOUS SPECIES OF FISH
(Per cent)

Species	*Crude protein (N×6.25)*	*Volatiles*	*Ash*	*Lipids*
Red hake	80.9	7.7	13.5	0.18
Atlantic menhaden	78.5	3.8	19.4	0.18
Atlantic herring	87.5	5.9	10.8	0.19
Northern anchovy	80.0	6.1	16.8	0.07
Ocean pout	86.0	1.5	15.0	0.24
Alewife	86.0	2.3	15.7	0.09
Moroccan sardines	79.7	4.4	—	0.21

TABLE 4. ESSENTIAL AMINO-ACID COMPOSITION OF FPC PREPARED FROM VARIOUS SPECIES OF FISH AND FROM DRIED WHOLE EGG

(Per cent of protein)

	Whole egg	*Hake*	*Atlantic menhaden*	*Alewife*	*Northern anchovy*	*Atlantic herring*	*Ocean pout*	*Moroccan sardine*
Lysine	6.40	8.28	7.89	8.19	8.06	8.53	7.93	8.58
Histidine	2.40	2.05	2.29	2.08	2.31	2.13	1.99	2.82
Arginine	6.56	6.47	6.44	6.31	6.25	6.12	6.89	6.26
Threonine	4.98	4.15	3.96	4.05	4.23	4.23	4.10	4.14
Valine	7.42	4.88	5.13	4.96	5.06	5.45	4.52	5.20
Methionine	3.14	2.93	2.96	3.03	3.05	3.19	2.91	3.06
Cystine	2.34	0.86	0.58	0.65	0.72	0.71	0.70	—
Isoleucine	6.64	4.33	4.12	4.25	4.34	4.37	4.00	4.40
Leucine	8.80	7.54	6.95	7.25	7.38	7.62	6.64	7.18
Phenylalanine	5.78	4.49	3.84	4.06	3.98	4.05	3.69	4.14
Tryptophane	1.65	0.97	1.11	1.27	1.31	1.20	1.12	0.97

The amino-acid composition has often been used as an indicator of the nutritive value of FPC. Table 4 shows the amino-acid composition of FPC made from various species of fish, and that for whole egg. The protein in whole egg is considered a natural protein of high nutritive value. The different FPC compared favourably with whole egg. The most obvious differences were the lower values for tryptophane and cystine.

Nutritive value of FPC

The data from chemical analyses of the various FPC are merely indications of nutritive value. Animal-feeding studies are needed to evaluate the utilization of the protein in FPC, both as a sole source and as a supplementary source of protein.

Nutritive value of FPC as a sole source of protein

In studies at the Center, FPC was incorporated into diets at a 10 per cent protein level, and the diets were fed to normal weanling rats for 28 days. A diet containing 10 per cent protein from casein was used as a control. Weight gain and feed intake were recorded and the PER (protein efficiency ratio) was calculated. Table 5 summarizes the PER values obtained from studies evaluating hake-FPC and Atlantic menhaden-FPC. In general, the PER values were equal to or better than casein. The average values for the 22 samples of hake-FPC were statistically significantly better than casein. Atlantic menhaden-FPC was comparable to casein.

TABLE 5. PER VALUES OF FPC PREPARED FROM VARIOUS BATCHES OF RED HAKE AND ATLANTIC MENHADEN COMPARED WITH CASEIN

	No. of analyses	*Average protein efficiency ratio*[a]	*Range*
Hake-FPC	22	3.29[b]	2.93—3.63
Atlantic menhaden-FPC	6	3.05	2.97—3.11
Casein	8	3.00	—

a Values adjusted to a casein value of 3.00.
b Statistically significantly better than casein.

Another study compared the nutritive value of single samples of FPC made from seven different species of fish. Table 6 indicates that the nutritive value of FPC made from various species of fish was also equal to or better than casein. Northern anchovy-FPC was the most nutritive. FPC made from Atlantic menhaden, ocean pout, and Moroccan sardines was comparable to casein. The results of these investigations demonstrate that FPC prepared by the isopropanol extraction method will probably have a nutritive value equal to or better than casein.

TABLE 6. NUTRITIVE VALUE OF FPC PREPARED FROM VARIOUS SPECIES OF FISH COMPARED WITH CASEIN

	Average daily weight gain (g)	*Average daily food intake (g)*	*Protein efficiency ratio*[a]
Red hake	5.21	14.8	3.19
Atlantic menhaden	4.60	13.9	3.05
Atlantic herring	5.32	15.0	3.15
Northern anchovy	5.18	14.6	3.25
Ocean pout	4.68	13.8	3.06
Alewife	5.28	15.2	3.17
Moroccan sardine	4.98	15.7	2.96
Casein	4.35	13.0	3.00

a Protein efficiency ratio $= \frac{\text{weight gained}}{\text{protein consumed}}$. Values adjusted to a casein value of 3.00.

Stillings *et al.* [2] conducted a series of experiments to determine the sequence of limitation of the essential amino acids in FPC produced by isopropanol extraction of whole red hake. Diets were prepared containing 1.28 per cent nitrogen from FPC and 0.32 per cent nitrogen from various combinations of amino acids. The diets were fed to weanling rats for four weeks; weight gain, feed intake and PER were determined. In an analysis of two different samples of hake-FPC prepared by the same process, the amino acids were grouped according to their limitation from greatest to least, as follows: *(a)* methionine; *(b)* histidine, tryptophane and threonine; *(c)* valine, isoleucine and phenylalanine; *(d)* leucine, lysine and arginine.

Nutritive value of FPC used as a protein supplement

Fish-protein concentrate is intended for use only as a protein supplement, and not as a sole source of protein. This cannot be emphasized strongly enough. Numerous nutritional studies have been conducted on the effect of supplementing various vegetable protein sources with fish-protein concentrate. Substantial increases in nutritive value have been obtained in all cases. The results of one study, [3] in which wheat flour was replaced with 5 to 25 per cent FPC, illustrate the point. The mixtures were incorporated into diets at a 10 per cent protein level and fed to weanling rats for four weeks. Table 7 shows the results of this trial feeding. Supplementing wheat flour with 15 per cent hake-FPC markedly increased the weight gain, feed intake and PER value. The higher levels of supplementation had little additional effect on any of the variables investigated.

TABLE 7. NUTRITIVE VALUE OF WHEAT FLOUR SUPPLEMENTED WITH FPC WHEN FED TO RATS IN 10 PER CENT PROTEIN DIETS

Protein source		Average daily weight gain (g)	Average daily feed intake (g)	Protein efficiency ratio[a]
Wheat (%)	*FPC* (%)			
100		0.90	8.45	0.92
95	5	3.17	13.34	2.07
90	10	4.70	15.55	2.65
85	15	5.79	16.64	3.04
80	20	5.77	16.86	2.99
75	25	5.43	15.58	3.06
0	100	5.75	16.10	3.13
Casein		4.85	14.24	3.00

a Protein efficiency ratio = $\frac{\text{weight gained}}{\text{protein consumed}}$. Values adjusted to a casein value of 3.00.

USES OF FPC IN FOOD PRODUCTS

Bread

Very little published information exists on the changes that take place in the rheology of doughs and in the characteristics of bread made from flour that contains varying amounts of FPC. Hence, the National Center for Fish Protein Concentrate conducted studies using FPC made from hake and from other species of fish to examine the changes.

Bread supplemented with hake-FPC

In this study, [4] mixtures of high-protein wheat flour and hake-FPC were prepared containing 0, 5, 10, 15, 20 and 25 per cent FPC. Table 8 indicates that more water was required to bring the dough to the same degree of development with each increment of FPC, that is, from 59 per cent for 0 per cent FPC to 70.2 per cent for 20 per cent FPC. Less water—68 per cent—was needed for the 25 per cent FPC mixture. The replacement of 5 per cent of the flour with FPC increased the stability of the dough markedly; from 5 to 20 per cent FPC, its stability remained almost constant, and it increased when 25 per cent FPC was used in the mixture.

Tolerance index and 20-minute-drop are indices that mark the rate of the dough breakdown. Tolerance index was measured 5 minutes after the Farinograph curve reached its peak. The 20-minute-drop is measured 20 minutes after the water is first added to the flour mixtures. Both of these indices showed that the addition of FPC improved the stability of the dough.

TABLE 8. FARINOGRAPH CHARACTERISTICS OF DOUGHS MADE FROM MIXTURES OF WHEAT FLOUR WITH VARYING PERCENTAGES OF FPC

FPC as % of wheat flour	*Absorption (%)*	*Arrival time (minutes)*	*Stability (minutes)*	*Peak time (minutes)*	*Tolerance index (BU)*	*20-minute-drop (BU)*
0	59.0	1.2	10.8	5.5	30.0	70.0
5	61.0	2.0	17.2	8.5	20.0	50.0
10	63.6	2.2	18.2	10.2	20.0	30.0
15	67.6	4.2	16.8	10.0	20.0	30.0
20	70.2	4.0	18.0	10.0	—	—
25	68.0	4.0	44.0	7.0	20.0	—

Note: BU = Brabender units.

TABLE 9. CONSISTENCY OF DOUGHS MADE FROM MIXTURES OF WHEAT FLOUR CONTAINING VARYING PERCENTAGES OF FPC AFTER A 45-MINUTE AND 180-MINUTE REST PERIOD

FPC as % of wheat flour	Total extension at the end of		Maximum resistance at the end of		Area under curve at the end of	
	45 min (mm)	180 min (mm)	45 min (BU)	180 min (BU)	45 min (cm^2)	180 min (cm^2)
0	185	150	460	580	116	104
5	178	148	480	660	114	125
10	102	130	530	700	103	116
15	105	118	520	740	73	113
20	98	95	515	680	72	91
25	68	68	850	880	82	78

Note: BU = Brabender units.

Table 9 shows the values obtained for the consistency of the doughs containing FPC. The extensibility of the doughs was less at the end of the 180-minute relaxation period for the 0 and 5 per cent FPC doughs than at the end of the 45-minute relaxation period. It increased for the 10 and 15 per cent FPC doughs, but remained constant for the 20 and 25 per cent FPC doughs.

The addition of FPC increased the resistance against deformation, that is the stiffness and shortness of the dough as measured by the height of the curve. At the end of the 45-minute rest period, the resistance increased with the addition of 5 per cent FPC, then remained nearly constant for the 10 to 20 per cent FPC doughs. With the addition of 25 per cent FPC, the resistance to deformation increased. At the end of the 180-minute rest period, the maximum resistance increased with each increment of FPC except for the dough with 20 per cent FPC.

The energy needed to bring about a break in the dough along a predetermined path is proportional to the area under the curve. At the end of the 45-minute rest period, the amount of energy needed to rupture the dough was about the same for the 0 and 5 per cent FPC doughs. The energy requirement decreased when 10, 15 and 20 per cent FPC was used in the dough. The amount of energy needed for the 25 per cent FPC dough increased slightly.

After 180 minutes of relaxation, more energy was needed to rupture the doughs with 5 to 15 per cent FPC than was needed to rupture the doughs with no FPC. The energy needed to break the doughs with 20 and 25 per cent FPC was less than that for the dough with no FPC.

The loaf volume of the bread containing varying amounts of FPC decreased markedly with each increment of FPC—from 12 per cent at the 5 per cent FPC level to 36 per cent at the 25 per cent FPC level. The loss of volume in the studies was somewhat greater than the loss reported by the South African investigators [5], who used a 90 per cent extracted flour and calcium acetate in a formula similar to that used by the Center. In the South African tests the loaf volume decreased 3 to 5 per cent at the 5 per cent level of enrichment and 8 to 18 per cent at the 10 per cent FPC level. The variability of the percentage loss was not due entirely to the addition of FPC but to the baking quality of the original wheat flour used in the tests.

Table 10 shows the results of the sensory evaluation. With each addition of FPC to the formula, the bread became a darker brown. The judges liked the appearance of the bread crumb containing 5 per cent or 10 per cent FPC nearly as well as they liked the standard bread with no FPC. The appearance of the bread containing 15, 20 or 25 per cent FPC was less acceptable.

In this investigation, texture referred primarily to feeling in the mouth and chewiness, since the judges were blindfold. Those conducting the tests did not want the colour of the bread to influence the evaluation of texture and flavour. The judges found very little difference between the bread with no FPC and the bread with 5 or 10 per cent FPC. The bread containing

TABLE 10. SENSORY EVALUATION OF BREAD SUPPLEMENTED WITH VARYING PERCENTAGES OF FPC

FPC (%)	Appearance	Texture	Flavour
0	3.3 ± 0.12[a]	3.0 ± 0.08[a]	3.1 ± 0.06[a]
5	3.0 ± 0.16	2.8 ± 0.13	2.8 ± 0.19
10	2.8 ± 0.14	2.6 ± 0.16	2.8 ± 0.14
15	2.6 ± 0.16	2.0 ± 0.16	2.1 ± 0.25
20	2.3 ± 0.17	2.4 ± 0.18	2.4 ± 0.12
25	1.8 ± 0.13	1.5 ± 0.15	1.4 ± 0.12

[a] Standard error of mean.

10 per cent FPC was somewhat crumbly in texture, a characteristic that became more pronounced with higher amounts of FPC in the bread.

The typical bread flavour decreased with the augmentation of the level of FPC. The judges liked the flavour of the bread with 5 or 10 per cent FPC as well as they did that of the bread with no FPC. Bread with higher levels of FPC, however, was less acceptable.

In Chile, Donoso *et al.* [6] found that panelists accepted bread enriched with 3 per cent fish flour equally well as bread containing no fish flour. At the 6 per cent fish-flour level, colour influenced the acceptability of the bread more than the flavour. Bread with 9 or 12 per cent fish flour was acceptable, but was considered different from regular bread in colour, flavour and texture.

Stillings *et al.* [7] conducted an animal-feeding study to determine the nutritive value of the enriched bread. The bread was incorporated into the diets in two different ways. First, the diets were formulated to contain

TABLE 11. NUTRITIVE VALUE OF BREAD SUPPLEMENTED WITH FPC AND INCORPORATED INTO THE DIET EITHER AT THE 10 PER CENT PROTEIN LEVEL OR AT 80 PER CENT BY WEIGHT

Mixtures used to make bread		Diets containing 10% protein		Diets containing 80% bread	
		Average daily weight gain (g)	Protein[a] efficiency ratio	Average daily weight gain (g)	Weight gain per bread intake (g/100 g)
Wheat (%)	FPC (%)				
100	0	1.13	1.13	1.07	16.4
95	5	2.89	2.04	4.20	37.6
90	10	4.31	2.53	5.93	51.4
85	15	4.98	2.86	6.22	56.3
80	20	5.24	3.04	6.39	58.4
75	25	5.99	3.35	6.34	58.1
Casein		5.34	3.28		

[a] Protein efficiency ratio = $\frac{\text{weight gained}}{\text{protein consumed}}$

TABLE 12. CRUDE PROTEIN AND LYSINE CONTENT OF BREAD SUPPLEMENTED WITH FPC

FPC as % of bread mixture	Crude protein (N×6.25) as % of dry matter	Lysine	
		As % of crude protein	As % of theoretical calculation
0	16.0	1.97	97
5	19.6	3.32	97
10	23.2	4.35	100
15	27.4	5.09	101
20	31.7	5.36	97
25	34.5	6.06	102

1.6 per cent nitrogen from the bread samples. Second, the diets were formulated to contain 80 per cent by weight of the bread samples. Both diets had the same caloric value. Table 11 gives the results of this study. Diets containing 1.6 per cent nitrogen from the bread showed a steady increase in nutritive value with each addition of FPC. Diets containing 80 per cent bread with 10 per cent FPC produced near maximum weight gains. Table 12 indicates that very little lysine was lost during the processing of the FPC-wheat flour mixtures into bread.

Morrison and Campbell [8] reported that the addition of 10 per cent FPC to white bread increased the PER value by 198 per cent. Yáñez *et al.* [9] found that 6 per cent FPC and 12 per cent dried-milk solids produced similar increases in the protein values of the bread. With both supplements—FPC or dried-milk solids—however, there was some loss in the quality of the protein during baking.

Bread supplemented with FPC made from other species of fish

FPC made from other species of fish was also incorporated into bread at the 10 per cent level and evaluated by a panel. The experimental bread was compared to bread containing 10 per cent hake-FPC; the results are shown in table 13. The flavour and texture of the bread were on the average nearly as acceptable as that made with hake-FPC. There was less acceptance of the texture of menhaden-FPC. There was strong objection to the appearance of the bread containing anchovy-FPC and alewife-FPC, which was quite grey in colour.

Pasta

Pasta supplemented with hake-FPC

Semolina and varying amounts of hake-FPC (0, 3, 6, 9 and 12 per cent) were used to make macaroni products. [10] Water was added to the semolina-FPC mixture to the point where it was free flowing, yet cohesive

TABLE 13. SENSORY EVALUATION OF BREAD SUPPLEMENTED WITH 10 PER CENT FPC MADE FROM VARIOUS SPECIES OF FISH

Species	*Appearance*	*Flavour*	*Texture*
Hake (control)	2.8 ±0.13[a]	3.0 ±0.21[a]	3.0 ±0.26[a]
Ocean pout	2.5 ±0.22	2.5 ±0.17	2.4 ±0.48
Anchovy	1.5 ±0.17	2.4 ±0.20	2.5 ±0.27
Herring	2.3 ±0.30	2.8 ±0.33	3.0 ±0.21
Atlantic menhaden	2.1 ±0.18	2.5 ±0.22	1.9 ±0.23
Alewife	1.9 ±0.07	2.1 ±0.23	2.3 ±0.33

[a] Standard error of mean.

under pressure. The mixture was extruded and the resulting pasta was air-dried overnight.

The pasta became darker with each addition of hake-FPC; the colour turned from a bright yellow for the plain semolina pasta to a darkish grey yellow for the pasta with 12 per cent hake-FPC. During cooking, much of the dark colour leached into the cooking water.

Table 14 shows the per cent of solids and protein in the cooking water. The percentage of solids remained about the same within each cooking time (8, 18 and 28 minutes) regardless of the amount of FPC in the pasta. There was an increase of solids in the cooking water, however, as the time of cooking increased. The protein in the cooking water increased with the increased amount of FPC in the pasta; the maximum amount was found at the 28-minute cooking time.

Table 15 shows the effect of adding FPC on the swelling (volume) and water absorption of the pasta during cooking. The addition of 3, 6 and 9 per cent FPC appeared to retard the swelling of the pasta after the 8-minute cooking time, yet about the same amount of water was absorbed as with the control. At the end of the 18-minute cooking time, the 9 per cent FPC pasta did not increase in volume as the pasta supplemented by less or more FPC. At the end of 28 minutes, the 9 and 12 per cent FPC pasta had become quite soft and no longer retained its shape.

A sensory evaluation was conducted of the pasta containing the various amounts of hake-FPC. When FPC is one of the ingredients of a food product, odours are more likely to be detected when the food is hot. The pasta was, therefore, served in warm, mildly salted distilled water. No differences were detected between the 0 and 3 per cent FPC. A few of the judges were able to detect a slight difference in odour in the 6 and 9 per cent FPC pastas. There was a distinct odour difference with the 12 per cent FPC pasta. The judges liked the flavour of the 0, 3 and 6 per cent FPC-semolina pasta, but showed a definite dislike for that containing 12 per cent FPC. The addition of 3 per cent FPC to semolina did not change the texture of the cooked pasta. Levels of 6 and 9 per cent FPC tended to harden the pasta, but with 12 per cent FPC the pasta cooked to the same degree of hardness as with 0 per cent FPC.

TABLE 14. PERCENTAGE OF SOLIDS AND PROTEINS REMAINING IN THE WATER AFTER COOKING PASTA

Composition of pasta		Cooking time					
		8 minutes		18 minutes		28 minutes	
Semolina (%)	FPC (%)	Solids	Protein	Solids	Protein	Solids	Protein
100	0	0.6	0.057	0.9	0.084	1.0	0.085
97	3	0.7	0.065	0.8	0.090	1.0	0.091
94	6	0.7	0.080	1.1	0.101	1.1	0.098
91	9	0.6	0.085	1.0	0.104	1.0	0.104
88	12	0.8	0.091	1.1	0.100	1.1	0.121

TABLE 15. INCREASE IN VOLUME AND WEIGHT OF PASTA MADE FROM SEMOLINA AND VARYING AMOUNTS OF FPC AFTER COOKING
(Per cent)

Composition of pasta		*Cooking time*					
		8 minutes		*18 minutes*		*28 minutes*	
Semolina	*FPC*	*Volume*	*Weight*	*Volume*	*Weight*	*Volume*	*Weight*
0	0	111	165	166	271	179	342
97	3	101	166	159	271	183	346
94	6	105	167	153	271	162	354
91	9	100	162	133	269	143	334
88	12	136	164	164	275	179	338

TABLE 16. NUTRITIVE VALUE OF MIXTURES OF SEMOLINA AND VARYING AMOUNTS OF HAKE-FPC BEFORE AND AFTER PROCESSING INTO PASTA

Protein source		*Before processing*		*After processing*	
Semolina (%)	*FPC (%)*	*Average daily weight gain (g)*	*Protein[a] efficiency ratio*	*Average daily weight gain (g)*	*Protein[a] efficiency ratio*
100	0	0.85	0.98	0.81	0.90
97	3	2.47	1.90	2.31	1.83
94	6	4.20	2.52	3.80	2.38
91	9	5.12	2.91	4.74	2.69
88	12	5.56	3.12	4.98	2.94
Casein		5.02	3.00	4.78	3.00

[a] Protein efficiency ratio = $\frac{\text{Weight gained}}{\text{protein consumed}}$. All values were adjusted to a PER of 3.00 for casein.

Table 16 shows the results of a nutritional evaluation of mixtures of semolina and hake-FPC before and after processing into pasta. The nutritive value was increased when FPC was added to semolina. When the various mixtures of semolina and hake-FPC were processed into pasta, there was a slight decrease in nutritive value. [11]

Kwee *et al.* [12] found that nutritious and acceptable pasta could be made from mixtures of varying amounts of corn, soya, rice and tapioca flours, mixed with 10 or 20 per cent hake-FPC and 15 to 25 per cent semolina. The pasta that contained a high proportion of rice flour was particularly acceptable. The other samples, containing corn, soya, and tapioca as basic ingredients, were also acceptable, except those containing 60 per cent corn and 10 per cent rice, 35 per cent soya and 25 per cent tapioca, and 60 per cent tapioca and 10 per cent soya. The pasta with a higher percentage of tapioca tended to be too soft. The cooking losses were high for the pasta that contained sweet potato powder. The greatest protein losses in the cooking water were observed for the pasta that contained high percentages of soya. In most cases, the nutritive value of the cooked pasta was equal to or better than casein.

Pasta supplemented with FPC made from other species of fish

Pasta made with 10 per cent FPC from other species of fish was also evaluated (see table 17). Due to the variation in colour of the FPC used in preparing the pasta, the final product also varied in colour. Pasta made with alewife-FPC, anchovy-FPC and herring-FPC was especially dark. Upon cooking, the colours bleached markedly but still remained greyish in tone. The pasta made with ocean pout-FPC and Atlantic menhaden-FPC were as acceptable as the pasta made with hake-FPC.

Texture in this case refers to degree of hardness when the pasta was cooked in boiling water for 10 minutes. The pasta was evaluated against a 9-point scale: 1, hard; 5, *al dente;* and 9, soft. The results showed that the

TABLE 17. SENSORY EVALUATION OF COOKED PASTA WITH 10 PER CENT FPC MADE FROM VARIOUS SPECIES OF FISH

Source of FPC	*Appearance*	*Texture*	*Flavour*	*Odour*
Hake (control)	3.0 ±0.00[a]	6.1 ±0.81[a]	3.0 ±0.41[a]	2.8 ±0.29[a]
Ocean pout	3.1 ±0.28	4.2 ±0.49	2.8 ±0.20	2.8 ±0.30
Anchovy	1.0 ±0.00	5.6 ±0.69	2.5 ±0.25	2.5 ±0.22
Herring	1.8 ±0.13	5.2 ±0.59	2.9 ±0.31	2.9 ±0.23
Atlantic menhaden	2.6 ±0.27	4.4 ±0.62	3.0 ±0.15	2.8 ±0.32
Alewife	1.5 ±0.22	5.1 ±0.48	2.7 ±0.26	2.8 ±0.24

a Standard error of mean.

pasta made from hake-FPC was a little softer than the others. The differences, however, were not significant.

To eliminate the influence of colour on the evaluation of flavour and odour, this part of the evaluation was done in a darkened room. The judges found no significant differences in the flavour or odour of the pastas that contained the different FPC.

Crackers

A study was conducted to evaluate the effect on acceptability and nutritive value of adding hake-FPC to saltine crackers. The crackers were made in the pilot plant of the National Biscuit Company, according to their formula. FPC was added to the formula replacing the same amount of wheat flour at levels of 0, 4, 8, 12 and 16 per cent. Somewhat more water was needed to bring the dough to the proper consistency; otherwise the ingredients and the processing procedures were the same. Table 18 shows the proximate composition of the enriched crackers. The protein content of the cracker nearly doubled when 12 per cent of the flour was replaced with FPC.

TABLE 18. PROXIMATE COMPOSITION OF CRACKERS CONTAINING VARYING AMOUNTS OF FPC
(Per cent)

FPC content	*Protein (6.25 × N)*	*Moisture*	*Fat*[a]	*Ash*
0	9.4	3.6	10.0	3.4
4	12.0	3.2	9.4	3.8
8	15.3	2.7	9.6	4.0
12	17.9	3.1	9.8	4.5
16	20.2	2.3	10.1	4.9

[a] Determined by ether extraction.

The nutritive value of the crackers was rated in a rat-feeding study, in which diets contained 8 per cent protein either from the crackers, casein or hake-FPC. Table 19 shows that substantial increases were obtained in weight, feed intake and PER values when crackers were enriched with 4, 8, and 12 per cent FPC. There was no significant increase between the 12 per cent and 16 per cent enrichment. In all cases the results were lower than those for casein or hake-FPC alone.

Table 20 shows the results of the sensory evaluation. The appearance of the fortified crackers was less acceptable than that of the unfortified crackers. However, the texture and flavour of crackers enriched with 4, 8, and 12 per cent FPC were nearly as acceptable as for the unenriched crackers. The addition of FPC to the saltine cracker seemed to make it more crispy and crumbly. The addition of FPC at the 4 and 8 per cent levels gave the crackers a "shrimpy" flavour.

TABLE 19. NUTRITIVE VALUE OF CRACKERS SUPPLEMENTED WITH VARYING LEVELS OF FPC AND INCORPORATED INTO DIETS AT 8 PER CENT PROTEIN LEVEL

FPC content (%)	*Average daily weight gain (g)*	*Average daily feed intake (g)*	*Protein efficiency ratio[a]*
0	0.32 ±0.02[b]	6.57 ±0.20[b]	0.61 ±0.04[b]
4	1.34 ±0.04	10.28 ±0.46	1.75 ±0.05
8	1.95 ±0.07	10.69 ±0.26	2.31 ±0.05
12	2.75 ±0.13	12.60 ±0.43	2.75 ±0.05
16	2.87 ±0.08	12.83 ±0.22	2.77 ±0.04
Casein	2.93 ±0.11	12.22 ±0.39	3.01 ±0.10
FPC	3.48 ±0.08	12.92 ±0.22	3.34 ±0.07

a Protein efficiency ratio = $\frac{\text{Weight gained}}{\text{protein consumed}}$

b Standard error of the mean.

TABLE 20. MEAN VALUES FOR 50 SENSORY EVALUATIONS OF CRACKERS CONTAINING VARYING PERCENTAGES OF FPC

FPC as % of flour	*Appearance*	*Texture*	*Flavour*
0	3.9 ±0.15[a]	3.1 ±0.11[a]	3.0 ±0.10[a]
4	3.4 ±0.11	2.9 ±0.08	2.9 ±0.09
8	3.1 ±0.10	2.9 ±0.08	2.7 ±0.08
12	2.8 ±0.08	2.7 ±0.10	2.8 ±0.11
16	2.1 ±0.12	2.3 ±0.12	2.4 ±0.13

a Standard error of the mean.

Cookies

Cookies are not notably high in protein content, but they are eaten in large quantities as a light dessert or a snack and can therefore contribute significantly to the dietary intake of individuals, especially children.

Cookies supplemented with hake-FPC

The formula used to determine the nutritive value of an FPC-enriched cookie appears in table 21. The addition of 10 per cent by weight of FPC, replacing the same amount of flour, not only increased the crude protein content from 5.4 per cent to 8.1 per cent, but also did not produce any undesirable or unacceptable changes in flavour, odour or appearance. The two obvious changes were: (*a*) as the amount of FPC was increased, the degree of sweetness in the cookies decreased, and (*b*) the colour turned from a bright yellow to a dull grey-yellow. The nutritive value of the cookies containing 0 per cent and 10 per cent FPC was determined in a feeding test. Rats were fed a mixture of cookies, vitamins and minerals. Cookies with no FPC had a PER value of 0.9 while those with 10 per cent FPC had a PER value of 2.3. In this feeding study the control diet, casein, had a value of 3.1. [13]

TABLE 21. FORMULA FOR A BUTTER COOKIE
(Grams)

Butter or oleomargarine	110
Sugar	200
Egg	50
Water	60
Vanilla	4
Cake flour	222[a]
Salt	1
Baking powder	7

[a] Cake flour was replaced by FPC at levels of 5, 10 and 15 per cent by weight, respectively.

Cookies supplemented with FPC made from other species of fish

A bland sugar cookie was used to evaluate the effects of adding FPC prepared from various species of fish on the sensory characteristics. The formula used was the same as that given in Section 10—50 of the American Association of Cereal Chemists' *Cereal Laboratory Methods.* [14] FPC was added at levels of either 5 or 10 per cent replacing the same amount of flour. At the 5 per cent level, the FPC did not significantly alter the sensory characteristics.

Table 22 shows the results of the sensory evaluation when 10 per cent FPC was used. The appearance of cookies made from anchovy-FPC and alewife-FPC was less acceptable than that of the control sample. No significant differences were found, however, in the flavour and texture of all of the cookies.

TABLE 22. SENSORY EVALUATION OF COOKIES CONTAINING 10 PER CENT FPC MADE FROM VARIOUS SPECIES OF FISH

Source of FPC	*Appearance*	*Flavour*	*Texture*
Hake (control)	2.9 ±0.23[a]	2.8 ±0.13[a]	2.9 ±0.18[a]
Ocean pout	2.9 ±0.23	3.1 ±0.23	2.3 ±0.39
Anchovy	1.6 ±0.22	2.6 ±0.26	2.6 ±0.36
Herring	2.2 ±0.13	2.4 ±0.26	2.8 ±0.25
Atlantic menhaden	3.1 ±0.38	2.7 ±0.33	2.8 ±0.36
Alewife	1.4 ±0.16	2.1 ±0.23	2.7 ±0.36

[a] Standard error of the mean.

The sensory characteristics of cookies were sometimes changed when FPC was added at a level of 10 per cent. However, the products were still quite acceptable to judges. Slight objections to flavour could be overcome by the addition of flavour components.

FPC beverage

A formula for a hake-FPC beverage is being studied with the aim of producing a product that can be spray-dried and reconstituted when it is to be used.

Fish-protein concentrate can be used to prepare an attractive, tasty, and nutritious beverage. The composition of the formula tested at the National Center for Fish Protein Concentrate is comparable to cow's milk in protein and fat content, but with twice the amount of carbohydrate. A stabilizer-emulsifier was used in the formula in order to make a stable suspension. The beverage, as prepared, was then dried and the resulting material examined. The powder dissolved on the tongue and left no gritty residue. It can be used as the basis of infant formulae, or it can be flavoured and coloured to appeal to older age groups. The chocolate-flavoured powder has a very acceptable taste; in fact, with minor changes, it could be used in candy bars or frozen desserts.

Forty-four grams of the dried powder dispersed in 200 grams of water will make a drink comparable to an 8-ounce glass of milk (table 23). The caloric value of the hake-FPC beverage is higher than cow's milk, because of the higher carbohydrate content. The essential amino acids, lysine and methionine, are higher and arginine is twice as high in the FPC drink; the others are equal to or a little lower than the same amino acids in cow's milk.

A preliminary study of the nutritive value of the FPC beverage demonstrated that it was higher than casein and somewhat lower than the value of the FPC used to make the beverage.

TABLE 23. COMPARISON OF THE COMPOSITION AND THE CALORIC VALUE OF AN 8-FLUID OUNCE SERVING (244 g) OF FPC BEVERAGE AND WHOLE MILK

	FPC beverage[a]	*Milk*[b]
Protein (g)	9.2	8.5
Fat (g)	12.0	11.9
Lysine (g)	0.762	0.664
Methionine (g)	0.298	0.210
Threonine (g)	0.398	0.393
Valine (g)	0.458	0.586
Phenylalanine (g)	0.369	0.415
Histidine (g)	0.180	0.224
Arginine (g)	0.628	0.312
Tryptophane (g)	0.089	0.120
Leucine (g)	0.674	0.839
Isoleucine (g)	0.402	0.544
Calories	221.0	158.0

a Amino-acid values shown are averages of 25 analyses, except for 11 analyses for tryptophane, of the FPC used in beverage

b Values for composition were taken from "Amino Acid Content in Foods", *Report No. 4*, Home Economics Research Division, Agricultural Research Service, United States Department of Agriculture, Washington, D. C., 1957.

Soups

Soups offer a large variety of flavours and combinations. They can be prepared from FPC alone with the addition of spices, flavouring and the like, or from a mixture of FPC, legumes and/or vegetables. Since legumes play an important role as a protein source in the diets of many populations, formulae combining FPC and legumes might be very useful.

The Center laboratory has studied this category of food only limitedly. Studies made of split pea and tomato soups, for instance, indicate that with the proper flavouring and formula it is possible to prepare very palatable products.

Several experiments were made to freeze-dry soups. The product had a good colour, texture and flavour. The proximate compositions shown in table 24 are the values for the dried soups. The FPC soup was prepared using FPC as the sole source of protein. The pea soup was a combination of *legume* protein and FPC.

TABLE 24. PROXIMATE COMPOSITION OF FREEZE-DRIED SOUP CONTAINING FPC
(Per cent)

Product	*Crude protein (N×6.25)*	*Fat*[a]	*Ash*	*Moisture*
FPC soup	26.2	29.5	7.9	20.9
Pea soup	24.0	31.0	8.5	4.0

[a] Determined by ether extraction.

In a sensory evaluation of pea soup containing varying amounts of hake-FPC, the panelists liked the soup that contained 5 or 10 per cent hake-FPC just as well as the soup with no FPC.

Thirty-four grams of the FPC soup powder dispersed in 170 g of water will make a brown soup base containing 8.9 g of protein. A similar serving of pea soup will supply 8.3 g of protein.

SUMMARY

Studies at the National Center for Fish Protein Concentrate have demonstrated that FPC can be prepared from several species of fish by an isopropanol extraction process. The composition of FPC made from different species of fish was slightly more variable than when made from the same species. Normally, however, the protein content ranged from 80 to 85 per cent and the fat content was less than 0.3 per cent. The nutritive value of the FPC was equal or slightly better than that of casein.

Several studies examined the effects of incorporating FPC into a variety of food products, such as bread, pasta, crackers, cookies, beverages and soups. They showed that, with minor changes in formulae, FPC can easily be added

to food products at levels of 5 and 10 per cent without markedly altering the sensory characteristics of the products. At the same time, the addition of FPC to food products significantly improves their nutritive value.

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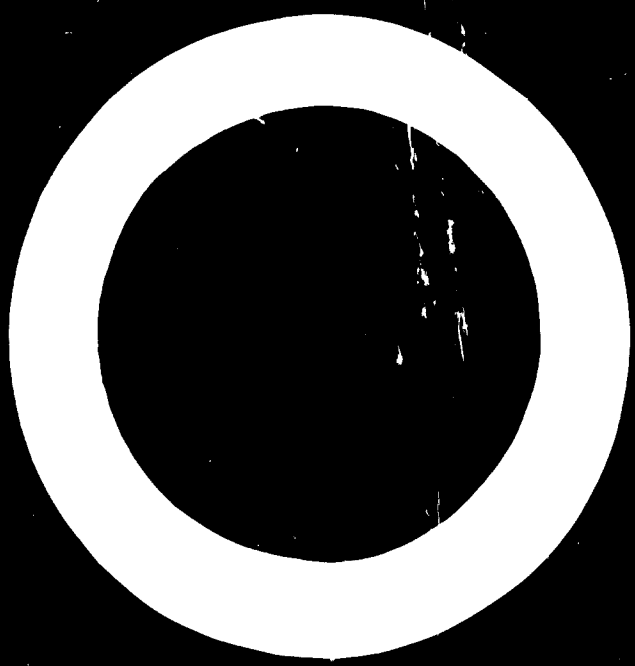

15. THE PRODUCTION AND USE OF *NUOC MAM* IN THE IVORY COAST*

Although Africa is largely free of famine, many African peoples still suffer from malnutrition caused by an insufficiency of protein in the diet. In the Ivory Coast, for example, vegetable protein from manioc, yams, plantain, millet and rice is plentiful, but animal protein is rare. Owing to the inadequate supply of livestock, the most abundant source of animal protein is the fishing industry along the Atlantic seaboard.

The Government of the Ivory Coast has endeavoured to ensure the maximum distribution of the products of Ivory Coast fisheries to urban and rural inhabitants and has promoted the breeding of freshwater fish. Unfortunately, however, the transport of perishable foddstuffs over long distances presents complex problems and inland areas are either poorly supplied with fish or often not supplied at all.

A country that has faced the same nutritional problems for centuries, Viet-Nam, has perfected a method of preserving the essential nutritive elements of fish by the manufacture of *nuoc mam*. Although it is commonly believed to be a sauce made from rotten fish, in fact *nuoc mam* can only be produced from very fresh fish. The product results from a natural process of self-digestion of the fish's flesh by its own enzymes. In the process the fish is protected from bacterial rotting by near saturation with marine salt.

Nuoc mam, which is not just a condiment but a genuine foodstuff, has high nutritive value because it provides the components of protides—not the protides themselves—in the form of amino acids, mineral salts and vitamins, especially vitamin B_{12}. These can be completely assimilated by the human body. By comparison, the highest rate of digestibility for other meat or non-meat foodstuffs is 96 per cent. The difference of 4 per cent is highly important, according to nutrition experts.

A small intake of *nuoc mam* considerably enhances the value of inferior vegetable protein and is an effective element for balancing the African diet. Recent studies carried out by the Institute of Breeding and Veterinary Medicine of Tropical Countries (Institut d'Elevage et de Médecine Véterinaire des Pays Tropicaux) in Paris have proved that amino acids that are scarce in the carbohydrate intake in Africa exist in surplus in *nuoc mam*. Small amounts

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* Paper presented to the meeting by A. Faubeau, Director, Societé FINUMA, Abidjan, Ivory Coast.

of *nuoc mam* can provide a balanced diet for children after weaning and are equally beneficial for workers who cannot afford fish or meat every day. The additional protein is especially vital for children, since their physical and intellectual growth depends on the quality of their diet during their first five years.

Nuoc mam contains the following nutritive elements in different amounts depending on its quality:

Amino acids: aspartic acid, serine, glutamic acid, proline, glycine, alanine, tyrosine, histidine, arginine and, above all, the nine amino acids essential to the growth and maintenance of the human body that is threonine, valine, cystine, methionine, isoleucine, leucine, phenylalanine, lysine and tryptophan;
Mineral salts of: phosphorus, bromine, iodine, calcium, magnesium, iron, sodium chlorine, fluorine and others;
Vitamins: PP, B_1 and, in particular, B_{12}.

The food value of *nuoc mam* and the ease with which it can be used have prompted the Government to study the possibility of its manufacture from fish caught off the shores of the Ivory Coast. Studies were entrusted to the Company for Economic Studies and Industrial Management (Compagnie d'Etudes Economiques et de Gestion Industrielle). According to the findings, confirmed by specialized laboratories, several types of fish plentiful in the coastal region near Abidjan can be used to manufacture a *nuoc mam* of excellent quality and keeping properties. The product also combines well with Ivory Coast cuisine and can be widely adapted for use at Abidjan and in the interior of the country, where valuable nutritive elements are especially needed. In general, it fits well into the traditional recipes of African countries, since it is easily substituted for salt.

Until recently, *nuoc mam* was not well known in the Ivory Coast, since it had to be imported from Viet-Nam and consequently was priced too high, 1,100 to 1,200 CFA francs per litre. However, the product manufactured industrially at Abidjan, which contains at least 15 g of "total nitrogen" per litre (a superior quality according to Vietnamese regulations), can be sold throughout the Ivory Coast at approximately 400 CFA Francs per litre.

Aware of the great potential of *nuoc mam* for improving the diet of the people of the country, the Government of the Ivory Coast has authorized and participated in the establishment of the first large-scale brining industry of its type in Africa, if not in the world. (In Viet-Nam the *nuoc mam* industry is divided among many small-scale family briners. This multitude of processors in the best years produces as much as 100 million litres of *nuoc mam*.)

The experiment in the Ivory Coast has been specifically motivated by the following considerations:

Studies showed that an excellent quality of *nuoc mam* could be manufactured profitably there;
the establishment of the industry would cost relatively little and would not require complex industrial equipment;

its manufacture would not require highly trained specialists nor a large labour force;

the product is unusually acceptable to the people of the Ivory Coast. (A really new food—one quite distinct from existing foods—usually encounters resistance where food habits are traditional and its introduction requires learning new recipes.)

Nouc mam is of considerable therapeutic value because of its vitamin content, including B_{12}, which helps to prevent anaemia, and trace elements, including calcium and especially iodine, which are effective against goitre. It can be preserved in well-capped bottles for many years without deterioration. Artisan or family production is possible, as in Viet-Nam, once there are enough trained workers. And, finally, the industry can make use of small fish, which are not normally utilized because they have a low commercial value.

The young *nuoc mam* industry of the Ivory Coast has the modest initial aim of producing 1.2 million litres per year, to be achieved through progressive increases of 400,000 litres per year. The cost of financing is about 60 million CFA francs, of which 35 million is registered capital representing approximately the first investment instalment. The majority of the subscribed capital is held by citizens of the Ivory Coast.

The undertaking in the Ivory Coast is in the interest of all Africa. Even without the impetus of extensive advertising, the product is being ordered from central African republics, and private experts or technical assistants representing Mali, Cameroon and other countries have approached the Ivory Coast seeking help to establish their own *nuoc mam* factories.

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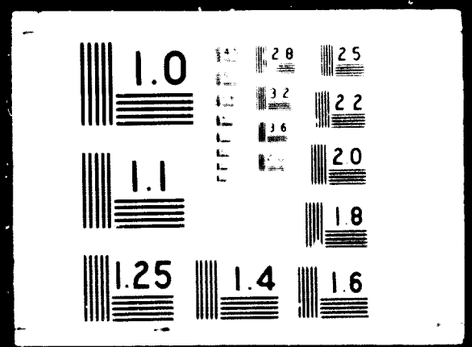

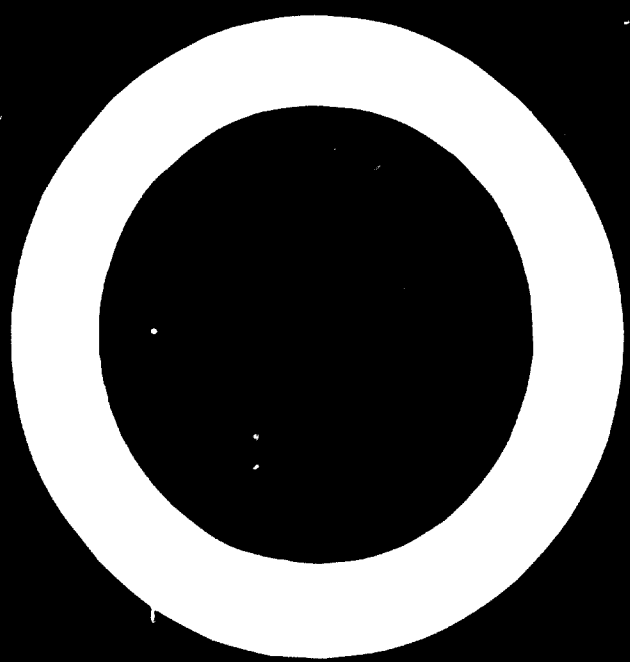

16. THE US/AID PROGRAMME FOR EVALUATING AND PROMOTING FPC*

In 1967, the United States Marine Sciences Council authorized the Agency for International Development (US/AID) to develop fish-protein concentrate for overseas use. At the time appraisals indicated one conclusive argument for the introduction of FPC and pointed out a number of undetermined aspects relating to its production, marketability and acceptability.

It was established that FPC was highly nutritious, with a protein content of 75 to 80 per cent. It had been produced up until then, however, under laboratory conditions, representing only a preliminary step.

The following questions concerned cost of production, markets and consumer acceptance:

There was no actual commercial production of FPC;
The economic feasibility of FPC production had not been gauged, especially its cost/protein value compared with other available protein sources;
There were no markets for FPC nor effective demand for FPC and FPC-fortified products;
The degree of consumer acceptance of FPC-fortified products was unknown.

In short, formidable obstacles had to be overcome if FPC were to achieve its potential.

Taking these difficulties into consideration, AID developed a programme to determine the applicability of FPC in reducing hunger and malnutrition. Its effort was concentrated on FPC feasibility studies and on the purchase of a specific quantity of FPC for distribution and experimentation.

Feasibility studies

Interdisciplinary teams consisting of fisheries experts, economists, food technologists and marketing specialists visited twelve countries in 1967 to

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* Paper presented to the meeting by J. B. Cordaro, Program Co-ordinator, Food from the Sea Service, Office of War on Hunger, United States Department of State, Washington, D. C., USA.

determine which offered the best conditions for the establishment of a viable FPC industry. The recommendations of the teams were that Chile, the Republic of Korea and Morocco could provide demonstration sites for FPC feasibility studies. The teams employed the following guidelines in making their selection:

Adequate fish resources and harvesting systems, capable of providing at least 20,000 tons annually in addition to present landings at a price of about $22 per ton;
Favourable attitude of the host government;
The scientific and technological capability to carry out research needed to develop a local FPC programme:
The ability to construct and operate a plant suitable for FPC production;
Locally based food companies capable of and willing to market new or modified foods containing FPC;
- Suitable foods for incorporating FPC which could be made available to under-nourished people in low income groups (samples for market studies would be drawn from among these people);
Transportation and distribution systems capable of serving groups where a demonstration programme might be conducted.

Since it was recognized that no country could satisfy all of these criteria, the countries recommended were considered the best qualified.

The teams based their judgement on these assumptions:

That an FPC plant could use any underutilized fishery resource found to be acceptable for the manufacture of FPC;
That the economic operation of an FPC plant would require a minimum supply of 100 tons of fish daily for 200 days annually;
That ethanol could be substituted for isopropanol in the manufacture of FPC without significant modification in the process or in the characteristics of the final product;
That FPC could only be sold either as part of a staple food already established in the market or as an ingredient of a new, formulated food;
That the demonstration programme would be directed to people in the low income groups, and that distribution of FPC-fortified foods to people outside the money economy would have to be undertaken as a non-commercial activity—by the government or other feeding programmes.

On the basis of these recommendations, AID awarded a contract in June 1968 to General Oceanology, Inc. of Boston, Massachusetts, to conduct experiments in Chile and the Republic of Korea. The objective of these studies, which consisted of market analyses, supply analyses, and product development and testing, was to determine whether and by what means a viable FPC industry could be established.

Market analyses

Market analyses were designed to determine if FPC-fortified foods were acceptable to the people for whom they were intended; to identify opportunities for introducing FPC-fortified products into government and other institutional feeding programmes, and into commercial channels; and to establish whether sufficient potential demand existed to justify the building of an FPC plant. It was first necessary to identify the values, beliefs and environmental and other factors contributing to the dietary patterns and food concepts of the target groups.

Analysis of supply

The object of this phase of the studies was to determine whether an adequate supply of inexpensive underutilized fish was available and could be landed; the cost and selling price of FPC and FPC-fortified products; and the relationship between FPC cost and scales of production.

Product development and testing

Product development and testing were concerned basically with the techniques of fortifying staple foods with FPC and with testing them for flavour and price acceptability.

The conclusions of the Republic of Korea feasibility study were the following:

> Protein malnutrition exists in certain target groups, especially among weaning infants, pre-school children, pregnant or nursing women, and members of low income groups (both urban and rural);
> Present economic considerations and raw material shortages mitigate against starting a commercial FPC operation in Korea. Alternatives exist, however, for improving the utilization of fish that might encourage the production of FPC;
> FPC can contribute towards alleviating the protein shortage if the goal is to provide the cheapest source of animal protein.

Unless the government of a country is interested in and committed to the use of FPC in its feeding programmes, and will agree to purchase a certain amount of the product from the plant, there is little chance that an FPC industry will be established. In Chile, the Government indicated that it would use 50 to 60 per cent of the anticipated capacity of the plant, which is designed to produce between 4,000 and 5,000 tons of FPC annually. Other markets for Chile are the pasta industry and weaning infants and baby foods. Because of the high risk of the enterprise and the changes in concepts and processes that FPC is expected to go through in the next years, General Oceanology is amortizing a plant in Chile over a five-year period rather than the usual 10 to 20 years.

Purchase of FPC

Another aspect of the AID programme has been to purchase FPC in order to provide sufficient quantities for product development and acceptability tests and to supply high quality protein for use in pre-school feeding programmes. The purchase of FPC by AID is in accordance with the Foreign Assistance Act (1968), which encourages the expenditure of funds for FPC and other protein concentrates. (An AID attempt to launch an FPC industry in the United States through a guaranteed purchase proved uneconomical, and the contract was terminated when the product was judged unsatisfactory.)

The main possibilities for the use of FPC lie in maternal and child health programmes, school lunch and other child-feeding programmes and in national nutritional programmes. The fortification of food in developing countries is often hindered, however, by lack of central processing facilities and of product standards that can be changed and policed, insufficient control of the distribution system to ensure product quality and safety, and the absence of an institutional promotion programme or commercial markets that reach the groups in need.

To overcome these and other problems, AID has developed a programme designed to obtain reliable data on consumer acceptance, product stability and packaging requirements of FPC and FPC-fortified food products, working closely with American voluntary agencies, such as the Church World Service, Catholic Relief Services, CARE, Unitarian Universalist Service Committee and others. The goal is to determine how FPC can be used to fortify foods under safe and wholesome conditions and whether the FPC-fortified foods are acceptable to test groups. The method of testing will follow a similar pattern from country to country, taking into account different types of foods, eating habits, customs and taboos. The evaluation team, with the co-operation and assistance of AID missions and host governments, will select possible foods for FPC fortification that are relevant to the country's traditional cuisine or specific feeding programmes. Formulae will be developed to incorporate optimal amounts of FPC into these products. And to help assure acceptance, detailed information will be gathered about the normal feeding routines of the various institutions and schools taking part in the programme, the degree of interest and competence on the part of the personnel, and the expected levels and variation of FPC fortification. Finally, the programme will observe the following operating principles:

It should be as inobtrusive as possible (ideally, the test groups should be unaware that the experiment is being conducted or that they are being observed);

Within a particular test group, 100 or more people will be served together;

At least one technician in addition to the regular kitchen staff should supervise serving and the recording of data;

There should be various levels of FPC fortification and different timing of its use.

AID goals in Morocco

The AID project for the introduction of FPC into Morocco illustrates how the Agency intends to implement its programme. The plan involves a joint effort on the parts of the Government of Morocco, AID and the United Nations. The over-all objectives of the project are: to determine the feasibility of establishing an economically viable fish-protein concentrate industry in Morocco and to develop a method of introducing FPC and FPC-fortified products into the Moroccan food system; and to develop a marketing and distribution plan for feed-grade FPC produced by the SONAFAP plant at Agadir.

To achieve these objectives, the AID contractor, in close consultation with FAO and UNIDO, will concentrate his efforts on the following:

> Determining the economic potentiality of converting sardines into FPC and the demand required to justify the operation of an industry in Morocco;
> Establishing the cost/protein value of utilizing FPC as opposed to the cost/protein value of alternative proteins or mixes of proteins available or potentially available for use in Morocco;
> Developing new food formulae utilizing FPC, testing the acceptability of all FPC-fortified products through target groups, and setting up a system whereby these products can reach the target groups;
> Analysing the economic practicality of producing feed-grade FPC at SONAFAP, its marketing and distribution.

Taking into consideration the fisheries data supplied by FAO, the AID contractor will analyse the variables of harvesting, preserving and transporting sardines to determine the lowest possible cost of FPC production and the cost-demand curve at various production levels. He will also analyse all other factors, including the utilization of by-products and feed-grade FPC production, relevant to determining the over-all cost of producing FPC in Morocco. (UNIDO is expected to provide much of the data for this analysis, for example, that for labour, equipment and operating costs, overhead costs and margin of profit desired.)

On the basis of this analysis and engineering data supplied by UNIDO, the AID contractor will recommend locations for FPC plants and their size, and specify the form of the distribution system for least-cost production, marketing and distribution of FPC. These recommendations must consider the existing SONAFAP location vis-à-vis other potential sites. In addition, the contractor will select the most suitable process for converting sardines into FPC. He will determine the possibilities for foreign investment in an FPC industry in Morocco. And, with assistance from FAO, he will assess the potential for FPC and FPC-fortified products as exports in international trade.

A market survey will be designed to collect all information required to determine the practicality of using FPC to fortify certain food products for non-institutional and institutional protein-deficient target groups in Morocco.

For non-institutional use, the contractor will identify selected protein-deficient target groups in representative rural and urban areas by age, income levels, geographic location, dietary habits, factors that influence dietary patterns, and the Government's policy and plans for dealing with the nutritional problem. Within the non-institutional target groups, the contractor will emphasize infants, pre-school-age children and pregnant and lactating women.

For institutional use, the contractor will identify, describe and quantify institutional feeding programmes, such as school lunch, industrial canteens, army mess, maternal and child health and others.

The contractor will be responsible for identifying all food products and types of products consumed by both target groups that are potential vehicles for FPC fortification, in terms of:

The technical practicability of fortifying with FPC;
The potential that these FPC-fortified products have for improving the quality and quantity of the protein intake of the target groups;
The price structure of the foods and food ingredients normally consumed and used by the target groups, and the factors that determine these prices;
The additional cost FPC adds to the fortified product, and the product's acceptance in economic terms;
What effect, if any, the traditional market structure might have on the processing and marketing of FPC-fortified foods;
The possible interest of local private manufacturers in FPC products;
Measures and programmes—government and private—that might be used to promote FPC (these recommendations would include advertising and educational campaigns that could be carried out by FAO and UNIDO).

The data gathered by this survey will be used to develop product formulae and processes for incorporating FPC into certain foods, to promote new food concepts consistent with the needs and preferences of the target groups, and to undertake tests to determine taste and cost acceptability of these FPC-fortified products.

Once the degree of acceptance has been established, the contractor, working with the Government, local manufacturers, FAO and UNIDO, will develop a plan to manufacture and test FPC-fortified products for a sufficient period of time to derive reliable and significant data to assess the potential market for FPC in Morocco.

The objective of determining the market for feed-grade FPC will be to place the production at SONAFAP on a sound economic basis. To this end, the AID contractor will evaluate and analyse the present procedures for marketing and distributing feed-grade FPC manufactured at the SONAFAP plant at Agadir and recommend methods to improve domestic and export marketing and distribution. In this, he will work with UNIDO personnel

engaged in making improvements at the SONAFAP plant and will utilize suitable production and engineering data that they have developed.

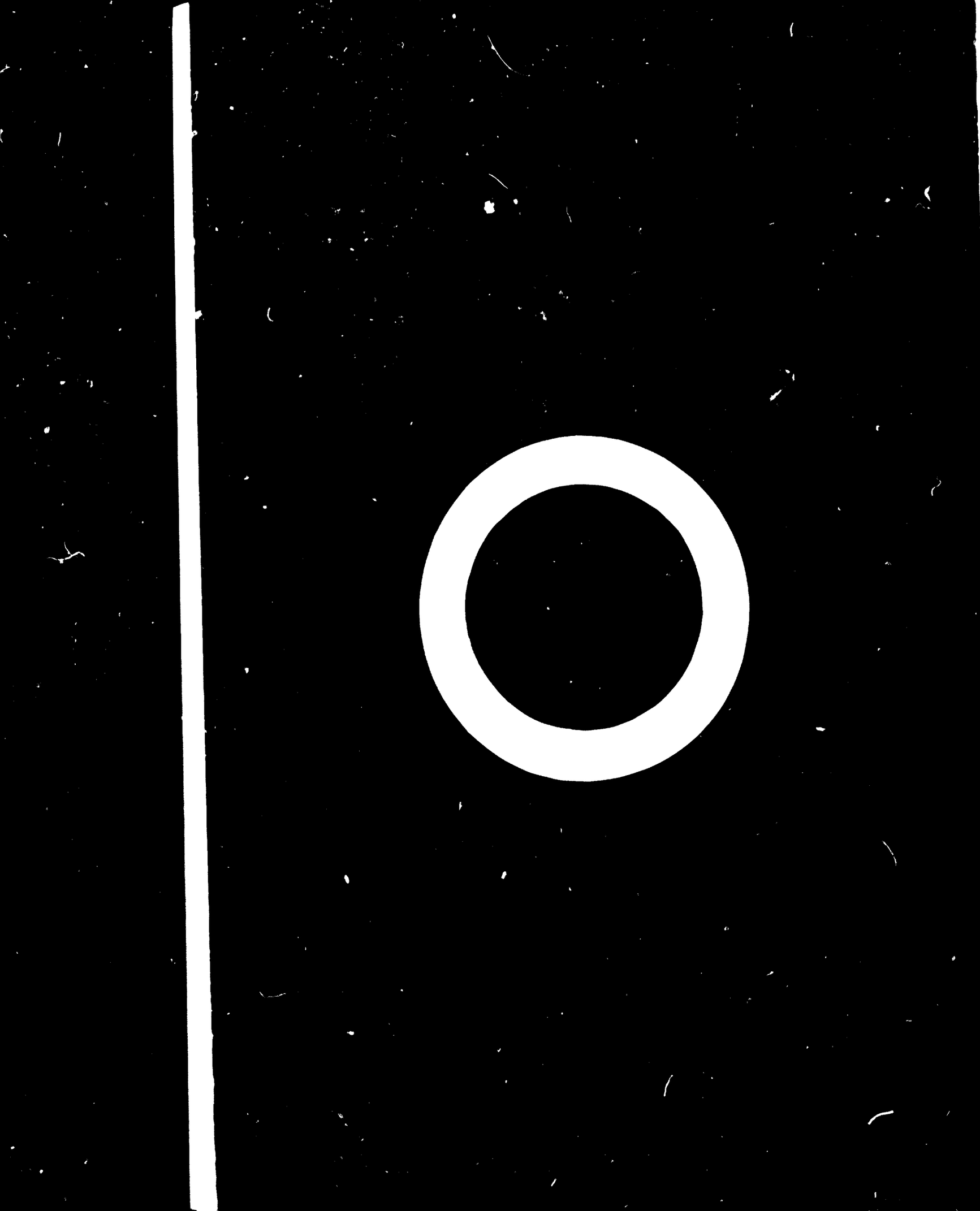
Summary

Although the AID feasibility study is to be carried out in close consultation with FAO and UNIDO, the final AID report should be useful in itself for investment and as the basis for other decision-making. It is anticipated that UNIDO, with the assistance of AID and FAO, will review the activities relating to the possibility of establishing an FPC industry in Morocco and suggest a follow-up to assure that the recommendations are effectively executed. The AID contractor is expected to participate in drawing up the recommendations.

Marketing

In order to market FPC successfully, it must be made available in a palatable and desirable form. The development, promotion and marketing of FPC-fortified foods that would be desirable to the consumer requires the most urgent attention. Present efforts are totally inadequate. The FPC so far available has not yet proved sufficiently attractive when incorporated into human foods to encourage individuals to pay for the product or governments to subsidize it. Work on acceptability of FPC is of major importance, together with research to modify its properties. Such research might yield new products with interesting properties that could be employed usefully to improve the characteristics of the staple foods. In all probability a similar level of research and development could determine ways in which FPC might offer positive advantages to the consumer, including an increase in nutritive value when suitably employed in the preparation of acceptable foods.

The greatest hurdle in the way of the widespread introduction of low-cost protein foods of indigenous origin into the diets of developing countries lies in their acceptance. To a much greater degree than heretofore, studies of cultural habits and attitudes pertaining to food, systematic marketing surveys and the application of commercial experience to new food products are required for the promotion of new protein foods. If acceptable food products containing FPC are successfully promoted and consumed, ample private capital should be forthcoming to help develop an FPC industry.



17. UTILIZATION OF FPC: AN ANALYSIS TO HELP FORMULATE NATIONAL NUTRITION POLICY

Comparative costs of reference protein

Few guidelines exist to assist governments in deciding on the objectives of national nutrition programmes. Scientific analysis is needed not only of fish-protein concentrate and other staple fortification possibilities but also of the implications for nutrition of national agricultural and other policies affecting investment in foods.

For the purpose of discussion, therefore, the authors use a hypothetical model (developed by Sidney M. Cantor Associates) that considers price, reference protein[1] and other relationships in a hypothetical developing country suffering from a protein gap. The model considers important traditional foods as well as sample protein-fortified foods. Calculations are used to show price rankings of reference protein [2] of various traditional and protein fortified foods as compared with a staple — in this case, rice. These price rankings can be modified and extended to permit other comparisons such as those related to consumer demand and acceptability, protein calorie utilization efficiency and attractiveness for investment.

The calculations attempt to answer the question, what would be the best product to invest in if a government or a private investor, or both, were interested in a product (1) which could provide low-income groups with the highest possible yield of reference protein; (2) whose price per unit of reference protein was low relative to a staple cereal — in this case, rice; and (3) which was in strong demand by low-income consumers and likely to increase in demand as incomes rose.

The calculations show the effects of a particular set of price relationships at a particular time. As these price relationships change, the calculations may yield quite different results. Their sensitivity has been demonstrated in a test with the results of an analysis of soybean product consumption in a sample country. The consumption of soybean products in this country is largely in the

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[*] Paper presented to the meeting by Gerald D. Bernstein, Idmon, Inc. (formerly of General Oceanology, Inc.); Sidney M. Cantor, Sidney M. Cantor Associates, Inc.; and Solomon H. Chafkin, American Technical Assistance Corp.

[1] A protein of high biological value, containing a specified pattern of amino acids completely utilizable for anabolic purposes at maintenance levels. See FAO/WHO (1965), *Protein requirements*, Rome, p. 68.

form of bean curd, and the price of bean curd is significantly higher than all other soybean products consumed by humans. If the adjustment in price is made to reflect the price of bean curd, the use of soybean becomes less practical than fortification by either soy concentrate or FPC.

The analysis does not satisfy the private investor's need to know in highly specific terms the details of certain projects—capital requirements, cost of production, potential sales and profits, financial terms, potential return on capital and other critical variables. Nor does the analysis at this stage answer questions that government planners need to know in connexion with the allocation of government resources or the encouragement or discouragement of the allocation of private resources. However, the calculations can be extended to estimate the effects on the balance of payments, or on employment, or on the costs to the economy if one means of achieving nutrition objectives are adopted rather than another.

For the purposes of this study, the price per kilogram of reference protein is taken as a basis for comparison. A summary appears in table 1, where "price ranking of reference protein" is defined as the price of the reference protein in rice divided by the price of the reference protein in the particular foodstuffs.

TABLE 1. PRICE COMPARISONS OF REFERENCE PROTEIN IN TRADITIONAL FOODS

	Price of reference protein in US ($/kg)	*Price ranking of reference protein (rice = 1.00)*
Cereals		
Rice	4.26	1.00
Barley-H	2.61	1.62
Barley-N	2.30	1.86
Wheat	2.78	1.53
Other	3.41	1.25
Vegetables		
Soybeans	0.61	7.05
Soybeans (as bean curd)	1.60	2.66
Other pulse	0.73	5.80
Potatoes-sweet	10.19	0.42
Potatoes-white	4.78	0.89
Other	18.52	0.23
Animal		
Beef	2.98	1.43
Pork	1.85	2.30
Chicken	1.85	2.30
Fish-dry	0.86	5.00
Fish-fresh	0.84	5.40
Fish-shell	1.89	2.25
Milk	9.44	0.45

Comparisons of traditional foods show the superior position of soybeans and pulse among vegetable sources and the distinct advantages offered by fresh and dried fish over other sources of animal protein. The implications of these rankings with respect to economic policy are discussed later in this section.

A similar comparison for protein-fortified foods appears in table 2.

TABLE 2. PRICE COMPARISONS OF REFERENCE PROTEIN IN FORTIFICATION AGENTS

Protein-fortified foods[a]	*Price of reference protein in fortification agent in US $/kg*	*Price ranking of reference protein (rice = 1.00)*
Lysine, 0.2% in wheat	0.14	31.5
Soy concentrate, 6.0% in wheat	0.54	7.8
FPC, 5.0% in wheat	0.36	11.7

a Price of lysine, soy concentrate and FPC are $1.00 per pound, $0.27 per pound, and $0.25 per pound respectively.

It should be noted that the superior position of lysine fortification compared with soy concentrate and FPC is based upon the price per unit of only the additional protein made available by the fortification agent. This "incremental cost" differs from the evaluations made by D. M. Hegsted comparing lysine and FPC fortification of wheat flour under specified cost assumptions. His findings, which are summarized in table 3, are based on "total" or "integral cost"—the cost per unit of the total protein in a unit of fortified wheat flour; that is, the protein normally in wheat plus the protein made available by the fortification agent.

TABLE 3. EFFECT OF PROTEIN FORTIFICATION OF WHEAT FLOUR ON THE NUTRITIVE VALUE AND COMPARATIVE COST OF UTILIZABLE PROTEIN

	Protein content[a] *(%)*	*Nutritive value*[b] *(%)*	*Utilizable protein*[c] *(%)*	*Cost/100 lb*[d] *($)*	*Cost of utilizable protein/lb ($)*
Wheat flour	13.75	24	3.20	8.00	2.50
Wheat flour + 0.2% lysine . HCl	13.94	38	5.30	8.20	1.55
Wheat flour + 0.5% lysine . HCl	14.25	46	6.55	8.50	1.30
Wheat flour + 0.5% lysine . HCl + 0.3% threonine	14.55	56	8.14	8.95	1.09
Wheat flour + 5% FPC	16.66	42	7.00	8.85	1.26
Wheat flour + 10% FPC	21.26	50	10.68	9.70	0.91

Source: D. M. Hegsted, Professor of Nutrition, Harvard University.
a N×6.25 (all tests are based on nitrogen content).
b Nutritive value compared with nutritive value of lactalbumin.
c Protein content × RNV (relative nutritive value) = utilizable protein.
d Cost estimates upon regular bread flour at $5.50/100 lb at New York with shipping costs to India (as an example) of approximately $2.50/100 lb (courtesy of Bernard Rothwell, Bay State Milling Company, Boston). Lysine, threonine, and FPC taken as $1.00, $0.25/lb, respectively.

Cost of total protein versus cost of incremental protein

The incremental cost of lysine fortification is cheaper than that of FPC. The total cost of FPC fortification, however, is cheaper than that of lysine. (See table 4.)

TABLE 4. COST OF TOTAL PROTEIN COMPARED TO COST OF INCREMENTAL PROTEIN

	Cost ($/kg)	*Protein content (%)*	*Protein efficiency*	*Reference protein (g/kg)*	*Cost of reference protein ($/kg)*
Lysine fortification (0.2%)					
Wheat	0.10	13.0		42.2	2.37
Lysine (incremental protein)	2.22	0.2		35.0	0.13
Mixture (total protein)	0.10	13.2	0.585	77.2	1.35
FPC fortification (5%)					
Wheat	0.10	12.35		40.0	2.37
FPC (incremental protein)	0.56	4.25		61.0	0.46
Mixture (total protein)	0.12	16.60	0.608	101.0	1.21

Consideration of the cost of total protein versus cost of incremental protein is important in determining the choice of objectives facing a government in the process of developing a nutrition policy. If the government decides to import its protein in the form of fortified wheat flour, the Hegsted total-cost-of-protein analysis would apply and FPC fortification would appear more feasible than lysine. If the government decides to fortify all of its current domestic wheat production, which already provides the population with a certain quantity of protein, it would need to know at what cost it could obtain the additional protein supplied by each of the alternative fortification agents. In this case, the analysis of cost of incremental protein could apply and lysine could increase the protein supply at the minimum cost. The assumption that lysine is available at $1.00 per pound is of critical importance. If the price were $2.68 per pound, FPC would be equivalent to lysine in the analysis of cost of incremental protein, provided that the FPC cost remained at $0.25 per pound.

Thus, using L-lysine at the 0.2 per cent level, the cost of adding one kilogram of reference protein to the diet is $0.13 versus $0.46 with the use of FPC at the 5 per cent level. If, however, the cost per unit of total protein is used as a basis, FPC appears superior to lysine; the cost of total protein using FPC is $1.21 and the cost using lysine is $1.35. The difference would be more pronounced at higher levels of FPC.

Planners are especially concerned with the cost of obtaining new protein resources. They regard the protein from the existing wheat crop as a resource already available and are more interested in comparing net costs of new

protein from alternative fortification agents. If a planner wishes to develop the maximum amount of additional protein by encouraging new wheat production and the fortification of this wheat, the cost of total protein of the protein-fortified food would be critical. In this case, wheat flour fortified with FPC, as the Hegsted analysis indicates, would provide this new protein at the lowest cost.

Cost effectiveness

A preliminary cost-effectiveness analysis can be made by comparing the costs of total and incremental protein in the light of a stipulated national objective for the improvement of nutrition. When the stipulated objective has as a condition to avoid the expenditure of substantial foreign exchange, commercial imports of wheat may be rejected regardless of how low the international price may be. When the stipulated objective has as its target group infants and weaning children, the limited capacity of these children to consume large amounts of cereals that would be required in lysine-fortified food to obtain a satisfactory amount of protein would argue in favour of FPC for cost effectiveness. But this objective itself raises a new problem relating to formulating new products for child feeding.

An additional and critical element to be weighed is the "delivered cost" of protein. Again the analysis depends upon the aim of the government. A general objective to provide more protein to low-income families at the lowest delivered cost might be best served by lysine fortification of noodles and other wheat products distributed commercially. Limiting the target groups to children might lead to a highly specific child-feeding programme utilizing FPC as a milk additive or FPC plus cereals and amino acids in special food formulas distributed through maternal and child health centres. Here the delivered cost per head might be much higher than a general fortification programme, but the total cost might be much lower. Moreover, if the policy also aimed at increasing the survival rate of children as a necessary precondition for accelerated family planning, the benefits of child-feeding programmes would be enhanced.

Cost of closing the protein gap

A reference protein deficit of 31,000 tons was estimated for the sample country used in this study. The cost of making up this deficit with conventional protein sources (table 5) ranges from a high of $140.7 million for rice to a low of $27.6 million for fresh fish. The fortification agents are in themselves lower in cost, but in each case a substantial increase in the domestic wheat supply is needed in order to obtain the required protein through fortification.

The total cost of closing the protein gap by lysine fortification of the existing plus the newly required wheat supply would substantially exceed the total cost (fortification agent plus new wheat) of an FPC or soybean fortification programme or of an expansion in domestic fish supplies. Use of a soybean meal would also be cheaper. The additional wheat required for a lysine programme would present special problems in the use of scarce agricultural land to avoid displacing other protein sources, as well as special foreign-exchange problems arising from commercial wheat imports.

TABLE 5. COST OF PROVIDING 31,000 TONS OF REFERENCE PROTEIN BY INCREASING THE SUPPLY OF SELECTED PROTEIN SOURCES

	Cost (million dollars)		*Per cent increase over present supply needed to fill protein gap*
Rice	140.7		21
Barley	81.4		35
Wheat	91.8		300
Soybeans (bean curd)	59.2		63
Beef	98.5		308
Pork	61.1		458
Chicken	61.1		465
Fish (fresh and processed)	27.6		33
Lysine (0.2% in wheat)	4.4	(plus $30.3 for additional wheat)	(100% more domestic wheat or equivalent imports)
FPC (5.0% in wheat)	12.0	(plus $7.4 for additional wheat)	(24% more domestic wheat or equivalent imports)

NUTRITION OBJECTIVES AND RESOURCES ALLOCATION

The clear and strong commitment of the government to national economic growth will inevitably lead to a consideration of policies that seek to improve the standard of living, especially that for low-income groups. The government must eventually delineate national nutrition objectives, and in doing so, it is important to take into account early the consequences of economic policies on nutrition and to seek ways of harmonizing nutrition objectives with other national goals.

The government may, it it chooses, formulate national objectives and policies aimed at low-income groups generally or at special target groups, such as weaning children and pregnant and nursing mothers. Its decisions in this regard will be guided by whether a commitment to achieve nutrition objectives is feasible in the light of other national commitments and what

kinds of re-allocations of resources would be called for in order to fulfil a nutrition objective, including the achievement of an optimal calorie-protein balance. Major actions to improve the diet would immediately and directly require a re-assessment of agricultural and fisheries policies and resources, balance of payments policies, subsidies or other incentives to producers of some classes of foods, and a variety of other policies that had helped to shape the existing allocation of public and private resources.

In the short term, it may not be possible to assign a high priority to nutrition objectives if such action will have adverse effects on such overriding issues as the country's balance-of-payments position. It would seem unlikely, for example, that the government would wish to encourage a massive increase in the supply of fresh fish for its domestic market if such action diverted energy and attention from the aim of expanding fish exports. Even if such an increase in the domestic supply of fish were attained without adversely affecting fish exports, it would still be necessary to examine the investment implications of expanding the fish harvesting, storage, processing and delivery systems.

On the other hand, the question will undoubtedly arise whether sufficient attention and resources are being devoted to increasing domestic supplies of fish relative to the attention and resources now accorded, for example, to the development of a poultry industry. The nutrition costs and benefits from fish and poultry raise legitimate questions as to the relative emphasis given to each industry.

The role of FPC in nutrition planning

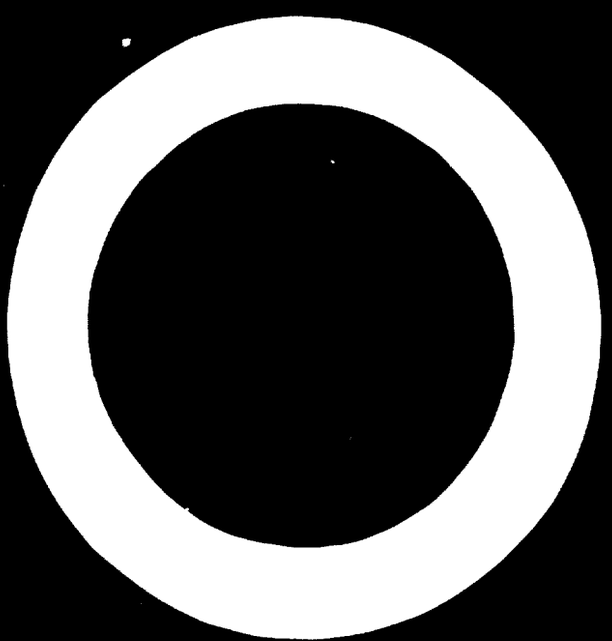
The obvious attractiveness of fresh and dried fish in improving the diet justifies the intensification of efforts to expand the domestic fish supply and to reduce costs to the consumer. But even if this could be accomplished, it is not clear that it would solve the special problems of vulnerable groups such as weaning children. Here, the government may find the choice of solutions especially difficult. For example, the greater availability and lower price of milk may be one effective strategy, but it presents problems in the high costs of developing a domestic milk industry as well as in the foreign-exchange costs of importing relatively low-priced non-fat dry milk from countries where there is a surplus of milk.

A second solution is fortification of cereals. The most practical vehicles for commercial fortification are products made from wheat flour. These include noodles, biscuits, soups and some beverages. All of these foods, as well as new baby food preparations, will cost more if they are fortified, and the government must decide whether or not to subsidize the food industry in order to assure maximum utilization of the fortified foods by low-income groups. The government will also have to examine whether free distribution through existing maternal and child health centres would be a more efficient system for reaching target groups than a generalized commercial food fortification programme.

The cost of fortifying food with domestically produced FPC is likely to be quite high compared with the cost of fortifying food with FPC imported from a country such as Chile which enjoys abundant supplies of cheap raw material. The provision of 31,000 additional tons of reference protein per year—the estimated requirement—would call for substantial imports of FPC. Special feeding programmes for weaning infants, however, would entail lower annual imports but would probably require increased domestic expenditures to establish a food distribution system that would reach the target group.

It is highly doubtful that private investors would find an FPC enterprise attractive under current conditions in the sample country. Although there is considerable interest among noodle manufacturers in fortifying their products with FPC, the price at which they would find FPC attractive is far lower than would be possible considering current prices for raw fish in that country. Government subsidy and guaranteed purchase arrangements would be needed to interest private groups in an FPC-manufacturing venture.

A government-subsidized plant to produce FPC for low-income groups using domestic fish resources would redistribute the country's protein supply. Poor people who cannot afford much fish would get more protein in noodles and other wheat-based foods. The entry of another buyer into the market, however, would also tend to increase the price of fresh fish, with an adverse effect on middle-income groups. Unless FPC can be produced without adversely affecting the supply of fresh fish already available in the diet, the possible benefits of government subsidy to improve nutrition are cancelled out.



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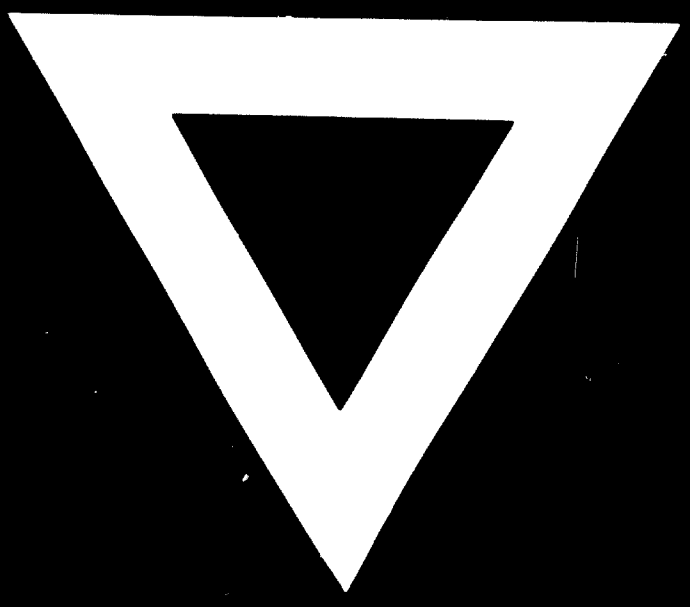

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