MIT-UNICEF STUDIES ON THE PRODUCTION OF FISH PROTEIN CONCENTRATE FOR HUMAN CONSUMPTION

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ABSTRACT

Specific problems relating to (1) the dehydration, defatting, and deodorizing of fresh whole fish and (2) the defatting and deodorizing of commercial fish meal were studied at the Massachusetts Institute of Technology, under the sponsorship of UNICEF in consultation with FAO. The effect of processing variables on the quality of the final product was also investigated.

INTRODUCTION

In many parts of the world where populations suffer from the effects of a serious and increasing shortage of dietary protein, vast fish resources are known to exist. Yet, in many such localities, those resources have remained virtually untapped because facilities for the conservation, storage, and distribution of fresh or processed fish are lacking.

In order that locally existing marine products can be made available as food, it has been contemplated to prepare from fish a stable product of high nutritional value that can be readily stored and transported and used as a valuable supplement to local diets. The product usefulness and stability required cannot be achieved without the removal of water to reduce bulk and weight and to minimize bacterial and enzymatic spoilage; lipids and lipid-related compounds must also be removed, since their usually highly reactive nature makes them likely to be rapidly oxidized, with the formation of flavors and odors disagreeable to most people. Apart from impairing the palatability, such oxidized products may also produce undesirable side effects, such as gastric upset.

Numerous methods for producing such a fishery product have been published or are the subject of patent applications. Most of the published work, however, appears to refer to laboratory investigations only. Comprehensive studies correlating the evaluation of biological protein quality with processing data are seldom reported.

Among procedures suggested for the preparation of fish protein concentrates, solvent-defatting and solvent-deodorizing showed promising results and so were further investigated. Processing methods based upon these operations vary mainly in the method of dehydration, choice of solvent or solvents, and conditions of extraction. In an effort to clarify the effects of these variables on the composition, protein quality, and taste- and smell-characteristics of the final product, the United Nations International Children's Emergency Fund (UNICEF), in consultation with the Food and Agriculture Organization (FAO), arranged for a study of those problems by the Department of Food Technology of the Massachusetts Institute of Technology (MIT). This study was completed in 1961. The purpose of this paper is to summarize the results.

In this summary, we report on the following: the raw material selected; the processing methods and equipment used; and the effect of the processing variables on the final product.

RAW MATERIALS SELECTED

The raw material selected for processing by different methods included: (a) various types of commercial fish meal produced on the Atlantic Coast of the United States; (b) whole fish--such as cod, haddock, pollock, mackerel, etc.--obtained fresh from Boston; (c) fish

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meal produced from Chilean hake (merluzza) by a conventional commercial process (screw-press extraction and hot-air drying[1]); and (d) fresh frozen and degutted merluzza. Both the Chilean fish meal and the frozen fish were shipped in cold storage to Boston, where they were stored in a refrigerated warehouse.[2]

PROCESSING METHODS AND EQUIPMENT

The processing methods investigated in these studies were performed with two basic sets of equipment.

The first set of equipment consisted of a jacketed 40-liter vacuum kettle equipped with an agitator-scraper and connected to a four-stage steam-jet vacuum system. This apparatus, shown in figure 1, was used both for vacuum drying and for simultaneous dehydration and extraction procedures.

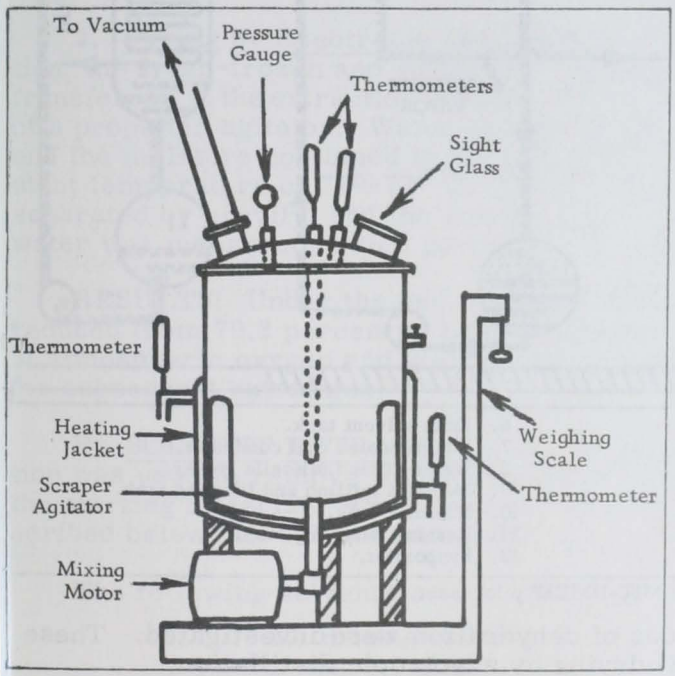


Fig. 1 - Vacuum dehydrator.

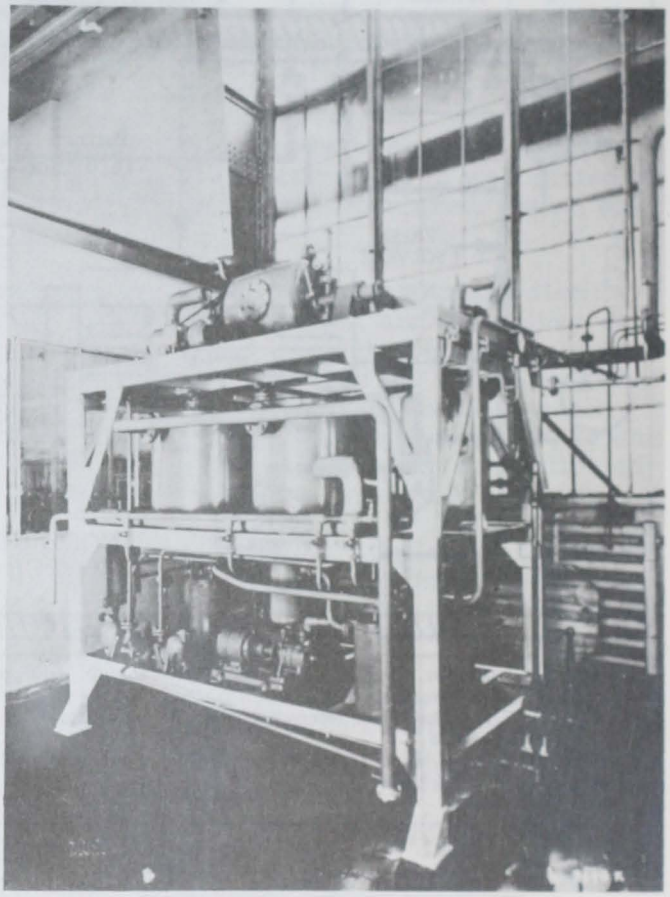


Fig. 2 - MIT-UNICEF pilot plant.

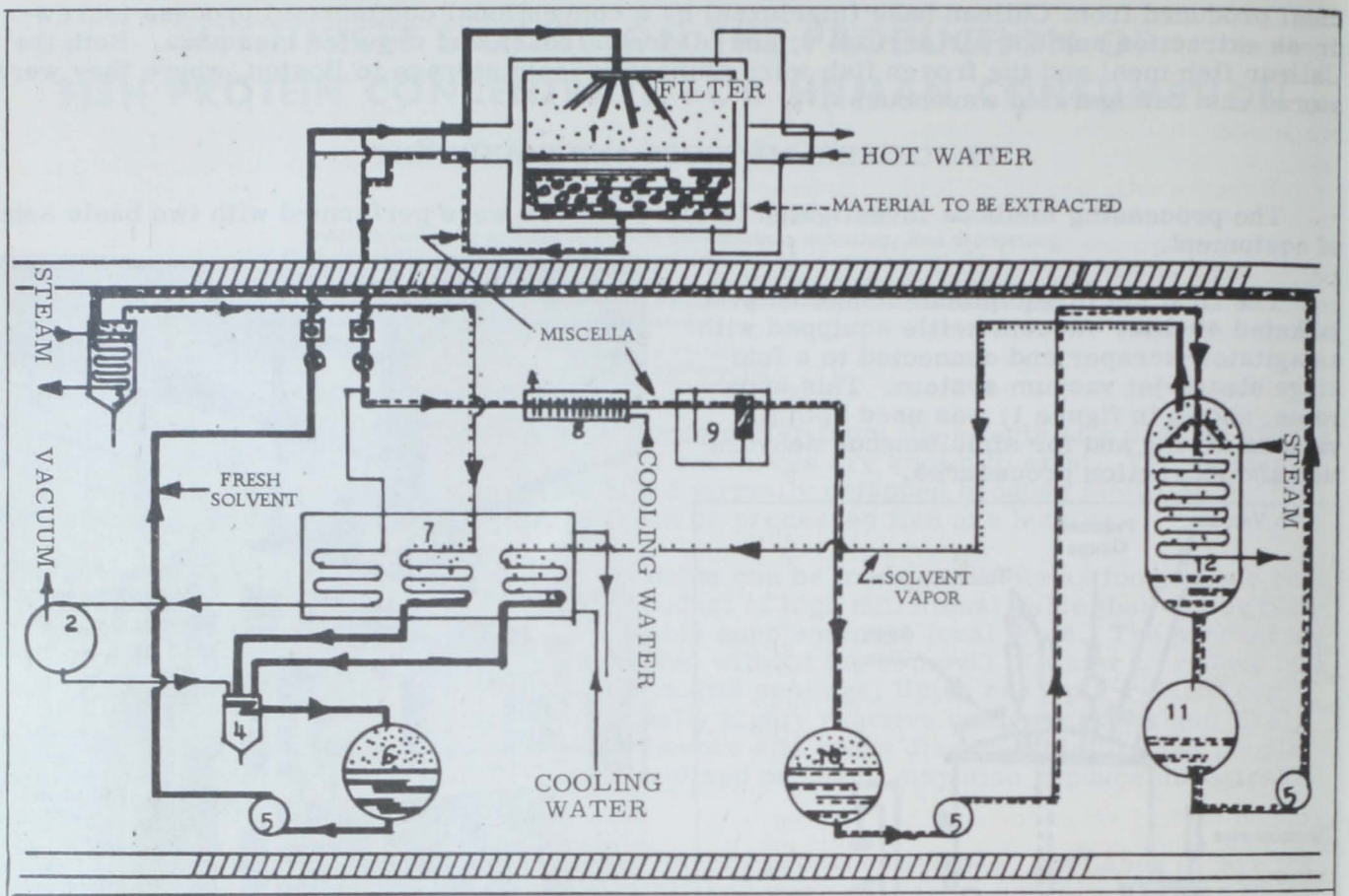
The second set of equipment was a self-contained extraction pilot plant, provided by UNICEF specifically for this study. This package was complete with tanks, pumps, motors, etc. It consisted essentially of an extraction vessel of 40-liters capacity and of equipment for solvent recovery, heating and circulation of water, and production of vacuum. This equipment is illustrated in figure 2, and a typical flow sheet is shown in figure 3. All samples of fish protein concentrate prepared and studied in this investigation were processed in this pilot plant, which was installed and operated on the premises of the Dehydrating Process Company in North Woburn, Mass.[3]

In the preparation of a fish protein concentrate, the moisture, fats, and other lipids must be removed. These components may be extracted in various ways, either separately or simultaneously. We accordingly describe the three following methods studied: (A) dehydration; (B) solvent extraction; (C) simultaneous dehydration and extraction.

1/This meal had been manufactured in the Swiss-Chilean fish meal plant, ISESA, in Quintero, Chile.

2/Thanks are due to Walter Meier, Director of the ISESA fish meal plant in Quintero, Chile, for his assistance in providing both the fish meal and the fresh frozen merluzza used in these studies.

3/Thanks are due to John Ryan for his kind cooperation and permission to operate the pilot plant on the premises of his factory, the Dehydrating Process Co.



Legend:
1. Extractor, pressure jacketed, with manhole, equipped with two filters.
2. Concentrator for removing solvent from extracted residue.
3. Hexane/water separator.
4. Vacuum tank.
5. Pumps.
6. Fresh solvent tank.
7. Water-cooled coil condenser.
8. Water-cooled miscella cooler.
9. Miscella settling and filtering tank.
10. Miscella tank.
11. Residue receiving tank.
12. Evaporator.

Fig. 3 - Typical flow sheet of MIT-UNICEF pilot plant.

A. DEHYDRATION METHODS: Two methods of dehydration were investigated. These were (1) vacuum drying in oil suspension and (2) drying by azeotropic distillation:

1. Vacuum Drying in Oil Suspension: PROCEDURE: In the vacuum-drying-in-oil-suspension process, the fresh-frozen and gutted fish were ground and mixed in a Rietz disintegrator with about equal weights of an edible oil. The mixture was then transferred to the vacuum kettle, and moisture was removed from the fish slurry at 40° C. (104° F.) by the application of vacuum and continuous agitation. The vacuum kettle, mounted on a platform scale, was equipped with service connections so that the rate of water removal and the dehydration end-point could be estimated. A schematic representation of the process is given in figure 4.

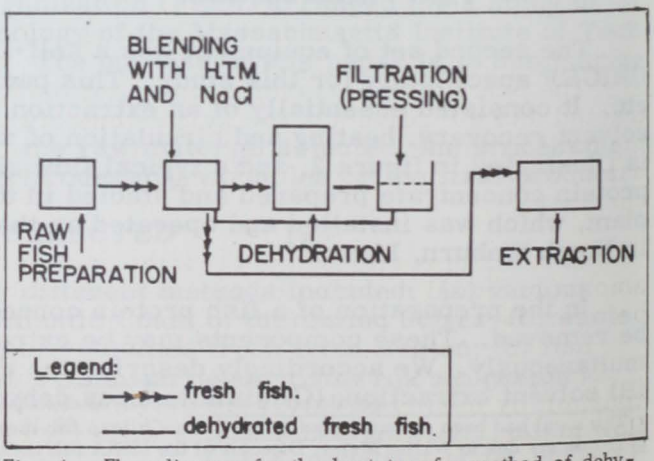


Fig. 4 - Flow diagram for the heat-transfer method of dehydration.

RESULTS: Under the experimental conditions used, the moisture content of lean fish

materials could be reduced approximately from 80 percent of the fish to 8 percent of the meal in about 1.5 hours. To reduce the moisture level of the meal from 8 percent to 4 percent usually required an additional 2.5 hours. Table 1 gives the results of some dehydration experiments in which different species of fish were used.

Table 1 - Composition of Some Lean Fish and Corresponding Meals Obtained by Vacuum Drying in Oil Suspension

Fish Species	Fresh Fish		Dehydrated Fish (Meal)	
	Moisture Content	Alcohol-Extractable Content	Moisture Content	Alcohol-Extractable Content
	(Percent)			
Haddock	79.0	3.57	5.2	0.75
Pollock	78.4	3.78	2.9	7.73
Merluzza	79.2	3.62	4.4	0.59

Experiments designed to determine the influence of the ratio of oil to fish on the rate of vacuum dehydration of comminuted fresh pollock showed that approximately equal amounts (by weight) of oil and fish gave a satisfactory rate of dehydration.

This method permits dehydration of fish at low temperatures in the absence of atmospheric oxygen, yielding a product that is of a light color and of a texture that is well suited to subsequent solvent extraction. Certain experimental problems were encountered, but on the whole, this method proved to be promising and practicable.

2. Drying by Azeotropic Distillation: PROCEDURE: For drying by azeotropic distillation, the fresh-frozen and gutted fish was ground in a Rietz disintegrator, and the slurry was transferred to the extraction vessel. The mass was slurried with 1,2-dichloroethane by means of a propeller agitator. Water at 120° C. (248° F.) was then circulated in the vessel jacket, and the moisture contained in the fish slurry was boiled off with the solvent vapor at a constant temperature of 71°-72° C. (159.8°-161.6° F.). The azeotrope was condensed, water was separated by gravity, and the solvent was recycled to the extraction chamber. The collected water was measured, which permitted the dehydration end-point to be estimated.

RESULTS: Under the experimental conditions used, the water content of merluzza was reduced from 79.2 percent to below 5 percent. The method allows dehydration in the absence of atmospheric oxygen and yields a fairly light-colored meal having a texture that is suitable for subsequent extraction.

B. SOLVENT EXTRACTION: In the processes investigated in this study, solvent extraction was used to remove lipids as well as lipid-related and odor-bearing constituents from the starting material. Except for the simultaneous dehydration and extraction method described below, all solvent extraction operations were carried out in the UNICEF pilot plant.

The following solvents or combinations of solvents were used:

1. Hexane, followed by ethyl alcohol.
2. Ethyl alcohol.
3. 1,2-dichloroethane, followed by methyl alcohol.

The extraction chamber of the pilot plant was charged with both the material to be extracted and the solvent. The kettle contents were then heated to a temperature slightly below the boiling point of the solvent, and the extraction was carried out either by a succession of batch washings, or by continuous circulation of solvent through the rotating extraction chamber.

In batch operations, the duration of a washing cycle was varied from $\frac{1}{2}$ to 1 hour. The amount of liquid retained by the meal after draining varied somewhat but usually made up between 50 and 60 percent by weight of the drained meal.

In operations involving continuous circulation of solvent, the solvent flow rate was kept constant by means of valves on the solvent-intake and -outlet lines, and with the help of a flow meter. Settling and draining were carried out as in batch operations.

After the final draining of the liquid, the remaining solvent was removed as completely as possible from the extracted meal by application of heat and vacuum and by rotation of the

vessel. By this procedure, fairly satisfactory solvent removal was usually obtained in 2.5 hours. The temperature during removal of solvent was not allowed to exceed 80° C. (176° F.).

Extraction of commercial fish meals was carried out with commercial hexane, with 95-percent ethyl alcohol, or with both in order to examine the relative efficiencies of those solvents in removing the fatty and odor-bearing components of fish. Results obtained with various commercial fish meals indicate a marked difference between hexane and ethyl alcohol in the extent to which those solvents will remove extractable matter. A quantitative examination of the respective extracts obtained indicated that hexane extracts largely oil, whereas ethyl alcohol extracts the oil as well as an appreciable amount of matter not extractable with hexane. Meals extracted with hexane were found to retain most of the fish odor, whereas the extraction with ethyl alcohol produced marked deodorization both in the meals that had previously been extracted with hexane and in the meals that had not been so extracted.

In summary, it appears (1) that extraction of fish meals with hexane alone will yield an essentially oil-free, but not deodorized product, and (2) that extraction with ethyl alcohol, or a solvent of similar properties, is required for satisfactory deodorization. Furthermore, results obtained in continuous and batch pilot-plant extractions of commercial white-fish meal with ethyl alcohol show that such extraction progresses in two distinct steps: (1) an initial washing stage in which the rate of flow of solvent controls the rate of extraction; and (2) a second stage in which diffusion of oil from within the meal particles controls the rate of extraction. For a given fish meal, the rate of diffusion was not materially affected by variations in the rate of solvent flow; and the rate of extraction in this stage was essentially a function of the length of time in which the solvent is in contact with the meal.

C. SIMULTANEOUS DEHYDRATION AND EXTRACTION: Procedure: In the method employing simultaneous dehydration and extraction, fresh-frozen and gutted fish was ground, acidified slightly, and processed at atmospheric pressure with successive batches of 95-percent ethyl alcohol in the vacuum kettle. The initial weight ratio of alcohol to wet fish was 1.5:1. In this stage, the mixture was held at 50° C. (122° F.) for 4 hours with continuous agitation. At the end of the period, the excess liquid was filtered off, and the resulting mash was reduced to about 50-percent dry solids in a hand press. The resulting press cake was disintegrated and reslurried with an equal weight of 95-percent ethyl alcohol made slightly alkaline. This mixture was held at 50° C. for 30 minutes, re-acidified, and the resulting fish solids were separated by filtration and pressing as before. After disintegration, the material was transferred to the pilot plant and extracted five times with recycled ethyl alcohol, pressed again, and further extracted with three batches of fresh 95-percent ethyl alcohol. Extraction and desolventizing were conducted as described earlier (see "Solvent Extraction"), except that the duration of each washing cycle was 1 hour; the extraction vessel was rotated for 5 minutes every 15 minutes, and the temperature of the meal during extraction was kept between 55° and 60° C. (131° and 140° F.).

Results: A dry and practically odorless product was obtained. Typical data for moisture, protein, and residual alcohol-extractable content in the finished product are presented in table 2, which gives a general summary of these studies.

This method of processing permits dehydration, defatting, and deodorizing at low temperatures, and with one solvent, while protecting the fish from atmospheric oxygen. The large amounts of alcohol required for dehydration, however, pose some recovery problems.

D. CONCLUSIONS: The dehydration and extraction experiments reported here were not exhaustive, so they can serve only to illustrate the possibility of drying and defatting fish and fish meal by the methods described. The observations do not permit a comprehensive cost analysis of the methods; in practice, costs will depend very much upon the design and engineering details of the plant chosen. Selected data on merluzza meals and protein concentrates are given in table 2 which, for comparison, also contains data for fresh-frozen gutted merluzza, commercial merluzza meal, and a lyophilized (freeze-dried) sample of fresh-frozen merluzza.

Table 2 - Composition of Fish Protein Concentrates and Meals Prepared from Chilean Hake (Merluzza) by Different Methods of Dehydration and Extraction

Sample	Moisture Content	Method of Dehydration	Solvent(s) Used for Defatting & Deodorization	Residual Alcohol Extractables (Dry Basis)	Protein (Extract-Free & Dry Basis)	
					Crude	"True" 1/
	%			%	%	%
Fresh-frozen gutted merluzza	79.2	-	-	17.5	91.4	84.5
FPC2/ from fresh-frozen gutted merluzza	4.4	Vacuum drying in oil suspension	95% ethanol	0.62	87.4	-
FPC from fresh-frozen gutted merluzza	3.8	Extraction with 95% ethanol	95% ethanol	1.0	87.0	83.3
	2.4	Azeotropic, with 1,2-dichloroethane	Methanol	0.84	84.2	74.5
Commercial merluzza meal	5.2	Cooking, screw-pressing, & hot-air drying	-	12.2	81.1	75.6
FPC from commercial merluzza meal	3.6		Hexane & 95% ethanol	0.39	76.6	-
	3.4		95% ethanol	0.56	76.2	-
Meal from fresh-frozen gutted merluzza	4.9	Lyophilization	-	17.1	85.3	83.9

1/Nitrogenous compounds precipitated by cupric hydroxide.
2/Fish protein concentrate.

EFFECT OF PROCESSING VARIABLES ON THE FINAL PRODUCT4/

PROCEDURE: The final part of these studies consisted in preparing fish protein concentrates by five different processes and evaluating the products. These concentrates were made from merluzza fish meal, commercially prepared by "ISESA," and fresh-frozen gutted merluzza. The commercial fish-meal process consists of cooking and pressing the fish, disintegrating the press cake, and drying in steam-jacketed dryers with circulation of air. Drying time is approximately 4 hours.

The frozen fish used was prepared in Chile from strictly fresh gutted merluzza, and shipped frozen to Boston. Both the meal and the frozen fish were stored in Boston at -23° C. (-9.4° F.), and portions withdrawn as needed in the experiments.

The fish protein concentrates were prepared as follows:

A. Concentrate No. 1 was prepared from the commercial meal by successive extractions with hexane and ethyl alcohol. The extractions were performed in the UNICEF pilot plant. The hexane treatment consisted of eight batch washings, each lasting 30 minutes, after which the solvent was removed from the meal. The temperature during extraction was held at 50° C. (122° F.) and during removal of solvent below 70° C. (158° F.). The hexane-extracted meal was then given nine washings with recycled ethyl alcohol, followed by three washings with fresh 95-percent ethyl alcohol, each batch requiring 1 hour. Temperature during the alcohol extraction was 55° to 60° C. (131° to 140° F.), and below 80° C. (176° F.) during solvent removal. The finished product was stored in containers at -30° C. (-22° F.) until withdrawn for testing.

B. Concentrate No. 2 was prepared in the same manner as was Concentrate No. 1 except that the extraction with hexane was omitted.

C. Concentrate No. 3 was prepared by slurrying the commercial meal with water, acidifying slightly, and allowing the mash to soak for 3 hours at room temperature. Further treatment was similar in all respects to that described under "Simultaneous Dehydration and Extraction." The finished product was then handled similarly to Concentrate No. 1.

4/Thanks are due to Frank Piskur, then Director of the Fishery Technological Laboratory, U. S. Bureau of Commercial Fisheries, College Park, Md., for the chemical and biological analyses of the processed meals and fish protein concentrates.

D. Concentrate No. 4 was made by processing the frozen merluzza as described on page 10 in "Simultaneous Dehydration and Extraction," and the finished product was again handled as in the case of Concentrate No. 1.

E. Concentrate No. 5 was prepared from frozen merluzza by first dehydrating it azeotropically in the pilot plant with 1,2-dichloroethane as described in "Drying by Azeotropic Distillation." The resulting meal was then given five batch washings with recycled methyl alcohol and three further washings with fresh methyl alcohol. Extraction, draining, and desolventization were carried out as described in "Solvent Extraction," except that the temperature during extraction was maintained at 60° C. (140° F.), and the time required for desolventization was 3.5 hours. The finished product was handled as in the case of Concentrate No. 1.

A summary of the five methods used in preparing these fish protein concentrates is given in table 2.

RESULTS: Proximate chemical analyses of the experimental fish protein concentrates and the raw materials from which they were prepared were performed, and the results indicated some interesting differences. It was found that both the frozen fish and the commercial fish meal contained appreciable amounts of nonprotein nitrogen, but that this material seemed to be removed by the processing in the case of Concentrates 3 and 4. The higher muscle-to-bone ratio in the dressed frozen fish, as compared to the whole fish used for production of the meal, resulted in a higher protein level in the former (on a dry basis) than in the latter; furthermore, the cooking and pressing involved in the meal production resulted in a loss of nitrogen.

Biological evaluations were made of the five experimental concentrates and of the commercial meal. Feeding studies were made with rats over a 4-week period using a casein diet as the control. Under the experimental conditions, rats fed the fish meal and Concentrates 1-4 showed significantly better growth and feed efficiency than rats fed casein.

All the experimental concentrates smelled faintly of fish--those prepared from commercial meal slightly more so than those prepared from frozen fish. Concentrates 4 and 5, prepared from frozen fish, were lighter in color than were the commercial fish meal and Concentrates 1, 2, and 3 prepared from this meal. Although they varied in texture, all concentrates were free-flowing in contrast to the commercial meal, which showed a tendency to cake.

Since none of the experimental fish protein concentrates was completely odorless, all of them were incorporated into bread at two levels of concentration to permit assessment of their practical usefulness. Bread baked with the commercial meal was used as a control. Fish protein concentrate was substituted for wheat flour at the rate of 5 and 10 percent of the total amount of flour called for in the bread recipe. The breads were then judged for appearance, odor, and taste. The results of these tests can be summarized as follows: a fairly acceptable bread was obtained when 5 percent of the experimental fish protein concentrate prepared from commercial fish meal was incorporated into the bread. The same results were obtained when protein concentrate prepared from frozen fish was incorporated at the 10-percent level. Bread baked with the commercial meal itself was found unacceptable by 90 percent of the judges at the 5-percent level and by 100 percent of the judges at the 10-percent level. Bread baked with Concentrates 1, 2, and 3 was found acceptable by about 80 percent of the judges at the 5-percent level and by about 60 percent at the 10-percent level. Bread baked with Concentrates 4 and 5 was found acceptable by 89 percent at the 5-percent level, and by 85 percent of the judges at the 10-percent level. Since appearance and "feel" of a product such as bread can affect the judgment of other qualities, these results undoubtedly also reflect to some extent differences in appearance, texture, and other intangibles.

CONCLUDING REMARKS

During the work reported here, the emphasis was placed on the technical feasibility of preparing a nutritious fish protein concentrate suitable for use as an ingredient in food, and

no attempt was made to evaluate comprehensively the basic engineering requirements and the economics of any of the methods examined. A number of problems were encountered which indicated that considerable experimentation and engineering development are required before the processing technology of fish protein concentrate can be advanced on a broad basis. Unfortunately these could not be followed up within the framework of the investigation.