New Products and Markets for Menhaden, *Brevoortia* spp.

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ABSTRACT—Although menhaden, Brevoortia *spp., represent 23.5 percent of United States commercial fishery landings, they represent only about 2.6 percent of the total landed value of fishery products. New food products and markets are needed to increase the economic value of the menhaden resource. This paper describes investigations of menhaden as a raw material for both traditional and new forms of food products. Canned menhaden is a logical food product, but the production of a menhaden surimi with good functionality has recently been demonstrated. The U.S. Food and Drug Administration has placed partially hydrogenated menhaden oil on the GRAS list of ingredients for food products, but a decision on the status of nutritionally beneficial refined menhaden oil is not yet available. Refined menhaden oil is currently the raw material for biomedical test materials being used in research approved by the National Institutes of Health to determine the health benefits of fish oils and omega-3 fatty acids. The test materials are being produced, with strict quality controls, at the NMFS Charleston Laboratory.*

Introduction

The search for new, higher valued products and markets for menhaden, *Brevoortia* spp., utilization has become more urgent because of the uncertain economic future of the fish meal and oil industry. Meal and oil prices recovered sharply between 1986 and 1988, but have dropped significantly since 1988. Price competition from soybean meal continues. Menhaden oil also faces price competition, and the traditional market in Europe is uncertain. Menhaden represented 23.5% of U.S. commercial fishery landings in 1989 but less than 2.6% of the total value (NMFS, 1990). There is a definite need for new value-added food products and there have been several recent developments that are pertinent. These include: 1) The construction and operation of a menhaden surimi experimental demonstration plant, 2) the submission of a petition to the U.S. Food and Drug Administration for use of menhaden oil in food products in this country, and 3) extensive publicity and heightened interest in the health benefits of omega-3 fatty acids.

Menhaden Characteristics

Physical and Sensory Characteristics

A majority of U.S. consumers have never heard of menhaden, and most of those who have are of the opinion that menhaden are inedible or at least unsuitable for human food. Menhaden are generally small, contain many fine bones, and have a high oil content. Yearly averages vary, but Atlantic menhaden, *B. tyrannus*, may range from 100 to 150 g and Gulf menhaden, *B. patronus*, from 80 to 120 g in the bulk of the catch in a typical harvest season.

Menhaden contain large amounts of highly unsaturated fatty acids that are prone to rapid oxidation. They have a reputation for rapid spoilage. It has been shown, however, that if menhaden are chilled rapidly and held at about 0°C they can produce good food products in appropriate product forms (Hale and Ernst, 1986).

Chemical Composition

The oil content of menhaden, as with other members of the herring family, varies greatly by season. Moisture varies with fat content, and the two combined are equal to about 80 percent of the total constituents. Protein content of whole menhaden is generally within the range of 15-17%, while the edible flesh averages about 18-19% protein. Dubrow et al. (1976) reported proximate and fatty acid compositions for Atlantic menhaden over the 1967-1969 seasons. Monthly average fat contents peaked in October at about 21% while the overall mean value was 14.4% fat. The fat content of Atlantic menhaden delivered to the surimi demonstration plant in 1987 peaked in October, but at less than 12% (Bimbo et al., 1988).

Miller et al. (1986) reported proximate compositions for ten different collections of Gulf menhaden in 1984. Fat contents ranged from 9.9 to 22.5% with a mean value of 14.2%. They also reported proximate and amino acid compositions and yields for several dressing, processing, and waste material fractions as well as for the whole Gulf menhaden.

Joseph (1985) reported fatty acid profiles for both Atlantic and Gulf menhaden oil samples collected during the 1982 and 1983 seasons. Monthly composite oil samples were supplied by three commercial reduction plants on the Atlantic coast and nine commercial plants on the Gulf coast. Annual mean values for major fatty acids were similar, within experimental variation, for Atlantic and Gulf oils. There were, however, some highly significant differences between seasonal samples of Gulf menhaden oils. Bimbo (1989) has also reported fatty acid profiles from Atlantic and Gulf menhaden oils.

Appropriate Product Forms

Menhaden are not suitable for the standard fresh or frozen fillet markets because of their bone content and susceptibility to lipid oxidation. Successful food products must be processed in a manner

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to eliminate these problems. Appropriate product forms include canned products, to soften bones and protect against oxidation, and surimi, with mechanical separation of bones and removal of oxidation catalysts by washing. The special properties of menhaden oils also point to promising commercial products. The substantial omega-3 fatty acid content of menhaden oil may have significant nutritional and/or therapeutic benefit as a constituent of appropriate food products. Protection from oxidation is, of course, essential. There are a number of other potential menhaden products which are discussed in this paper.

New Protein Products in Traditional Forms

Canned Products

Canned small pelagic fish species make a significant contribution to world protein supplies, and a truly international market has developed for them since World War II (Lanier, 1981). Menhaden fit the definition for small pelagic species as contained in Lanier's FAO report: "...commonly characterized by their abundance...density of schools, comparatively high fat content, and the very different properties (particularly oil and fat content) of individual fish between seasons." Canning is a particularly appropriate preservation method for fish such as menhaden because the bones are softened during heat processing and the sealed can protects against lipid oxidation (Fig. 1). Lightly smoked and canned menhaden were reported to have very good sensory acceptability (Hale and Ernst, 1986). Dressed, filleted, and minced forms of menhaden were canned and evaluated by Johnson et al. (1988). Fillets packed in oil or broth, or dressed menhaden (brined for a firmer texture) were said to have the highest potential. The market for canned fish is highly competitive, but it represents a realistic possibility for utilization of menhaden for food. The use of menhaden oil as a canning medium could provide health benefits based on its content of important omega-3 fatty acids. At the National Marine Fisheries Service (NMFS) Charleston Laboratory, we have evaluated some excellent experimental sardines (herring packs), prepared by a commercial company using a refined, deodorized menhaden oil rather than a vegetable oil (Bimbo, 1988a).

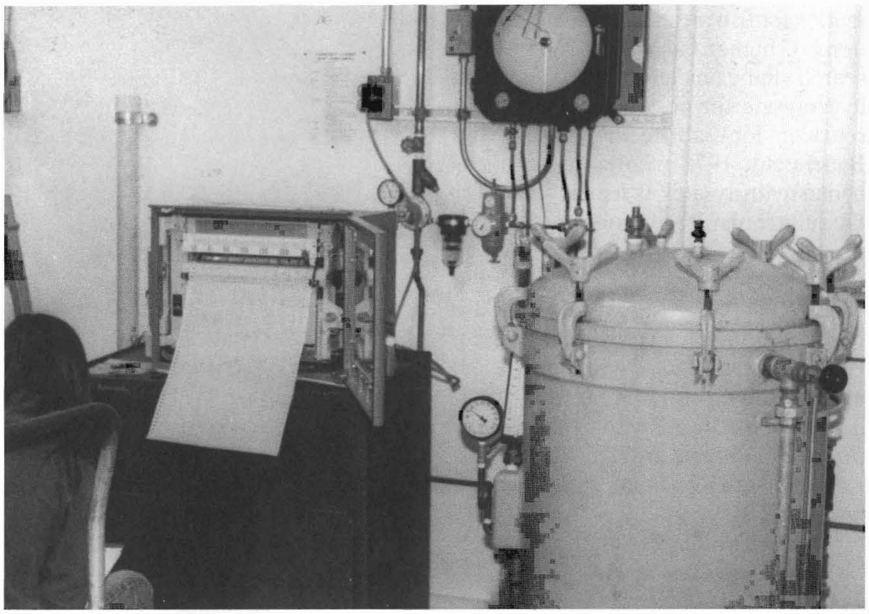

Figure 1.—Canning is an appropriate process for the use of menhaden as food.

Preserved Products

In addition to the familiar early use of menhaden as fertilizer, many menhaden were preserved for food by salting in early 19th century America. More recently the development of salted, dried products prepared from several species, including Atlantic menhaden, were reported. However, the salted dried menhaden did not generate interest at an Asian trade show (Huang et al., 1986).

The smoking of menhaden produces a desirable flavor, but bones are a problem in menhaden that are smoked but not heat processed. Menhaden may also be pickled to produce products similar to those prepared with Atlantic herring, *Clupea harengus*.

Sausage Products

Fish sausages are a common food product in Japan but not in the United States. Efforts have been made for several years to have minced fish approved as an ingredient in frankfurters. Experimental frankfurters containing minced fish or surimi from several different species have recently been prepared at the NMFS Charleston Laboratory and supplied to the U.S. Department of Agriculture for nitrosamine analyses and analytical methods development. They have developed a new, more accurate analytical method and have shown that nitrosamines are not the problem that was earlier indicated for franks containing nitrite and minced fish. Frankfurters containing menhaden mince or surimi had very low levels of nitrosodimethylamine (Pensebene and Fiddler, 1988).

Bischoff (1986) reported on a well accepted "sea dog" frankfurter containing 50% surimi plus turkey and vegetable oil. Menhaden surimi or mince, despite its darker color would be suitable for this type of food application. Other emulsified meat products, such as a sandwich loaf or breaded nuggets, are also potential food applications.

Nonfood Specialty Products

Menhaden are an important bait species for fishermen, and they have been used in canned pet foods and in a variety of industrial products over the years. In addition to feeds, menhaden proteins or oil have been used in paints, plastics, cosmetics, and fertilizers (Lanier, 1985). Aquaculture feeds represent a growing market for fish meal. Additional applications of higher value suggested by research studies include: 1) A menhaden hydrolysate for possible use as a milk replacer for calf feeding (Hale and Bauersfeld, 1978); 2) the use of menhaden hydrolysates as fish peptones for the culture of microorganisms (Green et al., 1973); 3) use of menhaden as an ingredient in intermediate-moisture pet foods (Rasekh et al., 1976); and 4) the use of diluted menhaden solubles as an emulsion fertilizer for house plants and agricultural crops (Aung et al., 1984). These potential applications show some promise, but none are likely to have an impact on the menhaden industry.

Protein Products in New Forms

Menhaden Surimi

During recent years most American consumers have become familiar with surimi-based analog products, primarily in the form of imitation crab legs. An excellent description of processing methods for surimi and analog products was published by Lee (1984). During 1976-86, U.S. imports of surimi rose from about 1 million to 13.4 million pounds. Imports of surimi-based seafoods rose from 2.8 million to 61 million pounds. Most imports have now been displaced by domestic production, but U.S. consumption of surimi products was estimated at 135 million pounds in 1988 (Vondruska et al., 1989). Thus, the surimi market was seen as an opportunity for developing food products of higher value from menhaden.

Lanier et al. (1983) explored the use of menhaden for surimi production in both pilot and semi-commercial trials. Surimi prepared from Atlantic menhaden had excellent gel-strength when cooked in a 2-stage process at 40°C followed by 90°C. Surimi prepared from Gulf menhaden was lighter in color, but had a higher fat content and a lower gel-strength than the comparable Atlantic menhaden surimi.

The processing requirements for the preparation of minced intermediates or surimi from menhaden were also discussed by Regier et al. (1985). Extended menhaden holding studies in refrigerated seawater, chilled seawater, or on ice indicated that any of the methods are effective providing the fish are chilled rapidly after harvest. Processing procedures and yields were also described for both Atlantic and Gulf menhaden (Fig. 2, 3).

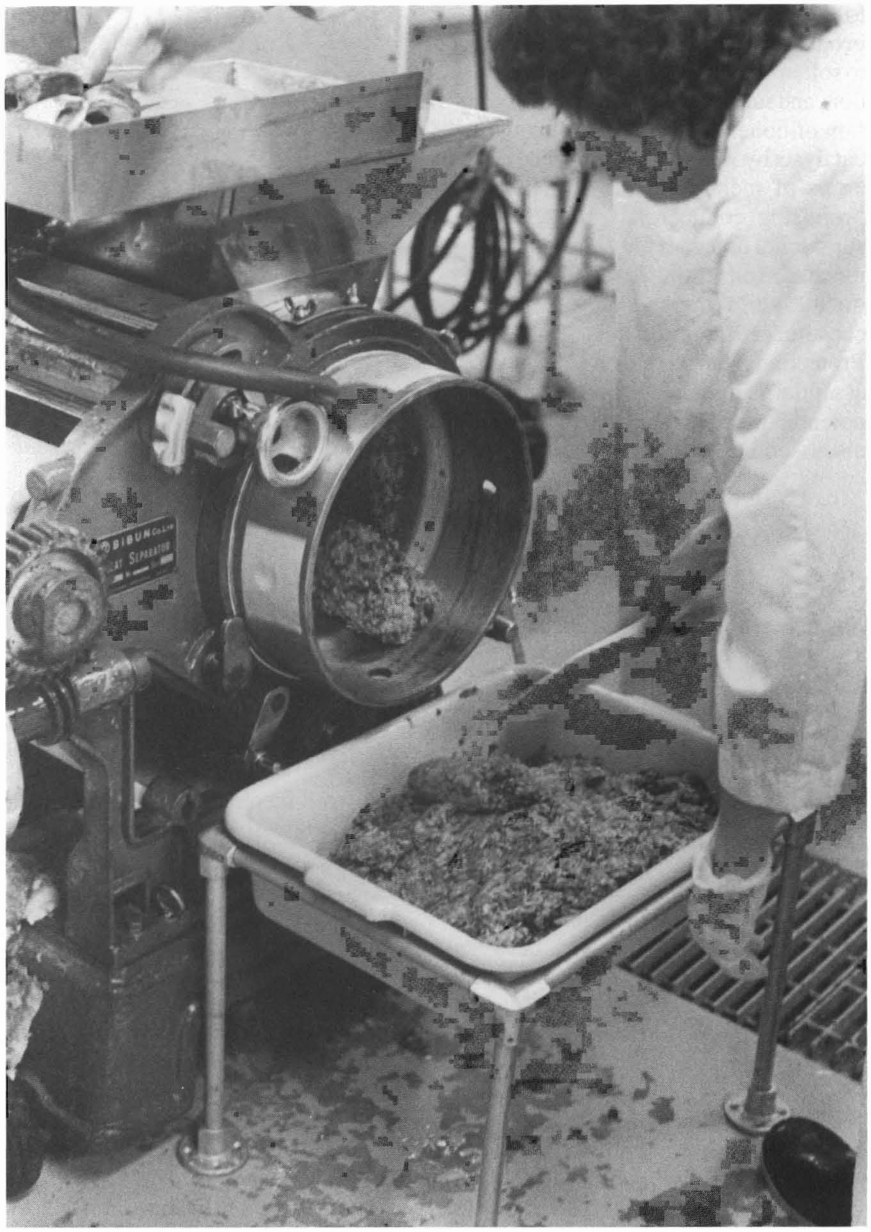

Figure 2.—Menhaden mince is prepared by mechanical separation of bones and skin.

Demonstration Plant

In 1985, the U.S. Congress designated increased funding for research and development into the conversion of menhaden into surimi. In 1986 an R&D contract for a 2-year, $2 million project was awarded to Zapata Haynie Corporation[1]. About $1.3 million in government funds was included. A pilot demonstration plant capable of producing one ton of surimi per day was constructed

[1]Mention of trade names or commercial products does not imply endorsement by the National Marine Fisheries Service, NOAA.

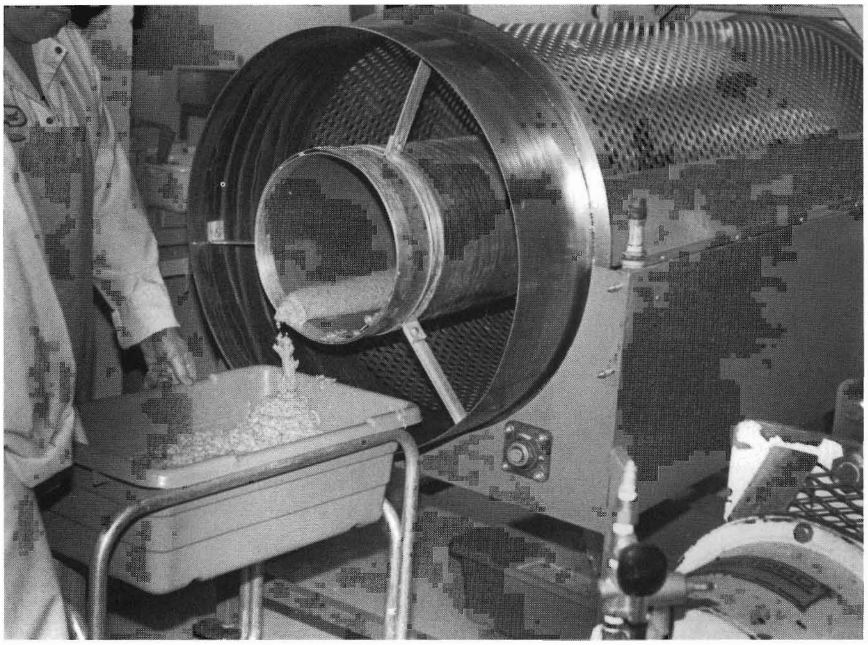

Figure 3.—Washed mince is partially dewatered with a rotary screen in the surimi process.

by Zapata Haynie adjacent to their meal and oil plant in Reedville, Va. The plant and the menhaden surimi processing operations carried out during the 1987 and 1988 fishing seasons have been described by Bimbo (1988b). Menhaden surimi was made available to researchers and manufacturers to investigate product applications. A production plant trial showed that the menhaden surimi had the functionality required for machine processing into analog products. Crab analogs were produced which were quite acceptable despite a somewhat darker color than the normal commercial product.

The following conclusions were made in the final contract report (Zapata Haynie, 1989):

1) Menhaden will produce a functional surimi with good gel properties, but with a gray color and slight residual flavor.

2) Economic feasibility is projected for a plant with a capacity of 22 tons of surimi per day.

3) The continuous wash with centrifugal separation gave a better yield and product quality in addition to being more labor efficient than the batch washing process.

4) Rapid chilling of the fish at harvest is essential for a quality surimi product.

5) Menhaden should be marketed in food products capitalizing on high protein, low fat properties and not as a white fleshed seafood analog ingredient.

Additional New Products

Fish purees, as defined by Miller et al. (1986), are pre-cooked before mechanical deboning or mincing and most of the fat is retained in the product. Such a product has nutritional advantages over surimi, from which fat and soluble protein have been washed out. Purees can be blended with a variety of food products as a source of beneficial omega-3 fatty acids. Miller has done extensive product development work with purees prepared from menhaden and from a number of popular food fishes.

The functionality of menhaden surimi for analog production has been demonstrated, but the darker color is a problem with most current analog shellfish product forms. Color would be less of a problem in a product that combined the surimi with machine-separated blue crab meat. There are other potential products such as breaded oyster analogs that would be compatible with the darker color. Fast food products have been studied at Virginia Polytechnic Institute, and researchers at the University of Georgia have incorporated menhaden surimi into a very acceptable pasta product (Bimbo, 1988b).

Menhaden was a primary species for fish protein concentrate (FPC) investigations in the late 1960's (Dubrow et al., 1976). The economics of FPC were not favorable, but a new dry fish protein product called Marinbeef is currently produced and marketed by the Japanese. The processing and properties of Marinbeef have been described by Suzuki (1981). It is functional, can be reconstituted to a hamburger-like consistency, and represents another potential product application for menhaden.

Oil-based Products

World production of marine oils totals about 1.5 million metric tons (t) (Bimbo, 1989). Marine oils account for a little over 2 percent of the world production of fats and oils. Menhaden oil production was 0.10 million t in 1989, valued at $23.2 million (NMFS, 1990). Menhaden oil accounted for 97 percent of the total U.S. fish oil production. The volume of menhaden oil produced each year fluctuates because of natural variations in both the abundance of stocks and the oil content of menhaden. For the 10-year period of 1980-89, the average annual menhaden oil production was 0.132 million t.

Use of Menhaden Oil

Most of the fish oil produced in the United States is exported to western Europe. There the oil is partially hydrogenated for use in margarines and shortenings. Except for the United States, all countries producing marine oils utilize them in foods. In the United States, fish oils are being consumed in only two forms: 1) Imported fish oils are being marketed in capsules as food supplements and 2) small quantities of fish oils are being consumed as canning oils. However, this was not always the case. Before the disappearance of the California sardine in the early 1950's, large amounts of hydrogenated fish oils were consumed in margarines and shortenings in this country. During the peak years of usage, 1930-40, U.S. fish oil consumption for all edible purposes was 68,000 t per year. Menhaden oil was never included on the GRAS (Generally Regarded as Safe) list, and in 1955, when the standard of identity for oleomargarine was established by the U.S. Food and Drug Administration (FDA), fish oil availability had diminished and no one requested that fish oils be included on the list of acceptable ingredients (Bimbo, 1989). Thus, for menhaden oil to be included in margarine two legal actions must be taken: 1) GRAS status must be established and 2) the standard of identity must be amended.

Oil has always been an important product of the menhaden industry. Prior to World War II, menhaden oil was used in the manufacture of a variety of industrial products. However, technological advances eventually led to the exclusion of fish oils in many of these products. Most menhaden oil is now exported for food use. The functional properties and low cost of the oil make it attractive for such uses. Because of its special properties, some menhaden oil is still sold in the United States for certain industrial applications. Some of the products containing menhaden oil include protective coatings, lubricants, printing inks, carriers of insecticides, caulks and sealants, surfactants, plasticizers, and leather treatment agents. Fish oil fatty acids are raw materials in the production of a wide range of chemical derivatives. Menhaden oil is also utilized as an important nutrient in the diets of poultry, livestock, and fish, both in the form of oil and as a component of menhaden fish meal. Because of the current nutritional interest in omega-3 fatty acids, for which menhaden oil is a major source, animal scientists are exploring avenues by which these fatty acids can be incorporated into the meats we eat.

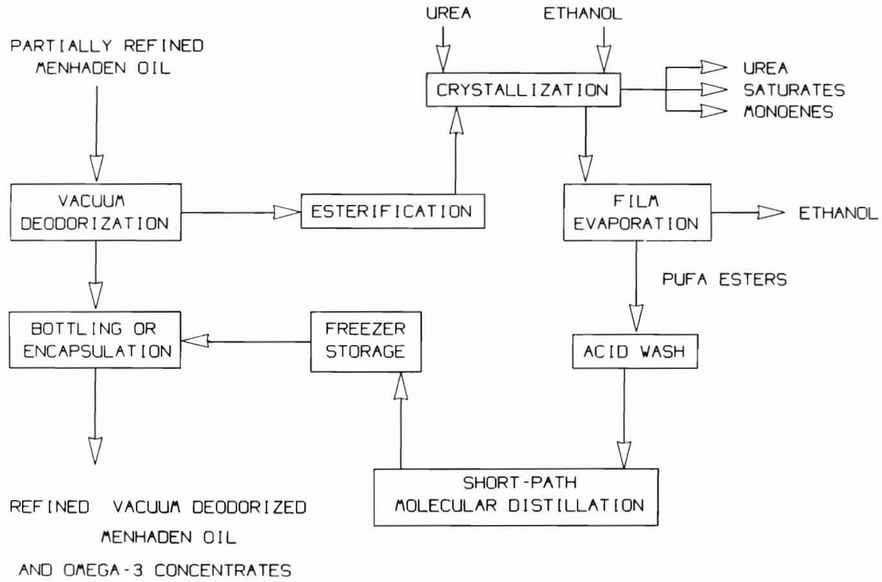

Figure 4.—Basic process for the preparation of biomedical test materials from partially refined menhaden oil at the NMFS Charleston Laboratory.

Biomedical Test Materials

Appreciation of the unique and important contribution of seafood lipids (oils) to human health really began with the publication of a series of Danish studies on the low incidence of heart disease in Greenland Eskimos. A number of subsequent studies in this and other countries led to the hypothesis that increased consumption of seafoods or fish oils rich in omega-3 polyunsaturated fatty acids (PUFA) can have direct and positive influence in preventing or ameliorating many degenerative disease processes (Lands, 1987; Kinsella, 1986). At a conference held in 1985 entitled "Health Effects of Polyunsaturated Fatty Acids in Seafoods," leading researchers in this area concluded that a significant limitation in the research was the lack of adequate supplies of quality-assured test materials of consistent composition to explore the many research frontiers identified by the conferees (Simopoulos, et al., 1986). Under a 1986 Memorandum of Understanding (MOU) between NOAA and the National Institutes of Health (NIH), it was agreed that the NMFS Charleston Laboratory would provide a long-term consistent supply of test materials, derived from menhaden oil, to facilitate evaluation of the role of omega-3 fatty acids in health and disease. An interagency committee in the Division of Nutrition Research Coordination of NIH, the Fish Oil Test Materials Advisory Committee (FOTMAC), provides the review and approval mechanism for the distribution of quality-assured/quality-controlled test materials to researchers. The applicants are investigators who are funded by NIH or other research organizations.

Production and Quality Control

The production facility at the Charleston Laboratory includes equipment for preparation of biomedical test materials from partially refined menhaden oil as outlined in Figure 4. Also available for fractionation of concentrates are a process-scale high performance liquid chromatograph (HPLC) and supercritical fluid CO_2 fractionator (SCFF). Test materials are produced by a number of physical and chemical separation techniques. Menhaden oil, which has undergone winterization, alkali refining, and bleaching by the supplier, is passed through a wiped film deodorizer to reduce cholesterol, organic contaminants, and fishy odors and flavors to very low or undetectable levels. The antioxidant TBHQ and vitamin E in the form of alpha- and gamma-tocopherol, are added to the product receiver. The yield of deodorized oil is about 75 kg per 8-hour day. A portion of this oil is reserved as a test material; the balance is used to produce omega-3 concentrates.

To produce a test material containing at least 75 percent omega-3 polyunsaturates, the menhaden triglycerides are transesterified to produce fatty acid ethyl esters. The esters are reacted with urea dissolved in hot ethanol and the solution is cooled overnight. Upon cooling, the straight chained saturated and monounsaturated esters form adducts with urea which precipitate from the alcoholic solution, thereby concentrating the nonadducted polyunsaturated esters. After the ethanol is stripped from the solution in a film evaporator, the neat esters are distilled in a wiped film molecular still to remove oxidation products, polymers, color bodies, and additional cholesterol. An initial charge of 80 kg esters yields about 12 kg of purified omega-3 concentrates. Purified eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) are also produced, with portions of the omega-3 concentrates serving as feed stock. Either HPLC or SCFF, or a combination of the two procedures, are used to produce the purified fatty acid esters.

Refined fish oil containing protective antioxidants is available in bulk or in soft-gelatin capsules; refined oil without antioxidants is available in bulk upon special request. In addition, soft-gelatin encapsulated food grade vegetable oils (corn, olive, and safflower) are available for use as placebos. Because of the instability of the omega-3 ethyl ester concentrates, they are provided only with antioxidants but may be obtained either in bulk or in soft-gelatin capsules; encapsulated ethyl esters of corn, olive, and safflower oils are produced for use as placebos. Purified EPA and DHA are available only in bulk and in small quantities and contain no antioxidants.

Production of the test materials is monitored by a series of quality control chemical analyses whose results demonstrate that proper procedures were used during each phase of production. The most important analyses include: High performance gas-liquid chromatography for organic contaminants (PCB's and pesticides), sterols, antioxidants, and fatty acid composition; measurement of peroxide value to detect signs of oxidation; and sensory evaluation of odor and flavor by a trained sensory panel. Test materials undergo additional quality assurance analyses including trace metals, macroelements, oxidation products, and microbiological tests before shipment to approved investigators.

Second International Conference

A Second International Conference on the "Health Effects of Omega-3 Polyunsaturated Fatty Acids in Seafoods" was held in Washington, D.C., in March 1990. The conference of distinguished investigators, from around the world, critically reviewed research data collected during the past 5 years.

About 40 invited papers were presented. Session topics included information on the relationship of omega-3 fatty acids to growth and development, advances in mechanisms of action, heart disease and hypertension, rheumatoid arthritis and inflammatory mediators, diabetes, psoriasis, and cancer. Over 80 posters were presented representing researchers from about 20 countries around the world. Several significant conclusions were drawn during the conference. The essentiality of omega-3 fatty acids was firmly established, and the role of DHA was clearly defined in the field of human growth and development. The necessity for the inclusion of this important fatty acid in infant formulas was mandated, and the practice of long-term feeding with formulas that do not include the omega-3 fatty acids was questioned. The role of the omega-3 fatty acids in prevention or treatment of several disease states was clearly confirmed. Significant advances were made in the understanding of the biochemical mechanisms of action in the areas of cardiovascular disease, inflammation, and cancer.

A milestone of the meeting was the establishment of the Society for Fatty Acids and Lipids. The Society held its charter meeting at the end of the conference. Another milestone of the meeting was the presentation of data that demonstrated that as little as three meals of fish per week, coupled with a decrease in total fat intake, provides striking protection against mortality from cardiovascular disease.

FDA Petition

It is ironic that there is such interest in increasing the amount of omega-3's in the foods we eat, yet refined menhaden oil lacks FDA's approval for food use. In June 1986, the National Fish Meal & Oil Association submitted a GRAS petition to the FDA for both refined menhaden oil (RMO) and partially hydrogenated menhaden oil (PHMO). In September 1989, the FDA extended GRAS status to hydrogenated and partially hydrogenated menhaden oils, but delayed a decision on RMO. The results of a study contracted by FDA were reported by the Mitre Corporation in February 1989. The Mitre Report found no serious problems with the safety of refined menhaden oil (Bimbo, 1989). A decision on GRAS status for RMO, with its content of beneficial omega-3 fatty acids, is awaited by industry and consumers.

Potential Uses

Partially hydrogenated menhaden oils may be blended into shortenings and margarines subject to FDA approval and amendment of the standard of identity for margarine. The use of refined menhaden oil with the omega-3 fatty acids preserved, however, could have a more significant impact on consumer products. Since the hydrogenation process destroys omega-3 fatty acids, the oil constituents purported to have important biological effects, the challenge to the food industry is to develop new products in which the omega-3 fatty acids are protected. In addition to the potential uses as a canning oil, menhaden oil could be used in mayonnaise and salad dressings if properly protected from oxidation by antioxidants and special packaging. An Institute of Food Technologists (IFT) Short Course on Seafood Technology in June 1988 included some information on current research into the preparation of such food products incorporating refined fish oils (Bimbo, 1988a). Work conducted in Europe, under the sponsorship of the International Association of Fish Meal Manufacturers, included evaluations of pastes and spreads, mayonnaise, salad oils, yogurt, canned fish, and several types of sausages. Fish oils were blended in differing proportions with other oils or fats into the products. Some flavor problems were encountered, but many products with significant fish oil content were fully acceptable.

The production and evaluation of margarines containing refined, unhydrogenated fish oil were recently reported by Young et al. (1990). The quality and shelflife of margarines containing refined fish oil (at 20% of the fat content) were tested with three different packaging methods and two different antioxidants. The results showed that the experimental margarine containing fish oil had a refrigerated shelflife of at least 10 weeks and the quality was similar to that of the all-vegetable oil control margarine. The results also indicate a way in which refined menhaden oil could enjoy a higher valued use and provide beneficial amounts of omega-3 fatty acids to consumers.

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