13 Marine Nutraceuticals for Food Fortification and Enrichment

13.1 INTRODUCTION

It is well known that optimal health could be realized only through adequate intakes of nutrients. Developments in the area of human nutrition in the twentieth century led to identification, isolation, and purification of many nutrients. Most foods may be deficient in one or more nutrients. Sometimes nutrients, which are present in original food material, may be partially or fully lost as a result of processing, storage, packaging, and handling. The modern food processing technology is aware of the possibility of loss of nutrients at various stages of processing and therefore takes necessary steps to minimize such losses. In view of consumer interests in nutrition, a major area of modern food technology is related to formulation and designing of foods to achieve specific nutritional quality objectives.[1,2]

13.2 DIETARY GUIDELINES

Regulatory agencies the world over provide appropriate guidelines on intake of nutrients for the purpose of maintenance of public health. Food-based dietary guidelines (FBDGs) are advisory notes from regulatory agencies for healthcare professionals and consumers on requirements of adequate nutrient contents in diet, with a view to meet the nutritional needs. These guidelines can address the relevant public health concerns regarding whether they are related to dietary insufficiency or are in excess. The establishment of FBDGs is a key strategy to reach the nutritional goals of a population and an important tool in national food and nutrition policy development. These guidelines aim to promote general nutritional well-being as well as to prevent and control both ends of the spectrum of malnutrition: under and overnutrition.[2,3] In 1997, the Food and Nutrition Board of the U.S. National Academy of Sciences issued new guidelines for nutrients now known as dietary reference intakes (DRIs). These new values were designed to address both serious vitamin and mineral deficiencies and daily intakes that promote good health.[4,5] The recommended daily allowances (RDAs) were developed by the Food and Nutrition Board to serve as the benchmark of nutritional adequacy in the United States as the minimum values needed to avoid serious disease. The RDA for protein for U.S. men aged 19–24 is 58 g and for women of the same age group is 49 g. The recommendation for fat is 30% or less of total energy required. Over the years, the RDAs have undergone modification as the safe upper levels of micronutrients so that consumers can ingest these substances

at levels that prevent deficiency and the pathogenesis of chronic disease but avoid intakes that could have problematic effects. Scientific knowledge regarding the roles of nutrients in addressing classical nutritional deficiency diseases (such as rickets) and to the reduction of risks of chronic diseases such as osteoporosis, cancer, and cardiovascular disease expanded dramatically since the inception of the RDAs.[6,7] On November 9, 2004, the United States Food and Drug Administration (U.S. FDA) published a draft guideline for the food industry, entitled "Substantiation for Dietary Supplement Claims Made under Section 403(r)(6)," which is intended to describe the amount, type, and quality of evidence a manufacturer has to substantiate a claim under the Section of the Act (see Appendix).

13.3 SUPPLEMENTATION

Supplementation refers to periodic administrations of pharmacological preparations of nutrients as capsules or tablets or by injection when substantial or immediate benefits are necessary for the group at risk. Nutritional supplementation should be restricted to vulnerable groups, which cannot meet their nutrient needs through food (such as women of childbearing age, infants and young children, and elderly people).[8,9] Some examples are supplementation with iron, which is recognized as the only option to control or prevent iron deficiency anemia in pregnant women and that with folic acid for women of childbearing age who have had a child with neural tube defect to prevent recurrence. Eating more of foods rich in antioxidants, such as the vegetables and citrus fruits has been shown to be protective. When this is not possible due to certain health conditions, nutritional supplements could be used.[5,10] Vitamin E and β-carotene supplementations are popular approaches to address cardiovascular disease and lung cancer.

The concept of "dietary supplement" (DS) was initiated in 1994 when the U.S. Congress passed the Dietary Supplement Health and Education Act (DSHEA). The "DS" went beyond vitamin, pills, and tablets, allowing the addition of specific metabolites that had some demonstrated relationship to a disease/health condition. The DSHEA also allowed the product to bear a health-based structure–function claim with specific rules as to what could be said.[11] In addition, a DS has to have a supplement facts panel instead of nutrition facts panel. The act did not define functional foods or nutraceuticals, but these terms began to be used simultaneously with DS at that time. Under the DSHEA, the DS manufacturer is responsible for ensuring that a DS is safe before it is marketed. In general, no claim should be made for a food that represents the food that is intended to cure, mitigate, treat, or prevent any disease, since such a claim can cause a food to become subject to regulation as a drug. FDA regulations allow "health claims" that a substance in the diet on a regular basis "may help reduce the risk" of a named disease.

Recently, however, apprehensions have been raised in using the approach of supplementation to address these diseases. It has been now recognized that the most promising outcome with respect to nutrition and positive health is through dietary patterns, and not nutrient supplements. It was suggested that the relative presence of some foods and the absence of certain other foods was more important than the level of individual nutrients consumed. Notwithstanding justification for nutrient

supplements to certain segments of the population (e.g., the elderly), there were insufficient data to justify an alteration in public health policy from one that emphasizes food and diet to one that emphasizes nutrient supplements.[12,13] Supplements may not be necessary if a variety of foods are being eaten, which can ensure good supply of daily nutrients, since a balanced diet provides all the nutrients required by the body. While supplements provide some minerals and vitamins, they do not provide all of the food components needed for good health, since there are at least 42 nutrients needed each day. Further, physiological stress conditions like surgery, trauma, and burns do increase the need for nutrients. In addition, there are some apprehensions on the harmlessness of supplements. Earlier unrecognized risks caused by nutrient toxicity and nutrient interactions have surfaced during intervention studies. Very high doses of many vitamins like A, B_6, C, and D as also certain minerals, if taken regularly may cause grave health problems. Excess of one nutrient causes either a nutritional imbalance or increase in the requirement of other nutrients. Apprehensions have also been raised on the efficacy of certain antioxidants such as vitamin E to function in the body, when supplied as supplement.[14,15] Because of these reasons, it is preferable to depend on nutritive foods rather than supplements.[16]

13.4 FOOD FORTIFICATION AND ENRICHMENT

One of the techniques to compensate nutritional deficiencies in food is by a process known as fortification, that is, external addition of the nutrient to the food. The added nutrients are called "fortificants" or "additives," which are added to a commonly consumed food, referred to as the "vehicle." It is possible for a single nutrient or group of micronutrients to be added to the vehicle. Such externally added nutrients include vitamins, minerals, proteins, amino acids, and fatty acids, which enhance the nutritional value of the food. In addition to improving the nutritive value, inclusion of certain additives also help improve other qualities of the food. Thus, vitamins C and E and β-carotene may function as antioxidants in foods, β-carotene may enhance color, while proteins and specific fatty acids modify the texture and therapeutic values of foods.[15] The technique, probably, is the easiest way to reach the population segments at risk of chronic diseases due to such deficiencies. For example, iodine, vitamin A, and iron deficiencies are important public health problems in developing countries and often coexist in vulnerable groups, such as pregnant women and young children. These deficiencies can be corrected by fortification of the respective nutrients. Addition of iodine to common salt is the earliest example of fortification to address the disease of goiter, which was recommended by the French chemist Boussingault in 1833. The technique was commercialized in 1924 in the United States. In later years, with the advent of nutritional labeling and increased public interest in nutritional properties of food, fortification of foods became a major tool for the food industry for marketing of processed foods. During recent years, several foods have been targeted to enhance their nutritional value by appropriate inclusion of additives. Most vitamins cannot be synthesized by the body and must be supplied by the diet. Examples include fortification of milk with vitamin D, margarine with vitamin A, and breakfast drink substitutes with vitamin C. Protein level of breads can be increased up to 12% by addition of protein-rich fortifiers

such as milk. Fortifications of wheat flour with iron and vitamin B_1 and salt with iodine are other successful examples. Apart from its well-conceived aim of prevention of diseases, in modern times, fortification is increasingly being used not only to protect against deficiencies but also to receive maximum health benefits.[9,16]

The term "additive" referred in fortification technology is defined differently by different regulatory agencies. Under the U.S. law, components described as additives may have a nutritional element. However, according to the European Union, an additive is defined as a compound that provides a technological rather than nutritional function to the food. It is also important that the product should be acceptable to individuals who may have a reduced appetite or interest in food. In a workshop held by the International Life Science Institute (ILSI), in Lisbon in 1997, experts from key European countries concluded that addition of nutrients can provide an effective and safe strategy to improve actual micronutrient intake and status.[10] Successful instances of fortification-induced eradication of diseases include the conquest of pellagra in the United States by niacin fortifiction of white flour, the virtual elimination of goiter by iodination of salt and the reduction of neural tube defects by folate fortification of cereal grains.[9–11]

13.4.1 Requirements for Fortification

There are at least three essential requirements or conditions that must be met in any fortification program: The fortificant should be effective, bioavailable, acceptable, and affordable; the selected food vehicle should be easily accessible and a specified amount of it should be regularly consumed in the diet. Further, detailed production instructions and monitoring procedures should be in place and enforced by law. The development of a fortification policy must be based on rigorous criteria that embrace both positive and adverse consequences.[11–13,16] Information on commercial aspects of techniques, nutrient databases, and formulation worksheets for food product development have been provided.[13,16] The important factors need to be considered when formulating a food product with added nutrients are given in Table 13.1.[13]

There are important scientific and policy issues that must be resolved before programs for fortification can be considered. The data needs, constraints, and limitations for fortification programs have been identified recently, which include five general areas, namely, (1) human requirements and nutritional status, (2) bioavailability, (3) interactions among nutrients, (4) interactions of fortification nutrients with carrier foods, and (5) the safe upper limits (or upper reference levels) for these nutrients. While all these aspects need to be discussed in developing a fortificaton strategy, the domain of greatest controversy is the establishment of upper reference levels or nutrient toxicity.[10] It is to be noted that the older population generally differs from younger adults not only by age but also by health status. The elderly group is not a homogenous population and their different health and social problems influence their nutritional status. Attention must be paid to environmental, phychological, and physical parameters in evaluating their nutritional status and interactions.[11–13,17] Sometimes, fortification may have adverse impact on acceptability of the product. Unappealing flavor of fortified foods is often a hurdle. The problem can be addressed

TABLE 13.1
Factors Need to Be Considered When Formulating Food Products with Added Nutrients

Overall product composition	The physical and chemical properties of a food such as pH, water activity, oil, or water content influence nutrient stability. Macroingredients such as protein and fiber may affect stability and bioavailability of nutrients. Fortification can cause change in sensory characteristics. Essential minerals such as iron can cause adverse reactions in the color and flavor of foods, while ascorbic acid can lower pH and impart tartness. Need corrective steps to combat these changes
Ingredients interactions	Interaction among the nutrients and with other food components is a key factor in viable added nutrients present in food products. For example, vitamin C may improve the absorption of iron, which in turn can accelerate degradation of vitamins
Processing considerations	Most vitamins are unstable at high temperatures; while most nutrients are not adversely affected by heat. Freezing is generally beneficial for nutrients; however, blanching and washing can cause loss of water-soluble vitamins
Shelf life and packaging	Package selection is affected by intended use and shelf-life considerations. For example, vitamin C and β-carotene must be protected from oxygen. Shelf-life loss can be overcome by adding appropriate nutrient overages
Nutrigenomics	Nutrigenomics is how nutrients affect genes and enable foods to be developed that can be used to prevent and treat diseases. The application of nutrigenomics may allow food product developers to better target condition-specific foods

Source: Adapted from www.fortitech.com.

by addition of sweetener, food acids, chemical derivatization of nutrients, microencapsulation, and addition of bitterness inhibitors, as shown in Table 13.2.

13.5 SOME EXAMPLES OF FOOD FORTIFICATION

13.5.1 Iodine

Deficiency of iodine is because of its sparse distribution in the earth's surface resulting in its low contents in plant foods. Although foods of marine origin are naturally rich sources of iodine (see Chapter 9), their consumption is not enough throughout the world to take care of the problem. The situation has made iodine deficiency disorders exceedingly common among populations. Common salt is a recognized vehicle for fortification of iodine and the fortified salt is probably the ideal way to virtually

TABLE 13.2
Methods to Make Fortified Foods More Palatable

Methods	Example/Remark
Addition of sweeteners	Addition of sweeteners such as aspartame (L-aspartyl-L-phenylalanine) and saccharin to reduce the intensity of off-flavor
Food acids	Food acids such as DL-malic or citric acid reduce intensity of off-flavors and bitterness by chelation of metals. Acidity of the product can be varied to reduce intensity of bitterness
Chemical derivatization/ substitution	Protection of sulfur groups of cysteine and methionine by derivatization such as acetylation of methionine to *N*-acetyl-methionine to improve taste. Replacement of cysteine with cystine gives a neutral taste. Solubility of the product is an important criterion for acceptability
Microencapsulation	Coating of functional food additive helps its slow release into the food matrix. Bitter peptides could be coated with a hardened edible fat or wax
Addition of bitterness inhibitors	Cyclodextrins, maltols, etc., plastein reaction in the case of protein hydrolyzates

eliminate iodine deficiency disorders. The safe level of iodine fortification usually lies between 25 and 50 mg/kg salt. The actual amount should be specified according to the level of salt intake and magnitude of deficit at the country level.[18–21]

13.5.2 Vitamins

Addition of vitamins to foods is often necessary to enhance the nutritive value of food with a view to provide health protection, without causing any health risks to any consumer group. International expert groups have aimed at establishing tolerable upper intake levels for vitamins (and also minerals), although lack of conclusive data on their safety is a major obstacle to this work. Assuming 95% intake of vitamins and minerals from food together with a daily multivitamin mineral pill, the calculation of total dietary intake levels of all vitamins and minerals can be calculated to develop a fortification strategy.[20,22] Folic acid is a typical candidate for fortification. An adequate intake of folic acid is very important for women of childbearing age for proper birth weight and reduction of neural tube defects. A higher intake of folic acid may lower homo-cysteine levels in adults since elevated plasma homo-cysteine levels are considered an independent risk factor for heart disease. In addition, folate may improve the mental condition of the elderly population. Most population groups may not easily reach the required level of folic acid; therefore, folic acid fortification has been recommended. The United States initiated mandatory folic acid fortification of cereal-grain products in January 1998, with an approved level of 140 mg/100 g product, which will increase the average woman's intake by only 100 mg/day. Dairies generally enrich milk by introduction of vitamin A and vitamin D, riboflavin, niacin, and thiamine hydrochloride as dry mix. Vitamin C is destroyed by the heat treatment of milk, so it is added into milk in the oxidized form or as dehydro-ascorbic acid. New data continue to emerge regarding the health benefits of

vitamin D beyond its role in bone. The intakes associated with those benefits suggest a need for levels of supplementation, food fortification, or both that are higher than current levels. The current tolerable upper level of vitamin D established by the U.S. Food and Nutrition Board is 50 μg, or 2000 IU. A group of U.S. researchers has found that this upper intake level could be raised fivefold. A human clinical trial data published support a significantly higher upper level. A prevailing concern, however, exists regarding the potential for toxicity related to excessive vitamin D intakes. Collectively, the absence of toxicity in trials conducted in healthy adults that used vitamin D dose ≥250 μg/day (10,000 IU vitamin D_3) supports selection of this value as the upper limit.[23,24] Inclusion of vitamins (and minerals) may, however, contribute to the problems by adding a persistent metallic note; such flavor interactions may be additive or complementary to each other.

13.5.3 Minerals

Deficiencies of calcium and iron may be common among population that do not take adequate amounts of milk and meat.[15,18] The prevalence of iron deficiency and anemia in vegetarians and in populations of the developing world is significantly higher than in omnivore populations (see also Chapter 8). Food fortification with iron is recommended when dietary iron is insufficient or the dietary iron is not bioavailable. Absorption of heme iron is high (20–30%) and its bioavailability is relatively unaffected by dietary factors. The traditionally eaten staple foods represent an excellent vehicle for iron fortification. Examples of foods, which have been fortified, are wheat flour, corn (maize) flour, rice, salt, sugar, cookies, curry powder, fish sauce, and soy sauce. Incorporation of vitamin C and other enhancers promote absorption of iron. A rapid colorimetric method for determination of iron in fortified and unfortified foods has been reported. The method consists of hot acid extraction of iron in the presence of hydroxylamine, and measuring the color after mixing the extract with a chromogen reagent, namely, bathophenanthroline disulfonic acid.[25]. Increased intakes of selenium-enriched foods may benefit human health. Selenium supplementation of populations with low or deficient in the mineral may improve measures of health and reduce the risk of cancer, especially prostrate cancer in men. Foods may contain different amounts and chemical forms of selenium, and therefore the benefits of the mineral may depend on the particular type of the mineral consumed.[26]

A multicomponent fortification of salt involving iodine, vitamin A, and iron has been attempted. Potassium iodate, retinyl palmitate, and ferric pyrophosphate were microencapsulated in hydrogenated palm fat by spray cooling. The microcapsules were added to common salt. During storage for 6 months, color change in the triple-fortified salt was negligible, and iodine losses were only about 20%. Losses of retinyl palmitate were 12% during the period, suggesting encapsulation by spray cooling an ideal way for fortification of salt with the nutrients.[21] Fortification of cereal staple foods is a potentially attractive intervention for zinc deficiency, which could target the vulnerable population groups of children and pregnant women. Zinc fortification would perhaps decrease the prevalence of stunning in many developing countries having low-zinc diets.[2] Calcium has been high on the lists of nutrients recommended

for fortification, as a result of widespread deficiency of the mineral, especially among the elderly. Fortification has been suggested to enhance the intake of calcium among the U.S. population, which, despite more than 20 years of awareness of the importance of calcium to health, remains suboptimal. As a result, since the beginning of 1999, calcium-fortified foods have appeared in large numbers in the United States and most of them have met with commercial success. Over 1000 calcium-fortified products were introduced in the last 5-year period, more than two-thirds in the beverage and snack categories. The different calcium salts such as gluconates, oxides, and sulfates, most commonly used as supplements or fortificants exhibit comparable bioavailabilities. Choice of salt will depend mainly upon cost, compatibility with the manufacturing process, and consumer acceptability. However, interaction with food, tablet, or beverage matrices can degrade intrinsic absorbability substantially. As a consequence, each product must be explicitly tested to establish the degree to which its calcium is available to consumers.[6,7,27] A survey of consumer preferences for minerals revealed that 67% of the general public believed that they were deficient in calcium, magnesium, iron, zinc, and potassium. They prefer beverages as good source of calcium and ~23% of the population consume such beverages once per day, and 24%, one to six times per week.[28]

13.5.4 Carotenoids

The overall intake of several natural antioxidants including carotenoids present in foods has been associated with lower incidence of various ageing diseases. Besides these, carotenoids have other functions including its usage as food colorants (see Chapter 8). Carotenoids have been therefore used to fortify foods. A functional food, oil, rich in fatty acids and antioxidants, colored with carotenoids extracted from the microalga *Chlorella vulgaris*, has been developed. For extraction of the carotenoid, the microalga was crushed in the presence of vegetable oil and ethanol or acetone and subjected to supercritical CO_2 fluid extraction (SFE) at a pressure of 300 bar and varying temperatures. The recovery of carotenoids was 100% with oil at room temperature for 17 h, 70% with oil at 100°C for 30 min, 69% with supercritical CO_2 at 40°C and 300 bar.[29] The behavior of multicarotenoids systems in a functional food has been studied. The interactions between α-tocopherol, β-carotene, and lycopene in the formulation of a nutritional supplement using a *simplex-centroid* design and response surface methodology (RSM) were examined. The antioxidant activity (AOA) of the product was evaluated by determining the inhibition of spontaneous autoxidation. The results showed that no synergism occurred between the three compounds when rat brain homogenate was used as the oxidizable substrate, and also suggested that RSM can be applied to estimate the behavior of mixed ingredients in nutritional supplements.[30]

13.5.5 Proteins and Amino Acids

Populations who largely consume cereal-based diets need to get adequate proteins. Cereal products such as breads are ideal candidates for protein fortification.

Conventional breads are low in protein (8.5–9.5%) but quite high in carbohydrates (45–52%). Protein level of breads is increased by the addition of fortifiers such as milk solids, extra gluten, soybean flour, and cottonseed flour. In the process, some of the starches of flour are replaced by the fortifiers, leading to increase in the level of proteins up to 12%. Uses of protein supplements are quite common among athletes and physically active adults. Instead of whole protein, protein hydrolyzates can be used for the purpose. Protein hydrolyzates consist of a small fraction of free amino acids and short peptides, a broader spectrum of medium-sized peptides, and substantial amount of high-molecular-weight materials (see Chapters 3 and 4). Nutritionally complete products intended to address metabolic disorders usually have their protein components, partially or wholly provided by amino acids or by protein hydrolyzates. Protein hydrolyzates, being often bitter in taste, may require certain additives to mask their bitterness (see Chapter 3). When amino acids are used as fortifiers, they added in the product well above their threshold level. Since most amino acid products have unappealing taste, these products are flavored using sweet fruity notes to enhance their acceptability. The majority of such clinical nutrition products are in the form of either a readymade drink or as a powder to be dissolved in water. Therefore, while preparing the product, the insolubility of several amino acids such as tyrosine, cystine, and histidine needs to be addressed. For example, tyrosine has a poor solubility of 45 mg% in water at 25°C. The solubility could be improved by using amino acid derivatives such as hydrochlorides, converting them to ester or by the use of soluble peptide containing these amino acids. The relationships between physicochemical and functional properties of protein hydrolyzates in nutritional products are shown in Table 13.3.

TABLE 13.3
Relationship between Physicochemical and Functional Properties of Protein Hydrolysates in Nutritional Products

Chemical and Physicochemical Properties	Functional Properties
Molecular size	Solubility
	Viscosity
	Gelation
	Emulsifying capacity
	Flavor
	Osmolarity
Surface activity (hydrophobicity)	Emulsifying capacity
	Foaming
Interactions with carbohydrates and lipids	Browning (Maillard reaction)
	Flavor formation
	Solubility
Interactions with minerals	Thermal stability
	Solubility

13.5.6 Probiotics

Since Metchnikoff's first observation that the unique longevity of the Bulgarians might be associated with yogurt in their diet, there has been considerable interest in the health benefits of foods containing "therapeutic microorganisms." The animal or human gut is inhabited with a heavy load of bacteria belonging to diverse nature; at least one-third of these bacteria are useful in the digestion of food. It is believed that if these positive therapeutic microorganisms are maintained, the unwanted bacteria are less able to cause disease and irritation. Probiotics (meaning "pro-life") are foods containing live beneficial bacteria. Probiotics are defined as "live microbial feed supplements that beneficially affect the host animal by improving its intestinal microbial balance."[31] Two of the most common probiotic strains are lactobacilli and bifidobacteria. Lactobacilli are beneficial microorganisms of particular interest because of their long history of use for processing foodstuffs and for preserving food by inhibiting invasion by other microorganisms that cause food-borne illness or food spoilage (see also Chapter 3). The largest category of foods containing lactic acid bacteria is fermented or cultured dairy products. It is advisable to get probiotics from foods than from supplements, as there is a synergistic effect between the components of food and probiotic cultures. Foods such as yogurt and buttermilk are the most recognized foods providing probiotics for the gut. These dairy products provide a number of high-quality nutrients including calcium, protein, bioactive peptides, and conjugated linoleic acid, which strengthen the body's immunity and gastrointestinal functioning. Table 13.4 shows health benefits of probiotics. In contrast to probiotics, prebiotics are the foods that help the probiotics grow and multiply. Wheat, onions, garlic, banana, tomatoes, etc., are examples of prebiotics. Biomedical research currently offers new prospects of application of lactobacilli for applications and this may have far-reaching results in the future. Many fermented products containing lactobacilli have been recently released on the market. Some of them contain new *Lactobacillus* spp. of nondairy origin, such as *L. rhamnosus* GG, isolated from the healthy human intestinal flora. In view of current interests in the field, the European Food Safety Authority (EFSA) has adopted a generic approach to

TABLE 13.4
The Health Benefits of Probiotics

Synthesis of vitamins, primarily B vitamins
Increased availability of nutrients
Decreased lactose intolerance
Boost of immune response
Control of pathogenic bacteria by antimicrobial substances such as cytokines, butyric acid, and bacteriocins
Stimulation of the growth of lactic acid-producing bacteria, favoring digestion, especially milk and milk products
Strengthening of the gastrointestinal membrane, for protection against infection
Prevention of the growth and activity of unwanted bacteria, including the bacterium, *Helicobacter pylori*, known to cause peptic ulcers

the safety assessment of microorganisms used in food/feed and the production of food/feed additives. New specific guidelines, granting a "long-standing presumption of safety" status to *Lactobacillu*s genus based on its long history of safe use has been proposed.[31,32]

13.6 MARINE INGREDIENTS FOR FOOD FORTIFICATION AND SUPPLEMENTATION

Marine products offer a number of ingredients for a variety of fortification programs. These include polyunsaturated fatty acids (PUFA) (omega-3 fatty acids), proteins, minerals, glucosamine, and chondroitin sulfate. These will be discussed in the following sections.

13.6.1 Omega-3 Fatty Acids

The PUFA (omega-3 fatty acids) particularly, eicosa pentaenoic acid (EPA), and docosahexaenoic acid (DHA) have been recognized as important therapeutic agents, as discussed in Chapter 5. One of the major sources for the requirement of PUFA is through regular consumption of marine products. They can also be derived from other PUFA-rich products such as algal oil or on the availability of foods containing linoleic and linolenic acid, which are elongated and desaturated for conversion into PUFA. It has been, however, recognized that during the past few decades, intake of omega-3 fatty acids by general public is rather poor, resulting in an undesirable increase in the ratio of omega-6 to omega-3 fatty acids. This discrepancy has been mainly attributed to increase in consumption of seed oils (corn, soybean, palm, etc.), which are rich in omega-6 fatty acids. The strategy to get adequate quantity of PUFA includes keeping omega-6 PUFA in the diet as low as possible, consumption of omega-3 PUFA-rich diet and intake of omega-3 PUFA supplements including microencapsulated fish oil (FO). EPA and DHA, which can serve as important fortificants for the development of nutritional products that can address several biological functions.[33,34] Marine fishes are good sources of omega-3 fatty acids, the isolation of which has been discussed in detail. Several marine oils are available for DS and functional food manufacture, providing sources of EPA and DHA, and in some cases vitamins A and D. Oils ranging from cod liver to sardine are offered by several manufacturers.[34,35] Table 13.5 indicates some commercial sources of PUFA.[16,35]

13.6.1.1 Marine Oil-Fortified Products

Marine oil has been used to fortify food products such as mayonnaise, margarine, bread spreads, and bakery products. Recently, increased incorporation of DHA into margarines and baby foods has been promoted to enhance brain-memory development. Bread spreads containing 40% fat incorporating refined, deodorized, unhydrogenated FO in vegetable oil and butter oil has been developed. The product contained wheat powder and gelatin as emulsifying agents and potassium sorbate as preservative and antioxidants. Other products include salad dressing and bakery products.[34] Supplementation with EPA and DHA has been recognized to be more effective than use of their precursors such as linoleic acid in the food, since the bioconversion

TABLE 13.5
Commercial Sources of Essential Fatty Acids

Fatty Acid	Product	Individual Source	Levels (%)
EPA	Seafood	Alaska pollock	12.5–14
		Cod	10
		Menhaden	10
		Salmon	12
		Tuna	6
		Antarctic krill	Varies
		Sardine	Varies
DHA	Seafood	Alaska pollock	6–7
		Cod	10
		Menhaden	13
		Salmon	4
	Animal	Tuna	17
	Single cell oils	Atlantic krill	—
		Egg yolk	2
		Crypthecodinium	47
		Schizochytrium	25
Omega-6 LA	Vegetable oil	Corn	59
		Soy	50
		Canola	30
ARA	Single-cell oil	Mortierella	8
	Animal	Egg yolk	4

Source: Adapted from Ohr, L.M., *Food Technol.*, August 2005, 95; Swanson, M.A. and Evenson, P., *Food Additives*, 2nd ed., Marcel Dekker, New York, 2002. With permission from Taylor & Francis Ltd. (www.informaworld.com).

efficiency is less. Further, such fortified products can have improved bioavailability of omega-3 PUFA.[36] The current thinking among scientists is that it is better to consume both the EPA and DHA rather than DHA alone since both are found in FO at a ratio of around 1:5.[33]

Fish could be cultured under specific conditions such as diet, to have appreciable levels of PUFA in their muscle. Development of PUFA-enriched Atlantic salmon was reported using aquaculture. Four diets containing either 100% of Peruvian FO, capelin oil, soybean oil, or rapeseed oil as supplemental oil were fed to triplicate groups of salmon for 135 days. After slaughter, half of the fish were smoked, while the rest were analyzed as raw (without smoke treatment). For smoked and raw fish, the left fillet was analyzed as fresh fillet while the right fillet was frozen and stored at −20°C for 2 or 4 months before analyses. Fish-fed diets enriched with FO had firmer texture than fish-fed rapeseed oil diet. Water-holding capacity (WHC) and color characteristics were influenced by dietary oil source. Fish-fed FO-diets had significantly higher color than fish-fed vegetable oil–diets. Frozen storage decreased the firmness of raw fillets and the WHC of raw and smoked fillets. Color was affected by

frozen storage, whereas muscle carotenoids concentrations slightly decreased. Lipid oxidation was more pronounced in fish-fed high levels of *omega-3* fatty acids, which increased with frozen storage.[37] In another comparable study, poultry feed was supplemented with FO at a concentration of 2–4%. The FO-fed chicken was later used to make chicken frankfurters. These frankfurters had higher contents of EPA and DHA and a lower content of omega-6 fatty acids. No significant differences were found in pH, cooking yield and moisture, fat, protein, ash, and cholesterol contents, and sensory quality.[38]

13.6.1.2 Process Optimization

The principal technological hurdle in amending the diet with FO, however, is the high degree of unsaturation and associated sensitivity to oxidation. The resulting compounds adversely influence flavor apart from having negative consequences on the biological system. The problem could be addressed by certain control measures. These include storing the products at refrigerated temperatures and excluding oxygen from the packages. Another alternative is addition of precursors of PUFAs, such as linolenic acid. However, due to poor bioconversion these have to be added in extra measures to give sufficient DHA as required in the product.[39] Partial hydrogenation is another method to control oxidation of PUFA. Incorporation of partially hydrogenated oils in baked goods did not show oxidation as judged by sensory analysis. Mayonnaise-containing specially deodorized unhydrogenated menhaden oil was found to have a shelf life of 14 weeks under nitrogen, which is an acceptable shelf life for a refrigerated product. FO in the hydrogenated form has also been used as a component of margarines. The objective was to enable people to consume 1–2 g of EPA and DHA per day by means other than eating fish or resorting to DSs. The product was commercially acceptable with shelf life of 10 weeks, and quality comparable to the all-vegetable control product. Hydrogenated and partially hydrogenated menhaden oil, which generally contain 13% EPA and 8% DHA, has been given generally recognized as safe (GRAS) status by the U.S. Food and Drug Administration (see Chapter 5).

Menhaden oil mixed with defatted soy flour extract demonstrated the greatest stability by producing the lowest TBA reactive oxidation products and retaining the highest concentrations of DHA and EPA after heating at 150°C for 30 min. A range of 62.8–71.5% of DHA and 67.7–75.9% of EPA remained in the FO with defatted soy flour extract, while only 29.9% of DHA and 37.2% of EPA were retained in the FO with no addition. The effect was due to the presence of the highest level of total phenolic content (11.3 μg catechin equivalent/g) in the defatted flour extract, with 55 mg/g isoflavones in the defatted soy flour extract The order of free radical scavenging capability measured was also for the defatted soy flour extract.[40]

Polyols have been incorporated into FO emulsions as a means for the inhibition of lipid oxidation and also for suppression of fishy flavor. Selected polyols were evaluated for their performance as antioxidants and modifiers of oxidation pathways in a model system. Oil/water (O/W) emulsions were prepared with freshly steam-deodorized menhaden oil. A layer of emulsion in aluminum pans held at 5°C was exposed to 2550 lx fluorescent lights for 24 h before peroxide values and volatile flavor compounds were analyzed. AOA was observed for fructose, sucrose, raffinose,

sorbitol, or mannitol when incorporated at 16% of the aqueous phase into model FO-in-water emulsions. Peroxide values were suppressed 10–18% in treated samples compared to control samples. The data supported a hypothesis that either or both free radical scavenging and transition state metal chelation activities were provided by polyols in FO emulsions. Also, polyols retarded the water-requiring retroaldol decomposition of (*E*,*Z*)-2,6-nonadienal to (*Z*)-4-heptenal in the model systems and the reaction may be involved in some suppression of fishy flavors in emulsions.[41] Flavonoids obtained from agrofood products are natural antioxidants in control of oxidation of PUFA. Besides increasing the shelf life of seafood, addition of these compounds was recognized beneficial due to the induction of apoptosis of cancer cells. Thus, fish muscle supplement with bioactive antioxidants appears to give a stable functional food offering the combined action of omega-3 fatty acids and natural polyphenols.[42]

FO with 33% omega-3 fatty acids was microencapsulated through spray-drying in a matrix of *n*-octenylsuccinate-derivatized starch and either glucose syrup or trehalose. Samples showed no difference in physicochemical properties as determined by measurement of particle size, oil droplet size, true density, and Braunauer, Emmett and Teller (BET) surface adsorption parameters. Upon storage at low relative humidity, lipid oxidation was decreased in trehalose-containing samples indicating that in the amorphous state trehalose is a more suitable wall material for microencapsulation than glucose syrup. The retarded oxidation of trehalose-containing samples may be attributed to the unique binding properties of trehalose to dienes. At 54% relative humidity, a rapid oxidation of the microencapsulated oil was observed upon crystallization of trehalose, which limits the range of applications to products to be stored at low humidity.[43]

The influence of fortification of selected instant foods using two types of encapsulated FO powders on their sensory qualities was determined. Since FO had some adverse sensory effects on the product, incorporation of flavorings for masking of undesirable odors allowed higher levels of FO addition to instant foods. The decrease of sensory quality of flavored and nonflavored samples stored in the air-permeable conditions was detected after 1 and 3 weeks, respectively. However, vacuum-packed samples showed no changes in sensory quality. The results showed that it was possible to fortify instant foods with microencapsulated FO at limited levels, especially when spray-dried powders were used. It was also observed that one portion of fortified instant foods might provide up to 16% of the minimal recommended daily intake of long chain omega-3 PUFA.[44]

13.6.1.3 Therapeutic Benefits of PUFA-Fortified Products

The therapeutic benefits of omega-3 PUFA have been discussed in Chapter 5. Such benefits accrued from consumption of fortified products are discussed in this section. Influence of feeding commercial diets fortified with omega-3 and omega-6 PUFA on arachidonic acid (ARA) content, PUFA equivalent (PE) (calculated as 0.15 × linolenic acid [LA] + [EPA] + [DHA]), and ratio of omega-6 to omega-3 PUFA acids were determined in different meat portions including breast, thigh, and fillets in chickens, turkeys, common carp, and rainbow trout. Arachidonic acid (AA) content was in the range 20 mg/100 g in fillets of rainbow trout fed the diet with linseed oil (LO) to 138 mg/100 g of thigh meat of chickens fed the diet based on maize, for a period of 90 days. AA content in breast meat of turkeys fed the diet with LO or FO did not

differ from that of rainbow trout fillet. Apart from all fish samples, both breast and thigh meat of turkeys fed the diet with either LO or FO gave the recommended value of <4 for the ratio of omega-3 to omega-6 PUFA. AA content in the tissue increased significantly with increasing dietary LA in both chicken and all turkey tissues.[45]

Supplementing the diet with DHA and also ARA can have beneficial effects in human amnesic patients. The patients were given 240 mg of ARA and DHA or 240 mg of olive oil for 90 days. Subjects with mild cognitive dysfunction showed a significant improvement in immediate memory functions and attention. Subjects with organic brain lesions showed a significant improvement in immediate and delayed memory functions.[46] Dietary supplementation of arachidonic and dosahexaenoic acids improves cognitive dysfunction. Taking high dose of omega-3 supplements daily decreased the severity of symptoms associated with ankylosing spondylitis, a chronic disease that mainly affects joints of the spine and hips. The patients were given a high dose (4.55 g) or low dose (1.95 g) daily supplement of omega-3 fatty acids. The subjects in the high dose group exhibited a notable decrease in disease. Supplements of omega-3 FO appeared to be an alternative treatment with fewer side effects to nonsteroidal antiinflammatory rugs for the treatment of nonsurgical neck or back pain. Omega-3 fatty acids had an effect comparable to ibuprofen.[47,48]

A fortifying agent containing the fatty acids has been successfully examined for supplementation of baby foods. The study showed that babies who were breastfed from birth to 4–6 months and then randomly weaned—either to the formula supplemented with DHA and ARA or to a formula without them. The babies fed with the supplemented formula had improved visual activity at 1 year of age, compared to the babies fed with the nonsupplemented formula. Some infant formula developers are now offering DHA and ARA fortified formulas for toddlers up to 24 months old. Food manufacturers are also taking advantage of this opportunity by adding DHA to their food products. It is likely that such fortified foods in the markets may increase due to understanding of the role of these fatty acids in brain development and also cancer prevention.[49]

13.6.1.4 Regulatory Status

In the United States, most essential fatty acids are GRAS because of their historical presence in the diet, and are therefore exempt from the premarket approval.[49,50] The U.S. FDA in 2004 announced the availability of a qualified health claim for reduced risk of CHD on conventional foods that contain EPA and DHA. This approved health claim is believed to contribute to the influence of omega-3-containing products in the markets. The FDA recommends consumption of not more than a total of 3 g of EPA and DHA per day, with no more than 2 g/day from a DS. Being able to differentiate food products that contain both EPA and DHA means that food companies can create a source of strategic competitors advantageously because of the presence of these nutraceutical compounds in their products.[49,50] Table 13.6 indicates recommendations for supplementation of infant formula with DHA and ARA by expert panels.[16]

13.6.1.5 Marketing Campaigns

In view of the recognized nutritional advantages of EPA and DHA, marketing campaigns have been launched for many marine fish products that tend to affirm that

TABLE 13.6
Recommendations for Supplementation of Infant Formula with DHA and ARA

Recommendation	BNF[a]	ISSFAL[b]	FAO/WHO[c]
Preterm			
ARA (% of formula fat)	0.30%	1.0–1.5%	1.0%
DHA (% of formula fat)	0.3%	0.5–1.1%	0.8%
Preterm			
ARA (% of formula fat)	—	—	0.6%
DHA (% of formula fat)	—	—	0.4%
EPA/DHA ratio	—	>5:1	10:1

Note: DHA, docosahexaenoic acid; ARA, arachidonic acid; —, not given.

[a] BNF, British Nutrition Foundation, 1993.

[b] ISSFAL, International Society for the Study of Fatty Acids and Lipids, 1994.

[c] FAO/WHO, Food and Agriculture Organization/World Health Organization, 1993.

Source: Adapted from Swanson, M.A. and Evenson, P., *Food Additives*, 2nd ed., Marcell Dekker, New York, 2002. With permission from Taylor and Francis Ltd. (www.informaworld.com).

consumption of these fish is an appropriate method of satisfying consumer's need for a variety and nutritious, tasty, and healthy foods. These campaigns have resulted in positive changes in consumer attitude toward seafood.[51] According to a recent survey, 47% consumers associated omega-3 fatty acids with heart health and 32% considered themselves deficient in the compounds. Therefore, omega-3 fatty acids–fortified products are now generally accepted. Such products include frozen desserts, muffins, breads, sauces, margarine, pasta, cheese spreads, tuna burgers, yogurts, and salad dressings. These fatty acids are also finding use as nutrient supplement to flour in countries such as Germany and Norway. Since encapsulation prevents oxidation (see Chapter 14), encapsulated products are also available in the markets.[52,53] Canada, perhaps, is the first country to recommend fortification of infant formula with omega-3 fatty acids. One of the fortificants for the purpose is a new high-stability powder. MarinolTM OMEGA-3 HS Powder, a FO is one of several popular fortified products.[54,55] It is important to note that while developing such omega-3 PUFA-fortified foods, the total fat content, particularly the level of saturated fatty acids, must not exceed the dietary guidelines. The fortified food must be convenient, palatable, with no fishy odor/flavor and no fishy eructation following consumption. The food matrix should provide minimum or no resistance for release of omega-3 PUFA in the gastrointestinal tract to ensure maximum bioavailability. Particular attention needs to be paid to the material used for micro emulsification, as this may be an important criterion for the bioavailability of long-chain omega-3 PUFA.

13.6.2 Marine Proteins

Proteins from seafood by-products can have a range of dynamic properties and could preferentially be used in foods as binders, emulsifiers, and gelling agents.

Seafoods are recognized sources of high-quality proteins with many desirable functional properties. The fish protein powders are also good sources of potassium, phosphorus, and magnesium and amino acids (see Chapter 3). Fish protein hydrolyzates are generally used for the modification of functional properties of foods and in dietetic foods as a source of small peptides and amino acids. Its high dispersibility makes it suitable as a replacer for milk proteins and as an additive to cereal foods, soups, and bread and crackers.[56] Some entrepreneurs such as the Association of Danish Fish Processing Industries and Exporters have commercially produced fish-based protein powders for use in frozen products to enhance their functional properties such as water binding and frozen stability (see Chapter 3).

13.6.3 Minerals

Fish bone material derived from processing of large fish is a useful calcium source where the quantity of calcium is concerned. To use fish bone for food fortification purposes, the bone should be converted into an edible form by softening its structure. This can be achieved utilizing different methods including hot water treatment and hot acetic acid solutions addition (Chapter 8). A natural calcified mineral source is available for use in both functional foods and DSs, providing bioactive calcium, magnesium, and trace minerals for bone health and overall wellness. *Aquamin*™ is derived from *Lithothamnion* spp., a sea plant. The product is harvested from the portions of the sea plant that have naturally broken down and settled to the bottom of the sea. The ingredient is available in three forms, providing opportunities for a wide variety of applications, from baked goods and beverages to confections and DSs.[55]

13.6.4 Glucosamine

Glucosamine is a well-recognized nutraceutical for joint pain relief, which helps in the repair and maintenance of cartilage (see Chapter 6). Oral glucosamine supplementation has demonstrated effectiveness in combatting osteoarthritis. Glucosamine is absorbed easily into the human intestine because of its low molecular weight. Glucosaminoglycans and glycoproteins allow cells in tissues to hold together. In particular, *N*-acetyl-glucosamine is the final form, which together with glucoronic acid is polymerized to lubricant, hyaluronic acid. They are necessary for contraction and maintenance of virtually all connective tissues and lubricating fluids in the body. Daily intake of 1500 mg glucosamine sulfate may be the preferred treatment for knee osteoarthritis.[57,58] A diet-supplement composed of red ginseng (43.5%), glucosamine (25%), shark cartilage (25%), ascorbic acid (5%), and manganese chloride (1.5%) has been developed for relieving arthritic symptoms. Use of *N*-acetyl glucosamine (produced from chitin hydrolysis) as an additive in milk products has been described in a Chinese patent.[58] Enzymic production of *N*-acetyl-D-glucosamine (GlcNAc) from crab shell α-chitin was investigated with a view to using the GlcNAc as a functional food supplement or therapeutic agent. A crude enzyme preparation from *Aeromonas hydrophila* H-2330 was used for hydrolysis at 17°C, as the chitinases in the crude enzyme mixture were inactivated at higher temperatures. Yields of GlcNAc from α-chitin were 66–68% after 10 days.[59] Potential of supplementing beverages with glucosamine in hydrochloride or sulfate forms has been examined

with respect to their taste, consumer acceptability, and marketing potential.[60] An orange juice supplemented with glucosamine at 750 mg per serving has also been marketed recently in the United States. According to a company press release, two 8 fl oz servings deliver 1500 mg of glucosamine. Recently, a commercial glucosamine product has been accorded GRAS status by the U.S. FDA. The GRAS status permits the product to be used in a variety of specific mainstream foods and beverages.[61] Recently, *N*-acetyl glucosamine has been found feasible to fortify milk.[62]

13.6.5 Chondroitin Sulfate

The therapeutic effects of chondroitin in the cure of joint pain have been discussed (see Chapter 6). The compound is ideally obtained from shark cartilage. Recently, the content and biochemical properties of chondroitin sulfate in shark cartilage and finished cartilage powders being used as nutraceutical supplements were evaluated by analyzing unsaturated disaccharides after treatment with the enzyme, chondroitinase, and the results were compared with the specifications on the product labels. The recovery ranged from 95 to 102%. Furthermore, the average molecular weight and the origins of chondroitin sulfate in shark cartilage and finished products were evaluated by agarose gel-electrophoresis and assessment of disaccharide compositional patterns, respectively. Quantitative and compositional analysis of disaccharides after enzymatic depolymerization showed that the amount of CS in the samples was up to 29%. In the finished products, the content of chondroitin sulfate was 21.3% and its average molecular weight in the cartilage and finished product was approximately 40 kDa.[63]

13.7 COMMERCIAL STATUS

The U.S. National Marine Institute (NMI) observed that 65% of adults used a fortified food or beverage and 65% used a functional food in 2005. The NMI has projected a value of $35.6 billion in sales of functional and fortified foods in 2006.[64] The popularity of functional and fortified foods has increased in recent years due to a combination of strong marketing campaigns and growing body of scientific evidence that have contributed to rising consumer awareness and interests. The carbonated beverage industry, which has been facing negative criticism from the general public for the adverse effects of their products on health, is diverting to new beverages fortified with nutrients such as vitamins and minerals. The current interest in fortified products is also indicated by presentation of a total of 217 papers in the functional foods and health category under the symposium grid of Agricultural and Food Chemistry organized by the American Chemical Society at San Fransisco, in September 2006.

Of the various marine ingredients, omega-3 fatty acids are the most popular fortificants used by the industry. Foods fortified with omega-3 fatty acids are available, particularly in the United States, Europe, Japan, and Southeast Asia. These products include bread items and other baked goods, dairy products such as milk, cheese, yogurt, and chocolate milk, and infant formulae.[58,65] Some companies are marketing specialty drink products in Japan that are enriched with DHA. It has been estimated that opportunities for omega-3 fatty acids in the global nutrition and food fortification markets could reach an annual value of $500 million.[64] There are several forms

of FO supplements, which are available in 400–2000 mg capsules. A typical 1 g soft gel capsule of FO contains 180 mg of EPA and 120 mg of DHA. Natural FO capsules containing 50% EPA and DHA in a 1:5 ratio are now available. A more concentrated form of FO is the semisynthetic ethyl ester product containing 85% EPA/DHA. One such product contains 490 mg of EPA ethyl ester and 350 mg of DHA ethyl ester per 1 g capsule. Stable FO powders (such as Marinol TM OMEGA-3 HS Powder) have been commercially developed recently.[66] A commercial omega-3 powder is claiming to provide the health benefits of fish, without the taste and smell of fish. Another encapsulated omega-3 fatty acid from menhaden oil ingredient has also been developed to fortify baked goods. A commercial product, MEG-3™ containing powdered FO that delivers the health benefits of both EPA and DHA has been developed. A patented microencapsulation technology provides superior process tolerance and ease of formulation, without adding any fishy taste or smell to your product. The product provides food manufacturers with the highest concentration of bioavailable omega-3 in the marketplace.[65] Recently, a new milk with omega-3 fatty acids derived from FO has been introduced. The new line of premium half-gallons, Kemps Plus Milk, is now available in grocery stores throughout Minnesota and Wisconsin.[67]

Recommended FO products must contain antioxidants such as tocopherol to protect against their oxidation. Further, FO products that contain high quantities of vitamin A and D, which could be toxic, should not be used. In Europe and the United States these products are presented as having important cardiovascular benefits and labeled as FO products. Such claims were generally supported by a long list of clinical studies demonstrating the advantages of FO consumption on lowering triglycerides.[12] Currently, the estimated North American consumption for FO-based omega-3 fatty acids in DSs excluding infant formula is 6–10 times higher compared to the food sector. Sales of supplements in the United States were worth $230 million in 2004. Omega-3 fatty acids received a recent boost in the consumer awareness with both the FDA's 2004 qualified heart-health claim and the revised 2005 Dietary Guidelines for Americans. The dietary guidelines recognize that "limited evidence suggests an association between consumption of fatty acids in fish and reduced risks of mortality from cardiovascular disease for the general population."[65] In addition to those mentioned earlier, several DSs of marine origin have recently entered commercial markets. Some of these include astaxanthin, extracted from the microalga, *Haematococcus pluvialis*, and other microalgae products such as spirulina and chlorella, a carbohydrate extract from chlorella, claimed to boost the immune system against influenza, chitosan as a weight loss supplement, among others.[35] Table 13.7 gives examples of some commercially available microencapsulated omega-3 fatty acid powder products and Table 13.8 provides examples of some commercial foods fortified with omega-3 PUFA.[49,64,68–70]

In conclusion, several marine ingredients, because of their recognized biological activities have entered the nutraceutical market as food supplements. While the prominent ones are the omega-3 fatty acids, particularly DHA, other promising ingredients of seafood origin include calcium supplements, glucosamine, chondroitin sulfate, and proteins. Of these, glucosamine and chondroitin sulfate have already shown commercial promises. There are good prospects to avail therapeutic benefits of marine ingredients through fortification technology.

TABLE 13.7
Examples of Some Commercially Available Omega-3 Fatty Acid Powder Products

Product	Ingredients
Microencapsulated FO rich in EPA and DHA, light yellow	Gelatin and sucrose matrix, coated in starch, sodium ascorbate, ascorbate, tocopherol, and tricalcium phosphate
Microencapsulated FO high in EPA and DHA, light yellow	Caseinate and sucrose matrix, coated in starch, ascorbyl palmitate and sodium ascorbate
Encapsulated tuna oil, high in DHA, less fishy odor	Sodium cseinate, dextrose, monohydrate, dried glucose syrup, sodium ascorbate, mixed natural tocopherol, lecithin, dialpha tocopherol, and ascorbyl palmitate
Natural FO concentrate powder, typical taste	Carbohydrate, antioxidants, and free-flowing agent

TABLE 13.8
Examples of Some Commercial FO Powder Products and their Major Ingredients

Food Products	Trade Name/Brand	DHA/EPA and Dose
Beverage	Great Circles, USA	DHA/EPA
	Ultrabalance, USA	
Bakery products	Irish Pride, Ireland	FO (EPA/DHA)
	British Bakeries, U.K.	FO (EPA/DHA)
	Allied Foods, NZ	FO (EPA/DHA)
	Wegman's Food Markets, USA	OMEGA-3 fatty acids
	Coles high Top bread, Australia	37 mg/2 slices
	AP Foods omega-3 bread, Australia	200 mg/35g serve
Bar	Great Circles, USA	FO (EPA/DHA)
FO capsules	Most brands, Australia	300 mg/capsule
	MEG-3™ Ocean Nutrition, USA	omega-3 encapsulated powder
Spread	MD Foods, U.K.	FO (EPA/DHA)
	Golden Vale, Ireland	FO (EPA/DHA)
Various foods	*Novomega*™ National Starch Association (USA) and Omega Protein (USA)	EPA/DHA
Various foods	Kellog Co. and Martek, USA	DHA from microalgae
Infant formulae[a]	Mead Johnson Nutritionals, USA	DHA, ARA, and omega-6 fatty acids
Whole wheat bread[b]	Arnold Food, Co., USA	DHA/EPA
Margarine	Blue Band Idee! Uniliver, Netherlands	DHA, ALA, and B vitamins
Milk	St Ivel's Advance milk, U.K.	Omega-3 fatty acids
	Farmer's bestmilk, Australia	21.2 mg/250 ml
	Brown's (Heart Plus) milk, Australia	150 mg/250 ml

(*continued*)

TABLE 13.8 (Continued)

Partially skimmed milk	Neilson Dairy Oh! Partially Skimmed Milk, Canada	From cows that are fed diet rich in DHA
Yogurt[c]	Woodstock Water Buffalo Co., VT	100 mg EPA and DHA in 170 g serving
Orange juice	Oh Mega J, Canada Shwartz Sparky Ornage, UK	Omega-3 fatty acids

[a] Data taken from Ohr, L.M., *Food Technol*., 59(4) 63, 2005.

[b] Data taken from Sloan, A.E., *Food Technol*., April 2006, p. 23; Garg et al., 2006, *Newsletter*, U.S. Institute of Food Technologists, Washington, June 13, 2007.

[c] Data taken from Ohr, L.M., *Food Technol*., March 2006, p. 81.

Source: Adapted from Swansson, M.A. and Evenson, P., Food *Additives*, Marcel Dekker, New York, 2002.

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