IMPROVED UTILIZATION OF FISH OIL AS POTENTIAL NUTRACEUTICALS AND FUNCTIONAL FOODS

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ABSTRACT

It has been stated that a minimum intake of Omega-3 (n-3) fatty acids from marine oils would reduce the burden on health care tremendously as nearly one third of all diseases are life-style related. Although n-3 oils originating from marine algae, are predominant in the body of fatty fish such as mackerel and herring, the liver of white lean fish such as cod and halibut. More recently, n-3 oils from by-products of fishery and fish processing industries have attracted special attention. By-products from fish processing including heads, frames, skin and viscera contain considerable amounts of n-3 polyunsaturated fatty acid (PUFA) rich oil and utilization of marine by-products as good sources of n-3 oil are of great interest. The examination of fish as a source of PUFA has to be analyzed in conjunction with the extend of lipid oxidation in there by-product, particularly because there is no simple relationship between lipid oxidation level and PUFA losses. By-products that are PUFA-rich may also contain high levels of oxidation products if adequate care is not taken during transportation, storage and processing.

There is an increasing demand for eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) concentrates from the health food industry as food supplement and from the pharmaceutical industry for drugs but, with improved quality, the concentrated products will expand into the functional food market. To be successful use of n-3 PUFA concentrates as a broad based functional food ingredient technologies need to be developed that enable the incorporation into foods while protecting the oil from oxidation.

Key words: Fish oil, improved utilization, nutraceuticals, functional foods

LIPID CONTENT AND DISTRIBUTION IN FISH BODY

The temperate species due to their migratory patterns and highly seasonal generally contains more lipids that the leaner tropical species. For farmed finfish and shellfish, the total lipid content of the diet is important because lipids are a valuable energy source. Therefore, most farmed animals are usually fed high-energy/high-lipid diets to maximize growth rates, and thus their flesh tends to contain more lipid than wild examples of the same species sometimes twice as much. The major lipid storage sites in fish vary in different species. However, lipids are primarily located in the subcutaneous tissue, belly flap, muscle tissue, liver, mesenteric tissue, and in the head. The amount of lipid dispersed through the flesh decreases from the head to the tail, where the muscles used for swimming are located. Lipid content in the dark muscle is usually several times greater than that of the white muscles. There is also a considerable amount of lipid located in the myosepta surrounding the muscle. The dark muscle contribution to the flesh of clupeids and carangids is about 20% of total muscle, the contribution in mackerel reaching about 26%. Lean fish usually have mostly white meat, but dark muscle still contributes about 10% in the gadoids. Fish skin contains more lipid than the muscle tissue. The lipid content in the skin of lean fish (e.g., cod, blue whiting) averages 0.2 to 3.9% w/w. The lipid content of the skin of fat fish is much higher and can be more than 50% w/w. Among the other organs, only the roe and liver of some fish species play a role as foodstuffs. In cod, the roe can contribute up to 27% body weight.
(depending on the season), and may contain up to 70% w/w lipid. In a number of fish species (excluding the sprat), the lipid content of nonedible offal was higher than in fillets (with skin).

Composition of Lipids: The Lipid Classes

The lipid of fish flesh are mainly composed of phospholipids, triacylglycerols (TAG), and sterols; minor quantities of metabolic products of these; and small amount of unusual lipids such as glycolipids and sulfolipids. Triacylglycerols are the storage lipids in almost all commercial fish species. Because phospholipids are typically the other main lipid class found in fish flesh, the leaner the fish and the higher the proportion that phospholipids contribute total lipids. For this reason, phospholipids comprise almost 90% of total lipids of lean fish such as cod, with TAG contributing as little as about 1%. Due to anatomical and physiological reasons, the amount of structural lipids (phospholipids) varies between 0.3 and 0.5 per 100 g w/w of fish muscle and does not usually exceed 1% w/w. This is most likely the minimum level of phospholipids essential for the cell and organelle membranes.

Fatty acid composition

Fatty acid groups
Most fish lipids contain FA. The main groups of FA can be saturated (SFA), monounsaturated (MUFA), or polyunsaturated fatty acids (PUFA). The proportion of each FA group in the total lipid content from fish tissue differs and can depend primarily on the total lipid content (and hence lipid class composition) and can be affected by numerous biological factors. The total lipids of 25 Antarctic fish had on average 23.5, 37.7, 38.1% SFA, MUFA, and PUFA, respectively; 253 temperate Australasian fish had on average 30.5, 24.7, 39%; and 170 tropical Australasian fish had on average 37.5, 22.4, 37.8%. Thus, with increasing latitude, the proportion of total MUFA and SFA decreased and PUFA remained fairly constant. The net result was that the lipids were more unsaturated in colder water species.

Saturated and Monounsaturated Fatty Acids
Fish lipid SFA are dominated by palmitic acid (16:0) followed by myristic acid (14:0), their combined contributions accounting for about 90% of saturated acids in Baltic herring lipids. There are also a few percent of stearic acid (18:0), which is more abundant in warmer water fish. Also present are 15:0, 17:0, and 20:0, occurring at about 1% or less and generally considered to be of limited nutritive value.

Polyunsaturated Fatty Acids

Main Types of PUFA in Fish
The PUFA composition is the most characteristic trait of fish lipids. In aquatic animals, PUFA are usually long-chain (LC) with an (n-3) configuration. Quantitatively, they are mostly eicosapentaenoic acid 20:5(n-3)(EPA) and docosahexaenoic acid 22:6 (n-3)(DHA). In most carnivorous fish and invertebrates, DHA is usually more abundant than EPA (up to 2 to 3 times).

Small amounts (1 to 3% FA) of docosapentaenoic acid 22:5(n-3) (DPA) may also be present in fish flesh. The 18:3(n-3), 18:4(n-3), and 20:4 (n-3) acids occur in small (a few percent at most) amounts in fish lipids as well.

(n-3)/(n-6) Ratio

The ratio of (n-3) PUFA to (n-6) PUFA can be used to facilitate identification of high (n-3) PUFA foodstuffs. In general, the (n-3)/(n-6) ratio is higher for marine foodstuffs than terrestrial foodstuffs. This ratio is affected by a number of environmental and biological factors in fish. For example, a strong inverse relationship between (n-3) PUFA and MUFA was revealed in marine species from Antarctic to temperate to tropical waters (Dunstan et al.,
The slopes of this relationship were not significantly different for fish from different regions, but the intercept on each axis was reduced in lower-latitude waters due to the increased proportions of SFA and (n-6) PUFA present in warmer-water species. Also, the average (n-6) PUFA contents in seafood from the Antarctic, temperate, and tropical zones were 2.4, 7.8, and 10.5% of total FA, respectively; thus, the (n-3/n-6) ratio increased with latitude (Dunstan, et al., 1999).

Fig. 1. The relationship between n-3 PUFA and MUFA for species of seafood from the three latitudinal zones.

Factors Affecting the Lipids in Fish

Biological Role or (n-3) PUFA in Fish

There are many interacting external (temperature, salinity, food availability) and internal factors, including species, sex, physiological status (gonad maturity, condition, age), that determine and affect the lipid content and composition of aquatic organisms. The (n-3) PUFA are essential for the normal development of embryos, larvae, and the nervous system, and for the proper functioning of the sense organs of marine and freshwater fish.

Differences in composition may occur within a species, depending on the physiological status and sex. Muscle lipids in fat fish (e.g., pelagic fish) are used as an energy source for locomotion, are stored and later transported to gonads for reproduction, and are utilized during spawning migration and actual spawning.

A comparison of FA composition in lean fish flesh from various areas shows similar amount of total PUFA but variable proportions of individual (n-3) PUFA in them. The pattern of variation seems clear: freshwater fish contain less (n-3) PUFA than marine fish and the content of (n-3) PUFA increases with increasing latitude (Dunstan et al., 1999), which can be explained by adjustment of the membrane function to environmental constraints.

Diet

One of the main factors affecting the lipid composition of fish is diet. This is because all natural foodstuff contain lipids, and some of the dietary lipids are essential nutrients for maintenance of normal growth, disease resistance, fecundity and survival. Because of their
importance for these functions, dietary PUFA can be incorporated into structural lipids, stored for future requirements, or used to produce longer chain, more highly unsaturated FA or biologically active molecules eicosanoids (e.g., prostaglandins and leukotrienes). Whether stored as lipid reserves or used for structural purposes, lipid accumulation from the diet will change the lipid composition of the lipid composition of fish tissue. Fish diet does not affect the FA composition of phospholipids as much as it does that of the TAG. The TAG reflects the lipid composition of the diet, as shown by numerous nutritional and comparative studies on fish. However, fish can adjust their FA composition according to environmental pressure or physiological demands. This is evident from a comparison of the lipid compositions of flesh and diet. However, the FA compositions of various fish fed identical diets may differ.

Seasonal variations
A comparison of different fish species in terms of their lipid composition can be misleading if seasonal variations in each of the species are ignored. Fish muscle lipid content and composition change from season to season, the changes depending on fish species, age, sex, habitat, region, and year. The complex interaction of seasonal changes in diet, reproductive and migratory status, temperature, and salinity can induce these changes. The mean annual lipid content in Baltic herring flesh changed from one year to the next, but seasonal variability was similar between years and showed a very similar coefficient of variation. Seasonal changes in lipids of the edible parts and in the whole sardine showed a similar pattern in different years. Wider between-season difference are observed in fish of the temperate regions, with tropical fish showing much smaller changes. No studies dealing with variability in the Antarctic and/or Arctic fish though a full annual cycle.

Seasonal changes in the lipid classes within a species harvested from a certain area are characteristic and reflect the annual biological cycle of the species and its habitat, although they may be shifted somewhat in time. Seasonal changes in phospholipids of herring. Males and females usually differ in both the extent and rate of those changes. The spawning Baltic herring males and females lost 43% and as much as 70%, respectively, of their TAG. The lower limit of lipid content was lower in females than in males. Once spawning is finished and the fish resume intensive feeding, the muscle lipid reserves become replenished.

Susceptibility to oxidation
Compared with other food lipids, fish lipids are relatively more susceptible to oxidation. This is because of their high degree of unsaturation and low content of antioxidants compared to plant lipids. The \( \alpha \)-tocopherol content in fish muscle lipids ranged from 1 to 75 mg/g oil. In herring, the \( \alpha \)-tocopherol content ranged from trace amount to 66 mg/100g of lipids and varied over the season. The average carotenoid content in fish muscle varied between 0.043 and 0.283 \( \mu g/g \) w/w, but was much higher in the whitefish (Sebastes sp.): 0.776 \( \mu g/g \) w/w in muscle, 3.12 \( \mu g/g \) w/w in skin, and 1.45 \( \mu g/g \) fins (Czeczuga et al., 2000).

Compared with other food lipids, fish lipids are very sensitive to photooxidation, with thermooxidation being less pronounced. The lipid oxidation rate of seafood is species dependent, and is harvest and season dependent in a given species. The susceptibility of seafood lipids to UV-catalyzed oxidation did not correlate with PUFA, DHA, MUFA, or SFA contents. Sprat and herring lipids showed a weak relationship between hydroperoxide level (after 120 min of UV irradiation) and PUFA and DHA contents.

Effects of Processing on Fish Lipids

Chilling fish
Cold storage of fish in ice is not as important to autolytic and microbiological changes of lipids. Lipolysis does not directly affect sensory properties; the sensory effects of oxidation are masked by microbiological spoilage. The rate of lipolytic change is faster in whole than in gutted fish and fillets. Lipolysis proceeds more rapidly in muscles of feeding and pre-spawned fish than in spawning fish.
Freezing fish
Lipid deterioration in frozen fish is a very important quality problem. The extent of lipid oxidation in frozen lean fish is usually high, due to their high PUFA contents and because the membrane lipids are the first to be oxidized. However, if lean fish is stored frozen at an appropriate temperature (e.g., -28ºC, but not higher than -18ºC), lipid oxidation may not be perceivable until after 1 year of storage, due to the low contribution of lipids to muscle rancidity.

Lipid oxidation during frozen storage of fat and medium-fat fish is an important quality problem, primarily due to effects on sensory properties such as rancid off-odor (appearing earlier than off-odor), orange-brown discoloration, and texture changes. Changes in peroxide value (PV) and carbonyl compounds such as anisidine valus (AsV), benzidine value, carbonyl value, and thiobarbituric acid (TBA) proceed in a similar way during frozen storage of herring, mackerel, sprat, horse mackerel, and sardine. After approximately 3 months of storage, oxidation products increase rapidly. After approximately 6 months of storage, a decrease is observed, particularly in aldehydes due to their interaction with nitrogenous substances; the intensity of rancid off-odor is also reduced. Next, the amount of all oxidation products increase rancidly. The activity of the enzymatic and nonenzymatic prooxidative system in muscle increased slightly during the first 3 weeks of frozen storage (-18ºC) of herring and sprat, compared with that in unfrozen fish, particularly sprat.

Fish freshness at the moment of freezing is important in determining the type and extent of changes to lipids once the fish is frozen. Cold storage of whole herring and herring mince for 1 to 2 days prior to freezing, inhibited lipid during frozen storage and hydrolysis proceeded at a faster rate in minces and whole fish frozen immediately after capture and mincing, and also in those stored for a prolonged time (6 to 7 days) prior to freezing.

Cooked fish
Changes in fish lipids during heating depend on whether isolated lipids or lipid-containing tissue were being heated. The changes can be affected by the “history” of the fish lipids or tissue. This history includes how it was stored, as well as fish species, fishing season, and a number of other biological variables. Heating temperature is more important than duration of heating (Medina et al., 1998).

Medina et al., (1998) found a significant (16%) reduction in DHA after 60 min from heating salmon lipids at 150ºC. Heating (particularly at 160ºC) of oxidized lipids from herring (PV=200 mg 0/100 g lipid) affected some of the changes occurring during thermal treatment, but did not induce losses of LC(n-3) PUFA. Conjugated bonds form more readily in oxidized lipids: they were evident at a temperature as low as 60ºC and increased rapidly and linearly at 160ºC.

While the total lipid and FA compositions in fish do not usually change significantly during cooking, the type of treatment may substantially affects other lipids. During conventional heating (120ºC, 5 min) and microwaving (10 min, 90 W) of isolated fish lipids and muscle tissue, the trans isomer contents did not exceed 0.5% of all FA, but were somewhat higher during microwaving. Under those conditions, oxysterol content reached 63 and 43µg/g lipid for isolated lipids, 47 and 46 µg/g lipid for tissue, conventional and microwave cooked, respectively. The oxysterols compositional differed, depending on the heating conditions.

Canned fish
Thermal treatment (cooking and sterilization) causes preferential hydrolysis of DHA from the sn- position of phospholipids because the amount of DHA at that position is clearly reduced. PUFA losses during sterilization of minced bigeye tuna and halibut at 124ºC were recored in the free FA fraction only. There is no polished evidence of losses of (n-3) PUFA in canned products manufactured from fresh fish, compared with the raw material. Canning of mackerel (manufacture of mackerel in juice), frozen-stored for 4 months, resulted in an increased lipid oxidation level and a reduction in (n-3) PUFA, including 13 and 15% reduction in EPA and DHA, respectively. As a result of the removal of a certain amount of water and stored lipids, the contribution of (n-3) PUFA in precooked fish increases. Lipid composition in canned fish
in oil changes after sterilization, the product’s covering oil showing the presence of EPA and DHA and the exchange intensifying with time of storage. This leads to a substantial variation in the lipid composition of canned fish, including an “increase” in (n-3) PUFA both in the fish and in the vegetable oil in canned products Lipid oxidation in a canned fish product depends on the storage temperature and on the absorption of metal ions from the can, but is generally slow and takes a number of months. The fish in the can contains more oxidation products than the covering oil. Addition of α-tocopherol to the latter efficiently inhibited lipid oxidation in fish and in oil for up to a year after canning the herring. After 2 years, the amount of DHA in herring and in the covering oil was higher by 31 and 26% respectively, in α-tocopherol-enriched products than in those without the additive. An extreme example of canned mackerel stored for 17 years could not be consumed due to sensory changes, but it still contained about half of the initial EPA content and about 33 to 25% of the initial DHA content. Compared with fish juice, covering oil protects fish lipids during prolonged storage. Leaving the thermal drip from fresh fish or from fish frozen and stored for 1 to 2 or 3 months (herring, mackerel, and horse mackerel) formed during precooking in the can, inhibits lipid oxidation during canned product storage. In contrast, drip from fish frozen and stored for longer periods accelerates oxidation.

Although hydroperoxides and carbonyls degrade during precooking and sterilization, there is a correlation between the rancidity of frozen and canned fish (horse mackerel, mackerel, herring), and storage time. Canned fish packed in brine was better correlated than that packed in oil. Rancidity was assessed by the sum (converted to w/w) of PV + TBA + Intensity of “off odor” (in raw and cooked fish) and “off flavor”

The storages relationship with raw material quality was observed a month after canning. The correlation decreased thereafter. Canned fish available on the market are regarded as a good source of LC (n-3) PUFA. Their LC (n-3) contents depend primarily on the type of raw material, and specifically on its lipid content. However, canned fish may contain an abundance of oxidation products. Some samples of the covering oil of canned sardine available on the Italian and Swiss markets were found to contain trans-FA in amounts exceeding the EU-proposed tolerance level.

Due to the presence of LC (n-3) PUFA, fish lipids play an important nutritive and therapeutic role in the human diet. It is already known that LC (n-3) PUFA cannot be substituted by α-linolenic acid, and that EPA and DHA serve different functions in the human body. The value of fish as a source of LC (n-3) PUFA primarily depends on the lipid content and the regions from which the fish are harvested with the highest contents generally found in fat fish caught in colder regions (e.g., higher latitudes). The lipid composition of the muscle tissue of fatty fish changes throughout their biological cycle. Therefore, fish may differ in lipid content, FA composition, and therefore susceptibility to oxidation and lipolysis, depending on the fishing season. Lean fish and shellfish, both marine and freshwater, are nutritionally valuable because they contain mainly PUFA-rich phospholipids. Farmed fish, when fed appropriate feeds, may also be a very good source of LC (n-3) PUFA. Because of such variability between species, illustrated books of fish and their lipid compositions should be more readily available. The current review shows that lipid composition tables can never be more than a generalization, due to the intrinsic variability of lipids in a given species. Nutritionists, scientists, and large-scale producers of commercial products need to be aware of this.

In general, the processing technologies currently used cause no loss in LC (n-3) PUFA, therefore fish products can be a good source of those FA, provided the raw material is lipid-rich. The dynamics and extent of changes induced in muscle tissue lipids by the processing technology depend on initial lipid composition as well as on the pro- and antioxidative status of the tissue. Thermal stress is more severe in a very fresh fish (immediately after capture). However, for fish approaching deterioration. A moderately extended cold storage of a raw material may enhance lipid stability during and after treatment. Consequently, despite the decreased activity of prooxidative enzymes and α-tocopherol during storage of fish, the tissue (particularly that of minces) shows a predomination of antioxidative potential (proteolysis products, TMAO decomposition, phospholipid hydrolysis). Also, the presence of some oxidation products can create better conditions for
weak lipid-protein interactions that stabilize lipids. Frozen storage of fish, before it is subjected to thermal treatment (cooking, canning, frying), can increase the probability of adverse changes in lipids during and/or after treatment.

The examination of fish as a source of LC (n-3) PUFA has to be analyzed in conjunction with the extent of lipid oxidation in a product, particularly because there is no simple relationship between lipid oxidation level and (n-3) PUFA losses. Products that are (n-3) PUFA-rich may also contain high levels of oxidation products if adequate care is not taken during storage and processing. However, seafood remains the key source of beneficial LC (n-3) PUFA for the human population and will continue to do so. Efforts to continue to maximize efficient utilization and processing of this unique resource will therefore greatly assist global and regional fisheries, providing more stringent conservation of resources are implemented.

The major technical hurdle for the incorporation of efficacious quantities of EPA and DHA into food is to prevent lipid oxidation and the related fishy smell and off-flavors associated with lipid degradation. A variety of strategies have been attempted to prevent lipid oxidation in omega-3 fortified foods, with encapsulation (such as dry powder and liquid emulsion products) being the most established and successful approach. To avoid mouth detection and altered food texture, encapsulated oil particles must be smaller than 100 µm. Consequently, microencapsulation is the term generally used for encapsulating marine lipids for foods and the resulting product as encapsulated oil, microcapsule, powder, or particle.

**Quality of Lipid for Microencapsulation**

Marine lipids are highly susceptible to oxidation (i.e., autoxidation initiated by metal ions and photoinduced oxidation), which leads to the formation of off-flavor as well as the loss of nutrition value. It is important to attain high-quality oil with no rancidity of fishy off-flavor before microencapsulation because the sensory quality of fish oil normally correlates with sensory quality of the finished microcapsules. The color and contaminant levels of fish oil containing EPA and DHA can be improved through filtering, deodorizing, and winterizing the unrefined oil. To improve the shelf life of the oil, antioxidant such as rosemary extract or tocopherols are normally added. A final deodorization step, such as steam deodorization, is required to produce an oil of good sensory Quality. This final deodorization step remove oil degradation components such as aldehydes that are responsible for most of the off-flavor associated with partially degraded fish oil. Great care should also be taken during packaging (e.g., flushing with nitrogen) and storing (e.g., using containers that block light and heat) marine lipids prior to microencapsulation to ensure a good sensory quality of the oil after microencapsulation.

The Council for Responsible Nutrition (CRN) in Washington, DC (now the Global Organization for EPA and DHA omega 3, GOED omega 3) suggests that the quality of marine lipids for the supplement market should be based on four standards: free fatty acid (FFA) (acid value or AV), primary oxidation products (peroxide value or PV), secondary oxidation products (anisidine value or AnV), and total oxidation. FFAs are released from the acylglycerol or ethyl esters due to hydrolysis. The upper limit for FFAs in fresh oil is typically 0.05%. High levels of FFAs in marine lipid reflect a quality loss of the product. Indeed, FFAs exert a prooxidative effect on marine lipid. PV is a direct measurement of the hydroperoxides and expressed as the milliequivalent (meq) of peroxide-oxygen combined per kilogram of lipid. PV values of ≤1.0 meq/kg are typical for deodorized fresh oil. AnV is another measurement of the extent of oxidative deterioration. The AnV value is determined by spectrophotometric assay (at wavelength of 350 nm) of aldehydes and ketones in the lipid by reaction with p-anisidine solution. An AnV value approaching 10 indicates that considerable oxidation has occurred and the accumulation of rancid compounds. Therefore, PV represents oxidation at present and AnV represents accumulative oxidation. TV is an assessment of the total oxidation (TV=2PV+AnV). Detailed analytical procedures for lipid are available from source such as the official method and recommended practices of the American oil chemists’ society (AOAC method). However, even oil giving satisfactory values

108
are often unacceptable for microencapsulation purposes as it take only very minor quantities of specific aldehyde degradation products before they can be chemically detected in microencapsulated oils. A variety of more sensitive analytical method have been developed to measure low levels of strong smelling or tasting aldehydes present in processed of fish oil.

The natural profile of marine lipids extract from fish is normally given as 18% EPA triacycerol and 12% DHA triglyceride (TG18/12), although in most fish used for producing fish oil supplement the levels are actually lower. These standard process fish oil can also be concentrates to for example 30% EPA ethyl ester and 20% DHA ethyl ester (EE30/20),or 40% EPA ethyl ester and 20% DHA ethyl ester. Encapsulation (EE40/20) by conversion to ethyl esters and reaction with glycerol to reform triacylglycerol concentrates. Encapsulating the concentrated TG oil, in comparison to TG18/12, is more challenging because the higher concentration of EPA + DHA and increased processing make the oil more prone to oxidative deterioration.

Fish oil contain mixture of EPA and DHA. Sardine, anchovy, and menhaden oil contain a ratio of approximately 2:1 EPA and DHA, while tuna oils contain more DHA with a ratio of EPA and DHA approximately 1:5. Microbial oils used commercially contain mainly DHA with very little EA. There has been some debate regarding the relative stability and sensory properties of oils with different EPA to DHA ratios. For instance, a study on oxidative stability of PUFAs (99% purity) suggest that stability increased with high degree of unsaturation so that DHA more stable than EPA. However, an opposite trend was found in an earlier study with ethyl EPA and ethyl DHA (94.5 and 94.1% purity, respectively) where oxygen uptake of ethyl DHA was 1.6 time faster than that of EPA. A comparative study of fish oil and DHA microbial oil showed no different in stability if antioxidants are removed. It appears that if there is any difference in stability of oils containing difference ratio of EPA and DHA, including algal oils then this difference is minimal and all oil containing EPA, DHA, or a combination, need to be microencapsulated for stabilization and use in food.

Achieving microencapsulation for a particular food application depends on three factors: materials, technologies, and properties of the microencapsules. Materials include fish oil and sell constituents. Technologies are the microencapsulation “know how” or process. The number of properties to be evaluated in microcapsule can vary depending on the food application. Particle size, sensory, and oxygen barrier at a given temperature and moisture level are some examples of the microcapsule properties. The following section will describe the current status of microencapsulation of marine lipids based on the work of various research institutions and companies producing encapsulated marine lipids and marine lipid-fortified foods.

MICROENCAPSULATION TECHNOLOGIES

The many technologies for microencapsulation can be divided into two categories, one which uses a liquid as a suspending medium, such as in complex coacervation, and one which used a gas as a suspending medium into which a liquid phase is sprayed, such as fluidized bed coating. The former are made using a chemical process and the latter utilized a mechanical process. Although there are many different processes, all include three main steps: (1) dispersion or emulsion formulation, (2) capsule wall deposition, and (3) capsule isolation.

Marine Lipid-fortified Foods

In a 2001 survey of product, which incorporate omega-3 fatty acid from plant or fish sources into foods, dairy ranked third (15%) after pet food (29%) and dietary supplements (24%). Baby food, baked foods, and beverage attained the lowest ranking, 2% each. This ranking may not hold true today based on the continuous launching of new products since 2001 around the world, particularly in Europe and Australia or New Zealand. In the last couple of years, major new launches have occurred in breads and diary products and also in infant formula.

- Infant Formula
- Baked Goods
- Nutritional Bars
- Milk and milk-Based Products
- Nonmilk Beverages
- Processed Meats

Status Assessment

Base on the proliferation of marine lipid-fortified products in seven food categories for human consumption, microencapsulation could become a profitable and effective way to deliver marine lipids to the population at large. The limited number of products in certain food categories such as juice or breakfast cereals, however, indicates that the commercialization or microencapsulated omega-3 powder in foods is still at an early state. Furthermore, the low level of EPA and DHA incorporated into many food categories, in comparison to that proposed by various national and international organizations, suggests that elimination of fishy taste and smell remains a challenge. While a number of microencapsulation technologies and edible polymeric shell material can be applied to product encapsulated oils that are suitable for short shelf life foods like bread or UHT milk, the same cannot be said for other staple foods like cereal or salad dressing where longer shelf life or exposure to high moisture is a common occurrence. There are few technologies currently available that can deliver and stabilize efficacious doses of omega-3 oils in multiserving foods while still conforming to regulatory cost requirement for food products.

Summary

Given the well-documented health benefits of omega-3 fatty acids, microencapsulation is a good vehicle for delivering marine lipids, particularly EPA and DHA, to the public at large, from infancy to adulthood. There is currently a proliferation of functional food fortified with marine lipids around the world, particular in Europe and Australia or New Zealand.

Microencapsulated oils work best in dry food application such as baked goods, nutritional bars, using low dosages of EPA and DHA concentrates, or with shorter shelf life such as powder mixed. Achieving good sensory properties in wet food applications such as juice, higher EPA and DHA (>250 mg per serving), or longer shelf life such as cereals requires future development to improve current materials and processes.

Of the three main types of edible biopolymer reserved for shell materials, proteins and carbohydrates are most commonly used by nutraceutical companies and research institutions. Similarly, while there are numerous technologies to encapsulate marine lipids, only spray drying and complex coacervation are currently used commercially to stabilized EPA and DHA for food delivery. Encochelation marine lipids with phosphatidylserine holds good promise because the phospholipid shell provides a good moisture barrier and particle size is submicro, which is important for preventing setting in certain drink products. However, the cost of shell material and the limited stability of these small particles currently limit the commercialization of encochelation technologies.

The current strong demand for fortification for foods with marine oils, especially EPA and DHA, is creating a pull for research organizations and companies to develop technology to deliver these oils into foods in a manner that does not impact the taste and smell of the food. The shelf life of the microencapsulated ingredient must be equal to or longer than the shelf life of the food. The ingredient must also be acceptable in a regulatory sense and have little impact on the cost of the food. There is no doubt that the demand will result in continued development of new and improved technologies to microencapsulate marine oils for delivery in foods products.
REFERENCES


