Nutritional Aspects of Long Chain Omega-3 Fatty Acids and use in Bread Enrichment

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Abstract:

The current western diet which is high in long chain omega-6 polyunsaturated fatty acids (LC PUFA) and low in long chain Omega-3 PUFA may not supply sufficient omega-3 LC PUFA or an appropriate balance between these critical nutrients. This imbalance is believed to cause many varied diseases. Scientific evidence continues to show that low dietary intakes of Omega-3 LC PUFA are a prime factor in the development of cardiovascular disorders. The dietary intake of most western nations is 100-250 mg. Omega-3 LC PUFA per day causing a "dietary gap". New novel refined oils and powders having no "fishy " flavors can now be used to fortify foodstuffs including baked goods and thus help to alleviate dietary deficiencies.

The 1980s were a period of rapid expansion in scientific knowledge about polyunsaturated fatty acids (PUFA) in general, and omega-3 PUFA in particular. Both omega-3 and omega-6 PUFA are precursors of hormone-like compounds known as eicosanoids, which are involved in many important biological processes in the human body.(1) Recently it has been suggested that the typical "western" diet, which is relatively high in omega-6 PUFA and low in omega-3 PUFA, may not supply the appropriate balance of PUFA for proper biological function.(1,2) The imbalance is believed to cause many varied disease symptoms ranging from cardiovascular disease, hypertension, inflammatory and auto-immune disorders, depression and certain disrupted neurological functions. Long chain PUFA are now considered "conditionally essential" for infant growth and development

Evolution Of The Human Diet

Prehistoric humans evolved on a diet that consisted primarily of fresh fruits, leafy vegetables and animals. These foods provided a relatively equal balance of omega-6 and omega-3 PUFA upon which physiological and metabolic processes were established. The omega-6 to omega-3 ratio of approximately 1:1 remained virtually unchanged for millions of years. (1,3,4) Over the past 150 years, significant changes in the composition of the food supply of western societies resulted in an increase in consumption of omega-6 PUFA and a corresponding decrease in intake of omega-3 PUFA.

Today, the ratio of omega-6 to omega-3 in North America is estimated to be in the range of 10:1 to 25:1. (1,3,4,5) This alteration in the food supply and subsequent shift in the ratio of omega-6 to omega-3 PUFA is attributed to a number of factors. Modern food production methods decreased the omega-3 fatty acid content of many foods. Wild animals, once free to feed upon wild vegetation, were leaner and had significantly more omega-3 fatty acids in their tissues than today's farm raised commercial livestock. Today, domestic beef contains little to no detectable amounts of omega-3 PUFA.(1) Similarly, modern aquaculture produces fish that contain less omega-3 PUFA than those that grow naturally.

Cultural trends have influenced fat intakes as well. The industrial revolution introduced vegetable oil technology and popularized the use of cooking oils from sunflower, peanut, and corn---all good sources of omega-6 PUFA. (1) Critically for infants, reliance upon infant formula has increased in the latter half of this century. In contrast to human milk, North American formula is devoid of the essential omega-3 PUFA docosahexaenoic acid (DHA). (4)

Figure 1. Relative Percentages of Fat and Fatty Acid Families in the Evolution of Human Nutrition

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Leaf and Weber, (6)

<u>Chemical Structure and Nomenclature of Fatty Acids</u>

Fatty acids form the basic chemical structure of fats. Structurally, all fatty acids have a chain like structure varying in length from 2 to 20 or more carbons. The most common fatty acids in foods have an even number of carbon atoms ranging from 12 to 22 carbons.

<u>Saturated and Unsaturated Fatty Acids</u>

Fatty acids are classified as saturated, monounsaturated or polyunsaturated depending on the number of double bonds.(7). The most common saturated fatty acids in foods are lauric (12:0), myristic (14:0), palmitic (16:0), and stearic (18:0). (7,8) predominantly found in animal foods: meats and dairy products such as cheese, milk, butter and eggs and fats from beef and pork.(3,9). They are also abundant in the tropical oils, coconut, palm and palm kernel and vegetable shortening.

The term "unsaturated" means the hydrocarbon chain contains at least one double bond. Unsaturated fatty acids fall into two categories, monounsaturated (MUFA) and polyunsaturated (PUFA). Monounsaturated fatty acids contain only one double bond and are synthesized within the human body.(1) They are found in most animal fats including poultry, beef and lamb as well as nuts, seeds and corn. (3,8)

Polyunsaturated fatty acids contain two or more double bonds. There are two classes of PUFA: omega-6 and omega-3. The distinction between omega-6 and omega-3 PUFA is based on the location of the first double bond, counting from the methyl end of the fatty acid chain . Linoleic acid, an omega-6 fatty acid with 18 carbons and two double bonds, is the predominant PUFA in the western diet and commonly found in the seeds and oils of most plants (with the exception of coconut, cocoa, and palm, which have relatively low levels of omega-6 fatty acids) and in mayonnaise, salad dressing and margarine.

Alpha-linolenic acid,(18:3) an omega-3 fatty acid with 18 carbons and three double bonds, is found in appreciable amounts in green leafy vegetables, soybeans, linseed, rapeseed and canola oils, as well as phytoplankton, algae and fish Table 1. (3,10)

Linoleic acid and alpha-linolenic acid are precursors or "parent" compounds of omega-6 and omega-3 long chain PUFA.

Linoleic acid and alpha-linolenic acid can be metabolized within the human body into longer-chain fatty acids of 20 to 22 carbon atoms or more through a process of chain elongation and desaturation. Linoleic acid can be metabolized into gamma-linolenic acid (GLA), dihomo-gamma linolenic acid (DGLA) and arachidonic acid (AA).

Alpha-linolenic acid can be metabolized into eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). EPA and DHA can also be obtained directly from the diet from fish oils of both marine and freshwater sources. Table 2. (3,9)

Table 1. Dietary sources of various fatty acids

Polyunsaturated fatty acid

omega-6	omega-3
Linoleic acid (18:2 n-6)	**Alpha-linolenic acid (18:3 n-3)**
Safflower seed (55-81%)	Freshwater fish (1-6%)
Evening primrose (70-75%)	Marine fish (~1%)
Sunflower seed (20-75%)	Linseed (45-60%)
Grape seed (58-78%)	Green leaves (56%)
Soybean (44-62%)	Rapeseed (10-11%)
Sesame seed (35-50%)	
Corn (34-62%)	
Cotton seed (33-59%)	
Groundnut (13-45%)	
Black walnut (~62%)	
English walnut (~55%)	
Pine nut (~44%)	
Black currant (44%)	
Borage (38%)	
Peanut (29%)	
Olive (11%)	
Egg yolk (11%)	

Gamma-linolenic acid(18:3 n-6)

Borage (~20%)
Black currant (~20%)
Evening primrose(~10%)

Eicosapentaenoic acid(20:5 n-3)

Freshwater fish (5-13%)
Pacific anchovy (18%)
Capelin (codfish) (9%)
Mackerel (8%)
Herring (3-5%)
Sardine (3%)

Docosahexaenoic acid(22:6 n-3)
Sardine (9-13%)
Pacific anchovy (11%)
Mackerel (8%)
Capelin (codfish) (3%)
Herring (2-3%)
Freshwater fish (1-5%)

Note: Values in parentheses represent percent of total fatty acid, Lee,(3).

Table 2. Total EPA and DHA content of selected fish

Fish	gram/100gram*
Atlantic mackerel	2.5
Atlantic salmon,farmed	1.8
Pacific herring	1.7
Atlantic herring	1.6
Lake trout	1.6
Bluefin tuna	1.6
Sturgeon	1.5
Anchovy	1.4
Sprat	1.3
Sardines, canned,drained	1.1

Nettleton, (8)

- amounts specified may vary slightly according to season, and food availability

Essential Fatty Acids

Linoleic acid and alpha-linolenic acid are considered to be essential fatty acids (EFA) for human health because humans cannot synthesize them and must obtain them from dietary sources.(11,12) If there is a shortage of linoleic acid in the diet, its longer chain metabolite, arachidonic acid (AA), is also considered essential. Similarly, DHA and AA may be considered conditionally essential fatty acids under certain circumstances, particularly during infancy when the body's capacity to convert alpha-linolenic acid and linoleic acid is limited. (12-14)

Metabolism of Omega-3 and Omega-6 PUFA

The same group of enzymes are responsible for metabolizing both omega-6 and omega-3 PUFA, resulting in competition between the two PUFA families for these enzymes. (1) The relative oversupply of omega-6 PUFA in the diet may impair the transformation of omega-3 PUFA into its longer chain metabolites, EPA and DHA This can lead to a relative imbalance of the metabolic end products. (1,3,19,20) which are thought to be a major factor in the development of cardiovascular disease. Figure 2.

Roles in Human Health

Both classes of PUFA are important for normal biological function and are involved in a variety of physiological processes. Most clinical studies on the protective and therapeutic effects of omega-3 PUFA have used preformed EPA and DHA in the form of fish oil. The potential health benefits of fish oil include reduced risk of coronary vascular disease, hypertension and atherosclerosis as well as inflammatory and autoimmune disorders. (1,15-27)

Both LC omega -3 and omega-6 fatty acids are critical for the embryo and developing infant. During intrauterine life DHA and AA are incorporated into the phospholipid membranes of the retina and brain and continue to accumulate during the first two years of life after birth. Therefore, adequate intake of DHA and AA is critical during pregnancy, lactation and infancy
for proper development of these tissues. (28-36)

Recommended Intakes

In 1990, Canada issued separate dietary recommendations for omega-6 and omega-3 PUFA. (37) In the United Kingdom, the Department of Health recommends an omega-3 PUFA intake of a minimum of 0.2 percent of energy. (38) In addition, the Task Force of the British Nutrition Foundation proposes a daily omega-3 PUFA intake ranging from 0.5 to 2.5 percent of energy in the form of alpha-linolenic acid, which corresponds to 1-6 grams linolenic acid for men and 1-5 grams for women.

The FAO/WHO in a recent report on lipids and fatty acids in infant development recognizing the necessity of long chain PUFA recommended both DHA and AA to be included in infant formulas (39).

No specific Recommended Dietary Allowances for either omega-6 or omega-3 PUFA have been established in the United States. However, according to the most recent RDA text, "rapid developments in the field of fat-soluble dietary factors, and their physiological role will require periodic reappraisal of their significance in nutrition and the regulation of metabolic functions. The possibility of establishing RDAs for these fatty acids should be considered in the near future". (10)

The Food Industry and how to put fish into bread?

The fats and oils industry continues to feel the pressure from consumers to reduce fat intake in general and the industry is reducing or eliminating fat where feasible from products. This however is reducing essential fatty acid intake. To improve the nutritional value of certain foods omega-3 PUFA can now be added to breads. Bread is an excellent choice for "Nutraceuticals" or "pharmafoods" since it has many good characteristics on which to build. Structure function claims may be possible since the scientific evidence is strong and there may be sufficient "significant scientific agreement" as proposed by the FDA. Foods could be designed for pregnant and lactating mothers and young children can be contemplated. However the best opportunity is in fortifying bread for cardiovascular benefits.

"Novel" refining techniques to produce marine oils that can be added to a range of foods without affecting the flavor profile of the product are the key to success Previously, fish oils have been used only in a "hardened" or hydrogenated form to prevent the occurrence of fishy off-tastes and smells. Now, fish oils and dry powders, with microencapsulated oils are available for food fortification use. Only those specifically refined, protected and packed oils are suitable, such as those offered from Hoffmann La Roche under the "ROPUFA" label.

Today a wide range of PUFA products in oil and powder form are available for various applications. The oily forms are easily added to the lipid phase with care being taken to protect the readily oxidizable PUFA. The powdered forms are used mainly in dry goods such as bakery products and milk powders. These microencapsulated powders are dispersible in cold water, are exceptionally stable and these properties together with neutral taste make them ideal for enriching foods such as reduced fat products, milk drinks, salad dressings and juice drinks.

A Very Special Kind of Oil Refining.

The specific refining process for fish oils suitable for food applications is similar to standard techniques such as neutralizing the free fatty acids and bleaching Special deodorizing and absorption techniques remove peroxides, aldehydes and ketones are key to prevent development of off-flavors. Finally, stabilization with an antioxidant mixture of tocopherols, ascorbyl palmitate and lecithin protects the product from future degradation and oxidation (Chart 3). Packaging under an inert gas further protects the product until use.

Global Food Developments

Food technology has now advanced to the point where we can in theory enrich any food with a N-3 polyunsaturated fatty acid. Many are already marketed in the UK, Korea, Taiwan and Scandinavian countries. At the forefront of developments are infant and baby follow-on foods in Europe and the Far East, breads in Europe and UK, and margarine's now entering the mainstream in the UK with the launch of "Live" brand from Golden Vale and "Life" from the TESCO chain. The increasing popularity of heavier rye and multigrain breads in North America may offer opportunities for enrichment with omega-3 pufa. In Europe breads of these types are gaining in use, however the general awareness of long chain pufa as healthy components of the diet are higher than the general population in North America.

Application Trials in Bread

The fortification of bread with ROPUFA's was explored as a means of increasing the consumption of omega 3 fatty acids in the diet. Bread is an ideal medium for omega 3 pufa because the carbon dioxide given off in the proofing and baking processes protects the oil from oxidation while it is exposed to higher temperatures. This work was conducted by Hoffmann-La Roche with the intent of studying the baking properties, taste and aroma of breads containing Omega-3 ROPUFA products.

Roche products are available in two forms, ROPUFA 30 n-3 EPA Oil and ROPUFA 10 n-3 EPA Powder. The oil is a more concentrated form of omega-3 pufa and is more economical to use. However, both are easily formulated into bread.

To incorporate the oil into a baking fat, melt the solid baking fat, mix the ROPUFA oil into it at moderate temperature and allow the mixture to solidify. This modified baking fat can then be used as per usual. To put the oil into a flour premix, add it with flour in the ratio of 7.5 parts flour to 1 part oil. Mix this in a high speed mixer to obtain a free-flowing powder. For maximum stability, this mix should be used within a short time in production.

The ROPUFA powder can be mixed directly into the production batch but this can lead to uneven distribution in the final product. It is better to first mix the powder into a portion of the flour to make a concentrated premix which can then be distributed more evenly throughout the production batch.

For bread the following ranges are recommended (as a percentage of the finished product):

0.5 - 1.5% ROPUFA 30 n-3 oil

1.0 - 2.5% ROPUFA 10 n-3 powder

The addition level of the ROPUFA's is somewhat dependent on the type of bread being fortified. A white bread would be better if fortified at the lower end of the range while a dark bread could be enriched to the higher end of these ranges due to its more robust flavor profile.

A typical white bread formula is given in Table 3.

Table 3: White Bread Formula

	700 g	**strong white flour**
	450 ml	**water**
	25 g	**butter**
	15 g	**dried yeast**
	2 tsp.	**salt**
	17.28 g	**ROPUFA 10 n-3 EPA powder**
or	**5.76**	**ROPUFA 30 n-3 EPA oil**

The above formula yields a bread that has 0.24 g of PUFA in each 125 g of finished product. Except for the addition of ROPUFA, the recipe and processing times and temperatures for proofing and baking are the same. Laboratory evaluation of the finished product versus a control showed similar ratings for crust color, loaf shape and height, volume, crumb color, pores, aroma and taste.

Product made with a similar formula was shown at a local New York trade show. In addition, a spread containing 0.2 g of PUFA per serving was spread on the bread. Again, there was no discernible off-flavors or odors apparent.

Summary

With due care and proper precautions being taken, it is possible to produce a wide variety of foodstuffs enriched with LC PUFA. However each product must be considered on a case by case basis with expert help to formulate new products. Despite the technical issues this fortification concept offers bread makers a way to introduce a new range of foods associated with definite health benefits which will enjoy the support of the scientific community as helping in disease prevention. PUFA breads are finding increasing acceptance in Europe and perhaps the time is right in north America for marketers to consider new products.

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