Omega-3 fatty acids: nutritional aspects, sources, and encapsulation strategies for food fortification

Review

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This review focuses on health beneficial aspects of omega-3 fatty acids and microencapsulation technologies to prevent oxidation and off flavour formation in foods. The paper is broadly divided thematically in three sections. First section of this review discusses the biochemistry of omega-3 fatty acids, their classification and formation of off flavours due to oxidation of omega-3 fatty acids. Different sources of omega-3 fatty acids (alpha lenolenic acid (ALA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)) are also briefly explained. Second section discusses about major health effects of omega-3 fatty acids intake and briefly explains the effects on cardiovascular diseases, neurological diseases, cancer chemoprevention, controlling body weight, inflammation, etc. Inspite of so many health beneficial effects, fortification of these fatty acids to food products becomes a challenging task due to unstability and susceptibility of omega-3 fatty acids to oxidation. Microencapsulation has been hypothesised to be an effective technique to mask the unpleasant taste of certain ingredients and, more recently, to delay lipid oxidation of PUFA, which increases the stability of omega-3 fatty acids. Next section mainly focuses on different microencapsulation techniques, various water soluble and insoluble microencapsulates and about various food products fortified with microencapsulated omega 3-fatty acids.

Key words: Omega-3 fatty acids, microencapsulation, oxidation, linolenic acid, eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA).

INTRODUCTION

The major risk factors (alcohol use, tobacco use, high blood pressure, high body mass index, high cholesterol, high blood glucose, low fruit and vegetable intake, and physical inactivity) as measured in disability-adjusted life years (DALYs) account for 61% of cardiovascular deaths in the world (WHO, 2009). Most risk factors are associated with more than one disease, and targeting these factors can reduce multiple causes of disease. As can be seen from the example of ischaemic heart disease (Figure 1), some elements in the chain, such as high blood pressure or cholesterol, act as a relatively direct cause of the disease. Some risks located further back in the causal chain act indirectly through intermediary factors. These risks include physical inactivity, alcohol, smoking or fat intake.

Fat quality of the diet of many people is deviating significantly from what is recommended, which may have an adverse impact on health (Zevenbergen et al., 2009). Overweight is a major health problem with an increasing prevalence throughout the world (WHO, 2006). Dietary patterns, mainly those favoring fat intake, often have been blamed for the increase in adiposity (James, 2008; Rosengren, 2008). Polyunsaturated fatty acids (PUFAs) and monounsaturated fatty acids (MUFAs) are more
readily used in the biochemical cycles in animals and humans, whereas saturated fatty acids (SFAs) are more easily gets accumulated in adipose tissue (DeLany et al., 2000; Kien et al., 2005; Storlien et al., 2001). Dietary recommendations often advise to reduce the saturated and trans fat (TFA and SFA) intake and maintain or increase the intake of polyunsaturated fats (PUFA) (WHO, 2003). Of course, the contribution to the SFA and PUFA intake is determined by the amount of food consumed and the level of these fats in those foods. For some of the most common high-fat products, the fraction of trans fatty acid (TFA), SFA, MUFA and PUFA of the total fat is shown in (Figure 2). The increased intake of TFA is detrimental to health as shown in (Table 1) (Simopoulos et al., 1995).

**Biochemistry of Omega 3 Fatty Acids**

These are a family of 18–24-carbon fatty acids with three or more methylene-interrupted double bonds where the last double bond (from the carboxyl group) is three carbons from the methyl end of the molecule. The parent compound of the ω-3 PUFA is α-linolenic acid (ALA, 18:3 ω-3) from which all ω-3 PUFAs are derived (Figure 3).

The PUFA contains three methylene interrupted double bonds and is initially desaturated to stearidonic acid (SDA, 18:4 ω-3) via the Δ-6 desaturase, the rate-limiting enzyme in the metabolic pathway. Eicosapentaenoic acid (EPA, 20:5 ω-3) is formed following the elongation of SDA to eicosatetraenoic acid (20:4 ω-3) with the addition of two carbons and the subsequent addition of a double
Table 1. Adverse effects of trans fatty acids.

<table>
<thead>
<tr>
<th>Increase</th>
<th>Decrease or inhibit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-density lipoprotein (LDL)</td>
<td>Incorporation of other fatty acids into cell membranes</td>
</tr>
<tr>
<td>Platelet aggregation</td>
<td>Decrease high-density lipoprotein (HDL)</td>
</tr>
<tr>
<td>Lipoprotein (a) (Lp(a))</td>
<td>Inhibit delta-6 desaturase (interfere with elongation and desaturation of EFA)</td>
</tr>
<tr>
<td>Body weight</td>
<td>Cross the placenta and decrease birth weight (in humans)</td>
</tr>
<tr>
<td>Cholesterol transfer protein (CTP)</td>
<td></td>
</tr>
</tbody>
</table>

(Adapted from Simopoulos, 1995).

Figure 3. Metabolic pathway of ω-3 polyunsaturated fatty acids (PUFAs) and traditional food sources of these fatty acids in the U.S. diet. (Adapted from Jay et al., 2006).

Vegetable oils: canola, soybean, flax, Nuts: walnuts

Fish and fish oil, echium oil, black currant oil, genetically modified vegetable oils

Terrestrial meats

Conjugated linoleic acid (CLA) are a group of unsaturated fatty acids with 18 carbon atoms, and a mixture of positional and geometrical isomers with two conjugated double bonds (unlike linoleic acid, which has a non-conjugated diene). Usually there are two double bonds in CLA in C-9 and C-11 or C-10 and C-12 positions, and can be in either the cis or trans configurations (Basu et al., 2000). These isomers are minority components in the lipid fraction, and they are mainly found in the meat from cows and sheep, and the corresponding dairy products (Larsen et al., 2003; Thomas et al., 2003). CLA isomers have been extensively studied (specially trans-10, cis-12, and cis-9, ...
ω-3 fatty acids are extremely sensitive to oxidation upon exposure. It is of great interest to food manufacturers to use ω-3 fatty acids, as functional ingredients, to improve the nutritional profile of food products; however, lipid oxidation limits the utilization of the ω-3 fatty acids in processed foods (Frankel et al., 2002). These fatty acids undergo rapid and extensive oxidation and related chemical changes occur due to exposure to air, light or heat during processing. Therefore the challenge before the food manufacturer is to overcome the problems of oxidative rancidity that may develop from ω-3 fatty acids due to oxidation and harness the nutritional benefits of them by incorporating in the processed food items.

Formation of off-flavor

The primary products of the oxidation reaction described above are lipohydroperoxides and lipoperoxides. These compounds do not contribute to any off-flavor. The off-flavor is due to the homolytic or heterolytic cleavage of these primary products into the so-called secondary oxidation products. These secondary oxidation products consist of volatiles (aldehydes, alkanes, and ketones) which are responsible for (fishy) off-flavor (Jacobsen 1999; Ruth and Roozen 2000; Velasco et al., 2006; Kolanowski et al., 2007).

Sources of ω-3 fatty acids

Important ω-3 fatty acids in human physiology are α-linolenic acid (18:3, ω-3; ALA), eicosapentaenoic acid (20:5, ω-3; EPA), and docosahexaenoic acid (22:6, ω-3; DHA). In a carbon chain of 18, 20, or 22 carbon atoms these polyunsaturates have either 3, 5, or 6 double bonds, respectively. All double bonds are in the cis-configuration; i.e. the two hydrogen atoms are on the same side of the double bond. Sources of major ω-3 fatty acids (ALA, EPA, and DHA) are discussed below:

α-Linolenic Acid (ALA)

ALA is necessary for human health but cannot be manufactured by the body and is therefore called an essential fatty acid (Van and Systermans 2006). Mammalian cells do not contain enzymes capable of adding double bonds (desaturate) to fatty acids after the ninth carbon from the carboxyl end of the molecule. ALA is the only omega-3 fatty acid found in vegetable products. It is found in a wide range of plant products, such as nuts, seeds, fruits, vegetables, legumes, grains, and wild plants, such as purslane (Claytonia perfoliata) (Garg et al., 2006; Food Nutr.Board, 2002). Although some of these food products have a relatively high ALA content (e.g., English walnuts, 10%), most foods have relatively low levels (0.1%–0.7%) (Hunter 1990; Zevenbergen et al., 2009). Once ingested, the body converts ALA into EPA and DHA, the two types of omega-3 fatty acids more readily used by the body. ALA daily mean intakes are estimated to be 1.6 g and 1.1 g per day for men and women, respectively (Food Nutr Board., 2002). But the intake of ALA is far below the recommended level in many countries. In some countries, the gap is modest, but in others, the intake is less than half of the recommended level (Elmadfa et al., 2009). Figure 5 shows a number of the most nutrient-dense sources of ALA, ranked in order of g ALA/100 cal. Walnuts appear to be the richest source of ALA, but these are not common foods that are consumed by many people every day. Mayonnaise, margarines and liquid oils

![Figure 4. Structure of ALA, EPA and DHA (Adapted from Christiaan et al., 2010).](image-url)
Selected food sources of α-linolenic acid (ALA) are given in (Table 2). Some of the common plant oils have significant levels of ALA - e.g., 7% by weight in soybean oil, 10% in canola oil, and approximately 20% in hemp oil. Much higher amounts are found in the oils from flax, perilla (Japan and elsewhere), and chia (Argentina and

(Adapted from Kris-Etherton et al., 2000).
Table 3. Fish and Seafood Sources of DHA plus EPA.

<table>
<thead>
<tr>
<th>Source</th>
<th>DHA + EPA (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fish</strong></td>
<td></td>
</tr>
<tr>
<td>Anchovy, European, raw</td>
<td>1.449</td>
</tr>
<tr>
<td>Carp, cooked, dry heat</td>
<td>0.451</td>
</tr>
<tr>
<td>Catfish, channel, farmed, cooked, dry heat</td>
<td>0.177</td>
</tr>
<tr>
<td>Cod, Atlantic, cooked, dry heat</td>
<td>0.158</td>
</tr>
<tr>
<td>Eel, mixed species, cooked, dry heat</td>
<td>0.189</td>
</tr>
<tr>
<td>Flatfish (flounder and sole), cooked, dry heat</td>
<td>0.501</td>
</tr>
<tr>
<td>Haddock, cooked, dry heat</td>
<td>0.238</td>
</tr>
<tr>
<td>Halibut, Atlantic and Pacific, cooked, dry heat</td>
<td>0.465</td>
</tr>
<tr>
<td>Herring, Atlantic, cooked, dry heat</td>
<td>2.014</td>
</tr>
<tr>
<td>Mackerel, Pacific and jack, mixed species, cooked, dry heat</td>
<td>1.848</td>
</tr>
<tr>
<td>Mullet, striped, cooked, dry heat</td>
<td>0.328</td>
</tr>
<tr>
<td>Perch, mixed species, cooked, dry heat</td>
<td>0.324</td>
</tr>
<tr>
<td>Pike, northern, cooked, dry heat</td>
<td>0.137</td>
</tr>
<tr>
<td>Pollock, Atlantic, cooked, dry heat</td>
<td>0.542</td>
</tr>
<tr>
<td>Salmon, Atlantic, farmed, cooked, dry heat</td>
<td>2.147</td>
</tr>
<tr>
<td>Sardine, Atlantic, canned in oil, drained solids with bone</td>
<td>0.982</td>
</tr>
<tr>
<td>Sea bass, mixed species, cooked, dry heat</td>
<td>0.762</td>
</tr>
<tr>
<td>Shark, mixed species, raw</td>
<td>0.843</td>
</tr>
<tr>
<td>Snapper, mixed species, cooked, dry heat</td>
<td>0.321</td>
</tr>
<tr>
<td>Swordfish, cooked, dry heat</td>
<td>0.819</td>
</tr>
<tr>
<td>Trout, mixed species, cooked, dry heat</td>
<td>0.936</td>
</tr>
<tr>
<td>Tuna, skipjack, fresh, cooked, dry heat</td>
<td>0.328</td>
</tr>
<tr>
<td>Whiting, mixed species, cooked, dry heat</td>
<td>0.518</td>
</tr>
<tr>
<td><strong>Crustaceans</strong></td>
<td></td>
</tr>
<tr>
<td>Crab, Alaska king, cooked, moist heat</td>
<td>0.413</td>
</tr>
<tr>
<td>Shrimp, mixed species, cooked, moist heat</td>
<td>0.315</td>
</tr>
<tr>
<td>Spiny lobster, mixed species, cooked, moist heat</td>
<td>0.480</td>
</tr>
<tr>
<td><strong>Mollusks</strong></td>
<td></td>
</tr>
<tr>
<td>Clam, mixed species, cooked, moist heat</td>
<td>0.284</td>
</tr>
<tr>
<td>Conch, baked or broiled</td>
<td>0.120</td>
</tr>
<tr>
<td>Mussel, blue, cooked, moist heat</td>
<td>0.782</td>
</tr>
<tr>
<td>Octopus, common, cooked, moist heat</td>
<td>0.314</td>
</tr>
<tr>
<td>Oyster, eastern, farmed, cooked, dry heat</td>
<td>0.440</td>
</tr>
<tr>
<td>Scallop, mixed species, cooked, breaded and fried</td>
<td>0.180</td>
</tr>
</tbody>
</table>

(Adapted from Kris-Etherton et al., 2000).

elsewhere) with approximately 50-60% of the fatty acids being in the form of ALA.

EPA and DHA

EPA and DHA are polyunsaturated fatty acids that are found in marine products (20–40% of the total fat contents) and algae (40%) (Garg et al., 2006). Both are important fatty acids that enter the body through consumption of marine products, fortification, or as ALA. Several studies have revealed that these fatty acids play an important role in maintaining a healthy mind and body (Garg et al., 2006). Sources of DHA and EPA can be broadly categorized as following.

Fish and fish oil

Fish and fish oils are the richest sources of EPA and DHA, with contents ranging from 30% to 50% for both fresh and saltwater fish (Kinsella et al., 1990). DHA is the major ω-3 PUFA in fish whose levels are typically 2 to 5 times greater than EPA. Table 3 gives the levels of EPA plus DHA in a few selected fishes and seafoods. Nowadays, fish is the most common source of omega-3 in human diet, and oily fishes as Scombridae, Clupeidae and Salmonidae families (Rubio-Rodríguez, 2010; Mataix et al., 2003) are the fish species with the highest percentage of DHA and EPA in the foodstuff portion (Table 4). Fish oil usually presents higher amounts of omega-3 PUFA than seed oils (Table 5) (Mataix et al., 2003) or microalgae.

Algae and algae oils

Algae has a very important characteristic of algae is that it adapt rapidly to the new environmental conditions to survive, producing a great variety of secondary metabolites, which cannot be found in other organisms...
Table 4. EPA and DHA contents in selected species of fish.

<table>
<thead>
<tr>
<th>Species</th>
<th>Common name</th>
<th>g/100 g of foodstuff portion</th>
<th>C20:5 ω−3 (EPA)</th>
<th>C22:6 ω−3 (DHA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scomber scombrus</td>
<td>Mackerel</td>
<td>1.10</td>
<td>2.56</td>
<td></td>
</tr>
<tr>
<td>Mullus surmuletus</td>
<td>Red mullet</td>
<td>0.91</td>
<td>1.66</td>
<td></td>
</tr>
<tr>
<td>Sardina pilchardus</td>
<td>Sardine</td>
<td>0.62</td>
<td>1.12</td>
<td></td>
</tr>
<tr>
<td>Salmo salar</td>
<td>Salmon</td>
<td>0.50</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Thunnus thynnus</td>
<td>Ton</td>
<td>0.24</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>Engraulis encrasicolus</td>
<td>Fresh anchovy</td>
<td>0.14</td>
<td>0.80</td>
<td></td>
</tr>
<tr>
<td>Pagellus bogaraveo</td>
<td>Sea bream</td>
<td>0.12</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>Gadus morrhua</td>
<td>Cod</td>
<td>0.23</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>Merluccius merluccius</td>
<td>Hake</td>
<td>0.10</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>Conger conger</td>
<td>Conger eel</td>
<td>0.15</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>Luvarus imperialis</td>
<td>Swordfish</td>
<td>0.15</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Galeorhinus gelans</td>
<td>Dogfish</td>
<td>0.04</td>
<td>0.30</td>
<td></td>
</tr>
</tbody>
</table>

(Adapted from Matrix et al., 2003).

Table 5. Lipids (g/100g oil) in different kinds of seed and fish oils.

<table>
<thead>
<tr>
<th>Oil</th>
<th>SFA</th>
<th>MUFA</th>
<th>PUFA</th>
<th>ω3</th>
<th>ω6</th>
<th>ω6/ω3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunflower</td>
<td>12.0</td>
<td>20.5</td>
<td>67.5</td>
<td>0.10</td>
<td>63.2</td>
<td>632</td>
</tr>
<tr>
<td>Corn</td>
<td>14.5</td>
<td>29.9</td>
<td>55.6</td>
<td>0.90</td>
<td>50.4</td>
<td>56</td>
</tr>
<tr>
<td>Soya</td>
<td>15.6</td>
<td>21.2</td>
<td>63.2</td>
<td>7.30</td>
<td>51.5</td>
<td>7.05</td>
</tr>
<tr>
<td>Palm</td>
<td>47.8</td>
<td>37.1</td>
<td>15.1</td>
<td>0.30</td>
<td>10.1</td>
<td>33.66</td>
</tr>
<tr>
<td>Olive</td>
<td>14.3</td>
<td>73.0</td>
<td>12.7</td>
<td>0.70</td>
<td>7.8</td>
<td>11.14</td>
</tr>
<tr>
<td>Cod liver</td>
<td>22.6</td>
<td>20.7</td>
<td>56.8</td>
<td>19.8</td>
<td>9.0</td>
<td>0.04</td>
</tr>
<tr>
<td>Herring</td>
<td>21.3</td>
<td>56.6</td>
<td>22.1</td>
<td>11.9</td>
<td>12</td>
<td>1.01</td>
</tr>
<tr>
<td>Salmon</td>
<td>19.9</td>
<td>17.0</td>
<td>63.1</td>
<td>35.3</td>
<td>1.06</td>
<td>0.03</td>
</tr>
<tr>
<td>Sardine</td>
<td>30.4</td>
<td>14.5</td>
<td>55.1</td>
<td>21.2</td>
<td>8.0</td>
<td>0.27</td>
</tr>
</tbody>
</table>

(Adapted from Matrix et al., 2003).

Table 6. Fatty acid profile of algae.

<table>
<thead>
<tr>
<th>Fatty acids</th>
<th>Canned Himanthalia elongata</th>
<th>Dehydrated Himanthalia elongata</th>
<th>Undaria pinnatifida</th>
<th>Porphyra sp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>C14:0</td>
<td>9.57±0.81</td>
<td>5.65±0.35</td>
<td>3.17±0.31</td>
<td>0.53±0.21</td>
</tr>
<tr>
<td>C16:0</td>
<td>36.73±2.16</td>
<td>32.53±1.61</td>
<td>16.51±1.35</td>
<td>63.19±1.93</td>
</tr>
<tr>
<td>C16:1 ω7</td>
<td>3.00±0.38</td>
<td>2.79±0.25</td>
<td>3.70±0.88</td>
<td>6.22±0.70</td>
</tr>
<tr>
<td>C16:2 ω4</td>
<td>Trace</td>
<td>Trace</td>
<td>Trace</td>
<td>Trace</td>
</tr>
<tr>
<td>C16:3 ω4</td>
<td>0.06±0.01</td>
<td>4.38±1.33</td>
<td>2.31±1.94</td>
<td>1.56±0.51</td>
</tr>
<tr>
<td>C18:0</td>
<td>0.59±0.07</td>
<td>0.68±0.15</td>
<td>0.69±0.08</td>
<td>1.23±0.10</td>
</tr>
<tr>
<td>C18:1 ω9</td>
<td>22.64±1.80</td>
<td>19.96±2.01</td>
<td>6.79±0.90</td>
<td>6.70±1.16</td>
</tr>
<tr>
<td>C18:2 ω6</td>
<td>5.80±0.21</td>
<td>4.39±0.34</td>
<td>6.23±0.32</td>
<td>1.17±0.13</td>
</tr>
<tr>
<td>C18:3 ω3</td>
<td>6.77±0.79</td>
<td>8.79±0.71</td>
<td>11.97±1.75</td>
<td>0.23±0.16</td>
</tr>
<tr>
<td>C18:4 ω3</td>
<td>1.94±0.43</td>
<td>3.53±0.56</td>
<td>22.60±2.48</td>
<td>0.24±0.35</td>
</tr>
<tr>
<td>C20:1 ω9</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.70±0.26</td>
</tr>
<tr>
<td>C20:4 ω6</td>
<td>9.78±2.27</td>
<td>10.69±1.30</td>
<td>15.87±1.68</td>
<td>6.80±1.18</td>
</tr>
<tr>
<td>C20:4 ω3</td>
<td>0.35±0.19</td>
<td>0.88±1.80</td>
<td>0.70±0.14</td>
<td>0.07±0.02</td>
</tr>
<tr>
<td>C20:5 ω3</td>
<td>2.77±0.80</td>
<td>5.50±1.78</td>
<td>9.43±0.69</td>
<td>6.03±0.95</td>
</tr>
<tr>
<td>Saturated fatty acid</td>
<td>46.89±3.03</td>
<td>30.06±2.11</td>
<td>20.39±1.73</td>
<td>64.95±2.24</td>
</tr>
<tr>
<td>Monounsaturated fatty acid</td>
<td>25.64±2.18</td>
<td>22.75±2.26</td>
<td>10.50±1.78</td>
<td>18.91±2.81</td>
</tr>
<tr>
<td>PUFA6</td>
<td>27.47±4.73</td>
<td>38.16±7.84</td>
<td>69.11±9.01</td>
<td>16.10±3.31</td>
</tr>
<tr>
<td>PUFAs ω6</td>
<td>15.58±2.48</td>
<td>15.08±1.64</td>
<td>22.10±2.00</td>
<td>7.97±1.31</td>
</tr>
<tr>
<td>PUFAs ω3</td>
<td>11.83±2.21</td>
<td>18.70±4.84</td>
<td>44.70±5.05</td>
<td>7.20±1.48</td>
</tr>
<tr>
<td>Ratio ω6/ω3</td>
<td>1.32</td>
<td>0.81</td>
<td>0.49</td>
<td>1.21</td>
</tr>
</tbody>
</table>

(Source: Sanchez et al., 2004).

(Carlucci et al., 1999). Other important aspects related to the algae are (i) rapid growing (for many of the species) (ii) easy cultivation, (iii) possibility of controlling production of some bioactive compounds by manipulating the cultivation conditions. Algae contain higher amounts of PUFAs relative to the total lipid content (Table 6) (Sanchez et al., 2004; Plaza et al., 2008). Algae can therefore be considered as natural reactors and a
promising alternative to chemical synthesis of ω-3 fatty acids.
Algae oil is a good source of DHA and EPA omega-3 fatty acids. Marine algae, such as zooplankton and phytoplankton are actually the primary source of DHA and EPA. Higher content of DHA and EPA in fish oil is due to the fact that marine fish eat the algae and then store the omega-3 in their fat. Several studies have revealed that EPA and DHA derived from fish oil both have cardiovascular benefits (Balk et al., 2004; Kris, 2003).
Similarly, DHA from algae oil also has the same cardiovascular benefits. Jagnannathan et al. (2010) reported that supplementation of 1 g of algae oil in the vegetarians a day decreased their triglyceride levels by 23%, after eight weeks.

**Health effects**

Omega-3 fatty acids are considered essential fatty acids. The health benefits of dietary omega-3 fatty acids include reduced susceptibility to mental illness/neurological disorder, protection against heart disease, protection against cancer, and improved brain and eye function in infants (Whelan and Rust, 2006). Some of the prominent health benefits of the ω-3 fatty acids are summarised below:

**Cardiovascular disease**

Several articles have outlined the relationship of ω-3 PUFA and risk for cardiovascular disease (Kimmig and Karalis, 2013; Lorgeril et al., 2013; Balk et al., 2004). A variety of actions by which dietary ω-3 fatty acids prevent heart disease are: The major features of ω-3 fatty acids:

1. are prostaglandin and leukotriene precursors,
2. have antiinflammatory properties,
3. prevent arrhythmias (ventricular tachycardia and fibrillation),
4. inhibit synthesis of cytokines and mitogens,
5. stimulate endothelial-derived nitric oxide,
6. are antithrombotic,
7. have hypolipidemic properties with effects on triacylglycerols and VLDLs, and
8. Inhibit atherosclerosis.

Thrombosis can lead to myocardial infarction which is a major complication. The ω-3 fatty acids from fish oil have powerful antithrombotic actions. EPA inhibits the synthesis of thromboxane A2 from arachidonic acid in platelets (Goodnight et al., 1982). This prostaglandin causes platelet aggregation and vasoconstriction. As a result, fish oil ingestion by humans increases the bleeding time and decreases the stickiness of the platelets for aggregation to glass beads (Goodnight et al., 1982).

**Sudden death**

ω-3 PUFA is very effective in reducing the risk of sudden death (Christensen, 2003; Kris et al., 2003; Leaf et al., 2003). Proposed mechanisms have included their effects on fibrinolysis and reductions in circulating triacylglycerol levels, platelet activation, and the expression of vascular adhesion molecules (Kris et al., 2003; Vanschoonbeek et al., 2003).

There is growing evidence that a reduction in sudden cardiac death may be the greatest impact of dietary ω-3 PUFA. Sudden death accounts for as much as 50% of cardiovascular disease (CVD) deaths, and up to 80% of these are due to ventricular fibrillation. As such, attention has shifted from antithrombotic effects to their antiarrhythmic and plaque stabilization effects and ω-3 PUFAs reduce matrix metalloproteinases (MMP) expression increasing plaque stability, potentially reducing sudden coronary events (Chen et al., 2003; Alvarez et al., 2004; Fukumoto et al., 2004).

**Neurological disorders**

Omega 3 fatty acids are highly concentrated in the brain and these fatty acids appear to be important for cognitive (brain memory and performance) and behavioural (Balasubramanian, 2013) Brain is composed of 65% lipid and DHA is a significant portion of that. ω-3 HUFAs have been associated with neurological function (Marszałek et al., 2005).

Eicosapentanoic acid (EPA, 20:5, ω -3) and docosahexaenoic acid (DHA, 22:6, ω-3) are especially important during human brain development (Diwakar et al., 2008). Deficiency of omega-3-fatty acids leads to deficits in neurogenesis, neurotransmitter metabolism, and altered learning and visual function in animals and may result in several neurological disorders (Innis, 2008). Dietary omega-3-fatty acids are certainly involved in the prevention of some neuropsychiatric disorders, particularly depression, as well as in dementia, notably Alzheimer’s disease (Calon, 2007).

Fish or fish oil is the main source of EPA and DHA (Riediger et al., 2009). ALA may be a viable alternative to fish oil. However, its potency is milder in comparison to EPA/DHA, and its conversion to EPA/DHA is limited in human beings (Plourde et al., 2007; Williams and Burge, 2006). On the other hand, it was demonstrated that dietary ALA increases DHA levels in the brain but it does not increases the DHA levels in heart and liver (Barcelo-Coblijn et al., 2005).

Therefore external source of EPA/DHA intake in diet is highly recommended.
Cancer chemoprevention

Carcinogenesis is a multistage process which may span over 20 years, during which opportunities to reverse or suppress this disease in its early and premalignant stages may exist. Considerable attention has been directed towards identifying natural chemopreventive substances capable of inhibiting, retarding, or reversing multistage carcinogenesis.

Several reports have shown that Conjugated Linoleic acid (CLA) suppresses the development of multistage carcinogenesis at different sites (Gayda and Pariza, 1983). Different experimental animal models have shown that CLA inhibits initiation (Ip et al., 1991; 1997), promotion and progression (Cesano et al., 1998; Ip et al., 1997), metastasis (Hubbard et al., 2000; Kilian et al., 2002), and even the entire process of cancer development (Ip et al., 1994, 1995). The effects of CLA on carcinogenesis, as demonstrated in animal models, are shown in Figure 6 (Adapted from Ki Won et al., 2005). The cancer chemopreventive effects of CLA may involve diverse mechanisms, including anti-inflammatory, antiproliferative, and antimetastatic, indicating the blocking of tumor promotion and tumor progression processes in multistage carcinogenesis (Figure 6).

Controlling body weight

Obesity can be considered an important public health problem at present because it is a risk factor for the onset of diabetes, cardiovascular diseases, some cancers, and other conditions (Belury, 2002; Wang and Jones, 2004a). Although clinical and epidemiological knowledge about this disease has improved, the prevalence of obesity has increased enormously in recent decades in both industrialized and developing countries (Wang and Jones, 2004a).

It has been suggested that one of the dietary factors that has an important effect on controlling energy balance regulation is the content of conjugated linoleic acid (Brown and McIntosh, 2003, Pariza, 2004). Several studies have reported that CLA could have beneficial effects on body composition, and lipid or glucose metabolism (Terpstra, 2004). Researchers have found that the consumption of CLA isomers has beneficial effects (Blankson et al., 2000; Gaullier et al., 2004). The fact that the consumption of ω-3 fatty acids may have positive influences in energy balance and body composition has pushed food industry for considering incorporation of CLA/EPA/DHA in higher doses than the ones that exist naturally in some foods.

Alterations of lipid metabolism

Mechanisms responsible for the major disturbances of lipid metabolism observed in patients with the metabolic syndrome are illustrated in Figure 7A. The high lipolytic rate in visceral adipose depots provides the liver with large amounts of free fatty acids; high glucose and insulin concentrations increase lipogenesis, whereas impaired fat oxidation stimulates fatty acid esterification into triacylglycerols; this, together with an augmented synthesis of apo B-100 and of cholesterol, increases the formation and secretion of VLDL (Very Low Density Lipoprotein); and insulin concentrations maintain a high rate of VLDL conversion into IDL (Intermediate Density Lipoprotein) and LDL (Low Density Lipoprotein).
Cholesterol ester transfer protein–mediated exchanges of triacylglycerols and cholesteryl esters are activated by the high concentration of triacylglycerol-rich particles, which leads to the formation of small, dense LDL, namely in subjects with a genetic predisposition to the so-called B phenotype (Carpentier et al., 2006).

There is an impaired recognition of small, dense LDL by LDL receptors, which maintains high LDL-cholesterol concentrations in the circulation (Barrett et al., 2003). Supplementation with n-3 PUFAs favorably modifies many adverse serum and tissue lipid alterations related to the metabolic syndrome (Fig 7B).

The most consistent finding is a drastic reduction in fasting and postprandial serum triacylglycerols and free fatty acids (Weintraub et al., 1988). This has been observed with EPA and DHA alone (Woodman et al., 2002) and with their combination in fish oil; multivariate analyses suggest EPA enrichment in platelet phospholipids to be independently associated with serum triacylglycerol lowering (Leigh et al., 2002). Reduced VLDL production in the liver largely results from a decreased availability of free fatty acids released from adipose stores, together with the suppression of lipogenic genes and the induction of genes involved in fatty acid oxidation (Nestel et al., 1984). This regulation of gene expression proceeds through the inhibition of sterol response element binding protein 1 and the activation of peroxisome proliferator-activated receptor (Seo et al., 2005). Net production of apo B is also reduced. An increased lipolytic activity of lipoprotein lipase in extrahepatic tissues completes the hypotriglyceridemic effect of ω-3 PUFAs. ω-3 PUFAs have contrasting effects on LDL, with a general tendency toward slightly increased LDL-cholesterol concentrations; however, the potential associated cardiovascular risk is largely compensated for by a reduction in the fraction of
PUFA intake by women and infants

Polyunsaturated fatty acids amount in dietary intake and the ratio of omega-6/omega-3 is very important in human health and pathologies (Holman, 1986; Tapiero et al., 2002). A dietary supplement of DHA increases the maternal DHA and limits the decrease during the last trimester in which there is a preferential transfer from the mother to the foetus (Montgomery et al., 2003). The presence of large quantities of EPA and DHA in the diet slightly lengthens pregnancy, and improves its quality. Omega-3 fatty acids can help to prevent the development of certain cancers, particularly those of the breast and colon, and possibly of the uterus and the skin, and are likely to reduce the risk of postpartum depression, manic-depressive psychosis, dementias (Alzheimer’s disease and others), hypertension, toxemia, diabetes and, to a certain extend, age-related macular degeneration in women. (Bourre et al., 2004).

The ability of human foetus to synthesise LC-PUFA (Long chain polyunsaturated fatty acids) from EFA (Essential fatty acids) has been a matter of discussion since both ω-6 and ω-3 levels of LC-PUFA in plasma and erythrocyte of infants fed with artificial formulas are significantly lower than those found in breast-fed infants (Heird et al., 1997). In addition, several in experimental animals have shown that deficiency of ω-3 leads to impairment of brain and visual functions (Neuringer, 2000). Moreover, the level of DHA in the brain cortex and liver of preterm infants who died suddenly and that had been fed with artificial formulas was lower than of those fed with human milk (Farquharson et al., 1995).

Inflammation

The anti-inflammatory properties of ω-3 fatty acids, especially EPA, are due to competition with arachidonic acid (AA) as a substrate for cyclooxygenases and 5-lipoxygenase. The eicosanoids from the ω-6 and ω-3 fatty acids have opposite properties. The eicosanoids are considered a link between PUFA, inflammation and immunity (Simopoulos et al., 2002). The first evidence of the important role of dietary intake of omega-3 polyunsaturated fatty acids (PUFAs) in inflammation was derived from epidemiological observations of the low incidence of autoimmune and inflammatory disorders, such as psoriasis, asthma and type-1 diabetes, as well as the complete absence of multiple sclerosis, in a population of Greenland Eskimos compared with gender- and age-matched groups living in Denmark (Kromann et al., 1980). Most of these diseases are characterized by inappropriate activation of T cells resulting on and ultimately destruction of host tissues. In the 1980’s several independent lines of evidence suggested that changes in the natural history of hypertensive, atherosclerotic and chronic inflammatory disorders may be achieved by altering availability of eicosanoid precursors. Native Greenland Eskimos (Dyerberg et al., 1979) and Japanese (Hirai et al., 1982) have a high dietary intake of long chain omega-3 PUFA from seafood and a low incidence of myocardial infarction and chronic inflammatory or autoimmune disorders, even when compared to their Westernized ethnic counterparts.

OMEGA-6 TO OMEGA-3 RATIO

The optimal ratio of omega-6/omega-3 varies from 1:1 to 4:1 depending on the disease under consideration. Since many of the chronic diseases prevalent in Western cultures are multigenic and multifactorial, it is not surprising that the dose or the ratio differs. It is essential to decrease the omega-6 intake while increasing the omega-3 in the prevention and management of chronic disease. Furthermore, the balance of omega-6 and omega-3 fatty acids is very important for homeostasis and normal development. The ratio of omega-6 to omega-3 EFA is an important determinant of health. Therefore, appropriate amounts of dietary omega-6 and omega-3 fatty acids at a ratio of about 1:2:1 consistent with the recommended adequate intakes (Simopoulos, 2002).

MICROENCAPSULATION

Encapsulation is a process to entrap one substance within another substance, thereby producing particles with diameters of a few nm to a few mm. The substance that is encapsulated may be called the core material, the active agent, fill, or internal phase. The substance that is encapsulating may be called the coating, membrane, shell, carrier material, wall material, external phase, or matrix. The carrier material of encapsulates used in food products or processes should be food grade and able to form a barrier for the active agent and its surroundings.

Microencapsulation has been hypothesised to be an effective technique to mask the unpleasant taste of certain ingredients and, more recently, to delay lipid oxidation of PUFA in foodstuffs (Gouin, 2004). Recent studies have examined the protection against oxidative damage and physical properties of fish oil microcapsules employed in food fortification, emphasising the usefulness of this technique in preserving fish fatty acids from oxidation (Heinzelmann & Franke, 1999; Kagami et al., 2003; Drusch & Berg, 2008). Fish oil (rich in w-3 fatty acids) can be encapsulated to prevent off-flavor by a) minimising the chance of contact between oxygen and
fish oil, b) preventing contact between metal ions and fish oil, c) preventing direct exposure to light, and d) trapping off-flavor (Garg et al., 2006).

Methods of encapsulation

Water soluble microencapsulates disintegrate or dissolve in aqueous food products, and will therefore not be stable in many food products during storage. Therefore insolvibility of microencapsulates in aqueous products may be an important requirement, although this may lead to sandiness and consumer notice. On the other hand, bio-availability of ω-3 fatty acids upon consumption is another important prerequisite of microencapsulation which might be a concern if the microencapsulates do not dissolve or disintegrate in gastro-intestinal fluids. If the ω-3 fatty acids are not bio-available, then addition to food products is of no use. These two aforementioned requirements, that is, stability upon storage and high bio-availability in the human gastro-intestinal tract, are somewhat contradictory in nature. Both water-soluble and water-insoluble microencapsulates used for encapsulation of ω-3 fatty acids are discussed below.

Water-Soluble Microencapsulates

Spray-Drying

Spray-drying is based on the principle that when an aqueous dispersion of an oil-in-water emulsion containing carrier material dissolved in the water phase is converted into a dry powder by spraying the feed into hot dry air resulting in moisture evaporation. Relatively low spray-drying temperatures are appropriate to minimize the lipid oxidation (Balk et al., 2004; Drusch and Schwarz 2006). The characteristics of the final product depend upon the physical and chemical properties of the feed, the dryer design, and the operation. Resulting product may be in the form of powders, granules, or agglomerates. Examples of water soluble carrier material are maltodextrin, glucose syrup, proteins, sugars, gums, pectin, modified cellulose (e.g., hydroxypropyl methylcellulose or methylcellulose), and/or modified starch (e.g., octenylsuccinate-derivatized starch) (Drusch et al. 2007; Drusch and Schwarz 2006; Kagami et al. 2003; Keogh et al., 2001; Kolanowski et al. 2006; Tan et al. 2005).

Melt injection

This process is based on the pre mixing of fish oil in a starch matrix and with anti-oxidants, sugars, emulsifiers, and water at a temperature above 100°C followed by filtration and collected in a bath filled with cold organic solvent (e.g., iso-propanol or liquid nitrogen) (Valentinotti et al., 2006; Subramaniam et al., 2006) which solidifies the matrix and transforms it into a glassy state material. Upon washing with a terpene (e.g., limonene), the surface oil present is removed. It prevents the microencapsulated oil from oxidation, resulting in no unpleasant odour or taste development during storage. Two confocal scanning laser microscopic (CSLM) images of a sugar extrudate with fish oil included are shown in Figure 8 (a-b). As can be seen in image the oil droplets, represented by light spheres, are well distributed through

Figure 8 (a-b). CSLM images of Duralife® from Firmenich. The fish oil microencapsulate was embedded in low acryl embedding material and colored with a Nile blue solution. Sectioning of the embedded material was done using a microtome. Two laser lines from the argon/krypton laser were used to excite the fluorochrom Nile blue. The light spheres depict the fish oil droplets. The pictures were kindly provided by Ellen Drost (Unilever Research & Development Vlaardingen) and the Duralife® microencapsulates were obtained from Firmenich, Switzerland Adapted from (Adapted from Beindorff and Zuidam, 2010).
Figure 9 (a-b). CSLM images of two types of complex coacervates. The left side shows a mono-nucleated type with sunflower oil and on the right a poly-nucleated type of complex coacervate with fish oil is shown. In the CSLM picture, the light sphere depicts the oil core of complex coacervates and the dark circle around is the protein wall material. The images were kindly provided by Ellen Drost (Unilever Research & Development Vlaardingen) and the microencapsulates were obtained from the International Special Products, United Kingdom (left picture) and Ocean Nutrition Canada, Canada (right picture) (Adapted from Beindorff and Zuidam, 2010).

Extrusion

Extrusion process is commonly used for encapsulation of fish oil. Fish oil can be encapsulated into a mixture or dough by using an extruder with one or more screws in a continuous process (Van Lengerich et al., 2007). This process is employed at low temperatures (below 30°C) and low pressures (500–5,000 kPa). Emulsions using protein (such as sodium caseinate, wheat protein, or whey protein isolate), gum, or modified starch as an emulsifier are prepared, and mixed into 45–75 wt% of matrix materials (starch, flours, proteins, gums, etc.) with relatively high amounts of plasticizer (water and glycerol) and 0.5–4 wt% of an acidic anti-oxidant (ascorbic acid or erythorbic acid) using a twin screw extruder with a barrel temperature between 5°C and 10°C.

Water-Insoluble Microencapsulates

Complex Coacervation

It is a process in which coacervates are made via a liquid–liquid phase separation mechanism of an aqueous solution into a polymer-rich phase (known as coacervate) and a polymer-poor phase. According to the number of polymer type(s) present, the process can be identified as (simple) coacervation when only one type of polymer is involved or complex coacervation when two or more types of polymers of opposite ionic charges are present (Ke-Gang et al., 2005). Complex coacervation is most commonly used for encapsulation purpose. One of the colloids is usually gelatin or whey proteins, while the other is an oppositely charged colloid, like gum arabic, sodium, or carboxy methyl cellulose. Coacervation is started by making an emulsion of oil droplets in the aqueous colloidal solution. By decreasing the pH, the phase separation of the solution in a polymer-rich and a polymer-poor phase is obtained, and the polymers precipitate on the interface of the oil droplets.

Figure 9 (a-b) reveals the complex coacervates containing fish oil which can be present in two different morphologies: mono- and poly-nucleated format. The first type consists of a single oil droplet core surrounded by a hydrocolloid shell, whereas the second type consists of a multi-oil droplet core surrounded by a common hydrocolloid shell (Yan, 2003), here composed of gelatin and polyphosphate. The complex coacervates might be double coated by repetition of the complex coacervation process (Yan et al., 2004) or by entrapment in another glassy matrix (e.g., composed of maltodextrin and modified starch) by spray-drying, spray-granulation, or melt extrusion (Bouquerand et al., 2007) to enhance the storage stability and to prevent the dissolution in the
Calcium Carbonate Capsules

In this method calcium carbonate particles are adsorbed electrostatically on the negatively charged oil surface of a fish oil-in-water emulsion during stirring (Nakahara et al., 2006). The calcium carbonate shells only dissolve at low pH which can be achieved in the human body only when the food matrix, containing the calcium carbonate encapsulates, is present in the stomach. Salts, proteins, thickening, and/or stabilising agents might then be added, followed by freeze- or spraydrying. An antioxidant in the oil is also used. A scanning electronic microscopic image of a calcium carbonate microcapsule containing fish oil is presented in Figure 10 (a-b) (Beindorff and Zuidam, 2010). These encapsulates have been commercialized by the KITII Corporation under the name Calshell. The particle size of Calshell is approximately 20 µm which is rather small compared to other types of encapsulates. This can be an advantage because these small particles will not be noticed. Unfortunately, this technology is currently rather expensive.

Coated microencapsulates

Fish oil powder in the presence of 0.5% silica flow aid could be coated in a fluid bed by spraying with molten 30% (w/w) hydrogenated palm wax (Ponginebbi and Publisi, 2008). Presence of the lipophilic anti-oxidant L-ascorbic acid 6-palmitate in the lipid coating improved the oxidation stability of these microencapsulates upon storage better than the presence of the hydrophilic anti-oxidant Gravinol-T. A similar lipid coating might also be used by spray-chilling of 25–33 wt% spray-dried fish oil...
Foods fortified with omega-3 fatty acids

Wide range of foods can be fortified with omega-3 fatty acids. Examples are given below:

Eggs

Commercial table eggs are a poor source of ω-3 fatty acids although they contain a high proportion of n-6 PUFA (mainly 18:2 ω-6). The simplest way is to produce an egg enriched in linolenic acid (Van, 1997), which is a precursor of DHA (Hu et al., 1999; de Lorgeril et al., 1994). The hen is fed with a diet rich in linseeds, flaxseeds or their corresponding oils; as a result the egg’s yolk is enriched with alphanalenic acid (ALA) and the level of DHA is also enhanced (Ferrier et al., 1995). Eggs that are derived from ALA-fed hens have higher ALA contents, while hens fed EPA and/or DHA produce eggs with higher DHA levels. In either case, arachidonic acid levels are significantly reduced. This is important because eggs are particularly rich in arachidonic acid, and attenuating arachidonic acid and its subsequent metabolism to eicosanoids is believed to be a targeted effect underlying some of the benefits of n-3 PUFA (Lands, 2000; Larsson, 2004). However, most of the health promoting properties of ω-3 fatty acids are associated with DHA, the health benefits of ALA-enriched eggs could be limited (since the conversion of linolenic acid into DHA in human body is not always effective). This is especially so in the elderly and children when their diets are rich in ω-6 PUFAs. The second group or route to enhancing levels of ω-3 in the egg, by including pre-formed DHA in the hen’s diet, usually in the form of fish (menhaden, herring or tuna) oil, is a more promising one (Leskanich and Noble, 1997). Omega-3 eggs tends to be similar in organoleptic quality to regular table eggs but in some cases panellists were found to be able to detect changed flavours (Caston et al., 1994; Ahn et al., 1995). Hens on diet containing 15–20% flax seed gave a fishy flavour (Jiang et al., 1994; Leeson et al., 1998). Use of combinations of anti-oxidants in the hen’s diet could help to suppress these off-flavours (Farrell, 1998). Fishy taints in eggs are not detectable provided that the hens are fed 5% (or less) flaxseed or low levels of a high quality oil, e.g. 1.5% (or less) menhaden en fish (Scheideler et al., 1997; Maurice, 1994; Marshall et al., 1994). Beneficial effects of modified eggs, include lowered systolic and diastolic blood pressures (Oh et al., 1991), decreased plasma triglyceride concentration and platelet aggregation (Van et al., 1998). In some experiments, even total plasma cholesterol level was reduced (Lewis et al., 2000) due to consumption of modified eggs. Therefore, consumption of 1–2 omega-3 eggs daily may have health-promoting properties increasing ω-3 fatty acid levels in blood lipids and in some cases even reducing cholesterol and triglyceride levels in the plasma.

Milk and milk products

UFA content in milk fat varies from 25-35% depending on different factors like: breed, period of lactation, feeding regimen and season. More than 95% of UFA in milk fat is in the form of oleic acid, linoleic acid and α-linolenic acid (21–30%, 2–2.5% and 1–1.3% of total fat, respectively (Collomb et al., 2000). Unsaturated Fatty Acids (UFA) are claimed to have beneficial health effects therefore recent studies have focused on increasing the extent of unsaturated fatty acids (UFA), particulary of conjugated linoleic acids (CLA) in milk and milk products (Abu et al., 2002; Jones et al., 2005). Collomb et al., (2004) showed that the concentrations of oleic (C18:1), linoleic (C18:2) and α-linolenic (C18:3) acid and CLA isomers in milk depend upon the fat source fed to the cows. A dietary supplementation with sunflower seeds led to the highest content of the cis-9, trans-11 CLA (c9t11 CLA) isomer, which is considered a very health promoting fatty acid (FA). It represents 75–90% of the total CLA concentration in milk fat (Baumann et al., 2003) and was reported to show anticarcinogenic (Ha et al., 1990; Parodi, 1994), body fat reducing and growth-promoting (Chin et al., 1994) properties.

On the other hand, auto oxidation of these compounds may negatively affect the flavour and other sensory characteristics of dairy products. The auto-oxidation of the lipids in dairy products and the resulting off-flavours have been comprehensively studied (Widder et al., 1991). Several studies on the oxidative stability of milk, cheese and butter enriched in CLA showed no significant differences in flavour and sensory characteristics between CLA enriched and conventional products (Avramis et al., 2003; Lynch et al., 2005). Both whole milk and low-fat milk can be fortified with ω-3 fatty acids. In general, the levels of EPA and DHA for 200 ml of fortified milk ranges from 10 mg to 190 mg, while the levels of ALA in the ALA-fortified milk can be as high as 800 mg ALA/200 ml milk. Other dairy products such as yogurts are being fortified with distilled fish oils (Jay et al., 2006).

Surimi Seafood

Surimi is the functional ingredient for various surimi-based seafood products. It is obtained by washing fish mince with water resulting in a product containing mainly myofibrillar proteins and added cryoprotectants (Park, 2005). Surimi seafood is not fortified with ω-3 PUFAs. Britney et al.( 2011) reported that surimi can nutritionally-
enhanced with ω-3 PUFAs-rich oils (flaxseed, algae, menhaden, krill, and blend). Oil addition results in increased (P < 0.05) concentration of total ω-3 FAs in surimi seafood; however, the concentration of α-linolenic (ALA, 18:3 ω-3), eicosapentaenoic (EPA, 20:5 ω-3) and docosahexaenoic (DHA, 22:6 ω-3) acids depended on which oil was added. Since surimi seafood comprises formulated food products associated with marine sources of wide acceptance, it is a logical vehicle for increasing the consumption of ω-3 PUFAs without the need for dietary supplements in a pill or capsule form (Lanier et al., 1988).

Pasta, breads and cereal (Granola) bars

Bread products may also be fortified with ALA from flaxseed (up to 300 mg per 25 g slice) and some with a combination of fish oil and a product containing DHA and EPA in a ratio of 3.5:1). Some ω-3- fortified pasta products are being made with eggs from hens fed linseed oil (>50% ALA), a novel approach for the use of these eggs. Cereals and cereal bars high in ω-3 PUFA are typically fortified with ALA from flaxseed, with levels ranging from 2000–5343 mg per 55 g serving (one cup) for cereals, and 1500–2200 mg ALA per bar. No cereals that contained EPA/DHA could be identified (Jay et al., 2006).

Infant formulas and baby foods

Without radical changes of eating habits an alternative way to increase the intake of omega-3 PUFA is a fortification of various food products with fish oil (Trautwein, 2001; Kolanowski Laufenberg, 2006). Despite a desirable elevation of omega-3 PUFA intake, fortification of foods with fish oil might negatively impact sensory quality of foods, depending on the amount of added fish oil. These are the main limitations of fish oil use for food fortification with omega-3 PUFA (Lovegrove et al., 1997). However, microencapsulation is believed to stabilize fish oil against oxidation. It makes possible to transform the oil into a powder, where the small droplets of oil are surrounded by a dry matrix of proteins and/or carbohydrate coating materials (Heinzelmann et al., 2000; Keogh et al., 2001). Microencapsulated fish oil powder enables fortification of instant foods, as well as other powder form food products. The results of some studies showed that an increase in omega-3 LC PUFA intake by means of fortified foods could desirably affect human health (Trautwein, 2001; Metcalf et al., 2003; Wallace et al., 2000). In these studies, the bioavailability of omega-3 PUFA from fortified foods was demonstrated to be comparable with that from capsules. Currently, an increase in number of various foods fortified with omega-3 fatty acids by fish oil addition in liquid and powder (microencapsulated) form is observed on the international market (Trautwein, 2001; Kolanowski, 2006). Kolanowski et al., (2007) reported that it is possible to fortify instant foods with microencapsulated fish oil at limited levels, especially when spraydried powder is used. Oxygen presence strongly decreases sensory quality of fish oil-fortified instant foods during storage in the air-permeable conditions. Presence of a flavouring allows higher level of fish oil addition to instant foods due to masking of undesirable off-flavour. Nevertheless, during storage in the air-permeable conditions the amount of offflavours increases, this not occurred in the case of vacuum packed samples.

The major infant formula companies have infant formulas fortified with algae derived DHA (Bosewell et al., 1996) at levels designed to mimic human breast milk. And for those infants eating solid foods, new baby food products using ω-3-enriched egg yolks (60 mg DHA per 4 oz) have also made their way to the market place.

CONCLUSION

ω-3 fatty acids have important roles in the modulation and prevention of human diseases, particularly coronary heart disease. Certainly, the evidence is now strong that ω-3 fatty acids are essential for human development in utero and in infancy and are likely to have a role throughout life. The challenge for the public will be to understand that not all ω-3 PUFAs are the same: ALA is not the same thing as EPA and DHA. With the ever-changing composition of the food supply, scientists face even greater challenges with regard to their ability to ascertain health risks associated with diet. Various food products are fortified with ω-3 fatty acids. But ω-3 fatty acids are extremely sensitive to oxidation upon exposure which gives off flavour to food products. It is of great interest to food manufacturers to use ω-3 fatty acids, as functional ingredients, to improve the nutritional profile of food products; however, lipid oxidation limits the utilization of the ω-3 fatty acids in processed foods. Microencapsulation has been hypothesised to be an effective technique to mask the unpleasant taste of certain ingredients and, more recently, to delay lipid oxidation of PUFA, acting as a powerful means for increasing the intake of ω-3 fatty acids in foodstuffs.

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