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Enhancing and improving the extraction of omega-3 from fish oil

Rosaria Ciriminna[a], Francesco Meneguzzo[b], Riccardo Delisi[a], Mario Pagliaro[a,*]

[a] Istituto per lo Studio dei Materiali Nanostrutturati, CNR, via U. La Malfa 153, 90146 Palermo, Italy
[b] Istituto di Biometeorologia, CNR, via Caproni 88, 50145 Firenze, Italy

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ABSTRACT

Omega-3 fatty acids DHA and EPA derived from fish oil are widely marketed across the world as valued dietary supplements offering numerous health benefits to children and adults alike. Traditional extraction processes are energy intensive and use organic solvents. Green and sustainable alternatives are needed with the aim to significantly expand and improve the production of omega-3 extracts, especially with the aim to obtain these essential polyunsaturated fatty acids from fish processing waste available in >20 million tonnes/year amount.

1. Introduction

Driven by increasing awareness and growing incidences of chronic diseases such as high blood pressure, cancer, depression, cardiovascular and Alzheimer's disease, the global consumption of dietary supplements and nutraceutical products based on fish oil has rapidly expanded (Rizliya and Mendis, 2014). Fish oil, indeed, is the main source of omega-3 long-chain polyunsaturated fatty acids (PUFAs). Depending on the position of the first double bond from the methyl end group (ω end) of the fatty acid, long-chain PUFAs belong either to ω−6 (*n*-6) or to ω−3 (*n*-3) families (Fig. 1), with the position of the first double bond dictating much of the biological activity (Rustan and Drevon, 2005).

Fish oil derived from blue fish, in particular, is rich of both eicosapentaenoic acid (EPA, C20:5*n*-3) and docosahexenoic acid (DHA, C22:6*n*-3) which are the most investigated nutrients ever, (Lands, 2005) following the findings of two Danish medical doctors, Bang and Dyerberg, who analyzed blood samples from 61 male and 69 female Inuit living in a 1350 people village in northwest Greenland consuming a predominantly meat diet rich in PUFAs (Bang et al., 1971). They found lower levels of several types of lipids, including total cholesterol and plasma triglycerides, in comparison to the plasma lipids of healthy Danes; and made the hypothesis that this could explain the very low incidence of ischemic heart-disease and the complete absence of diabetes mellitus in Greenlandic Eskimos. Eight years later, the same scientists discovered that the Inuit had higher than normal amounts of two omega-3 fatty acids, DHA and EPA, in their plasma and platelet lipids, which led them to the hypothesis that these omega-3 fatty acids could protect the Inuit from the cardiovascular consequences of their high-fat diet (Dyerberg and Bang, 1979).

Ever since, biochemical and biomedical research on these omega-3 fatty acids literally boomed, with over 31,000 peer-reviewed scientific articles published by January 2016. In brief, in what Lands has called the "complex food web" supporting human energy and health needs, the former C_{20} and C_{22} highly unsaturated fatty acids present in acquatic foodstuffs play a critical role (Lands, 2009). Ingestion of fats dominated by *n*-6 fatty acids can promote the pathogenesis of many diseases, (Simopoulos, 2008) including severe coronary heart disease (Bernstein et al., 2010). To the contrary ingestion of *n*-3 fatty acids contained in oily fish or fish oil, rich in both EPA and DHA, is critical for both physical and mental health, playing an important role in infant brain and eye development (EFSA J., 2014).

In 2010, the European Food Safety Authority recommended an adequate intake of 250 mg/day for EPA plus DHA (EFSA J., 2010). The World Health Organization, since 2008 recommends a daily intake of EPA plus DHA of 250 mg in primary prevention of coronary hearth disease and 2 g in secondary prevention (FAO/WHO, 2008). The American Heart Association recommends a higher daily dosage (500 mg) for healthy adults, whereas the Linus Pauling Institute recommends that generally healthy adults increase their intake of omega-3 fats by eating fish twice weekly or, in case of lack of regular consumption of fish, a 2 g fish oil supplement several times a week (Linus Pauling Institute, 2014).

What happened in most countries, and especially in western countries, during the past century is that the dietary content of *n*-6 PUFA mostly derived from the consumption of vegetable oils, as such or added in almost every commercially prepared food, dramatically increased, whereas the consumption of *n*-3 PUFA correspondingly decreased, resulting in unbalanced *n*-6:*n*-3 PUFA ratio of about 15–20:1 whereas the ideal ratio should be 1:1 (Simopoulos, 2002). In brief,

* Corresponding author.
E-mail address: mario.pagliaro@cnr.it (M. Pagliaro).

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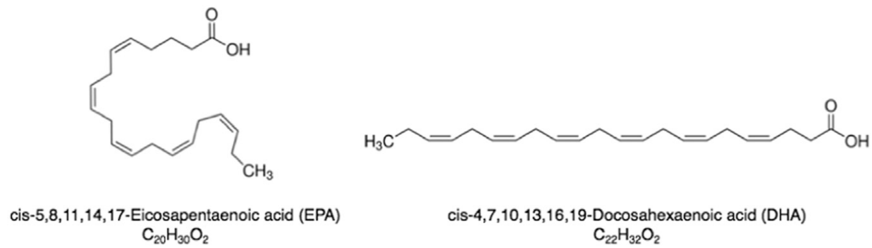
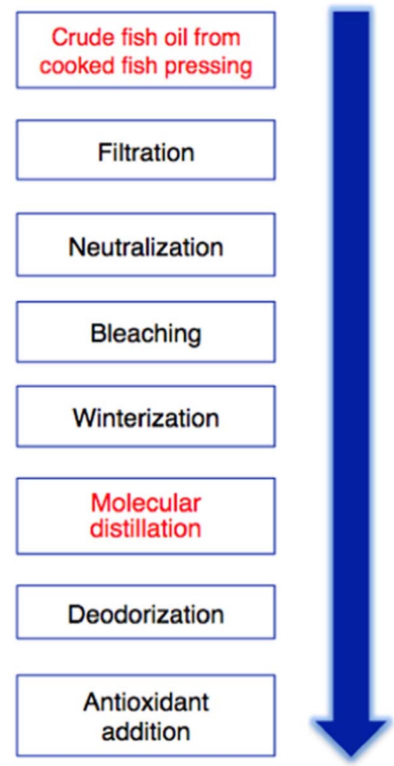


Fig. 1. Structure of the main *n*−3 (EPA, DHA) polyunsaturated fatty acids.

6.5 out of 7 billion people comprising the current world's population do not get sufficient intake of EPA and DHA (Micha et al., 2014). Considering a daily dosage of 250 mg, a *daily* production of 1625 t of EPA and DHA would be needed, not including the demand of fatty acids by hatcheries. Current yearly production of EPA and DHA enriched oils does not exceed 85,000 t which renders the scope of the effort needed to meet tomorrow's demand.

This situation has led to the rapid rise of the marine oil omega-3 supplement industry. Today, fish oil is the most popular supplement both in Europe (taken by approximately 20% of adults) and in the US with sales more than doubled worldwide between 2005 and 2012 (O'Connor, 2015). In general, other sources than fish exist which can be advantageously extracted, including algal oil and microbial metabolism of yeast, fungi, or microalgae (de Oliveira Finco et al., 2016). The focus of this study on blue fish is due to the waste of valued oily fish by-products which continues in several fisheries across the world (see below). Only approximately 5% of world fish oil production is used to extract its omega-3 contents for use as food ingredients and food supplements, with the remainder fraction being instead used for fish farming (Lembke, 2013). Hence, increasing the production of omega-3 derived from fishery by-products (only in the process of filleting up to 60% of the fresh fish is cut off and generally treated as waste) by recovering and transferring these important nutrients from the sea to the human food chain is a relevant opportunity to promote economic growth, environmental protection and human health at large. Investigating progress in fish oil omega-3 extraction, purification and stabilization methodologies, this study provides an overview of this sector of the emerging bioeconomy (Venkata Mohan et al., 2016).



Scheme 1. The conventional omega-3 production process based on molecular distillation.

2. New production methods and extract quality

Scheme 1 describes the conventional fish oil omega-3 concentrate production process. Once caught the small blue fish are cooked and pressed still on board the shipping vessel. The water-oil mixture is then separated from the protein by filtration and stored. The solid proteins will become fishmeal.

The omega-3 extraction process starts at industrial sites (Kolanowski, 2005). Here the water is removed from the oil with a 3-phase centrifuge. As mentioned above, most of this oil is then used in aquaculture to ensure that the farmed fish also contain a minimum amount of omega-3 fatty acids. The smaller portion of oil which goes to human consumption undergoes refinement in several consecutive steps including neutralization with alkalis to clear free fatty acids and decrease oil acidity, followed by bleaching to absorb pigments or contaminants, degumming ("winterization") to separate phospholipids, and deodorization with steam at 160–200 °C to remove smelly compounds. The refined fish oil thereby obtained, known as "18/12TG" (where 18 stands for "18% EPA", 12 stands for "12% DHA", and TG stands for "triglyceride"), contains only about 30% omega-3 fatty acids, with the remaining 70% being a varying mixture of other components including cholesterol, omega-6 fatty acids, saturated fatty acids, oxidation products and contaminants (Fig. 2) (García Solaesa et al., 2014).

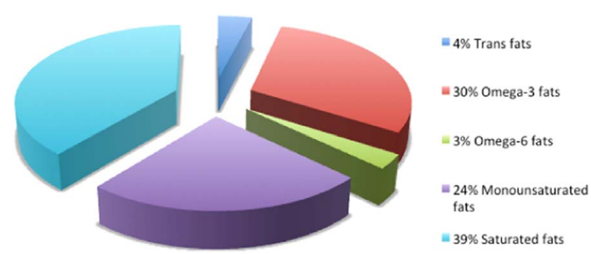


Fig. 2. Blue fish (sardine) oil typically contains about 25–30% omega-3 fats but also 39% saturated fats along with monounsaturated and *trans* fats. [Adapted from García Solaesa et al. (2014), with kind permission].

In general, the fish oil omega-3 industry is increasingly paying attention to quality with efforts undertaken to assure purity and stability of its products. For example, since 2004, a Canada's testing company manages a third party certification program for fish oils (International Fish Oil Standards) that in ten years has tested and certified more than 1500 fish oil products (from raw material to finished supplements) from 130 companies (Nutrasource Diagnostics, 2014). In 2010, Beltrán and co-workers in Spain, one of the world's leading countries in fish oil manufacturing, published a thorough review on the production of omega-3 concentrates (generally in omega-3 ethyl ester oil) (Rubio-Rodríguez et al., 2010). Amongst the most researched advances, the team reported extraction with super-