Bioactive Lipids from marine sources: Nutritional Properties and Functional food applications

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Introduction

The demand for marine lipids is steadily increasing due to their diverse applications. The major marine lipid sources include fish oil, liver oil, krill oil and algal oil. Among these, fish oil has been extensively studied due to its nutritional composition and proven nutraceutical health benefits. In addition, fish oil also gaining great demand by aquaculture Industry as a vital feed ingredient. The global fish oil market is projected to grow from $ 10.4 billion in 2025 to $ 24.6 by 2035. The leading fish oil producing countries are Peru, Chile, Denmark, United state of America, Norway, Japan, India, Iceland, Spain and Mexico. In this context ensuring the sustainable fish oil production is crucial. This can be achieved by by-product valorization, the development of cost effective and environment friendly lipid extraction process and the utilization of unconventional fishery resources such as krill, algae. These approaches can help to reduce overfishing and minimize resource exploitation. This paper highlights the nutritional and functional properties of fish oil and other marine lipids with emphasis on their applications for sustainable utilization.

Major Sources of marine lipids

Fish oil

It is one of the widely studied marine lipids for its functional and nutraceutical benefits in human health. Generally, fish contains 2-30% fat. Fish oil can be extracted from whole fish or fish processing residue (head, fin, skin, tail, bone, gut, liver). Fish oil is composed of fatty acids (saturated fatty acids -SFA, monounsaturated fatty acids -MUFA and polyunsaturated fatty acids- PUFA), triglycerides, vitamins (vitamin A and vitamin D). The major species used for fish oil extraction includes sardine, anchovy, pilchard, blue whiting, herring, menhaden, Alaska pollock, mackeral, sprat, sand eel, Shark liver is another source of marine lipids. It is rich in squalene, a highly unsaturated triterpene hydrocarbon. The concentration of squalene found in shark liver oil ranged from 50% to 90% depends on the species. The other species used for extraction of oil from liver includes cod, halibut and tuna.

Shrimp oil

In general, shrimp contains 1% to 8% fat depends on the species, gender, diet, geographical location and season. It has been reported that lipid content is high in shell (carapace, cephalothorax and head) than shrimp meat (Saqib et al., 2020). Shrimp oil composed of fatty acids (SFA, MUFA and PUFA), phospholipid (polar lipids), sterols (cholesterol) vitamins (vitamin A, vitamin D and vitamin E), carotenoids, pigments and minerals. Shrimp oil contains different forms of carotenoids such as α-carotene, β-carotene, astaxanthin, astaxanthin esters, β-cryptoxanthin, meso-zeaxanthin, canaxanthin, lutein, zeaxanthin and crustacyanin. It has been reported that carotenoid in shrimp oil composed of 41-59% astaxanthin monoester and 16-33% free astaxanthin and astaxanthin diester (8-43%) (Yang et al., 2015; Gomez-Estaca et al., 2017)

Krill oil

Krill oil is derived from Antarctic krill (*Euphausia superba*). Krill oil contains 40% to 80% phospholipids. The major phospholipids present in the krill oil includes phosphatidylcholine (44% to 99.80%) and phosphatidylethanolamine (0.20% to 24.74%). Krill oil contains 2.3% to 3.9% sterols, The cholesterol content in krill oil ranges from 18.95mg/g to 31.96mg/g. Krill oils also contain lower amount of triglycerides, diglycerides and omega-3 fatty acids. It has been reported that the phospholipid bound omega -3 fatty acids in krill oil are absorbed easily in intestinal tract (Thi-Phuong-Thao et al., 2024). Krill oils also rich in astaxanthin (40-5000mg/kg) and vitamin A (0.11mg/100g).

Seal oil

The major species used for extraction of seal oil is Arctic harp seals (*Pagaophilus groenlandicus*). The oil is extracted from its adipose tissue. The seal oil rich in omega-3 fatty acids (20-25%) in the total lipid content. The unique of seal oil is it contains EPA, DHA and DPA (docosa pentaenoic acid). It also contains squalene (1-3%), vitamin (vitamin E) and traces of phytosterols.

Algal oil

Algal oil can be derived from both micro and macro algae (seaweed). It is rich in essential fatty acids.

Algal oil composed of triacylglycerols, phospholipids and glycolipids. The major fatty acids present in the algal oil includes EPA, DHA, alpha linolenic acid, palmitic acid (C16-78% of SFA) and oleic acid (C18:1-16%). Algal oil contains fucoxanthin, a carotenoid which provides antioxidant properties and more health benefits in fish, shrimp and human nutrition. Algal oil also contains vitamins (vitamin A & vitamin B) and minerals (iodine, potassium, calcium, magnesium, phosphorous, iron, zinc)

Marine lipids – Extraction methods

The marine bioactive lipids can be extracted by various methods which includes i) steam cooking and pressing ii) chemical and enzymatic process iii) microwave assisted extraction iv) ultrasound-assisted extraction v) supercritical fluid extraction (SCF-CO2) A wide range of techniques have been used to extract oil from whole fish or fish waste. The selection of suitable lipid extraction method depends on the various factors such as nature of raw material and application of derived oil. In addition, the extraction methods also influence the purity and oxidation status of oil.

Nutritional properties of marine lipids

The major form of bioactive lipids present in the fish , shell fish and algae includes i) Omega – polyunsaturated fatty acids (Eicosapentaenoic acid and Docosahexaenoic acid) – It is abundant in fish, shell fish and algae ii) Phospholipids – It is mainly present in krill oil, fish roe and crustaceans iii) Glycerol - found in marine oils iii) Sterols – It is mainly found in seaweed and marine algae iv) Carotenoid – It is mainly present in the krill, salmon, shell fish and micro algae (*Haematococcus pluvialis*)

The marine lipids are mainly composed of triglycerides of fatty acids along with smaller amounts of sterols, phospholipids and fat-soluble vitamins. The fatty acids present in the marine lipids are classified into saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA). The nutritional composition of marine lipids is largely defined by its high concentration of long-chain polyunsaturated fatty acids (LC-PUFAs), particularly eicosapentaenoic acid (EPA-C20:5) and docosahexaenoic acid (DHA- C22:6). PUFAs are further classified to omega-3 and omega-6 fatty acids according to their double bond position on the carbon atom from the hydroxyl groups. The major omega-3 fatty acids present in the marine lipids includes EPA, DHA and alpha linolenic acid (C18:3). The major omega -6 fatty acids present in the marine lipids includes linoleic acid (C18:2). Generally, fatty acid profile of fishes are influenced by various factors such as species, dietary intake, season and feeding habits etc. The higher concentration of EPA and DHA found in the salmon, mackeral, sardines and anchovies. Unlike fishes, fish oil also contains omega-6 fatty acids. The nutritional value of fish oil is determined by the ratio of omega-3 to omega-6. The recommended ratio of omega-3 to omega 6 ratio for human health is 1:1 to 2:1.

Functional properties of marine lipids

Marine oils exhibit superior functional properties compared to animal lipids and vegetable oils due to their unique lipid profiles, balanced ratio of omega-3 to omega-6 fatty acids. The omega-3 fatty acids are very well known to have beneficial bioactivities including prevention of atherosclerosis, arrhythmias, reduced blood pressure, benefit to diabetic patients, protection against manic-depressive illness, reduced symptoms in asthma patients, protection against chronic obstructive pulmonary diseases, alleviating the symptoms of cystic fibrosis, improving survival of cancer patients, reduction in cardiovascular disease and improved learning ability. It has been reported that regular intake of fish and marine omega-3 supplement is linked to a lowered risk of cognitive decline and Alzheimer's disease (AD). Astaxanthin present in the shrimp oil also possess anti-oxidant, anti-inflammatory, anti-apoptotic, anti-tumor activities. The mechanism of action for bioactivities of marine lipids is given below;

Bioactive properties of marine lipids	**Mechanism of action**
Antioxidant	Scavenge free radical, decrease the oxidative stress
Anti-inflammatory	Production of metabolites of EPA, DHA
Anti-obesity	Decrease the VLDL synthesis from liver and increase HDL, reduce the plasma triglycerides level
Anti-cancer	Prevent carcinoma cell growth development, increase reactive oxygen species, inhibition of pro-inflammatory eicosanoids
Anti-thrombotic	Prevent thrombus formation
Neuroprotective	Inhibit neuroinflammation, regulate neurotransmitters and hormone level

Recommended intake of Omega3 – fatty acids

Several international scientific authorities have published recommendations for the daily intake of omega-3 PUFAs. Details are given below;

Organization	Recommended level
Health and Welfare Canada	1.0–1.8 g omega-3 PUFAs/day
International Society for the Study of Fatty Acids and Lipids (ISSFAL)	0.22 g DHA and EPA/day
British Nutrition Foundation (BNF)	1.4 g DHA and EPA/day (males) 1.1 g DHA and EPA/day (females)
Institute of Medicine (IOM)	0.5 g omega-3 PUFAs/day (for infants)
United States Food and Drug Administration (US FDA)	3 g DHA and EPA/day

Application of marine lipids

Marine lipids provide a wide range of functional and nutraceutical benefits for human health. They have found various applications in, feed, biofuel production and leather processing. However, its application in food and nutraceutical products is limited due to off-flavor and the oxidative instability of polyunsaturated fatty acids (PUFA). This limitation can be mitigated through advanced delivery systems such as microencapsulation and liposome technologies, which help improving stability and sensory acceptability. Several studies demonstrated that fortification of food with marine lipids enhances the bioavailability of bioactive compounds such as PUFA, carotenoids, astaxanthin etc. The major food items fortified with marine lipids includes dairy products (milk, yogurt and cheese), bakery products (bread, biscuits, muffin, cake, ready to cook products (noodles and pasta) and beverages.

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