Marine Bioactive Compounds and the Food Industry

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Marine by-products, including head, viscera, skin, and bones, often constitute over 50% of the biomass, which contains a wide range of biomolecules and is mostly underutilized. For example, sea cucumber by-products, mainly gut materials, represent up to 50% of sea cucumber body weight, which is a rich source of PUFAs and phenolic compounds (phenolic acids and flavonoids), exhibiting antioxidant activity. Hence, marine bioactive compounds hold a significant potential to be a potential candidate in the value-added nutraceutical, functional food ingredient, and natural health product sector that can be used for health promotion and food preservation. In particular, due to tremendous functional (e.g., stabilizing, emulsifying, gelling, and water-thickening) and biological (e.g., anticancer, antitumor, anti-inflammatory, antihypertensive, antidiabetic, wound healing, and antimicrobial) properties, marine-derived bioactive compounds have gained significant interest as a promising source of functional ingredients. For instance, due to antibacterial and antihypertensive properties as well as foaming and gel-forming capacities, proteins/peptides are considered one of the most promising ingredients in the functional food sector.

marine bioactive compounds | biological properties | functional foods | food industry

1. Introduction

The marine environment is a valuable source of numerous bioactive compounds with unique biological functions suitable for use as functional food ingredients. Marine products are rich in different kinds of polysaccharides, including SPs and chitin/chitosan, proteins, including both essential and non-essential amino acids, PUFAs, vitamins, minerals, carotenoids, and other bioactive compounds [1][2]. Various sources of marine organisms offer these bioactive compounds in varying quantities, and they can be incorporated into the food production process at different stages, from processing to storage [3]. Moreover, nowadays, consumers are becoming more conscious of the link between a wholesome diet and the prevention of diseases. Hence, marine-derived biologically active components have enormous potential to be the best ingredients for incorporation into foods as they enhance both the nutritional and economic value of the food. In the last decades, a wide range of marine-derived functional foods have been launched into the world market, which could be fortified with many functional ingredients, including antioxidants, vitamins, carotenoids, probiotics, minerals, fiber, PUFAs, polysaccharides, protein hydrolysates, and other dietary supplements. For instance, seaweeds have been incorporated in meat, dairy, confectionery, bakery, and pasta products due to their ability to reduce blood pressure, fight obesity, lower cholesterol content, and tackle free radicals. Most common commercially available seaweed-based supplements include seaweed-derived functional drinks and seaweed biscuits, among others [1][4]. Apart from this, marine-derived polysaccharides (e.g., chitosan, alginate, and carrageenan) and protein (e.g., gelatin) have gained extensive research attention as primary biopolymers for preparing edible films and coatings as they are available worldwide at relatively low costs with high performance [5][6].

2. Bioactive Marine Polysaccharides

The biological properties of marine-derived polysaccharides are determined by their chemical composition and structure. They can be derived from a wide range of marine organisms and possess several properties that make them ideal ingredients to incorporate into food. Algae, crustaceans, and most other marine organisms produce fucan/fucoidan, carrageen, hydrocolloids, and glycosaminoglycans like polysaccharides that are widely used in numerous commercial applications, particularly in food, beverages, and supplements [7]. For example, algal polysaccharides such as alginate, agar, and carrageenan are used as gelling, emulsifying, clarifying, thickening, stabilizing, and flocculating agents in various food products, including ice cream, candy, yogurt, meat product, and functional beverages [8]. Most of their functional properties, such as gelling and thickening, are due to the presence of polysaccharide–polysaccharide interactions as their unique structural characteristics. Agar forms stable gels and is widely used as an additive in dairy, bakery, and canned meat/fish products, soups, sauces, and beverages, and also in some culinary applications such as Japanese foods like “Tokoroten” (noodlelike agar gel) and “Mitsumame” (canned fruit salad with agar jelly) [6]. Furthermore, due to the high sugar content of agar, it can be used in confectionery industries, particularly in jellies, jams, fruit candies, puddings, and custards. Like agar, alginate also possesses the ability to form a firm and rigid gel that can be used in jams and puddings, and it is also important as a thickening agent in ice cream, sauces, ketchup, mayonnaise, and purees. Apart from that, the film-forming ability of alginate is used in pastries and fruit fillings to prevent cake moistening [7]. Moreover, some polysaccharides can bind large amounts of water and disperse it in food products. This property is exhibited in carrageenan-like polysaccharides that are used to modify the texture of food products by changing their water-binding and foaming attributes [1]. For example, carrageenan finds application in a variety of water-based gelled desserts and cake frosting. Additionally, it is employed in dairy products both on its own (e.g., processed cheese, flan, sterilized chocolate, and evaporated milk) or in conjunction with other gums such as locust bean gum (e.g., ice cream and cream cheese) [7][9]. Fucoidans are another complex sulfated polysaccharide isolated from different marine species, and because of their structural sulfated groups, they improve biological properties and make them suitable to incorporate into dairy products. Apart from fucoidan, other marine polysaccharides such as chitosans are ideal raw materials for edible and biodegradable films and as antimicrobial agents, additives, and nutraceuticals. In addition, meat products, including sausages, dairy products, and beverages, can be supplemented with polysaccharides like carrageenan, chitosan, and chito-oligosaccharides [4][5][10][11].

3. Bioactive Marine Peptides

Proteins and peptides derived from marine organisms display several unique functional properties, such as film-forming, gel-forming, and foaming capacities. For example, marine collagen and gelatin are widely used in the food industry as food additives mainly due to their gel-forming ability, film-forming, texture improvement, and water-holding capacity [6]. Furthermore, there has been much attention and considerable interest in the food industry about bioactive peptides due to their nutritional and therapeutic values. These biologically active peptides play crucial roles in metabolic regulation and modulation. Especially, proteins from fish, mollusks, and crustaceans are among the excellent sources of all essential amino acids. Fish protein powders and fish protein supplements, including fish protein hydrolysates (FPHs), are widely used in fish protein-incorporated food products, and they are available in the market. Fish protein powders are often produced by drying mechanically deboned fish flesh, which is washed with water or diluted in salt solutions (surimi). The amount of collagenous matter and myofibrillar proteins is relatively greater in surimi compared to fish flesh [12][13]. Therefore, dietary proteins can be replaced by fish protein concentrates without any effect on metabolic balance. When considering the functionality of these FPHs, several studies have revealed their high solubility [14]. Due to their high solubility, FPHs could successfully be incorporated into drink formulations. Several research groups have focused their attention on enhancing water-holding capacity in raw and cooked foods by introducing FPHs [15]. Apart from interaction with water, FPHs' interfacial and surface properties are linked to their interactions with fats and oils. These interactions determined the emulsifying and foaming properties of FPHs. However, bitterness associated with FPHs may hinder their use in several food applications. Therefore, further studies are needed to explore the interfacial properties of FPHs, including their emulsifying and foaming properties in functional foods and nutraceuticals. For example, salt, phosphate, and cyclodextrin were found to be important ingredients to mask the bitter taste of FPH [11]. Moreover, FPHs have the potential to be used as flavorings and as “extracts” to be added to food products like soups, bisques, frozen seafood, fillings, and snacks in order to enhance their flavor. When considering algal proteins, the class of phycobiliproteins (phycoerythrin, phycocyanin, and allophycocyanin) and lectins are two major groups of functionally active proteins, which show several beneficial functions, such as antioxidant and antidiabetic properties. Phycobiliproteins, water-soluble protein pigments, are found mainly in cyanobacteria and red algae (Spirulina) and are used as food dyes [16][17].

4. Bioactive Marine Polyunsaturated Fatty Acids

Enhancing food products with omega-3 PUFA fortification has been recognized as an effective approach to increasing their dietary intake (**Figure 1**).

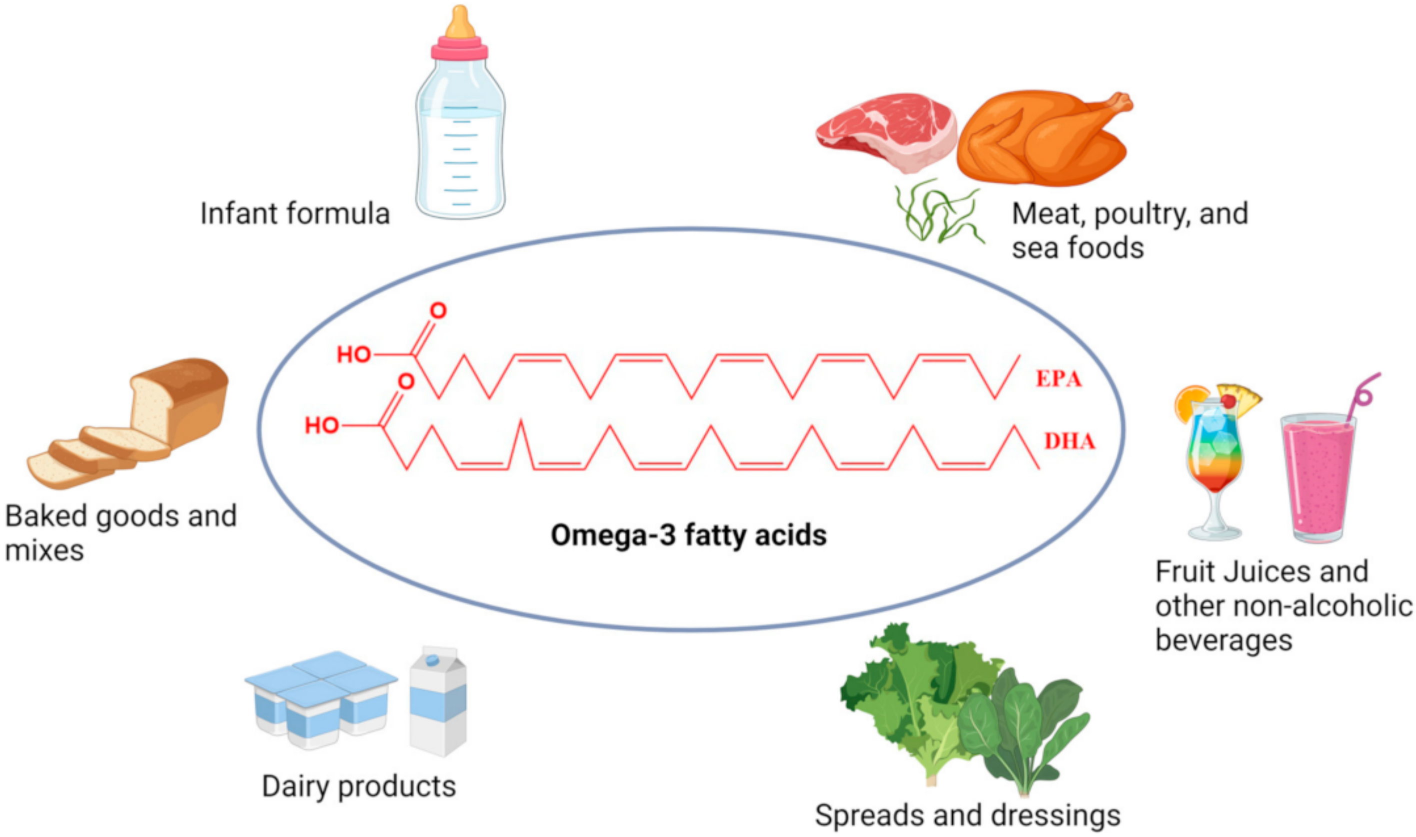

Figure 1. Common omega-3 fatty acids enriched foods available in the world market.

Fortification and microencapsulation are the most popular methods in this enrichment process. The inclusion of fish oil in food products such as bakery, dairy, and pasta by using modern technologies is a growing industry, and recent advances in this sector have resulted in a recognizable change in the functional food sector. For example, novel microencapsulated oil, which is known as MEG 3 (produced by Ocean Nutrition Canada; now DSM), has the ability to remain unaffected until it reaches the GI tract. However, preventing lipid oxidation and related fishy off-flavors associated with lipid degradation after incorporation of fish oil and, in the meantime, protecting the sensory attributes of food products are some of the major technical hurdles to overcome during the application [18][19]. The formation of both primary and secondary oxidation products in polyunsaturated fatty acids (PUFAs) over extended periods of storage significantly contributes to the degradation of quality in fish oil and food products that contain fish oil. Nevertheless, the extent to which fish oil can be fortified in products like bakery goods, dairy items, and other frozen foods has been limited primarily because fish oil is highly prone to oxidation over time. Recent studies have indicated that fatty acids present in fish oil might undergo oxidative deterioration [20]. As a consequence of this degradation of the original PUFAs, the possibility of forming reactive lipid radicals and ultimately unhealthy volatile off-flavor molecules is high. Generally, the oxidation of fatty acids (EPA and DHA) results in the production of different volatile aldehydes and ketones. Depending on the substrate and environmental compositions, these volatiles can vary. Moreover, they belong to several groups such as short-chain aldehydes (acetaldehyde, 2-propenal, propanal, and 2-butanal), long-chain aldehydes (hexanal, 2,4-heptadienal, nonal, and nonadienal), diunsaturated aldehydes (nonadienals and 2,4-heptadienal isomers), saturated aldehydes (hexanal, pentanal, and nonanal), ketones (1-penten-3-one), alcohols (1-penten-3-ol), hydrocarbons (pentane, 1-pentene, 2-methyl-1-

butene, 1,3-pentadiene, and 1-heptene) and acids (formic acid, propanoic acid, hexanoic acid, and butanoic acid) [18]. However, introducing or incorporating fish oil into foods is a challenging and difficult task as omega-3 PUFAs are extremely liable to oxidation. Moreover, executing preventive measures is not enough for industrial-scale usages of fish oil and fish oil-incorporated products. Hence, the use of antioxidants has gained attention in order to enhance the shelf life of oil-related food products by retarding the oxidation process. Particularly, synthetic antioxidants, such as butylated hydroxyanisole, butylated hydroxytoluene, t-butyl-hydroxyquinone, and propyl gallate, and natural antioxidants, such as tocopherols, ascorbic acid, gallic acid, and lactoferrin, among others, have been studied for preventing oxidation of bulk fish oil, fish oil emulsions, and other marine oils [21][22]. Nevertheless, crude fish oils often contain impurities and oxidation products. Due to their compositional characteristics, these oils are often considered a good source for tanning, margarine oil (hydrogenated), supplement, and aquaculture industries [23]. Therefore, refining and purification procedures should be practiced, especially before their incorporation into food products.

Recent studies on the sensory evaluation of foods enriched with fish oil have also revealed that the addition of fish oil can negatively affect the sensory properties of fortified foods [5]. Nevertheless, there are numerous instances of omega-3 fatty acid-enriched foods that are available in the market worldwide, while maintaining sensory attributes. These include meat and poultry products, eggs and egg products, bread and bakery products, spreadables, milk and dairy products, sauces, pasta, soft drinks, juices, and instant concentrates [23][24]. Therefore, the fortification of food products with long-chain omega-3 PUFA using unhydrogenated marine oils is a popular and growing area in the food sector. However, it is in demand to discover novel methodologies and creativity for devising cost-effective approaches to stabilize these beneficial oils for delivery in food systems for the betterment of consumers and for the industry itself to remain competitive.

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